THE IMPACT OF A CARBON TAX OVER THE BRAZILIAN ECONOMY IN 2030 - IMACLIM: THE HYBRID CGE MODEL APPROACH

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Keywords: Hybrid CGE Model, Climate Change Policies, Macroeconomic Impacts of a Carbon Tax, Unemployment Rate, IMACLIM-S BR.

Abstract

This paper analyses the impact of a carbon tax over the Brazilian economy. To assess the consequences of this climate policy the model IMACLIM-S BR was developed by the authors using a hybrid input-output matrix with base year 2005. The model is also innovative due to the integration of bottom-up, expert information, into a CGE framework. This methodology can be an interesting option to assess climate change policies specially if compared to CGE models using CES-like functions because it can simulate very high carbon prices which means large departures from the reference case. Results from the model show that the way that the carbon tax revenues is used by the government strongly influences the growth of the economy as well as GHG emissions, unemployment rate and the total debt of the government.

1. **Introduction**

Coordinated by its Ministry of Environment and Ministry of Science and Technology, Brazil presented its targets for voluntary contributions to GHG emissions abatement based on the National Climate Change Plan. The contribution proposed was to reduce

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emissions by between 36.1% and 38.9% in 2020 compared to 2005, the baseline year. Brazil may potentially meet these voluntary commitments under the new mechanisms that were discussed at COP 15 in the form of Nationally Appropriate Mitigation Actions (NAMA's), which enable the indisputable recognition of national mitigation efforts and ensure that the country is up-to-scratch in the global effort to combat climate change. Secondly, a conceptual base for implementing the reduction of emissions from deforestation and forest degradation (REDD) was established, which provides investments from developed countries to preserve forests in developing countries. In this context, Brazil announced its new law to regulate climate change actions, outlining goals and deadlines for reducing GHG emissions.

Brazil has indeed plenty of low cost mitigation options: on the one hand a huge capacity of mitigation from land-use changes and REDD at supposed low cost. On the other hand the energy matrix is one of the cleanest in the world (with over 47% of the domestic primary supply of energy coming from renewable energy sources (BEN, 2010)) and presents important opportunities for reducing emissions from both implementing energy efficiency methods and increasing the use of biofuels. If combined with appropriate economic instruments, such as a national carbon market, all options offer opportunities for an environment and economic efficient transition to low carbon economy.

Moreover policymakers in Brazil need to make decisions today about the magnitude and timing of energy-environment targets, and about the specific policy package that would best achieve them in terms of the usual policy-making criteria—economic efficiency, environmental effectiveness, and administrative and political feasibility. To do so, they need to know the extent to which their policies might influence employment, competitiveness, and economic structure: neither modeling perspective is able to give completely defensible advice for these requirements. To be particularly useful, an energy-environment policy model should perform fairly well in terms of three dimensions. It should be technologically explicit, including the possibility to adopt radically new technologies with realistic costs. It should be behaviorally realistic, including an assessment of how policies might affect the future in-tangible costs (specific consumer concerns and preferences) of acquiring new technologies. It should have macroeconomic feedbacks linking energy supply and demand to the evolution of the economy’s structure and total output.

The IMACLIM architecture was developed to meet those challenges and take the form of a CGE model enriched with the description of technological content of production to avoid the use of CES-like functions. One important prerequisite for that is the construction of so-called “hybrid” accounting systems inspired by fundamental Arrow-Debreu axiomatic. It consists in describing economic flows both in physical quantities and monetary values. This multiple or hybrid accountings enable to build models that guarantee that any project economy is supported by relevant “physical system” and conversely that technological deployment appears in realistic economic environment. Formerly a pure theoretical architecture, the availability of varied data and progress in processing enable today to build consistent hybrid accounts to calibrate models.

IMACLIM-S Brazil , is a national “hybrid” general equilibrium model (CGE) based on recent economic and energy data which enables to analyze the effects of a carbon price in Brazilian economy both at sectoral and global levels (sectoral costs, unemployment, income distribution, trade, and other macroeconomic indicators,…)

This paper presents an economic modeling architecture that was developed to examine the regulatory aspect of a carbon constraint on Brazilian economy whether it be a carbon tax or a carbon market at time horizon 2030.

2. IMACLIM-S methodology:[2] a Computable General Equilibrium (CGE) model simulating comparative statics

IMACLIM-S is a CGE model designed to assess medium- to long-term macroeconomic impacts of aggregate price - or quantity-based carbon policies, in an accounting framework where economic flows and physical flows (with a special focus on energy balances) are equilibrated. According to Ghersi *et al* (2009), the model is based on the standard neoclassical model in the main feature that its description of the consumers’ and producers’ trade-offs, and the underlying technical systems, are specifically designed to facilitate calibration on bottom-up expertise in the energy field, with a view to guaranteeing technical realism to the simulations of even large departures from the

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[2] In recent years, the IMACLIM-S framework has advanced significantly due to the work of Frédéric Ghersi, Emmanuel Combet and Camille Thubin under Jean Charles Hourcade scientific direction. They have developed the IMACLIM-S France version, which inspired and based the development of the Brazilian version.

reference equilibrium. Other significant features include (i) an aggregate treatment of the general technical change induced by the shifts in energy systems; IMACLIM-S thus operates in an endogenous technical change framework; and (ii) a sub-optimal equilibrium on the labor market.

IMACLIM-S calculations rely on the comparative-static analysis method: they provide insights that are valid under the assumption that the policy-induced transition from the reference equilibrium to its policy-constrained counterpart is completed, after a series of technical adjustments whose duration and scope are embedded in the elasticities of production and consumption retained. states that the transition process in itself is however not described, but implicitly supposed to be smooth enough to prevent e.g. multiple equilibriums, hysteresis effects, etc (Ghersi *et al* 2009).

IMACLIM-S is a ‘hybrid’ model in the sense that it pictures energy volumes that are not deduced from national accounts statistics and a single energy price hypothesis, but rather result from an effort to harmonize these macroeconomic data with energy balances and energy prices statistics in the reference year. The hybridization of the input-output table facilitates the integration of some engineering expertise about technical flexibilities at a given time horizon. In particular, energy efficiency improvements of equipments and infrastructures used by both the producer and the consumer are bounded by exogenous asymptotes[3]. As a result, the model exhibits price elasticities that gradually decrease as the relative energy prices increase (rather than constant elasticities) (Combet *et al*, 2010).

The income flow associated with the flow of goods starts with the remuneration of production factors plus net payments from/to the rest of the world. It continues with distribution operations orchestrated by the public administration between the four categories of agents: taxes (payroll taxes, corporate tax, income tax, etc.) and transfers (unemployment benefits, social benefits, pensions, etc.). Once they have made their consumption and investment choices, agents lend or borrow on financial markets depending on whether their exhibit positive or negative savings. This affects their financial positions and the associated income flows (debt services, interest payments).

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[3] For example in the Brazilian case expert-based information give asymptotes from around 75 to 95% of base year energy intensity at time horizon 2030 for heavy industry sectors.

The model is calibrated on 2005 data (2005 energy balance; 2005 input-output matrix, etc)

2.1. Layout of the model

IMACLIM-S operates by projecting the comparative static equilibrium of an economy (BAU scenario), and then the deformation of this equilibrium where a climate policy (carbon constraint) is implemented (derived equilibrium or policy scenario) (Figure 1).

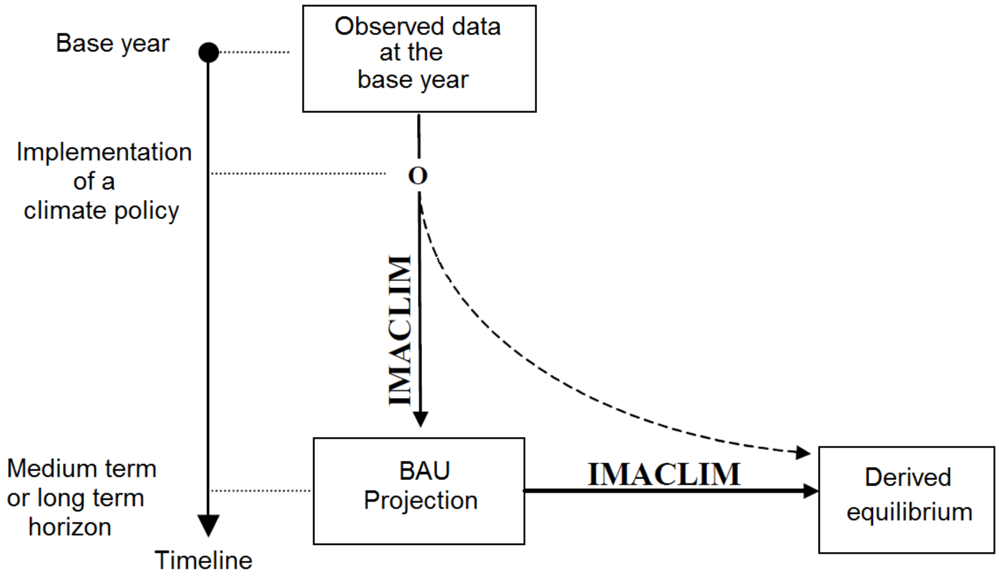

Figure 1 – IMACLIM-S layout (adapted from Ghersi, 2003)

The analysis of the impacts of climate policy is therefore given in two stages:

- BAU Scenario – The first step is the projection of the BAU scenario which considers exogenous hypothesis on GDP growth and energy projections, for example. These exogenous hypotheses are embarked by the model and a new equilibrium, based on a hybrid input-output table is achieved. The projection is specifically designed to integrate data of the energy system calculated by any bottom-up model, ensuring consistency in both quantities and prices.

- Policy Scenario – The derived equilibrium is a deformation of the BAU scenario reflecting the climate policy applied. Expert information about behavior of sectors under a carbon constraint (MAC curves) are embarked on the model, and IMACLIM-S equations related to the general equilibrium in quantities and prices should be again satisfied under those conditions in order to calculate a new equilibrium. This step will be explained in detail ahead.

2.2. Determinants of the macroeconomic impacts

The determinants of the macroeconomic impacts concerning the IMACLIM-S model were described in a very synthetic way by Combet *et al* (2010). The comparative statics analysis amounts to distort the ‘image’ of the no-policy economy by an external shock—the carbon tax. The particulars of this distortion are induced by the interaction of five sets of assumptions defining:

The adaptation of the productive system, through the adjustment of inputs (labor, capital, intermediate consumptions) to the variation of their relative prices, the evolution of total factor productivity (an endogenous technical progress coefficient is correlated to cumulated investment), and the influence of static decreasing returns.

The rigidity of the labor market, formalized by a wage curve that describes a negative correlation between unemployment and the average net wage (Blanchflower and Oswald, 2005, cited by Combet *et al*, 2010).

The impact on international trade: absolute exports and the relative contribution of imports to resources are elastic to terms of trade that evolve according to the cost of domestic production, facing constant international prices (the international composite good is the numeraire of the model).

Public budget constraints: the ratio of public expenditures to GDP is assumed constant; social transfers (per capita unemployment benefits, pensions, and other transfers) are indexed on the average net wage.

According to Combet et al (2010), assuming constant saving rates and the adjustment of fixed capital formation on the demand addressed to the production system, the model is ‘closed’ by computing the capital flows that balance current accounts. Equilibrium is determined by the simultaneous adjustment of the volumes traded with the rest of the world, the domestic prices, the level of activity and the interest rates.

2.3. Carbon tax revenues

An interesting question related to the carbon tax is where those revenues are going to be applied. Among almost infinite possibilities, there are two interesting and feasible applications of the revenues. First option is to use them to decrease the public debt, representing the common perception of a fiscal burden with no compensation on disposable income. Second option is to use them to decrease payroll taxes, under the constraint of budget neutrality, or a constant total public tax income to GDP ratio or else a constant public debt to GDP ratio.

Technical details of the IMACLIM-S Brazil model will be presented on the next section.

3. Technical content

In this section we explain in detail the features and technical content of the IMACLIM-S Brazil.

3.1. CGE framework and modeling choices

Our exercise is focused on the issue around a carbon market applied to sectors of heavy industry including oil refining and land-use change emissions. Nonetheless we have decided in this preliminary version to focus on industry leaving apart temporarily the land-use issue. Therefore starting from the former data base we had made, we chose to work with the 13 following sectors: 5 energy sectors: biomass, crude oil, natural gas, refined oil and coal products; 6 former industrial sectors: paper, cement, steel, non-ferrous products, chemicals and minerals 2 other sectors: Livestock and composite.

3.1.1. IMACLIM-PROJ: how to simulate a BAU projection for Brazil in 2030

The first step consists in building a no-policy projection for Brazil at time horizon 2030. It means projecting the I-O matrix by combining exogenous assumptions and equilibrium rules.

Globally, the BAU-scenario is based on scenario B1 ("surfando a marola") of PNE 2030[4] which gave among others a detailed energy balance projected for 2030 and hypothesis on real growth per sector.

The first step is to arrange PNE energy balance in the right I-O format with 18 sectors using exactly the same nomenclature and manipulations as what was done to transform the energy balance at base year. We get this way a detailed projection of intermediary and final energy consumption. Numerically, PNE energy projection gives the following real growth for energy sectors:

Energy sources	Biomass	Coal products	Crude oil	Natural Gas	Refined oil products and ethanol	Electricity
Annual rate of real growth	3,4%	5,7%	2,4%	6,3%	3,4%	4,5%
Multiplier between 2005 and 2030 domestic production	2,32	4,04	1,82	4,59	2,29	2,99

PNE study gave also hypothesis on real growth of domestic production for the others sectors:

Energy sources	Agriculture	Industry	Services
Annual rate of real growth	4,3%	3,7%	4,3%
Multiplier between 2005 and 2030 domestic production	2,83	2,46	2,83

Globally PNE projects a structural change towards a more services centered and "dematerialized" economy.

Those data combined with the hypothesis of constant technical coefficient for non-energetic inputs (in the absence of other sectoral information) enable to get the total I-O grid in quantities and pseudo-quantities and new energy intensity of sectors. Globally PNE scenario B1 projects energy efficiency gains:

Sectors	Energy	Industry	Composite

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[4] Plano National de Energia 2030, EPE, 2007

Variation of energy intensity between 2005 and 2030	- 3,75%	-3,76%	-6,97%

Final demand of goods (household and public consumption, investment and exports) is supposed to follow sectoral real growth. The Global material balance is adjusted with imports with classic supply and use equilibrium:

$$\mathrm{Y} + \mathrm{M} = \sum \alpha \,.\, \mathrm{Y} + \mathrm{C} + \mathrm{G} + \mathrm{I} + \mathrm{X}$$

As for price structure, the composite price of production and import is the reference fixed at one. Price calculations are based on the set of equations:

$$\mathrm{pY} = \sum \alpha \,.\, \mathrm{pCI} + \mathrm{w} \,.\, \mathrm{l} + \mathrm{pk} \,.\, \mathrm{k} + \pi \,.\, \mathrm{pY} + \tau \,.\, \mathrm{pY}$$

Where

pCI is the price of consumption, average price between producing price and import price plus commercial, trade and possible special margins.

W : wage
L: labor productivity
Pk : price of capital
K : capital productivity
Π : rate of profit
T : tax rate on production

Unit cost of labor, capital, and profit and tax rates are assumed to be constant through the projection.

Prices variations are linked to two main effects: energy efficiency gains decrease the price of production of the aggregates. Depending on the sector variation of ratio M/Y implies variation of average consuming prices and furthermore prices of production.

PNE study and IBGE give also hypothesis on population and labor:

	2005	2030
Population (in millions)(PNE)	185,473	239,260
Active population share	53%	57%

(IBGE)		

Assuming a constant unemployment rate (around 7,5%) enables to calculate labor productivity variation (multiplied by 2 in the composite sector).

The projection calculates also other macroeconomic data linked to financial flows between the four institutional sectors considered in the model (households, federal state, companies and rest of the world) and the dynamic of their accounts. This gathered all kind of flows: taxes on income, on profit, social revenues,...

The behavior of agents linked to those flows and the rate of flows are assuming to be regular.

A special focus is made on the dynamic of the debt of the institutional sectors. From 2005 to 2030 debts are supposed to be reduced every year by the financing capacity (CAF) of agents but this tendency is corrected by the CAF calculated for 2030 assuming a linear evolution of the CAF between 2005 and 2030. The formulae of debts calculations are the following:

$$\mathrm{D} = \mathrm{D0} - \Delta\mathrm{t} * \mathrm{CAF0} - \frac{\Delta\mathrm{t}}{2}\,(\,\mathrm{CAF} - \mathrm{CAF0}\,)$$

Where $\Delta t = 25$ years.

According to PNE, public debt in 2030 is fixed at 33,9 % of GDP (it represented 51,6% of GDP in 2005). This upgrading of public position was favored by global growth activity: a positive higher disposable income with a steady ratio of public expense and investment in GDP.

For households and companies, debts dynamics equations combined with a set of hypothesis on rates of transfers between institutional sectors[5] give the following state of accounts:

Households' debt position remains almost steady with a small decreasing CAF. Companies are the winner in this projection, they benefit the most for the growth. Their income increases in GDP proportion (+35%) like their investment and CAF which turns

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[5] Not developed here for concision

their debt in 2005 into a strong positive position in 2030. Such a state of accounts in 2030 is the first version and can be enrich by any expertise.

Globally this is a first try for a BAU projection. This could be completed by other constraints to get a more realistic picture for Brazil in 2030 such as assumptions on trade balance and share of investments in GDP.

3.1.2. IMACLIM: model structure to simulate carbon constrained derived equilibrium

In the model the carbon policy is implemented via a “carbon price” that increases aggregated energy prices for intermediary and/or final demand depending on the perimeter of the climate policy defined. This carbon price thus induces a “shock” to the BAU equilibrium so that impacted sectors react by trading-off between factors of production (supply side) or levels of final consumption (demand side) along innovation possibility curves built from BU analysis. In fact it is inappropriate to think about those curves as ruling trades-off starting from the BAU situation. However, to speak about the supply side, each “point” of the curve is supposed to stand for one given structure of production or “technology” (defined by technical coefficients and production factors) resulting from a stabilized adaptation of the productive system to the carbon price respective to a time horizon (here 2030) as if this carbon constraint had been implemented for some time in the past. Crossing the curves from the different sectors and agents provides insights on the final result in 2030 of an endogenous technical adaptation to the carbon price and its correlated impacts (cross-price evolutions) of the different sectors all together but without describing the exact path that led to the equilibrium in 2030. This is conforming to the principle of comparative statics.

This first version of the model focuses on the regulatory aspects of a carbon constraint specifically put on energy and industry sectors in Brazil. Therefore we directed our efforts to represent accurate trades-off in industry and energy production. Classic production functions distinguish usually four factors of production: energy, material, labor and capital. We make here the assumption that a carbon constraint only alters the energy and capital intensities of the industrial goods, and we keep constant its labor and material intensities between the no-policy and policy cases. In next section we explain in detail the way we built the innovation possibility curves for industry and energy sectors according to expert-based studies on mitigation options in those sectors[6]. In short those curves embed both trades-off between overall energy consumption and capital and trades-off between energy sources: fossil fuel versus biomass, coal and oil versus natural gas.

Currently land-use changes, composite good and final demand are not included in the carbon constraint perimeter.

Although it would be fastidious to report the complete features of the calculation method of carbon driven derived equilibrium, we provide in the following the main structure and equations for this calculation:

- Price structure: we use the same prices equilibrium as in the BAU-projection. Prices of production evolve with the remunerations of production factors plus mark-up and taxes:

$$pY = \sum \alpha \,.pCI + w\,.l + pk\,.k + \pi\,.pY + \tau\,.\,pY$$

Prices of consumption are adjusted from the average price p (between domestic and import price of production) with detailed specific margins depending on the agents plus the possible carbon charge proportional to the carbon content γ of the energy input:

$$pCI = p(1 + \tau margin) + \gamma * tC$$

Where tC is the constant margin price of carbon.

Price of production factor capital is supposed to be the price of capital "machine" and is thus the average price of goods dedicated to investments.

- Institutional sectors accounts and trades-off in supply and demand:

Households are represented by one unique representative agent driving the final private demand (C). Classically its net aggregated income increases with the sum of wages, of shares in productive sectors profits, social transfers and decrease with taxes (tax on income among others). its saving rate and investment rate (share of Gross Fixed Capital Formation (GFCF) in disposable income) are assumed to remain constant compared to BAU situation. Besides final consumption structure (C) is quite simple in this version of the model: the

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[6] The same studies that enabled to build the MACCs for the Brazilian Carbon Market Model

bill for each good is supposed to keep the same share of total expenditure for final consumption. This imposes a first basic level of substitution possibilities among goods depending on their relative price. Improvement could be made on households innovation possibility curve based on BU information[7] to upgrade the insights around the carbon charge on final consumption.

Private sector's global net income varies with the sum of shares of global profit and different transfers towards households and government. Global rate of gross capital formation of companies is the same as BAU situation. Moreover, as previously mentioned, at this stage of development non heavy industry or energy sectors have Leontieff production reactions. This is partly due to the focus on industry and energy we have made for this study. Nonetheless it will be very important for policy assessment to represent trades-off between energy and labor in labor intensive sectors such as agriculture or services if a carbon price is applied to those sectors. Our work was centered on the building of specific innovation possibility curves in each industry and energy sector considered: oil refining, paper, cement, steel, aluminum, chemical and mining.

Federal state's income varies positively with the sum of collected taxes and negatively with social transfers. Public expenses and level of GFCF are supposed to follow GDP variations.

Like in the BAU projection there is a common feature for every institutional sectors debt variations. Implicitly, the debt in a carbon constrained equilibrium in 2030 is linked to the relative CAF with the same linear fashion as in BAU projection and is actually directly derived from the BAU debt with the following formula:

$$D = DBAU + \frac{\Delta t}{2}\ (CAFBAU - CAF)$$

Where Δt stands for the moment in the past where the carbon policy has been implemented.

As for trade we consider that Brazil does not influence world prices then import prices are fixed and ratios of imports and exports on domestic production vary with the relevant relative prices through elasticities fixed at 1 by default of better assumption:

$$\frac{M}{Y} = \frac{MBAU}{YBAU} * \frac{pMBAU}{pYBAU}\frac{pY}{pM}$$

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[7] Linked to end-uses energy appliance or equipement changes for example

$$\frac{X}{XBAU} = \frac{pXBAU}{pMBAU}\frac{pM}{pX}$$

As for employment and labor market, the model includes a positive unemployment rate (u) ($(1-u) * ActivePopulation = \sum \frac{Y}{LaborPproductivity}$) and represents labor market bargains and tensions with a curve linking unemployment rate and average wage:

$$\frac{AverageWage}{PriceIndex} = AverageWageBAU * (\frac{u}{uBAU})^{\sigma}$$

The model is closed with the equilibrium on markets:

- Markets of goods and services:

$$Y + M = \sum \alpha . Y + \ C + G + I + X$$

- Investments and capital flows:

Interest rates impact the income of agents through the charge of their debt. Therefore they are adjusted so that the sum of the GFCF from households, companies and government related to their income match the total demand of investment: $\sum GFCF = \sum pI * I$.

Eventually, the levels of immobilized goods (I) are proportional to the sum of the aggregated capital consumption. This is a method to make a link between the fixed capital increase in 2030 and a proxy of capital stock represented by the aggregated capital consumption. It enables in this static fashion to represent the concrete counterpart of an increase of capital consumption (consecutive to energy-capital substitution for example) on the needed growth of production of capital "machine" on a steady economic path.

3.2. How to integrate expert-based information on mitigation options

Integration of expert-base information is facilitated by the hybrid representation of economic flows. As previously mentioned it is possible to build for each sector an innovation possibility curve (alternative to classic CES for example) based on tangible technical content coherent with the notion of comparative statics explained above. We built such curves for 6 industrial sectors (paper, cement, steel, aluminum (and others non-ferrous), chemical and mining) and for oil refining activities.

Expert-base data were taken from LCS and CMM. For each sector we have a list of discrete mitigation options to be possibly implemented over a 20 years long period (from 2010 to 2030) associated with a carbon price8. This carbon price is calculated as the minimum average price (on the 20 years long period) that makes the relative mitigation option profitable compared to the BAU scenario. In this calculation, along an exogenous scenario of growth for the sector studied and an exogenous path of energy prices, the actualized added capital costs (linked to the investment in new equipments for example) balance the hypothetic actualized carbon charge alleviation linked to energy consumption changes, whether it be energy efficiency gains or energy sources substitution from high to lower carbon content (fossil fuels to renewable biomass in particular). Such expert-based data are perfectly shaped to be used to calibrate an innovation possibility curve for each sector provided that two hypothesis are more or less valid: like energy consumption levels, added investments needed for technological change are proportional to the level of output. This enables to associate a carbon price to energy intensities variations and not absolute levels of consumption.

For each sector, the mitigation options considered are cumulative and independent. If such conditions are valid, for each sector studied and each energy source, it is possible to have a set of points linking one given level of carbon price (implemented from 2010 to 2030) to the final energy intensity adopted in 2030 (resulting from the adoption of all mitigation options with associated lower carbon prices). Then it only lacks to extrapolate those points with the right continuous function to embed the expert-base information with a compact format in a TD framework with total consistency with the BU expertise.

Almost every sector shows the same behavior along an increase of carbon price: (i)for small carbon prices, global energy efficiency gains are triggered and quickly reach an asymptote; (ii)for medium carbon prices there is a substitution between fossil fuel and renewable biomass. Added work is at his step needed to correctly embed energy sources substitutions. (ii) thus favors usage of specific functions showing an asymptote like function arctangent. Moreover it is easy to show that for efficiency gain, the level of energy intensity only depends on the ratio of a proxy of the price of energy (including the carbon charge) and of the price of capital. At last for each sector, it was then

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[8] See Brazilian Carbon Market Model paper

possible to calculate an arctangent function that links the total energy intensity to the ratio of the price of energy and the price of capital ($\mathrm{alpha}_{\mathrm{energy}} = \mathrm{f}\left(\frac{\mathrm{pE}}{\mathrm{pK}}\right)$) by the interpolation of the sets of points: $(\alpha 0(1 - \delta \mathrm{i}), (\mathrm{pE0} + \gamma.\mathrm{ti})/\mathrm{pK0})$ where δi is the level of efficiency gain of each mitigation option and ti the related carbon price.

Furthermore, under the assumption of minimization of costs of production we can show that the capital intensity can be easily derived from the energy intensity function through the formula:

$$kappa\left(\frac{pE}{pK}\right) = kappa\left(\frac{pE0}{pK0}\right) + \int_{\frac{pE0}{pK0}}^{\frac{pE}{pK}} f(p)dp - \frac{pE}{pK} * f\left(\frac{pE}{pK}\right) + \frac{pE0}{pK0} * f\left(\frac{pE0}{pK0}\right)$$

Eventually, we have calculated for each sector an innovation possibility curve based on the possible substitution between energy and capital truly consistent with the expert-base information. Moreover we can see that the level of substitution depends on the ratio $\frac{\mathrm{pE}}{\mathrm{pK}}$ and not only on the carbon price which enables to include cross-prices effect of the general equilibrium leading to a reexamination of expert-based MACCs.

Next section presents some runs of the model with three sectors to highlight in a preliminary version the global effects of a carbon price on Brazilian industry.

4. Results and Discussion

For the first set of runs and the sake of simplicity we decided to work at a quite aggregated level with three sectors:

- Energy sector (crude oil, biomass, natural gas, coal, refined oil and electricity)
- Industry sector (including the sectors of heavy industry previously detailed)
- Composite sector (agriculture, construction, transports and services)

As far as sectoral production trades-off are concerned we implemented substitution possibilities only for industry and between energy and capital with the same kind of arctangent function as previously described. For energy and composite we adopted

Leontieff production functions. A link to an energy optimizing model is one of the next steps of this research.

Moreover, the carbon tax is charged on energy and industry sectors but not on composite sector and final consumption.

Within the first set of runs the model calculated the impacts of a fixed carbon tax of 200 reais per ton under different carbon revenues distribution options, as follows :

- option 0: carbon revenues are used to decrease public debt and are not recycled
- option 1: carbon revenues are used to decrease payroll taxes under the constraint of budget neutrality
- option 2: carbon revenues are used to decrease payroll taxes under the constraint of a constant total public tax income relative to GDP
- option 3: carbon revenues are used to decrease payroll taxes under the constraint of a constant public debt relative to GDP

Figure 2 presents the GDP growth of the sectors according to the carbon revenues redistribution option. GDP on the BAU scenario is equal to one. It can be seen that inside every option, the energy sector is the one that have its GDP less impacted by the carbon tax, in fact option 2 increases the energy sector GDP. However, as we are going to show in the next figures, this bigger GDP doesn’t come from a bigger output, but to the increase of energy prices due to the carbon tax. Comparing results in terms of the carbon revenues redistribution option chosen shows that Option 1 have the strongest negative impact on the GDP, but it helps to reduce the debt of the government while Option 2 is the one that impacts less the GDP, but this is also the case that makes the debt of state bigger. This and other trade-offs will be more explored during the presentation of the results.

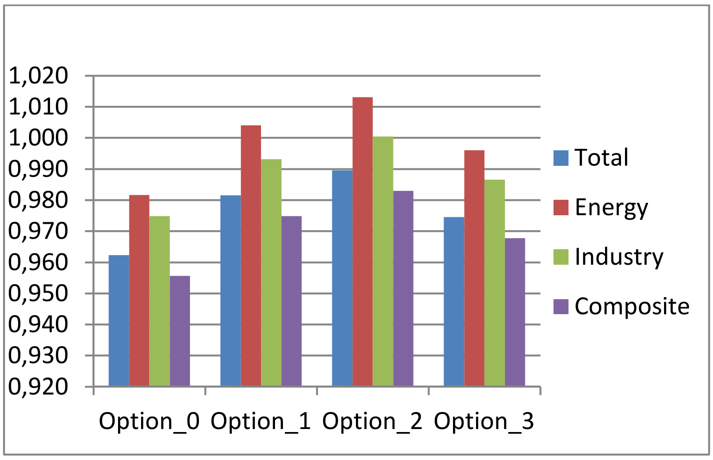

Figure 2 – Comparison of GDP Growth

The output growth of sectors is shown in Figure 3. Again, option 2 is the one that impacts less the GDP. If we compare sectors' results, it is clear that the energy sector was severely impacted by the carbon tax in terms of output, but as shown before, the GDP of this sector was the less impacted due to the rise of prices. The composite sector, less affected by the carbon tax, presents the smaller decrease in the output on every option.

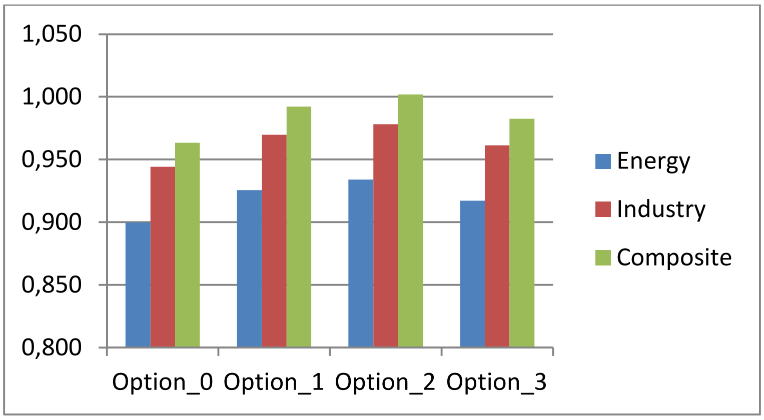

Figure 3 – Output Growth

Figure 4 presents the production price growth of sectors. As expected, the carbon tax promoted a significant rise on energy prices, but reduced composite prices (probably due to a smaller demand). Industrial prices did increase, but not as much as energy prices. Last two figures helps to understand why the energy sector had its GDP less affected by the carbon tax than the other sectors.

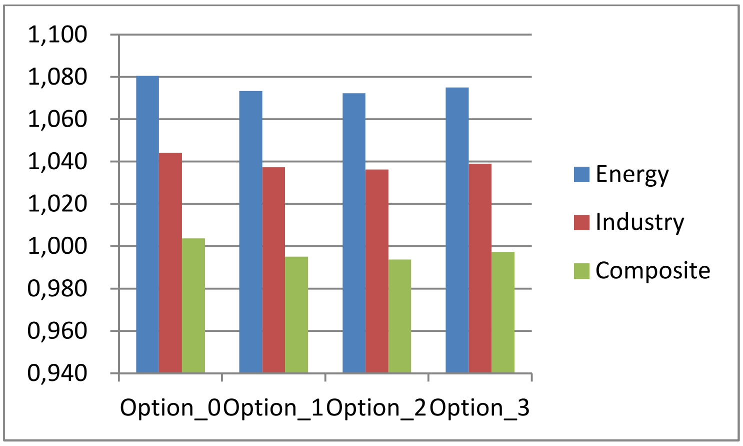

Figure 4 – Production Price Growth

Figure 5 presents a comparison between the different carbon revenues redistribution option in terms of the total number of jobs of the economy and the unemployment rate. Option 2 is the one that promotes best conditions to the labor market keeping the unemployment rate at 7,7%, very close to the BAU scenario, which rate was 7,5%. Option 0 has a severe impact on the total number of jobs, and increases the unemployment rate to 11,2%, with a total number o jobs lost bigger than 5 million.

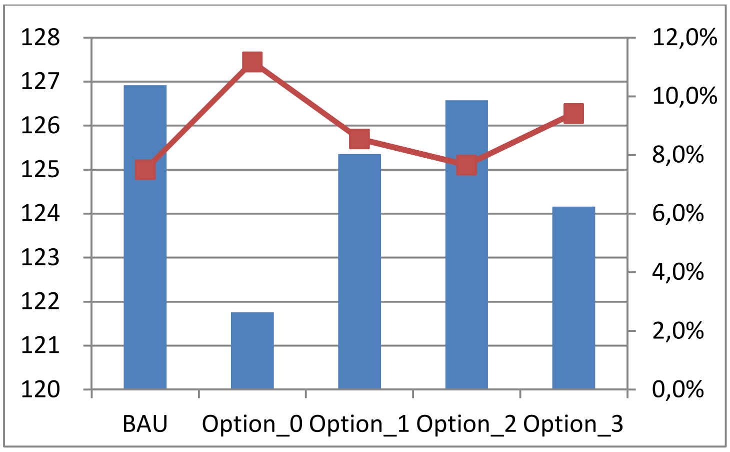

Figure 5 – Number of Jobs (millions, left axis) and Unemployment Rate (right axis)

Option 0 is the one with the biggest negative impact on the GDP and on the labor market, and, as figure 6 shows, it is the option that reduces the most GHG emissions. To compare the different carbon revenues redistribution options in terms of emission reduction and unemployment rate, we calculated the rate between total emission reduction and the total number of jobs lost due to the implementation of the carbon tax. The implementation of Option 2 leads to the best rate, around 150 tons CO_2 mitigated/Jobs lost.

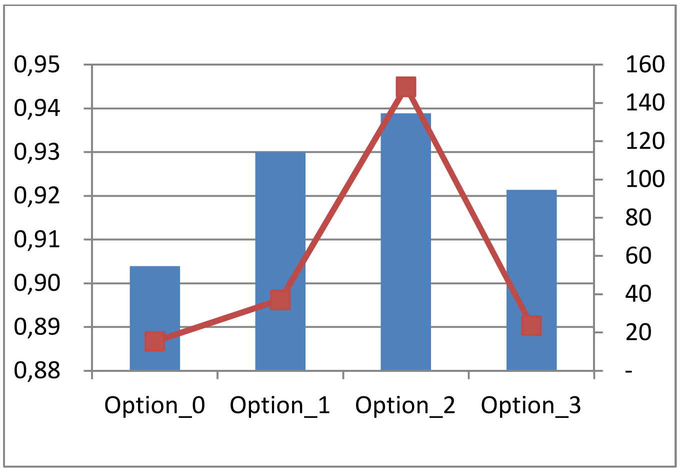

Figure 6 – Emissions Growth (left axis) and tons of CO_2 mitigated/ jobs lost (right axis)

Figure 7 presents the debt of the different institutional sectors according to the different carbon revenues redistribution option adopted. Although Option 2 promotes the smallest lost in terms of GDP and number of jobs, it is the one that increases the most the debt of the state. In the opposite position is Option 0, which reduces the debt of the state in more that 13% compared to the BAU scenario.

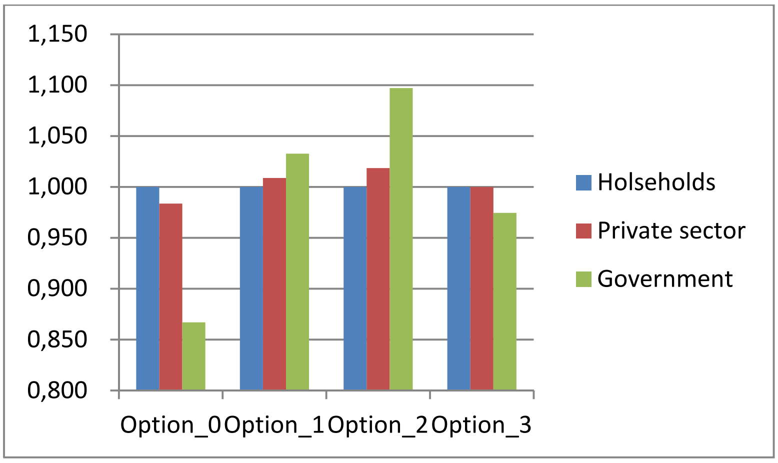

Figure 7 – Evolution of the Debt of Institutional Sectors

On the second set of runs, under option 1 (carbon revenues are used to decrease payroll taxes under the constraint of budget neutrality), the ,model varied the carbon price between 0 and 500 reais per ton in order to estimate a MACC for the sector industry and compare it to the “static” MACC.

Figure 8 presents a comparison between the expert based marginal abatement cost curve (Expert based MACC) and the IMACLIM marginal abatement cost curve (IMACLIM MACC) for the sector industry.

In the Expert based MACC abatement costs are calculated with fixed prices of energy and level of output, those one from the BAU scenario. The vertical part of the MACC is linked to the asymptote of efficiency gains.

IMACLIM MACC takes into account some macro feed backs that deform the former MACC. Two main effects can be noticed here:

- The crossed-price effects: the carbon tax shock induces a multiplier of energy prices. Indeed the carbon price implies a direct rise of the energy price of production amplified by the rise of industry price also linked to the carbon tax. On the whole the resulting price of energy faced by the industry is bigger than the "static" sum of the BAU price of energy and the carbon charge. Therefore with the same level of carbon tax the incitation for mitigation is higher when feed backs are taken into account which displaces the MACC on the right.

- The abatement linked to the decrease of production: in IMACLIM the carbon price induces a rise of industry price of production which in turn decreases the level of production to match a lower demand. That´s why there is no asymptote for the abatement on IMACLIM MACC.

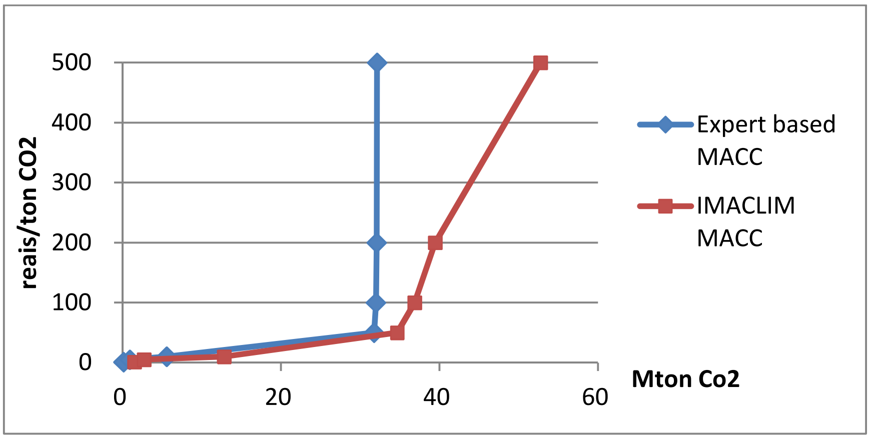

Figure 8 – Comparison between BU MACC and IMACLIM MACC

5. Conclusions

It is clear that the implementation of a carbon tax could have a negative impact over the Brazilian economy. In fact, with a 200 reais/ton carbon tax, the Brazilian GDP suffered, with a loss that ranged from 1% to 4%, depending on the way that the revenues from the carbon tax were recycled. This loss in the GDP produced an unemployment rate higher than what was observed in the BAU projection. But again, the way that the revenues from the carbon tax are recycled impacted directly on this indicator.

The unemployment rate varied approximately from 8% (under option 2) to 12% (under option 0). The carbon tax recycling option has also a strong consequence over the debt of the government. Results from this exercise showed that when the government uses the carbon tax revenues to pay the debt, the economy suffers a stronger negative impact than under any other recycling option. In the other hand, under recycling option 2 the economy suffers the smaller negative impact and the unemployment rate does not increase as under other recycling options, but the debt of the state increases almost 10% compared to the BAU scenario. When the indicator "tons of CO_2 mitigated per number of jobs lost" is compared for all recycling options it is clear that option 2 stands out with the best rate (approximately 150 tons of CO_2 abated per each job lost, against around 20 tons of CO_2 abated per lobs lost under option 0), helping to point out to the government which would be the best policy. It is important to say that those are preliminary results and that for examining the impact of a carbon tax over the economy, more mitigation options should be modeled, including other sectors like energy and land use.

Concluding, hybrid CGE models like IMACLIM present the assets linked to the general equilibrium meanwhile representing at sectoral level the technological trade-off coherent with expert-based assumptions. In practice the model can embark expert-based information in the compact format of specific curves and put it into a general equilibrium framework. By doing this, the model keeps extensive technological detail and all of its advantages, and in the other hand the macroeconomic feedbacks and costs are fully considered. This way IMACLIM-S BR can enrich and advance the discussion on climate policies in Brazil.

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