GHG EMISSIONS' TAX IN BRAZIL USING AN INPUT-OUTPUT MODEL[1]

ABSTRACT

The emission of greenhouse gases (GHG) generated by human activity is a major cause of global warming and climate change. There is considerable debate about the choice of the best mechanism to reduce emissions under a climate policy. In this regard, the aim of this paper is to measure the impact of a policy of taxing GHG emissions in the Brazilian economy as a whole and in the different household groups based on income levels. To do so, we derive a price system from a national input-output model that incorporates the intensity of GHG emissions, as well as a consumption vector disaggregated in ten representative households with different income levels. The main results indicate that taxation was slightly regressive, and had a small negative impact on output. There were, however, significant emissions reductions.

Keywords : Emissions; taxation; income distribution; input-output.

JEL CODES: C67; Q52; Q54.

1 Introduction

Greenhouse gases (GHG) emissions generated by human activity are one of the main causes of global warming and climate changes. Magalhães and Domingues (2013) argue that the rise of average temperature observed since the mid-twentieth century was largely caused by GHG concentration in the atmosphere. According to these authors, Brazil is strongly predisposed to suffer negative impacts of climate change. In the last fifty years, this country has experienced an approximate rise of 0.7º C in mean annual temperature, which is higher than the more optimistic estimative of global average rise of 0.64ºC. Therefore, climate policies should be elaborated to try to address the expectation of continued increases.

Developing countries, mainly Brazil, China and India have suffered pressure from the international community regarding the creation of climate policies due, in part, to their rapid GDP and emissions' growth (Rong, 2010).It is expected that CO_2 emissions in these countries generated? more than half

[1] This paper is a contribution of the Brazilian Network on Global Climate Change Research funded by CNPq Grant Number 550022/2014-7 and FINEP Grant Number 01.13.0353.00.

of global emissions in 2030, even though, in per capita terms, developed countries still occupy the first positions (Bosetti and Buchner, 2009; IEA, 2009). Figure 1 shows the percentage of global GHG emissions according to selected countries or regions.

<*Insert figure 1*>

Developing countries such as Brazil, China, India and Russia together contributed 39% of the global GHG emissions in 2009. It is important to highlight that the Chinese emissions alone accounted for 24% in the same year. On the other hand, Brazilian emissions were approximately 2.4%.

The Kyoto Protocol perhaps had been the major joint effort of policy with respect to global emissions control. Even though Brazil's participated as a non-Annex 1 country, it established the National Policy on Climate Change (PNMC) through Law 12.187/2009 that defines a voluntary national commitment to the adoption of mitigation actions with reductions between 36.1% and 38.9% of projected GHG emissions for 2020 (Magalhães and Domingues, 2013; Palsev and Gurgel, 2014).

There is still considerable debate regarding the choice of the best mechanism to reduce emissions as part of this climate policy. Among other points of contention, we can highlight: market mechanisms, subsidies, taxes, government regulations, carbon trade, carbon tax and cap and trade. However, a topic rarely addressed in the literature, especially for the Brazilian economy, is the impact that the adoption of such a policy would have on the economy, industries and emissions (Magalhães and Domingues, 2013). More than that, what would be, for instance, the distributional impact of an emissions taxing policy in Brazil?

The distributive issue associated with GHG emissions charges was discussed by Symons *et al*. (1994). For these authors, even a neutral tax reform would bring significant emission reductions in the United Kingdom, but with adverse distributional effects. Tiezzi (2005), on the other hand, discussed the charge introduced in Italy on 1999. The regressivity impact of this tax, however, has not been confirmed.

In developing countries, these kinds of studies are rare. For instance, Gonzalez (2012) tested different alternatives through revenues generated by a tax in Mexico. Subsidies on food caused a more progressive distribution while a compensatory reduction on taxes on manufactures (on goods) had a regressive outcome. In Russia, the best result, both on environmental and economic efficiency, was obtained from the taxing on labor (Orlov and Grethe, 2012). Given the oligopoly structure in the energy market, carbon taxation implies production decreases and induces mark-ups on some energy-intensive sectors. It is important to highlight that these two countries have more concentrated emissions in fossil fuel consumption.

In Brazil, Magalhães and Domingues (2013) applied a Computable General Equilibrium (CGE) model to endogenously determine the carbon price for achieve different emission targets. In short-run, the tax was regressive and the carbon price higher. Tourinho *et al*.(2003) simulated charges on CO_2 from the burning of fossil fuels using a Brazilian environmental CGE model. As expected, the model showed the displacement of resources in GHG intensive industries to less intensive sectors. As a result, the investment has increased. Both papers found a small and negative impact on household income, output and emission levels. In turn, Gurgel and Paltsev (2014), using a dynamic CGE model, evaluated the impact of alternative policies to achieve voluntary targets recently adopted by Brazil and concluded, among other things, that the direct emissions reduction from deforestation is the most cost-effective option. Here, the idea is testing outcomes using an alternative model to the CGE (IO model) and compare the results.

To sum up, tax impacts vary according to production and demand structure in each country; therefore, they are not readily generalizable. For Brazil, the literature suggests a regressive effect for emissions tax, generated because the poorest households are the ones with the highest emissions coefficient per dollar of expenditure.

Given the heterogeneity of emissions among different industries, multisectoral models such as input-output (hereafter, IO) and CGE are very suitable for measurement of climate policies impacts. Unlike CGE modeling, IO models are easier to operationalize. According to Rose (1995, p. 297): "The sectoral scheme of an IO table facilitates data collection, and its matrix representation facilitates data organization. The simplicity and transparency of this table are strengths rather than weaknesses." The traditional formulation of IO models, however, treats the economy by considering the demand side. To measure a taxing policy impact through this methodology, the supply-side IO models must be used. To accomplish this, the literature suggests the known pricing or Ghosh Input-Output models (Ghosh 1958; Leontief 1941; 1966; Miller and Blair, 2009).

Taking into consideration the supply-side perspective, this paper aims to measure the impact of GHG emissions taxing policy in the Brazilian economy as a whole and in different households' income levels. In this regard, we developed a pricing system from a national input-output matrix that incorporates the intensity of GHG emissions, as well as a consumption vector disaggregated into ten representative households with different income levels.

In contrast to previous studies, Brazilian emissions were disaggregated into more sectors, allowing a closer look at the different consumption patterns as well as calculations of the short-run effects on household income. This problem, when treated under a distributive perspective, becomes more relevant for Brazil, since this country has historically high levels of income inequality among people and regions.

The next section describes the methodological procedures. The third section reveals the database and the descriptive statistics, followed by the main results and discussion. The last section presents the main findings and policy directions.

2 Method

The basic equation of the IO model, according to Miller and Blair (2009), can be expressed by equation 1:

$$x = Z + f \tag{1}$$

Where x is the total output, Z is the intermediate input matrix, and f is the final demand. Then, the technical coefficient matrix is given by:

$$A = Z\hat{x}^{-1} \tag{2}$$

where each $A = [a_{ij}]$ shows the amount of input i used as intermediate good in the output of industry j. Therefore, Leontief model's solution can be represented by equation 3.

$$x = (I - A)^{-1} f \tag{3}$$

where $(I-A)^{-1}$ is the total impact matrix or Leontief Inverse matrix.

Emissions intensity (e) was calculated as the product of an emissions coefficient (m), i.e., the ratio between emissions of each economic sector and the total impact matrix on the economy:

$$e = m'(I - A)^{-1} \tag{4}$$

The dimension of vector e is $56x1$ and represents emissions released during the production chain of final goods.

Traditionally, in the input-output literature, two price models have been presented: Ghosh model (1958) and Leontief price model (1941, 1946)[1]. In this paper, we adopted the latter one, which

[1] It is important to highlight, however, according to Miller and Blair (2009), that both models produce the same results. For different interpretations of Ghosh model, see Dietzenbacher (1997), Oosterhaven (1996) and Mesnard (2009).

assumes that variations in production costs are converted into price increases. Thus, price (x') is equal to the sum of inputs cost to the value added (v) components.

$$x' = i'A\hat{x} + v' \tag{5}$$

Post-multiplying equation (5) by $\hat{x}^{-1}$, it follows that:

$$i' = i'A + v_c \tag{6}$$

If, $L = (I - A)^{-1}$ and $v_c = v'\hat{x}^{-1}$, and also called $i' = \breve{p}$, the price index for the base year is given by:

$$\breve{p} = L' v_c \tag{7}$$

If a tax on the amount of emitted CO_2 equivalent were charged in the productive sectors, the tax vector (*T*) be be defined as:

$$T' = \varphi e'\hat{x} \tag{8}$$

Given $\tau' = T'\hat{x}^{-1}$, and φ the rate per ton of CO_2 equivalent, R$ 50.00. Finally, the adjusted prices vector ($\tilde{p}$) is:

$$\tilde{p} = L'(v + \tau) \cdot \tilde{p} \tag{9}$$

Following Gemechu *et al*. (2012), if the monetary values of sectoral output are held constant, before and after tax, then the sectoral output becomes:

$$x_j^{\,1} = \frac{\breve{p}}{\tilde{p}_j} x_j^{\,0} \tag{10}$$

Total emissions after tax were calculated as:

$$e^1 = m'x^1 \tag{11}$$

Where x^1 is the vector of sectoral production after tax.

The impact on the price index (π) is given by:

$$\pi = \sum_{j=1}^{56} \tilde{p}_j \alpha_j \tag{12}$$

where α_j is the share which industry *j* production represents in the total output. The government revenue with new tax was estimated as:

$$R = \varphi m' x^1 \tag{13}$$

Assuming households maximize their utilities using a Leontief function, and their income and savings are unchanged, none of each representative household could afford the same basket of goods. Therefore, using price changes derived from the model, it is possible to calculate the income variation necessary to compensate households for the welfare loss. Formally, household welfare change (Δw_k) for decile *k* is the following:

$$\Delta w_k = (\sum_i c_{ik} * \breve{p}_j) - (\sum_i c_{ik} * \tilde{p}_j) \tag{14}$$

where c_{ik} is the quantity consumed by decile *k* from industry *i*.

Knowing that W_{ik} are total payments made by industry *i* to the labor related to the *k* deciles, and assuming industries usage of labor follows a constant share of production, the effect on labor income can be calculated as:

$$\Delta W_{ik} = \frac{W_{ik}}{x_j} \Delta x_j \tag{15}$$

where $\Delta x_j = x_j^{\;1} - x_j^{\;0}$, i.e., the sectoral change in production after tax.

On the other hand, the effect on total income is straightforward:

$$\Delta W_{ik} = W_{ik} + \sum_i W_{ik} + \sum_i \Delta W_{ik} \tag{16}$$

3 Database

The input-output matrix used was calculated at basic prices, from Tables of Resources and Uses of Brazilian Institute of Geography and Statistics (IBGE) base for the year 2009, according to the procedures described in Guilhoto and Sesso Filho (2005) using the hypothesis of "industry-based" technology (Miller and Blair, 2009).

To construct the emissions vector, the follow gases were taken into account: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) measured in carbon equivalents. The data were from *Estimativas anuais de emissões de gases do efeito estufa no Brasil*[2] (MCTI, 2013). These pollutants together constitute the so-called greenhouse gases[3] or GHG, which contribute directly to global warming.

Once the deforestation is curtailed, Brazilian emissions will become more adherent to economic cycles. In the Amazon, the deforestation has fallen from 27,772 km^2 to its lower level of 4,656 km^2, between 2004 and 2012 (INPE, 2014). Therefore, the Brazilian Panel on Climate Change estimates that emissions will rise again after 2021 due to energy and agribusiness sectors (PBMC, 2014). The estimations for Brazilian GHG emissions measured in CO_2 equivalent between 1990 and 2010 are reproduced in figure 2.

<Insert figure 2>

While land-use change and forestry (hereafter, LULUCF) emissions changed widely, one can observe a continuous and stable growth on other GHGs releases in the atmosphere, increasing 77% for the whole period. Given the erratic and seemingly detached behavior from the economic cycle, as well as the growing importance of other factors in the total emissions, the simulation did not include the LULUCF.

The household consumption disaggregation into different income deciles was made from data of Household Budget Survey (POF), while labor incomes were disaggregated according to data from the National Household Sample Survey (PNAD), both released by IBGE for 2009. For both surveys, household per capita income was used to split data into ten deciles. In order to be consistent with the IO data, only the shares of consumption and labor income for each household were used to disaggregate consumption and labor income vectors, respectively. Data obtained from PNAD shows clearly income concentration in Brazil, as one can observe in table 1.

<Insert table 1>

In 2009, the first decile had an average household income of R$ 61.67 per month, i.e., 10% of Brazilians received the equivalent of nearly 30 American dollars[4] per person. This value reaches R$

[2]*Annual estimates of greenhouse gases emissions in Brazil* (own translation). The steps to reconcile the surveyed sectors and the sectors in the input-output matrix are described on Annex 1.
[3] Despite the Sulfur Hexafluoride (SF_6), Chlorofluorocarbons (CFCs) and Hydrofluorocarbons (HFCs) are also considered as greenhouse gases, according to Genty *et al*. (2012), they have a small impact on global warming.
[4] Using the average exchange rate for 2009, when one U.S. dollar was equivalent to 1.99 reals.

2,684.09 for the 10% richest people. With regard to labor income, it corresponds to around 73% of total income on average, with all deciles having similar shares.

Using the combination of income and emissions data, indeed, in 2009, it is possible to observe the significant variation in emission levels between the ranges of household, as displayed in figure 3.

<Insert figure 3>

The emissions coefficient per dollar decrease reflects changes in consumption patterns as income rises. For that year (2009), the emissions per household remained relatively stable until the higher income deciles when the consumption scale effect is more prominent. Each considered GHG series showed similar behaviors.

As the concentration of consumer spending is higher than the concentration of emissions, a tax on GHG-intensive items would have a regressive effect on welfare as measured by consumption expenditure. The per capita household consumption ratio between the two highest income deciles and the two lower was 13.21. In the case of total emissions, the ratio was 4.09.

4 Results and Discussions

The results reveal that the taxation policy is capable of achieving its main goal: mitigate emissions. It was estimated that there would be a significant drop in the level of emissions, around 9.1% reduction for the whole economy. The government's estimated revenue from the new tax reached a high value of R$ 37 billion, and the production decrease was 1.54%. At the sectoral level, emissions variations are heterogeneous, as showed in table 2, for the 21 most polluting sectors.

<Insert table 2>

The most intensive CO_2 sector is Livestock and fishing, accounting for the largest absolute change and percentage of emissions during as a result of the tax introduction; a similar outcome was found for Transport. The underlying hypothesis of a linear production function implies that any change in emissions leads to a decline in sectoral output, which was weighted by rising prices; the emission coefficients remained constant. Therefore, the variation of GHG released into the atmosphere is inversely related to the price change.

In the simulation exercise conducted here, this negative impact reached R$ 84.4 billion, or 1.54% reduction of the total Brazilian production. Figure 4 indicates the sectors with the largest declines. The sectors displayed in figure 4, together account for 79.4% of the total effect. One can note that between them are services deeply related to household consumption, such as Transport, storage and mail, Trade and Lodging and food services. Some other sectors with high emissions (as shown in table 2) also appear: Food and beverage, Agriculture, Livestock and fishing and Oil refining, for instance.

<Insert figure 4>

Even though the policy actives its goal of reducing emissions, with a relative small drop in production, the sectoral changes in production suggests that sectors directly related to household consumption are the most affected. Therefore, given that a significant portion of the expense of lower income households is intended for the food and transport items, the result of the tax has the largest impact on the consumption of lower level income households, and thus the distributional effects become even more important.

Implementing the taxation policy, *coeteris paribus*, implies purchasing power losses for consumers, that can firstly be captured the increases in general prices. The total estimated effect on the general price index is relatively small, 1.01%; nevertheless, Agricultural, food and beverage prices, and some CO_2-intensive industries suffered the greatest variations.

According to the assumptions made about household consumption, the compensatory variation measures the income needed for each household with the same utility level after tax and associated price changes. Figure 5 shows the compensatory variation related to household consumption.

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Regarding the lower income deciles, the tax losses caused above 3.09% decline in welfare, reaching 1.18% for the richest household. This clear regressive pattern is related to the differences in consumption and income between households. While at the lower end of the income distribution items as food and transport account for the major shares, for upper levels, services are the major component. Consequently, as the most affected sectors are those related to basic consumption, the most affected people are the poorest.

Results for labor and total household income exhibits a similar pattern. Figure 6 shows the labor income and total income effects over the ten income deciles.

<Insert figure 6>

Analogous to the compensatory variation results (figure 5), the negative effect over income is greater for the beginning of the distribution. For the first decile, the decline is 3.72% for labor income, compared to 1.02% for the last decile. The impact is clearly smoothed when one is looking for the total income, with a more homogeneous distribution across the households. This behavior can be partially explained by the fact that the income from other sources rather than labor is basically pensions, retirement or social programs.[5]

We also calculate the Gini index[6] related to the household income before and after tax. With the taxation policy, we can see a marginal worsening in the inequality, since the Gini coefficient increased from 0.562 to 0.564.[7]

The results obtained here are similar to those found in the previous literature. The regressive aspect of the tax on pollutant release was considered by Seroa da Motta (2002), who estimated the environmental pressure exerted by income brackets in Brazil. In the specific case of GHG, Silva and Gurgel (2011) claim that the tax impact on GDP are small in the long run. For Tourinho *et al.* (2003), the charge over fossil fuel CO_2 emissions in 1998 generated small impacts for macroeconomic variables, even considering three different scenarios where the price of $C0_2$ tonnes varies between $3, $10 and $20. The most dramatic changes was on sectoral investments with the smaller emission-intensive sectors benefitting the most, as expected by the policy goals. However, the distributive aspects of emissions taxation was not treated in the studies of Seroa da Motta (2002), Tourinho *et al.* (2003) and Silva and Gurgel (2011).

Magalhães and Domingues (2013) introduce the first results for Brazil involving both the impacts of charges on GHG emissions and distributive impacts. The authors concluded that even if the families are directly compensated with the resources from the taxation, the final results are still regressive, or slightly progressive if the transfer is made directly to the poorest households. The estimated cost for 10% decrease in emissions was 1.26% of GDP through 2030. The result was claimed to be related to the energy matrix little intensive on fossil fuels, and the high levels of emissions for food production, deeply related to poor households.

In sum, the exercise hold here indicates that: i) as the income concentration is greater than emissions concentration, the tax shows regressive initial effects, measured by compensatory variation on household consumption; ii) when production changes, and consequently factor payments are taken into account, the regressive impacts are smaller, and almost disappear considering total income, not

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[5] It is worth mentioning that the *"Bolsa família"* program was created in 2004. Broadly speaking, the program goal was to transfer money for poor or extreme poor households.

[6] $G = 1 - \sum_{k=0}^{k=n-1} (X_{k+1} - X_k)(Y_{k+1} + Y_k)$. Where G is the Gini coefficient; X and Y are the cumulative proportion of the variables" population" and "income", respectively.

[7] The index was calculated using PNAD/2009 data on household income. For the index after tax, household income from labor was updated according to sectoral changes observed in the exercise. Therefore, it is worth nothing that the change in inequality here only captures changes in labor income between sectors, but cannot address eventual wage changes within sectors.

only labor income; iii) the effect over the price level and production was small, because the highest tax was on livestock that has a small portion in terms of gross production value; iv) for the first deciles, the largest portion of agriculture wages on overall income generated a regressive aspect in terms of total income.[8]

Therefore, it is possible a suggest convergence of findings in the literature about the small change in GDP, and the regressive aspect of a tax on emissions. However, in this paper, it is possible to see an important reduction on GHG emissions concomitant with a not-so-large change in terms of income distribution, giving support for the policy application even in the short-run. Nevertheless, other aspects not considered here could possibly generate a different result, like the implications on sectoral competitiveness, or the optimal tax value and its dynamic aspects. Other limitations are related to the applied methodology. The production, emissions and labor coefficients were constant in the simulation, and it was assumed that households react to price changes by retaining fixed expenditure shares in their budget constraint.

5 Conclusion and Policy Implications

This paper has calculated the distributive impact on Brazilian households of a tax on GHG. In the short-term, there is a significant reduction on emissions, but an uneven distribution of its burden. The poorest families are more affected in terms of their welfare. Since these families are also those who will suffer the deeper consequences of global warming, such a tax would require compensatory measures. Moreover, if GHG emissions are taken as a proxy for environmental pressure, then there is already an intense inequity; those people more exposed to higher environmental risks are those who contributed less for environmental degradation.

In the near future, the main drivers of Brazilian emissions will be food production and energy consumption. While on the supply side there are promising initiatives for reducing GHG emissions in agriculture, on the demand side, consumption of food tends to decrease as a proportion of household expenditures and household emissions. The energy demand however is expected to grow faster than the increase on renewable energy sources, due to investments on pre-salt oil reserves and the increasing costs of new hydropower plants. Despite its slightly regressive character, a tax on GHG emissions could be important to stimulate a more sustainable path for the energy sector.

[8] For example, for the first decile 36.75% of labor income comes from activities related to Agriculture, silviculture and forestry.

The effects on welfare of a GHG emissions tax goes far beyond the short-term changes in the price index and real income. For instance, it involves normative issues such as the preservation of future generations wellbeing, since the GHG released into the atmosphere today must have impacts on global warming over a broad time horizon.

Further investigation should also observe the impact in the long-term considering the recursive effects, as well as compensatory measures on income distribution and its implications. The model presented does not allow any changes in the technological matrix in response to the relative price modifications. Nevertheless, the focus was on household expenditure and labor profiles. In comparison to other studies, a more disaggregated matrix seems to soften the regressive impact of a carbon tax. In the midterm, reorientation towards less intensive sectors could also favor higher wages sectors.

It is important to highlight that consumption and income effects do not interact in the model, therefore all estimations are first-round effects. In real world, when income falls, household consumption also declines, and with reductions in consumptions, firms need to adjust their production creating a negative cycle. These are general equilibrium effects not taken into account here. Another improvement of this study is include the flows between households and government which is usual in the Social Accounting Matrix (SAM) and CGE model. This improvement allow us identify the compensatory effects from the government.

References

Bosetti, V., Buchner, B. Data envelopment analysis of different climate policy scenarios. Ecological Economics 68(5): 1340 –1354, 2009.

Dietzenbacher, E. In vindication of the Ghosh model: a reinterpretation as a price model. Journal of Regional Science 37(4): 629-651, 1997.

Gemechu, E. D., Butnar, I., Llop, M. and Castells, F. Economic and environmental effects of the CO2 taxation: an input-output analysis for Spain. Working Paper, 24, 2012. Available at: <http://www.urv.cat/creip/media/upload/arxius/wp/WP2012/DT.24-2012-1037-GEMECHU-BUTNAR-LLOP-CASTELLS.pdf>.

Genty, A., Arto, I. and Neuwahl, F. Final database of environmental satellite accounts: technical report on their compilation. WIOD documentation, 2012. Available at: <http://www.wiod.org/publications/source_docs/Environmental_Sources.pdf>.

Ghosh, A. Input-Output approach in an allocation system. Economica New Series 25(97): 58-64, 1958.

Gonzalez, F., Distributional effects of carbon taxes: The case of Mexico. Energy Economics 34: 2102-2115, 2012.

Guilhoto, J. J. M., Sesso Filho, U. Estimação da matriz insumo-produto a partir de dados preliminares das contas nacionais. Economia Aplicada 9(2): 277-299, 2005.

Gurgel, A. C., Paltsev, S. Costs of reducing GHG emissions in Brazil. Climate Policy 14(2): 209-223, 2014.

INPE – Instituto Brasileiro de Pesquisas Espaciais. Programa de Monitoramento da Floresta Amazônica Brasileira. Available at: <www.obt.inpe.br/prodes>.

International Energy Agency - IEA. CO2 Emissions from Fuel Combustion 2009. Edition IEA, Paris, 2009.

Leontief, W. The Structure of the American Economy, 1919-1939: An Empirical Application of Equilibrium Analysis. Oxford University Press: New York, 1941.

Leontief, W. Input output economics. New York: Oxford University Press, 1966.

Magalhães, A. S., Domingues, E. P. Economia de baixo carbono no Brasil: alternativas de políticas e custos de redução de emissões de gases de efeito estufa. Texto para discussão, n. 491, CEDEPLAR/UFMG, Belo Horizonte, agosto de 2013.

Mesnard, L. Is the Ghosh model interesting, Journal of Regional Science 49(2): 361-372, 2009.

Miller, R. E.; Blair, P. D. Input-output analysis: foundations and extensions. New York: Cambridge University Press. Second edition, 2009.

Oosterhaven, J. Leontief versus Ghoshian Price and Quantity Models. Southern Economic Journal 62: 750–759, 1996.

Orlov, A., Grethe, H. Carbon taxation and market structure: a CGE analysis for Russia. Energy Policy 51: 696-707, 2012.

PBMC – Painel Brasileiro de Mudanças Climáticas. Available at: <http://www.pbmc.coppe.ufrj.br/pt>.

Rong, F. Understanding developing country stances on post-2012 climate change negotiations: comparative analysis of Brazil, China, India, Mexico, and South Africa. Energy Policy 38(8): 4582-4591, 2010.

Rose, A. Input-output economics and computable general equilibrium models. Structural Change and Economic Dynamics 6: 295-304, 1995.

Seroa da Motta, R. Padrão de consumo, distribuição de renda e meio ambiente no Brasil. Texto para discussão 856, IPEA, Rio de Janeiro, 2002.

Silva, J. G.; Gurgel, A. C. Impactos de impostos às emissões de carbono na economia brasileira. In: XXXVIII Encontro Nacional de Economia, 2010, Salvador. XXXVIII Encontro Nacional de Economia da ANPEC, 2010.

Symons, E., Proops, J., Gay P. Carbon Taxes, Consumer Demand and Carbon Dioxide Emissions: A Simulation Analysis for the UK. Fiscal Studies 15(2): 19−43, 1994.

Tiezzi, S. The welfare effects and the distributive impact of carbon taxation on Italian households. Energy Policy 33: 1597–1612, 2005.

Tourinho, O. A. F., Seroa da Motta, R., Alves, Y., Uma Aplicação Ambiental de um Modelo de Equilíbrio Geral. Texto para Discussão, nº 976, IPEA – Instituto de Pesquisa Econômica Aplicada, Rio de Janeiro, 2003.

ANNEX 1 – MATCHING GHG EMISSIONS TO INPUT-OUTPUT SECTORS

The second Brazilian communication of the National Inventory Report brings the greenhouse gases emissions from 1990 to 2010. The data were presented according to both methodologies suggested by IPCC. The *Top Dow*, when the total supply of goods whose consumption causes GHG is taken as a reference for emissions. And the *Bottom Up*, the emissions are set to economic sectors following their consumption of those goods.

The correspondence between GHG sources to input-output sectors is shown in Figure A1. If an inventoried source matched more than one economic sector then its emissions were distributed accordingly to sectoral share on production or consumption. All the same, the emissions were made equivalent to intermediate consumption or sectoral production taken from Use and Make Tables. Hence the CO_2 emissions from fossil fuel burning by the energetic source were set trough the sectors: “Oil and natural gas”, “Oil refining and coke” and “Production and distribution of electricity”, accordingly to theirs fossil fuel consumption in the *Top Dow* inventory. Matching the input-output sectors to the National Inventory’s sources of GHG was made possible by the National Economic Activities Classification (CNAE). The CNAE codes are the reference for both, the Brazilian Energy Balance and the National Accounting System. The inventoried sources had theirs PRODLIST codes matched to CNAE codes.

Figure A1: Correspondence between GHG sources to input-output sectors (continues...)

Inventory sectors				**MIP sectors**
ENERGY	Fossil fuel burning	Energetic subsector		Oil and natural gas
				Oil refining and coke
				Alcohol
				Production and distribution of electricity
		Industry subsector	Cement	Cement
			Pig iron and steel	Manufacture of steel and derivatives
			Iron alloys	Manufacture of steel and derivatives
			Mining	Iron ore
				Other mining and quarrying
			Non-ferrous	Metallurgy of non-ferrous metals
				Metal products
			Chemical	Alcohol
				Chemicals
				Manufacture of resin and elastomers
				Pharmaceutical products
				Agrochemicals
				Perfumaria, higiene e limpeza
				Paints, varnishes, enamels and lacquers
				Diverse chemical products and mixtures
			Food and Beverage	Food and Beverage
			Textiles	Textiles
			Pulp and paper products	Pulp and paper products
			Ceramics	Other products of non-metallic minerals
			Other industries	Smoking products
				Vestment goods and acessories
				Leather goods and footwear
				Wood products
				Newspapers, magazines and discs
				Rubber and plastic goods
				Metal products
				Machinery and equipment, including maintenance and repairs
				Machinery for office and computer equipment
				Electronic materials and comunication equipment
				Automobiles, station wagons and pick-ups
				Trucks and buses
				Parts and acessories for automotive vehicles
				Furniture and products from diverse industries
				Other transport equipments
				Medical and hospital rquipment, measurement and optical
		Transport subsector		Transportat, storage and mail
		Agriculture subsetor		Agriculture, forestry, extractive
				Livestock and fishing
		Trade subsector		Trade
		Public Subsector		Public education
				Public heath
				Public administration and social security
	Fugitive emissiona	Coal mining		Other mining and quarrying
		Petroleum extraction and transportation		Oil and natural gas

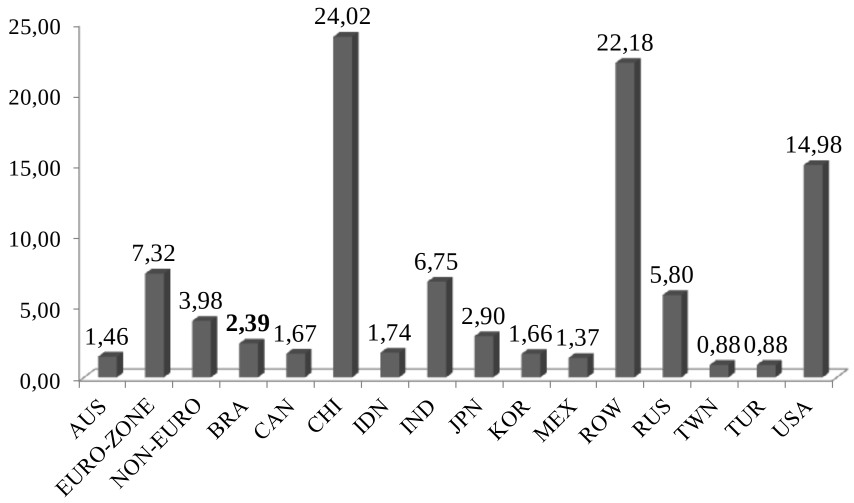
Source: Own elaboration, 2014.

Figure A1: Correspondence between GHG sources to input-output sectors (conclusion)

Inventory sectors			MIP sectors
INDUSTRIAL PROCESSES	Mineral products	Cement production (clínquer)	Cement
		Lime production	Other products of non-metallic minerals
	Chemical industry	Production of ammonia, adipic acid; nitric acid; other chemicals	Chemicals
			Manufacture of resin and elastomers
			Pharmaceutical products
			Agrochemicals
			Perfumes, hygiene and cleaning
			Paints, varnishes, enamels and lacquers
			Diverse chemical products and mixtures
			Agriculture, forestry, extractive
			Other mining and quarrying
			Food and Beverage
			Textiles
	Metallurgy industry	Pig-iron and steel	Manufacture of steel and derivatives
		Aluminum production	Metallurgy of non-ferrous metals
AGRICULTURE AND LIVESTOCK	Enteric fermentation		Livestock and fishing
	Treatment of animal wastes		Livestock and fishing
	Rice cultivation		Agriculture, forestry, extractive
	Burning of agricultural waste		Agriculture, forestry, extractive
	Agricultural soils		Agriculture, forestry, extractive
	Direct emissions	Animals on pasture	Livestock and fishing
		Synthetic fertilizers	Agriculture, forestry, extractive
		Animal waste	Livestock and fishing
		Agricultural wastes	Agriculture, forestry, extractive
		Organic soils	Agriculture, forestry, extractive
WASTE			Production and distribution of electricity

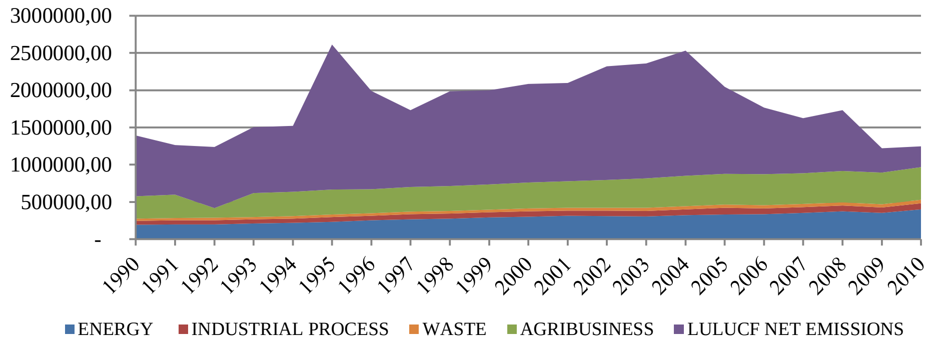
Source: Own elaboration, 2014.

Figure 1: Percentage of global GHG emissions per region - 2009



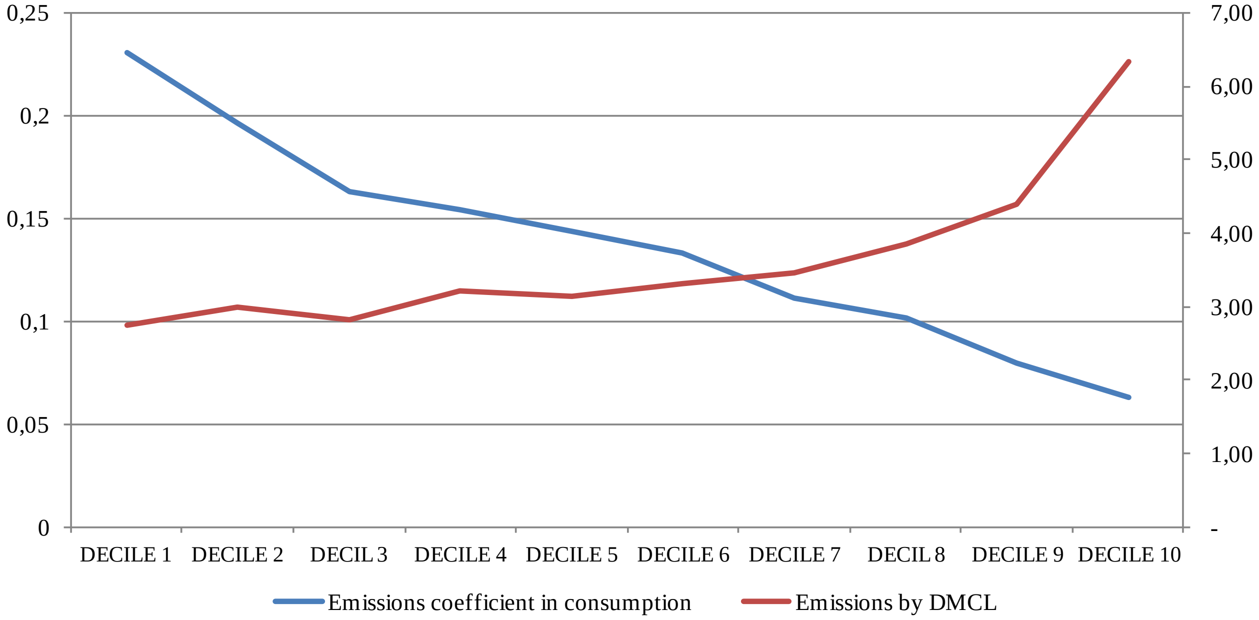
Source: Own elaboration based on World Input-Output Database (WIOD).

Figure 2 – CO_2 equivalent emissions by source, in Gg, between 1990 and 2010.



Source: MCT Data, 2013, p.12.

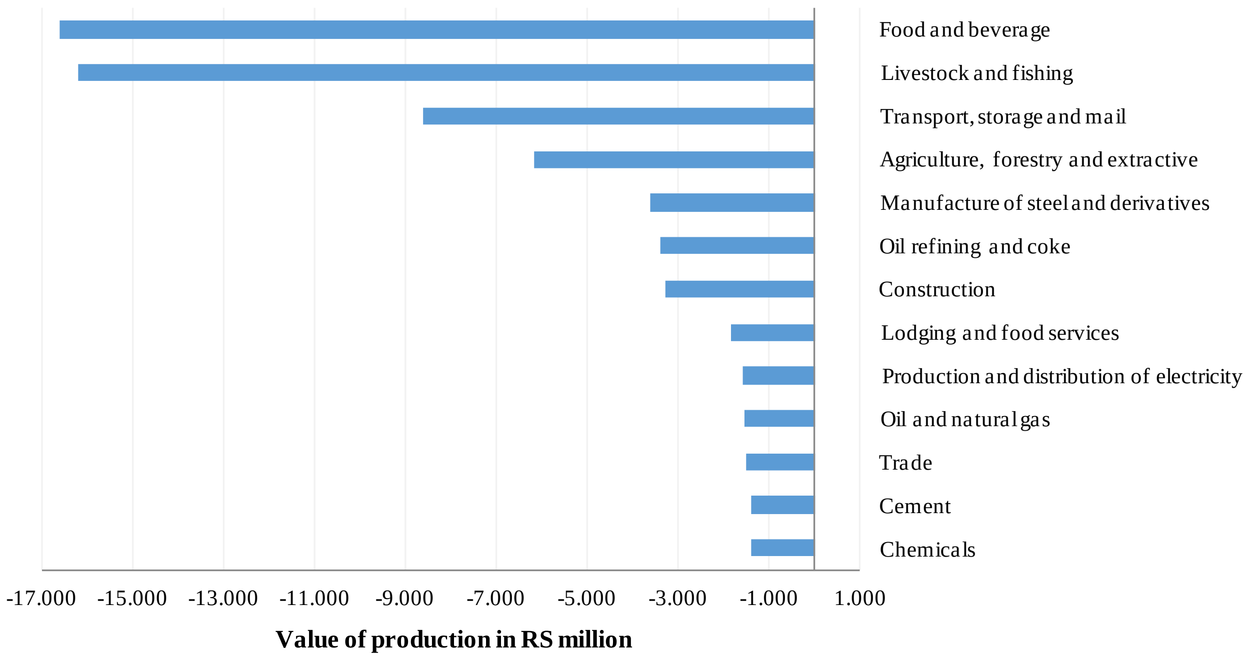
Figure 3 - Household CO_2 equivalent Emissions in 2009.



*On the left axis, for the series of consumption emission coefficients the values are in Gg per million U$. On the right axis, for emissions by households, values in 100 Gg.

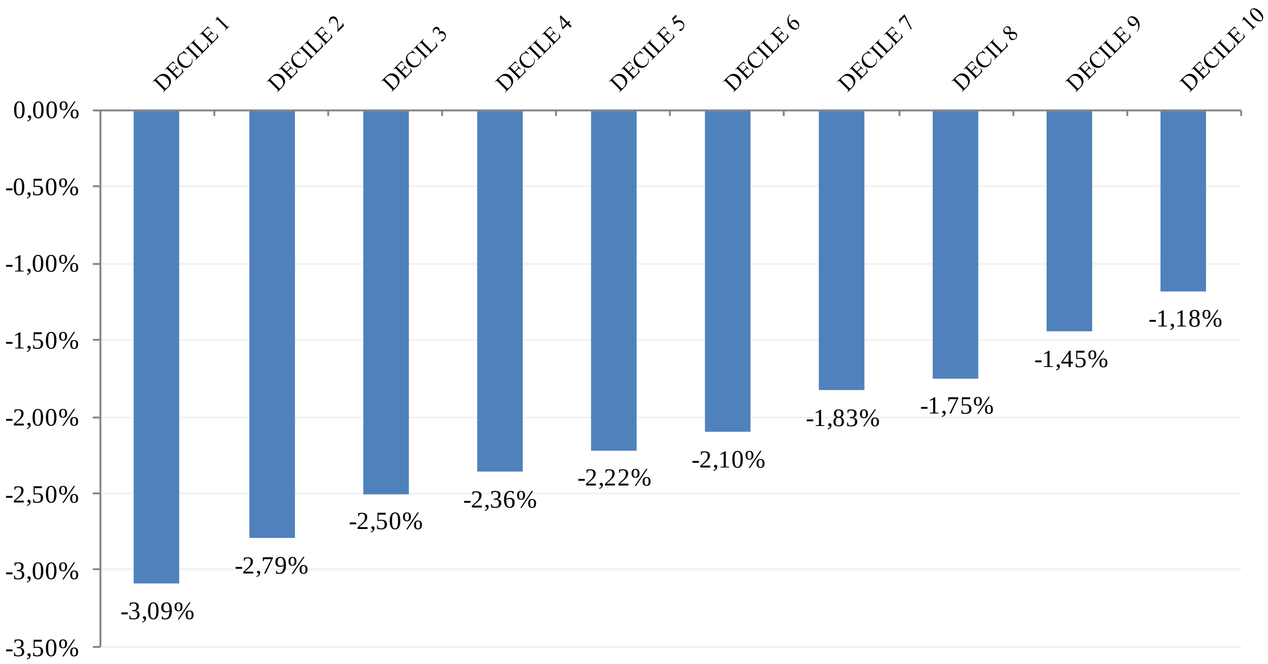
Source: Own elaboration, 2014.

Figure 4: Household consumption change effect



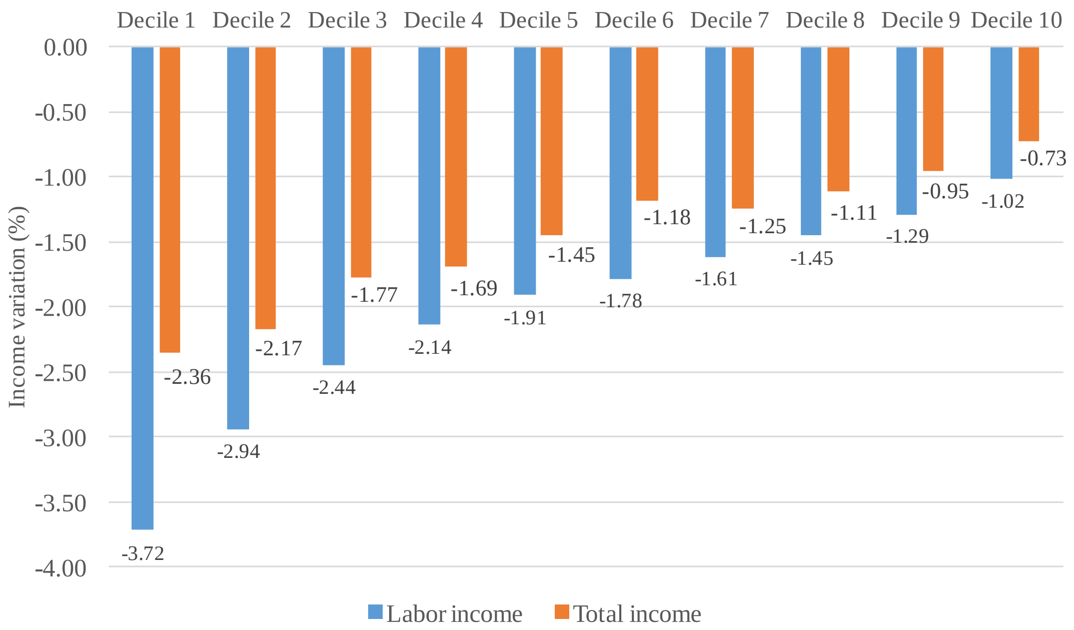
Source: Own elaboration, 2014.

Figure 5 – Welfare loses measured by compensatory variation



Source: Own elaboration, 2014.

Figure 6: Effects over labor income and total income



Source: Own elaboration, 2014.

Table 1 - Descriptive statistics of the income data per month by representative household (in real R$)

	Household per capital income				Household labor per capita income			
	Mean	Std. Dev	Min	Max	Mean	Std. Dev	Min	Max
Decile 1	61.67	32.31	0	106	39.13	104.10	0	900
Decile 2	137.16	16.71	107	165	101.53	192.92	0	1,300
Decile 3	201.47	21.06	166	232	146.43	246.86	0	2,000
Decile 4	266.73	21.01	233	300	211.29	312.81	0	2,200
Decile 5	337.08	21.72	301	375	255.99	348.91	0	2,500
Decile 6	426.87	29.40	376	465	282.98	390.33	0	3,500
Decile 7	529.77	40.86	466	600	409.76	491.48	0	3,890
Decile 8	696.46	56.99	601	800	532.33	626.29	0	5,000
Decile 9	1,004.92	135.82	801	1,293	740.90	901.66	0	9,000
Decile 10	2,684.09	2,515.47	1,294	94,669	1,920.25	3,266.91	0	150,000
Total	631.20	1,083.89	0	94,669	461.25	1,238.536	0	150,000

Source: Own elaboration based on PNAD data (2009).

Table 2 - Total CO_2 equivalent emissions by sector before and after tax, in Gg.

Sectors	Before Tax	After Tax	Variation
Livestock and fishing	339,829.00	285,011.59	-0.16
Transport, storage and postal mail	140,911.19	136,435.67	-0.03
Agriculture, forestry, extractive	100,126.36	96,630.97	-0.03
Manufacture of steel and derivatives	58,654.91	55,655.17	-0.05
Oil refining and coke	32,650.38	31,916.18	-0.02
Cement	28,402.67	25,068.37	-0.12
Other mining and quarrying	21,581.18	20,243.87	-0.06
Oil and natural gas	19,362.45	18,997.09	-0.02
Production and distribution of electricity	17,120.65	16,962.35	-0.01
Chemicals	12,671.26	12,397.48	-0.02
Other products of non-metallic minerals	12,084.05	11,719.51	-0.03
Metallurgy of non-ferrous metals	6,281.45	6,126.41	-0.02
Food and beverage	5,404.61	5,154.71	-0.05
Pulp and paper products	4,488.48	4,417.48	-0.02
Iron ore	3,530.32	3,485.18	-0.01
Alcohol	2,918.34	2,838.49	-0.03
Trade	2,100.35	2,093.98	0.00
Paints, varnishes, enamels and lacquers	1,859.99	1,830.30	-0.02
Public administration and social security	1,586.84	1,583.55	0.00
Construction	1,533.02	1,515.42	-0.01
Textiles	1,311.12	1,297.85	-0.01
Total for 21 sectors	**814,408.61**	**741,381.63**	**-0.09**
Total	**822,069.73**	**748,978.31**	**-0.09**

Source: Own elaboration, 2014.