Department of Economics- FEA/USP

Neutral carbon tax and environmental targets in Brazil

PAULA PEREDA
ANDREA LUCCHESI
CAROLINA POLICARPO GARCIA
BRUNO TONI PALIALOL

WORKING PAPER SERIES Nº 2019-02

DEPARTMENT OF ECONOMICS, FEA-USP
WORKING PAPER Nº 2019-02

Neutral carbon tax and environmental targets in Brazil

Paula Pereda (pereda@usp.br)
Andrea Lucchesi (andrea.lucchesi@usp.br)
Carolina Policarpo Garcia (carolina.policarpo@fgv.br)
Bruno Toni Palialol (bruno.palialol@usp.br)

Abstract:

We evaluate the effects of a carbon tax in the Brazilian economy using an input-output framework. First, we consider the impacts of a carbon tax of US$ 10 and US$ 50/metric ton of CO2 equivalent. As usual, the adoption of the carbon tax generates adverse effects on GDP, wages and jobs in the short term, but reduces emissions and generates new government revenues, especially in the case of the greater tax. Second, we consider a broader tax system reform. In this reform, we replace distortionary taxes by a tax on value added. To compensate for the loss of government revenue, we assume a carbon tax with equivalent revenue. We find that the net effect is a GDP increase of 0.47%, the creation of 533 thousand jobs and reduction of 1.6 million tons of CO2 emissions. Both scenarios exempt exports and levy imports to correct adverse effects on the country's competitiveness.

Keywords: carbon tax; input-output analysis; revenue-recycling effect; neutral tax burden

JEL Codes: H22; Q52; Q58

Neutral carbon tax and environmental targets in Brazil

Abstract.

We evaluate the effects of a carbon tax in the Brazilian economy using an input-output framework. First, we consider the impacts of a carbon tax of US$ 10 and US$ 50/metric ton of CO2 equivalent. As usual, the adoption of the carbon tax generates adverse effects on GDP, wages and jobs in the short term, but reduces emissions and generates new government revenues, especially in the case of the greater tax. Second, we consider a broader tax system reform. In this reform, we replace distortionary taxes by a tax on value added. To compensate for the loss of government revenue, we assume a carbon tax with equivalent revenue. We find that the net effect is a GDP increase of 0.47%, the creation of 533 thousand jobs and reduction of 1.6 million tons of CO2 emissions. Both scenarios exempt exports and levy imports to correct adverse effects on the country's competitiveness.

Keywords: carbon tax; input-output analysis; revenue-recycling effect; neutral tax burden.

1. Introduction

In November 2015, 150 countries participated in the 21st United Nations Conference on Climate Change in Paris (COP-21). On that occasion, the Brazilian government has committed to targets of 1.3 gigatons of equivalent carbon dioxide (GtCO2e) emissions in 2025 and 1.2 $GtCO_2e$ in 2030 (BRAZIL, 2015). Compared to 2005 emissions, these targets represent reductions of 37% and 43%, respectively[1]. Although Brazil already reduced its total emissions by 12% from 2005 to 2012, total greenhouse gas emissions, excluding land-use change and forestry, increased 18%, while *per capita* GDP rose by 17% (Freitas et al., 2016). This points to the need for a national climate policy that encourages a sustainable pattern of development, in addition to the control of deforestation. Among the possible actions to promote a low-carbon economy is the use of cleaner energy sources, and a tax on carbon emissions is one of the potential instruments to motivate its use.

---

[1] The iNDC-Br established targets related to land use, renewable energy and clean technologies to contribute to the IPCC goal of containing the global temperature increase to 2^o C by 2100. Among these iNDC-Br targets, the Brazilian government has committed to: a) restoring and reforesting 12 million hectares of forests by 2030; b) strengthening policies and measures with a view to achieving zero illegal deforestation in the Brazilian Amazon by 2030; c) compensating for greenhouse gas emissions from the legal suppression of vegetation by 2030; d) an 18% increase in the use of biofuels in the energy mix by 2030; e) reaching 45% of renewable energy sources in the Brazilian energy mix by 2030; f) encouraging the implementation of low-carbon agriculture and the recovery of 15 Mha of degraded pastures by 2030; and g) promoting the use of clean technologies in industry and measures to stimulate greater energy efficiency.

Alternatives also include the adoption of a cap-and-trade system. According to Goulder and Schein (2013), carbon taxes do not guarantee that emissions remain at desired levels, which is not the case with cap-and-trade system that prohibit emissions from exceeding a certain amount. Cap-and-trade has a greater ability to achieve broad sectoral coverage and the associated cost-effectiveness. This system may be politically easier to implement since most agents (erroneously) do not see it as a tax (Stavins, 2007).

Therefore, we study a carbon tax for two reasons: (i) the input-output framework accommodates a carbon tax[2] and (ii) it allows introducing a carbon tax as part of broader tax system reforms (Goulder and Schein, 2013; Zhang and Baranzini, 2004). There are also other advantages of a carbon tax over a cap-and-trade system, including the complexity of designing safe and fair cap-and-trade legislation and reducing the volatility of emission prices (Goulder and Schein, 2013).

Carbon taxes generate incentives to adopt innovative, cleaner and more efficient technologies[3]. We analyze the impacts of carbon tax adoption in Brazil on emissions and on various economic indicators. While it is common to propose new taxes to correct market failures, the Brazilian tax burden is high (36% of GDP in 2014), and the creation of additional taxes might encumber productive activity further. Thus, we also propose the correction of specific tax distortions in the country in order to obtain a neutral tax burden.

---

[2] This is not the case with cap-and-trade where a maximum emission should be calculated for each sector and no transactions between sectors would be allowed.

[3] Carbon taxes can also have distributional effects across income groups and sectors in the domestic economy and relevant impacts on the international competitiveness of firms, as there are asymmetries in the adoption of carbon taxes in other countries. The distributional income issue can be addressed by properly recycling the revenue from the tax, a topic explored in some studies. The domestic sector reframing, possibly including the exclusion of inefficient firms or those that are relatively more polluting, is unavoidable if the policy is successful, and the government can act to help reallocate the agents of the impaired sectors. Regarding the potential loss of international competitiveness of domestic firms, the solution usually adopted by governments, and in this study, is to consider mechanisms that offset the possible adverse effects when trading partners do not adopt similar policies, such as exemptions.

In particular, we consider the existing distortions from two fiscal levies: the Contribution to the Social Integration Program (PIS)[4], and the Contribution to Finance Social Security (Cofins)[5]. PIS and Cofins generate earmarked revenues for specific uses instead of going into the general fund. They give the government more discretionary spending power because revenues from taxes are subject to several constitutionally mandated set-asides, such as revenue sharing with state and municipal government. Both levies have a noncumulative incidence on the productive chain for most companies, and failures are observed in sectors that do not accumulate tax credits from suppliers. Thus, we propose the replacement of *PIS/Cofins* with a tax on value added (a VAT), which is how most countries collect such taxes. We explain the sources of the tax distortions in the next sections.

To estimate the short-term effects of such changes, we use the Brazilian input-output (IO) matrix from the Brazilian Accounting System[6] and the Brazilian Energy Balance (BEN)[7] for 2011. We consider the Brazilian Emission Inventory (BRAZIL, 2014)[8] emission factors to calculate the CO_2 emissions of all economic production and estimate the own-price elasticities of 128 products to calculate the shock from tax changes. We estimate the effects on GDP, employment, wages, CO_2 emissions and total tax receipt in Brazil.

The IO exercise assumes a shift in the final demand from marginal variations of tax incidence. We use the IO model for three main reasons. First, IO models have fewer data requirements, though capturing relevant inter-industry linkages, and in this sense, they are feasible

---

[4] PIS was created in 1970. The revenue from PIS finances unemployment insurance and other cash transfers related to labor markets in the country. The payers are companies, except micro-enterprises and small businesses. The tax is levied on the total revenue earned (0.65 or 3%, depending on the sector).

[5] *Cofins* is the contribution that finances social security programs (not to be confused with social security contributions to the pension system). It was created in 1991 and applies to the same group of companies as PIS, at rates of 3 to 7.6%, depending on the sector.

[6] The Brazilian Accounting System is computed by the Brazilian Institute of Geography and Statistics (IBGE). We construct the IO table according to methods of Guilhoto and Sesso Filho (2005) and with data provided by IBGE.

[7] *Balanço Energético Nacional* computed by the EPE (Energy Research Company), Ministry of Mines and Energy.

[8] Based on the IPCC (Intergovernmental Panel on Climate Change) guidelines.

instruments for the proposed analysis (Gemechu et al., 2014). Second, with this approach, the carbon tax becomes a comprehensive environmental instrument for final consumers, since it modifies their consuming behavior. Third, even though the main limitation of IO is that it assumes fixed coefficients, disregarding potential changes in industrial structure as a response to changes from the carbon tax, we believe that it gives relevant short-term responses, which are less sensitive to structural changes (longer-term changes).

We potentially overestimate policy impacts, since IO models do not consider supply-side constraints. Thus, a natural extension of this paper is the analysis using more flexible methods, such as computable general equilibrium (CGE) models. In CGE models, not only prices are endogenous to the model, but they also allow substitution effects in production and consumption. Despite their usefulness, CGE models require more data and have higher implementation costs than do IO models. In this paper, we chose IO model as a first assessment of short-term results from a carbon tax accompanied by correction of tax distortions in Brazil.

The paper is organized as follows: First, we present the literature review of the effects of a carbon tax on the economy in Section 2. Section 3 discusses distortions caused by PIS/Cofins collection in Brazil and how a carbon tax can include the environmental agenda in this context. We then present, in Section 4, the input-output framework, which we use to address the impacts of PIS/Cofins simplification along with the implementation of a carbon tax in the Brazilian economy. Section 5 presents our empirical results and discusses the implications of the tax changes proposed, and we summarize by discussing the main findings in Section 6.

2. Literature review

The climate change mitigation agenda motivated a broad range of studies trying to understand the impacts and effectiveness of carbon pricing policies.[9] There is not much debate on the mitigation effects of carbon pricing mechanisms on emissions. At the global level, Nordhaus and Boyer (2003), Whalley and Wigle (1991) and Manne and Richels (1990) estimate the impacts of a carbon tax on CO_2 emissions, and all of them show significant mitigation effects despite the different settings and tax rates. Many papers estimate the emissions effects of carbon taxes in specific countries.[10] As a rule, these studies find a reduction in emissions from the adoption of a carbon tax, but although usually small, the effects on GDP are negative without a compensation plan.

More recently, an extensive debate has emerged about carbon pricing policies as options to mitigate the expected changes in climate, while circumventing side effects and promoting less distortionary and more progressive tax systems. As Parry (2003) notes, both carbon taxes and cap-and-trade systems imply efficiency losses in the labor market, since they reduce real household wages by the general price increase. However, the efficiency losses can be offset by controlling other distortions from the tax system (e.g., when revenues from carbon taxes or permits offset the reduction of revenue due to the correction of some other distortionary taxation).

Indeed, there might be efficiency goals when combining carbon taxes (or permits) with other tax policies. Goulder and Schein (2013) argue that the adoption of carbon taxes seems to be on the rise, especially due to the complexity of designing safe and fair cap-and-trade legislation and the possibility of introducing carbon taxes as part of broader tax system reforms. The compensation

[9] See Keohane (2009) and Goulder and Schein (2013) for critical reviews of carbon tax versus cap-and-trade mechanisms.

[10] Some examples are Calderon et al. (2016) for Colombia; Allan et al. (2014) for Scotland; Gemechu et al. (2014) for Spain; Conefrey et al. (2013) and Wissema and Dellink (2007) for Ireland; Meng et al. (2013) for Australia; Lu et al. (2010) for China; Floros and Vlachou (2005) for Greece; Aasness et al. (1996) for Norway; and Goto (1995) for Japan.

effect that allows carbon tax revenues to reduce the level of distortionary taxes is known as the 'revenue-recycling' effect (Zhang and Baranzini, 2004).

Parry and Williams (2011) evaluate the welfare losses of reducing U.S. energy-related *CO2* emissions via carbon taxes and cap-and-trade systems and find that the net effect depends on how these policies interact with distortions in the economy created by the broader fiscal system. If an allowance rent is not used to increase economic efficiency, economy-wide cap-and-trade systems perform the worst in terms of cost-effectiveness. If revenues from a carbon tax substitute distortionary income taxes, then economy-wide carbon taxes may have slightly negative welfare effects.

Parry et al. (1999) analyze the welfare effects of a revenue-neutral carbon tax and non-auctioned carbon emissions permits, considering preexisting tax distortions in factor markets, and find that an appropriately scaled carbon tax is welfare improving while a cap-and-trade system increases welfare only if the environmental damage exceeds a specific value per ton of carbon.

The literature also explores the loss of competitiveness of domestic firms in international trade due to domestic carbon taxes adopted unilaterally. Jaffe et al. (1995) review over 100 studies of the potential effects of environmental regulations on the competitiveness of American industry. They conclude that studies attempting to measure the effects of environmental regulation on net exports, overall trade flows, and industry location decisions produce estimates that are either small, statistically insignificant or not robust to tests of model specification.

Zhang and Baranzini (2004) also review many empirical studies on existing carbon/energy taxes and conclude that competitive losses seem to be not significant. However, they consider that commitments to future emissions reductions may imply higher tax rates, with bigger potential effects on competitiveness than the ones computed in these studies. In fact, a more recent survey conducted by Carbone and Rivers (2017) concludes that carbon taxes and cap-and-trade systems lead to modest reductions in output and exports from emission-intensive sectors. According to the authors, on average policies designed to reduce emissions by 20% can reduce output by 5% and exports by 7% from emission-intensive trade-exposed sectors.

Potential competitive damage can generate some exemptions in the application of carbon taxes. Böhringer and Rutherford (1997) analyze the welfare costs of sectoral carbon tax policy exemptions for energy and export-intensive industries. Using a general equilibrium model for West Germany calibrated to 1990 data, they evaluate the excess costs of exemptions as a mean of saving jobs in specific industries relative to an alternative instrument, a uniform carbon tax with the addition of a wage subsidy for the industries exempted in the previous scenario. They find that the alternative scenario could achieve an identical level of national emissions and employment at a fraction of the cost.

Lin and Li (2011) estimate the real mitigation effects of carbon taxes on five northern European countries using a difference-in-differences approach. The results indicate that the carbon tax in Finland imposes a significant and negative impact on the growth of its per capita CO_2 emissions, while the effects of carbon taxes in Denmark, Sweden and Netherlands are negative but not significant. In Norway, the carbon tax has not achieved its mitigation effects. According to the authors, the mitigation effects of carbon tax diminishes due to the tax exemption policies applied to certain energy-intensive industries in these countries.

Additionally, numerous studies investigate the impact of carbon taxes on the household income distribution of countries, but there is no consensus in the literature on whether this would be a regressive or progressive tax. The regressive effect is well recognized for developed countries, for which the literature on the distributional effects of carbon taxes is somewhat consolidated. In those countries, a carbon tax usually burdens lower-income families, which generally spend a higher proportion of their income on energy and natural resources, than higher income families.

Some examples of work in this context are Callan et al. (2009), Brännlund and Nordström (2004), Labandeira and Labeaga (2002), Barker and Köhler (1998), Cornwell and Creedy (1996), Hamilton and Cameron (1994) and Pearson and Smith (1991).

The literature is scarcer for developing countries. As there are considerable differences in the sources of the energy matrix, transportation means, heating (usually, absence of heating systems) and goods consumed (such as processed food), the conclusions for developed countries cannot be translated to developing ones (Brenner et al., 2007). Indeed, the literature indicates that the progressive character of the carbon tax in developing countries depends on the ways the revenue raised is recycled in the economy. In particular, Freitas et al. (2016) use an IO model to study the distributional effects of a tax on greenhouse gases and find that the taxation system without any compensation would be slightly regressive and would have a small negative impact on output. Also in an IO framework, Grottera et al. (2017) test two options for revenue recycling in Brazil and find that direct transfers to low-income households make the carbon tax progressive, while exemption from labor taxes is a regressive path. Gonzalez (2012) finds that revenue-recycling is regressive when manufactured as a tax cut and progressive when implemented as a food subsidy in Mexico. For China, the study of Brenner et al. (2007) indicates that if revenue recycling happens to the public on an equal per capita basis, low-income (mainly rural) households would receive more than they pay in carbon charges, and high-income (mainly urban) households would pay more than they receive[11].

3. Brazilian tax system and a carbon tax

Brazil has one of the most complex and distortionary tax systems in the world (PwC, 2013). Although tax reform is one of the most discussed topics on the Brazilian political agenda, conflicts

---

[11] See also Van Heerden et al. (2006) and Timilsina and Shrestha (2002).

of interest among federal, state and municipal governments and between the stronger and disadvantaged sectors are obstacles to meaningful reform. Moreover, public deficits exclude any proposal that could result in a decrease in government revenue.

To include the environmental agenda in this context, we evaluate the impacts of a revenue-neutral carbon tax that would be offset by the correction of distortions from *PIS* and *Cofins*. These are federal taxes imposed on gross revenue earned by companies, as previously described. We chose these taxes because they significantly affect the competitiveness of domestic production and the efficient organization of the productive structure. Moreover, disputes between the federal tax administration and companies related to *PIS/Cofins* account for much of the tax litigation involving the federal government.

The tax incidence system is generally noncumulative, under which *PIS* and *Cofins* are levied on gross revenue at 1.65% and 7.6%, respectively, with offsetting credits from the acquisition of products and services to maintain the productive activity. These levies, in general, affect imports but exempt exports. However, exemptions and special schemes apply to many industries and firms, which makes the system even more complex and distortionary and creates legal uncertainty.

Many *PIS/Cofins* distortions arise from overlapping cumulative and noncumulative regimes. All companies subject to the presumed profit regime[12] are in the cumulative system, at higher rates, while companies subject to the real profit regime are generally in the noncumulative regime. Some companies work with both regimes - applicable on revenues from different activities, regardless of industry—and pay taxes on a cumulative basis, which reduces *PIS* and *Cofins* rates to 0.65% and 3.0%, respectively. The company is not entitled to input tax credits. In addition, some

[12] This is a simplified tax payment option available to companies with annual gross revenue equal or lower to R$ 78 million (or US$ 47 million, using 2011 average exchange rate).

sectors, such as telecommunications, pay taxes on a cumulative basis. This overlap between cumulative and noncumulative regimes generates a series of cumulative impacts along the production chain, which prevent, for example, the complete exemption of exports, when companies in the cumulative regime do not appropriate credits for taxes paid at the previous step of a production chain.

Even the noncumulative incidence regime is a subtractive system, which also generates distortions. In this system, credit generation is always 9.25% of the input even when the input is acquired from a company taxed by the cumulative regime at 3.65%. This incidence creates incentives for companies to artificially fragment, allocating part of the production process on deemed profit basis to companies that collect taxes at a rate of 3.65% and generate credits at a rate of 9.25%. This tax planning process makes the organization of production in the country irrational.

In addition, regardless of the incidence scheme, the Brazilian Federal Revenue Office has a very restricted interpretation of the input concept: goods and services purchased and not incorporated by the company into the final product do not generate credits. This has given rise to considerable litigation between companies and the Brazilian Federal Revenue Office.

Imports also face a significant number of exemptions. All imported equipment and input goods in the *Zona Franca de Manaus*[13] do not pay PIS/Cofins, for example. This is also the case for some specific goods, such as press paper, intermediate inputs for aircraft and boats (maintenance and construction), petrochemicals, naphtha and natural gas.

Given this distortionary system, we propose a carbon tax that would be offset by a value-added tax (VAT) that replace *PIS/Cofins* taxes. This proposed VAT would have a single rate reaching all goods and services in a noncumulative system for all industries and companies of all

---

[13] The Free Economic Zone of Manaus is a region located in the city of Manaus, State of Amazonas, Northern Brazil, where industries are provided with many tax exemptions to promote economic activities.

sizes without special schemes. Moreover, all taxes paid at previous stages of production would generate credits.

We construct the scenarios for this study using the structure of the VAT proposed. Beyond the static effects assessed here, there are also several other benefits that would arise from *PIS/Cofins* reform. These dynamic effects would take a few years to materialize and would mainly result from an increase in productivity from more efficient organization of the economy and reduced costs and legal uncertainty.

4. Empirical strategy

In this section, we present the data sources, methods and hypotheses of our analysis. At the end of this section, we also describe the scenarios we consider in this study.

Input-output analysis allows the identification of how each sector interacts with others during its production process. This is useful for our purposes for the following reasons: i) it allows the estimation of PIS/Cofins debits and credits among sectors; and ii) it allows the identification of how sectors change their production inputs when carbon-based energy sectors face taxation.

We use the national input-output matrix for 2010-2011 (base year 2011), built according to the method developed by Guilhoto and Sesso Filho (2005). This matrix is constructed based on the 2011 Supply-Use Tables (SUTs) provided by the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística [IBGE], 2017) and contains information for 68 sectors and 128 products.[14]

To calculate the impacts of a carbon tax on the economy, we build a hybrid matrix containing the amount of energy used by each sector. First, we create an energy requirements matrix $\mathbf{E}_{m\times n}$, where m indexes energy sources, and n indexes economic sectors ($m < n$). Then,

[14] It takes at least three years for IBGE to release the SUTs for a specific year. When this paper was written in 2015, the most recent SUTs available were those from 2011. We used the method of Guilhoto and Sesso Filho (2005) to construct the IO matrix, since at that time only preliminary data on the Brazilian national accounts were available.

matrix $\mathbf{E}$[15] substitutes the lines of the intermediary input flows matrix **Z** in the energy sectors –we call this matrix $\mathbf{Z}^*$. We do the same for the total production vector (**X**) and final demand (**Y**), creating $\mathbf{X}^*$ and $\mathbf{Y}^*$, respectively. The hybrid technical coefficient matrix, $\mathbf{A}^*$, is:

$$\mathbf{A}^* = \mathbf{Z}^*\left(\widehat{\mathbf{X}}^*\right)^{-1} = \begin{bmatrix} toe/toe & toe/\$ & toe/\$ \\ \$/toe & \$/\$ & \$/\$ \\ \$/toe & \$/\$ & \$/\$ \end{bmatrix} \tag{1}$$

Given final demand vector $\mathbf{Y}^*$, we calculate the production impacts of an energy demand variation ($\Delta\mathbf{Y}^*$) to the original model ($\Delta\mathbf{X}^* = \mathbf{L}^*\Delta\mathbf{Y}^*$, where **L** is the Leontief inverse).

To build matrix **E**, we rely on information from the Brazilian Energy Balance (BEN), which provides energy requirements (in tons) for 16 economic sectors plus residences. Since the sectors are more aggregated in the Brazilian Energy Balance, to make the Supply-Use Tables compatible with the BEN data, we aggregate the SUT sectors according to the BEN sectors' aggregation. Appendix 1 provides details of this aggregation. We also transform energy requirements into CO_2 to analyze emissions. Furthermore, we assume that CO_2 emissions are linearly correlated with energy requirements, so we can estimate both direct and indirect emissions by sector. For energy conversion to CO_2, we use the Brazilian Emissions Inventory, BRAZIL (2014), a publication based on the IPCC Guidelines (IPCC, 1997). This work provides CO_2 conversion coefficients that consider the characteristics of the chemical process and technology applied by each sector.

After building the hybrid versions of the 'use' and 'make' matrices as explained above, we must manipulate them in order to calculate the CO_2 emissions coefficients. First, we calculate the proportion of each product used in the total production of a specific sector:

---

[15] Matrix **E** is measured in toes (tons of oil equivalent).

$$b_{ij} = \frac{u_{ij}}{\sum_i r_{ij}} \quad (2)$$

where \u_{ij} is the element ij of the 'use' matrix, denoting the amount of product i used in the production of sector j, and $\sum_i r_{ij}$ is the total production of sector j. Second, we calculate the proportion of a sector in the national production of each good through the 'make' matrix.

$$d_{ij} = \frac{r_{ij}}{\sum_j r_{ij}} \quad (3)$$

where $\mathbf{R}=\{r_{ij}\}$ is the 'make' matrix for product i in sector j, such that r_{ij} is the amount of i produced by sector j and $\sum_j r_{ij}$ is the total production of good i.

Multiplying **B** by $\mathbf{D}t$, we find $\mathbf{A}p$, the technical coefficient input matrix. Each term of $\mathbf{A}p$ shows how many units sector j uses of product i to produce one unit. As we are working with hybrid matrices, these coefficients can be interpreted as the quantity of CO_2 that product i uses to produce one unit of product j. Thus, to find the CO_2 emissions coefficients, we merely sum the cells of $\mathbf{A}p$ that measure CO_2 emissions.

$$c_{i,CO_2} = \sum_k ap_{kj}\, , k \leq i \quad (4)$$

in which k are the lines substituted by CO_2. This method only calculates direct emissions coefficients. To consider the indirect impacts, we take the intermediate consumption coefficients and multiply them by a Leontief inverse matrix (Table 1 presents the calculated coefficients).

The input-output method also allows evaluating the impacts of a demand shock on employment, taxes, and wages, among others. Suppose sector j has a total output of x_j and employs ε_j workers. The coefficient of employment of sector j, ce_j, is given by:

$$ce_j = \frac{\varepsilon_j}{x_j} \quad (5)$$

and indicates the number of workers employed in sector *j* for each monetary unit produced by the sector. By calculating the coefficient of employment for each of the *n* sectors of the economy and ordering them in the form of a vector, we have the vector **ce** of order $n \times 1$. Thus, for a variation of ΔX monetary units in the production, the impact on the number of jobs Δε is given by:

$$\Delta\varepsilon = \widehat{\boldsymbol{CE}}\Delta\mathbf{X} \tag{6}$$

in which $\widehat{\mathbf{CE}}$ is a matrix of zeros with the elements of the vector **ce** on the main diagonal.

To estimate tax collection variation derived from the PIS/Cofins correction, we generate matrices with debit and credit rates. Vendors pay debit rates while consumers pay credit rates (applicable in the noncumulative regime).

Our main assumptions regarding these matrices are that 1) agriculture and public services are PIS/Cofins exempt and, therefore, do not generate credits; 2) the industrial sector, SIUPs,[16] construction, and commerce are subject to the noncumulative regime with a 9.25% debit, but they gain credits when buying from the industrial sector; 3) the services sector is composed only of companies that are subject to the presumed profit tax system and are therefore under the cumulative regime with a 3.65% debit and no credit rights;[17] 4) we adopt specific debit and credit rates for food and beverages and chemicals because most food items have zero rate and there are benefits for the chemicals sector.

Therefore, we build a matrix with net rates by comparing debit and credit matrices by subtracting one from the other in each cell. Based on the net rates[18] and intermediate consumption, we estimate the cumulative incidence of PIS/Cofins or the rates considering debits with no corresponding credits, due to taxation policies.

---

[16] Sector of industrial services related to utilities such as urban cleaning and sewage collection.
[17] The only exception is passenger transportation services.
[18] Where PIS-Cofins is charged.

To estimate the VAT[19] we consider two hypotheses. First, there is no cumulative incidence along the productive chain, i.e., all debits correspond to one credit. Second, the VAT rate is uniform for all goods and services.

We calculate the VAT rate as to equal the current PIS/Cofins incidence until final demand[20]. In other words, VAT revenue is expected to be lower than PIS/Cofins revenue, as it does not consider cumulative incidence. The difference between them corresponds to the carbon tax value that keeps the tax burden unchanged.[21]

Considering that these shocks are transmitted throughout the economy via prices, we need to understand how consumers react.[22] For this purpose, we estimate[23] the demand price elasticity ($\in_p^S$) for each product *s*:

$$\in_p^S = \frac{\partial q^S}{\partial p_f^S} \frac{p_f^S}{q^S} \qquad (7)$$

where p_f^S is the goods' price, as observed by individuals in the market. The next step consists of generating the shocks applied to the matrix. The first one is the carbon tax shock and the second is the PIS/Cofins–VAT substitution.

The carbon tax shock considers the total product CO_2 emissions (TPE).[24] For example, to produce \$100 of rice, the agriculture sector generates 0.5 ton of CO2. Therefore, taxation impacts

[19] The value-added tax (VAT) is a consumption tax commonly used in Europe and in other countries. Its main characteristic is that the buyer receives reimbursement after adding value and reselling a good.

[20] We only consider the static effects of the substitution.

[21] The carbon tax estimated to promote a neutral tax burden is US\$ 35.68/ ton CO_2.

[22] Note that exports are exempt from the carbon tax, so they are not affected by policy prices.

[23] We calculate the price elasticities based on Brazilian Household Budget Survey (POF/IBGE 2008-09, last survey available). Details are available upon request.

[24] We calculate total emissions by multiplying the CO_2 emissions coefficient by the net exports total production.

rice revenue in t + 1 by $\$\tau$ 0.5, where τ is the tax for a ton of CO_2. To verify the impact on rice prices ($p_{f,t+1}^{Rice}$) we have:

$$\frac{\Delta p_{f,t+1}^{Rice}}{p_{f,t}^{Rice}} = \frac{\left(p_{f,t+1}^{Rice} - p_{f,t}^{Rice}\right) q_t^{Rice}}{p_{f,t}^{Rice} q_t^{Rice}} = \frac{\$\tau.TPE}{p_{f,t}^{Rice} q_t^{Rice}} \qquad (8)$$

Using this new price and the estimated price elasticity, we can compute marginal consumer responses to the marginal price change:

$$\frac{\Delta q_{t+1}^{S}}{q_t^{S}} = \frac{\Delta p_{f,t+1}^{S}}{p_{f,t}^{S}} \widehat{\epsilon_p^{S}} \qquad (9)$$

The PIS/Cofins–VAT substitution shock considers the tax burden change transmitted through the productive chain to final prices. For example, consider that to produce \$1 million of steel there is a cumulative incidence of \$T1[25] of PIS/Cofins. VAT adoption implies a reduction or increase in steel tax receipts of \$T2[26] for each \$1 million of steel. The total effect on steel prices is then \$T = \$T1 + \$T2, which can be positive or negative depending on the sector.

Thus, PIS/Cofins substitution by a VAT has an impact of $\$\Delta T$ on steel revenues in t + 1, where $\$\Delta T$ equals $\$T$ times the value of steel sold (net of exports). We calculate the marginal impact on prices ($p_{f,t+1}^{Steel}$) as:

$$\frac{\Delta p_{f,t+1}^{Steel}}{p_{f,t}^{Steel}} = \frac{\left(p_{f,t+1}^{Steel} - p_{f,t}^{Steel}\right) q_t^{Steel}}{p_{f,t}^{Steel} q_t^{Steel}} = \frac{\$\Delta T}{p_{f,t}^{Steel} q_t^{Steel}} \qquad (10)$$

Accordingly, we evaluate consumers' marginal responses to the price variation using the estimated price elasticity:

---

[25] Always negative since removing cumulative incidence benefits all sectors.

[26] This can be either positive or negative depending on the sector.

$$\frac{\Delta q_{t+1}^{S}}{q_{t}^{S}} = \$\Delta T . \widehat{\in_{p}^{S}} \tag{11}$$

Note that the change in quantity is the consumers' response to a marginal variation in prices, such that an increase in the price of an input, e.g., through the taxation of fossil fuels via a carbon tax, might cause a reduction in the quantity demanded by all sectors that use such fuel directly or indirectly. Hence, the effects on GDP, wages, and jobs are a consequence of a quantity shock.[27] It is important to emphasize that this result makes conceptual and macroeconomic sense in the short run and it does not capture the effects in the subsequent time periods. In this sense, the assumptions adopted by the IO framework must be clear so that the conclusions can be relativized.

Scenarios

We study two main scenarios to evaluate the impacts of a carbon tax in the Brazilian economy. In the first one, we consider two different values for the carbon tax, US$ 10 and US$ 50. According to a World Bank report (World Bank, 2015), 85% of countries that implemented a carbon tax adopt values close to or below US$ 10/tons CO_2. Also, the European Emissions Trading System (EU ETS), the world's largest emission control system, adopts US$ 10/tons CO_2. US$ 50 is the tax for Brazil to meet the goals proposed in the INDC, according to a study by COPPE/UFRJ[28], one of the most renowned Brazilian research institutes in energy policy. Besides the US$ 50 tax, Brazil should also comply with the ABC Plan (Low Carbon Agriculture) and eliminate net deforestation throughout the country. The US$ 50 tax also provides a sensitivity test in comparison to the US$10 tax.

---

[27] The IO model assumes a linear relationship of production, number of jobs and wages. If a given sector uses *j* employees to produce *x* units (in monetary terms) and pays wages *w*, then the sector uses 2*j* employees to produce 2*x* units paying 2*w*. As the price changes are considered marginal, the effects on the economy are only related to a quantity shock. Any changes in wages and jobs are due to the reframing of the demand between sectors.

[28] Alberto Luiz de Coimbra Postgraduate Institute, Federal University of Rio de Janeiro.

In the second scenario, the carbon tax is a neutral tax. The idea is to correct existing distortions of two taxes (PIS and Cofins), that are cumulatively levied in the productive chain, by replacing them with a tax on value added (VAT). However, the correction in the PIS-Cofins taxes would lead to a reduction in tax revenue amounting to US$ 22.4 billion. The adopted carbon tax should collect this exact amount (US$ 22.4 billion), making the tax revenue neutral. The carbon tax that produces equivalent revenue is US$ 35.68/tons CO_2 (in 2011 values), generating a neutral tax burden. This carbon tax considers its negative effects on the economy, such as reductions in consumption of carbon-intensive goods, as well as the positive effects of the elimination of distortionary taxes.

5. Results

This section describes the short-term impacts of a carbon tax on the Brazilian economy using the theoretical framework developed in the previous sections. The carbon tax consists of the imposition of an emissions rate of *CO2* on carbon-intensive products, considering only emissions from burning fossil fuels and the economy's productive structure in 2011. All results consider compensation measures on exports and imports to restore the competitiveness of domestic production.

We analyze the impact of i) the adoption of a carbon tax of US$10/ton CO_2 and US$50/ton CO_2 (Scenario 1) and ii) the adoption of carbon taxation combined with the replacement of PIS/Cofins with value-added tax revenue (Scenario 2). As detailed in the methodology section, we use a 2011 input-output matrix, and all the monetary values reported are in 2011 US$.[29]

On the one hand, we utilize a rate of US$10/ton CO_2 because, according to Kossoy et al. (2015), 85% of countries adopting such taxation adopt values near US$ 10. On the other hand, we utilized the rate of US$ 50/ton CO_2 due to the study by (Koberle et al., 2015), which concluded that

[29] We use the average exchange rate in 2011: R$ 1.67/US$.

a carbon tax of US$ 50 is one of the important measures that should be implemented for Brazil to achieve its iNDC goals.[30]

In Scenario 1, the carbon tax alone (US$ 10 or US$ 50/ton CO_2) reduces GDP, wages, employment, and revenue from other indirect taxes due to the negative impact that the carbon tax has on final demand (excluding exports; see Table 2). However, there is also an increase in revenue due to the carbon tax and a decrease in CO_2 emissions (see Tables 3 and 4).

A rate of US$ 10/ton CO_2 has a negative impact on GDP and employment, both falling by approximately 0.2% as wages fall by 0.16%. At the same time, the net collection of indirect taxes increases by US$ 5.3 billion.[31] As expected, the application of a fee of US$ 50/ton CO_2 would produce a greater impact: GDP and employment would fall by five times more, by approximately 1%, while the net collection of indirect taxes would increase by US$ 26.3 billion. Interestingly, the decrease in GDP is concentrated in five sectors: 50% in commerce and services (because of its weight in the input-output matrix), 9.6% in other industries, 9.4% in the energy sector, 8.7% in agriculture, 5.9% in ground transportation,[32] 5.6% in food and beverage and 10.6% in others.

Emissions also fall, although the results are far from the targets announced for iNDC. Importantly, we discuss short-term effects, referring only to the reduction, at first, in demand for products intensive in fossil fuels, not considering the substitution effect between sectors and/or technological change.[33] When we analyze the emissions decrease by sector, the energy sector presents the greatest reduction in CO_2 emissions (-0.45% at US$ 10 and -2.23% at US$ 50),

[30] The study concluded that it would take three measures to achieve these goals: i) comply with a low-carbon agriculture plan, ii) achieve zero deforestation throughout the country, and iii) adopt a carbon tax of US$ 50/ton CO_2.

[31] Importantly, the collection considered in the input-output matrix refers only to indirect taxes, which are equivalent to 38.7% of the total tax burden in 2011. The total tax burden was R$ 1,462,660 million in 2011 (or US$ 874,844 million), according to the Federal Revenue Service.

[32] Ground transportation includes road transportation (industrial and private) and railway transportation.

[33] Further analysis would be needed to capture the effect that a change in relative prices would have on the transition to a less-intensive energy mix in emissions. Moreover, an important part of the national effort announced in the Brazilian iNDC refers to changes in land use: low-carbon agricultural production, deforestation control and forest restoration. None of these actions are considered in this study.

followed by food and beverages (-0.42% and -2.11% at US$ 10 and US$50, respectively) and ground transportation (-0.38% and -1.92%, respectively).[34]

As previously mentioned, one of the main criticisms of the adoption of a carbon tax is the adverse effects on a country's competitiveness. Companies that bear the tax can experience cost increases and reduced profit margins. One possible adjustment to offset the loss of competitiveness is the recovery of the carbon tax on exported products and the taxation of imports. Therefore, we consider a compensation percentage per sector, in terms of export value. For ground transportation, the sector most affected, the rate of US$ 10 ton CO_2 demands compensation of 2.4% of total exports by the sector and 11.1% for a rate of US$ 50 ton CO_2, followed by the steel sector (2.0% and 9.3%, respectively) and the air transportation sector (1.2% and 5.9%, respectively). In the case of imports, the percentage of the burden on a sector would be the same as that of exemption in the case of exports.

In Scenario 2, the simplification of PIS/Cofins generates a reduction in taxes collected corresponding to the elimination of the existing PIS/Cofins cumulative incidence in the production chain. The correction of this distortion reduces government revenues by approximately US$ 22.4 billion. The carbon tax rate that produces equivalent revenue is US$ 35.68/ton CO_2 (in 2011 values), generating a neutral tax burden of PIS/Cofins simplification. Since the PIS/Cofins and the carbon tax affect sectors in different ways, the effects on final demand (excluding exports) depend on the sector, although the total effect is positive, as can be seen in Table 6. The effects on GDP (0.47%), employment (0.53%) and wages (0.41%) are positive (Table 7), as the impact of replacing the PIS/Cofins with a VAT more than offsets the decrease in activity generated by the introduction of the carbon price, while simplifying the PIS/Cofins mainly affects sectors that buy goods and services from other sectors which are subject to the noncumulative basis. Thus, the tax on

[34] All the sectorial results are presented in the Supplementary Material.

emissions might primarily affect the major consumers of ground transportation, products of the steel industry and cement. Such products have emissions coefficients of 400, 290 and 153 tons of CO_2 per US$ produced, respectively.

In this sense, the main sectors that are positively affected (reduction of their PIS/Cofins payment) by the simplification are other industries (-37%), the public sector (-37%), textiles (-26%), food and beverages (-18%) and energy (-17%). The sectors that are negatively affected (increase in their PIS/Cofins payment) are commerce and services (47%) and ground transportation (3%). On the other hand, the sectors most affected by carbon taxation are other industries (26% of total carbon tax revenue), commerce and services (17%), ground transportation (17%), energy (12%) and food and beverages (11%).

Therefore, the rise in GDP is concentrated in five sectors: commerce and services (US$ 2.9 billion or 0.27%), other industries (US$ 2.9 billion or 0.27%), energy (US$ 2.5 billion or 0.99%), agriculture and livestock (US$ 1.04 billion or 0.91%) and textiles (3.37% or US$ 1 billion). The only sector to register a decrease in GDP is ground transportation (-0.05% or US$ 0.03 billion).

The application of a carbon tax equal to US$ 35.68 ton CO_2 in Scenario 2 may reduce emissions by 4.2 million tons CO*2* (1.1% of the total emitted in 2011). However, the economic growth generated by the simplification of PIS/Cofins might increase emissions by 5.8 million CO_2, resulting in 1.6 million tons of CO_2 (0.41% of the total emitted in 2011).[35] Analyzing the emissions reduction by sector, the greatest reductions occur in the ground transportation (2.21 million tons of CO_2), energy (0.72 million tons), steel (0.23 million tons), agriculture and livestock (0.19 million tons) and chemical (0.14 million tons) sectors.

---

[35] We consider the total emissions in 2011 at 378.1 million tCO2e according to National Energy Balance by sector and the IPCC emissions coefficients by energy source.

The carbon tax exemption represents 8.2% of total exports in the ground transportation sector, 6.8% of total exports in the steel sector and 4.3% of total exports in the air transportation sector. At the same time, the simplification of the PIS/Cofins payment has positive effects on the competitiveness of domestic production. This is the effective gain in competitiveness resulting in Scenario 2, which considers that the negative impact of the carbon tax on exports is fully offset, leaving only the gain in competitiveness resulting from the elimination of the cumulative PIS/Cofins payments. The three sectors most affected by this gain in competitiveness are ground transportation (4.9% of total exports), steel (4.6% of total exports) and air transportation (3.8% of total exports).

6. Final Remarks

We estimate the costs and benefits of a policy that stimulates a reduction in carbon emissions in Brazil. This policy is aligned with current efforts from the federal government to achieve the emissions targets set in the Brazilian Intended Nationally Determined Contributions (iNDC) for 2015. We analyze the adoption of a carbon tax, which is efficient to implement in a broader tax system reform using an input-output framework in comparison to other price mechanisms. (Goulder and Schein, 2013; Parry, 2003; Parry et al., 1999).

First, we evaluate the impacts of carbon taxes of US$ 10 and US$ 50 per ton of CO_2 (Scenario 1). On the one hand, we find that a carbon tax of US$ 10/tCO2e reduces GDP by 0.19% and destroys around 209 thousand jobs (a 0.21% fall out of 99,560 thousand jobs in 2011). On the other hand, it increases net government tax revenue on goods and services by 1.57% and reduces CO_2 emissions related to fossil fuels by 0.3% per year. A US$50/tCO2e carbon tax might reduce emissions by 1.5% per year while decreasing GDP by 0.94% per year and destroying around 1 million jobs (or 1.03% fall in relative terms).

To further contribute to the environmental and economic debate, we propose a combined policy that introduces a carbon tax and, at the same time, corrects some of the distortions in the Brazilian tax system (Scenario 2), a policy known as ’revenue-recycling’ (Zhang and Baranzini, 2004). Thus, two distortionary taxes (*PIS* and *Cofins*, which mainly apply noncumulatively on the productive chain) are replaced by a tax on value added. Then, we find the carbon tax rate that avoids the loss of government revenue, making the tax burden neutral. We also find that a carbon tax to offset the loss of US$ 22.4 billion revenue from the correction of the PIS/COFINS payments is US$ 35.68 CO_2. Therefore, negative effects on the economy of carbon taxation are more than offset by the positive effects generated by correction of the taxes tax distortions. The net effect is an increase in GDP of 0.47% and the creation of approximately 533 thousand jobs in the Brazilian economy. However, we observe a positive net effect on emissions, an increase of 0.41% in total emissions. Although carbon-intensive sectors are more affected by the carbon tax, the increased dynamism of the economy plays a significant role in the emissions amount.

The policy impacts the economic sectors in different ways. While simplifying the PIS/Cofins payments mainly affects sectors that buy goods and services from other sectors, which are taxed on a noncumulative basis (commerce and services, the public sector, other industries, textiles, food and beverages, among others), the tax on emissions affects the major consumers of ground transportation and the products of the steel and cement industries.

Our results do not capture all the environmental benefits of carbon taxation, as they disregard longer-term effects. Taxation tends to affect directly and indirectly consumption choices (e.g., substitution of gasoline for ethanol) and induces firms to adopt innovative practices and renewable resources (and, therefore, to change the industrial structure). We consider the exemption of exports and taxation of imports to address adverse effects on the country’s competitiveness. Although the neutral tax burden scenario shows that correcting tax distortions can benefit the economy, a carbon tax that just promotes a neutral burden tax is insufficient to mitigate emissions and achieve the iNDC targets. Even considering the scenario where a carbon tax alone is applied, results in terms of emissions are far from the targets announced in the Brazilian iNDC. A more aggressive carbon tax is necessary to achieve environmental goals.

We consider the relevance of discussing environmental and tax policies jointly in the country and explore opportunities related to the Brazilian tax revenue. In this paper, we use the IO model to assess the short-term effects of a change in final demand from a carbon tax introduction and correction of tax distortions in Brazil. Despite the limitations of using IO models, we believe that it gives relevant short-term responses, which are less sensitive to structural changes. A natural extension of this paper is the analysis using CGE models, which consider changes in prices. Despite their usefulness, CGE models require more data and have higher implementation costs than in IO models.

References

Aasness, J., T. Bye, and H. T. Mysen (1996) Welfare Effects of Emission Taxes in Norway. *Energy Economics*, 18, 335–346.

Allan, G., P. Lecca, P. McGregor, and K. Swales (2014) The Economic and Environmental Impact of a Carbon Tax for Scotland: A Computable General Equilibrium Analysis. *Ecological Economics*, 100, 40–50.

Barker, T. and J. Köhler (1998) Equity and Ecotax Reform in the EU: Achieving a 10 percent Reduction in CO2 Emissions Using Excise Duties. *Fiscal Studies*, 19, 375-402.

Böhringer, C. and T. F. Rutherford (1997) Carbon Tax with Exemptions in an Open Economy: A General Equilibrium Analysis of the German Tax Initiative. *Journal of Environmental Economics and Management*, 32, 189-203.

Brännlund, R. and J. Nördstrom (2004) Carbon Tax Simulations Using a Household Demand Model. *European Economic Review*, 48, 211-233.

BRAZIL (2014) Segundo Inventario Brasileiro de Emissões e Remoções Antrópicas de Gases do Efeito Estufa. Brazilian Ministry of Science and Technology. Available online in January 2017 at http://sirene.mcti.gov.br/publicacoes

BRAZIL (2015) Intended Nationally Determined Contribution Towards Achieving the Objective of the United Nations Framework Convention on Climate Change. Brazilian Federal Government. Available online in January 2017 at http://www4.unfccc.int/submissions/INDC/Published%20Documents/Brazil/1/BRAZIL%20iNDC%20english%20FINAL.pdf

Brenner, M., M. Riddle, and J. Boyce (2007) A Chinese Sky Trust?: Distributional Impacts of Carbon Charges and Revenue Recycling in China. *Energy Policy*, 35, 1771-1784.

Calderon, S., A. Alvarez, A. Loboguerrero, S. Arango, K. Calvin, T. Kober, K. Daenzer, and K. Fisher-Vanden (2016) Achieving CO2 Reductions in Colombia: Effects of Carbon Taxes and Abatement Targets. *Energy Economics*, 56, 575-586.

Callan, T., S. Lyons, S. Scott, R.S.J. Tol, and S. Verde (2009) The Distributional Implications of a Carbon Tax in Ireland. *Energy Policy*, 37, 407-412.

Carbone, J. and N. Rivers (2017) The Impacts of Unilateral Climate Policy on Competitiveness: Evidence from Computable General Equilibrium Models. *Review of Environmental Economics and Policy*, 11, 24-42.

Conefrey, T., J. Fitz Gerald, L.V. Malaguzzi, and R. Tol (2013) The Impact of a Carbon Tax on Economic Growth and Carbon Dioxide Emissions in Ireland. *Journal of Environmental Planning and Management*, 56, 934-952.

Cornwell, A. and J. Creedy (1996) Carbon Taxation, Prices and Inequality in Australia. *Fiscal Studies*, 17, 21-38.

Floros, N, and A. Vlachou (2005) Energy Demand and Energy-Related CO2 Emissions in Greek Manufacturing: Assessing the Impact of a Carbon Tax. *Energy Economics*, 27, 387-413.

Freitas, L., L. Ribeiro, K. Souza, and G. Hewings (2016) The Distributional Effects of Emissions Taxation in Brazil and their Implications for Climate Policy. *Energy Economics*, 59, 37-44.

Gemechu, E. D., I. Butnar, M. Llop, and F. Castells (2014) Economic and Environmental Effects of CO2 Taxation: An Input-Output Analysis for Spain. *Journal of Environmental Planning and Management*, 57, 751-768.

Gonzalez, F. (2012) Distributional Effects of Carbon Taxes: The Case of Mexico. *Energy Economics*, 34, 2102-2115.

Goto, N. (1995) Macroeconomic and Sectoral Impacts of Carbon Taxation. A Case for the Japanese Economy. *Energy Economics*, 17, 277-292.

Goulder, L. H. and A. R. Schein (2013) Carbon Taxes versus Cap and Trade: A Critical Review. *Climate Change Economics*, 4, 1350010.

Grottera, C., A. Pereira Jr, and E. La Rovere (2017) Impacts of Carbon Pricing on Income Inequality in Brazil. *Climate and Development*, 9, 80–93.

Guilhoto, J. J. M. and U. A. Sesso Filho (2005) Estimação da Matriz Insumo-Produto a Partir de Dados Preliminares das Contas Nacionais. *Economia Aplicada*, 9, 277–299.

Hamilton, K. and G. Cameron (1994) Simulating the Distributional Effects of a Canadian Carbon Tax. *Canadian Public Policy/Analyse de Politiques*, 20, 385–399.

Instituto Brasileiro de Geografia e Estatística. (2017) Supply-Use Tables. Available online in January 2018 https://ww2.ibge.gov.br/home/estatistica/economia/contasnacionais/2014/defaulttab_xls.shtm

IPCC (1997) IPCC Guidelines for National Greenhouse Gas Inventories. Available online in February 2017 at http://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html

Jaffe, A. B., S.R. Peterson, P.R. Portney, and R. N. Stavins (1995) Environmental Regulation and the Competitiveness of U.S. Manufacturing. What Does the Evidence Tell Us? *Journal of Economic Literature*, 33, 132–163.

Keohane, N. (2009) Cap and Trade, Rehabilitated: Using Tradable Permits to Control U.S. Greenhouse Gases. *Review of Environmental Economics and Policy*, 3, 42–62.

Koberle, A., A. Szklo, A. Lucena, J. Portugal-Pereira, P. Rochedo, and R. Schaeffer (2015) Beyond the Numbers: Understanding the Transformation Induced by INDCs. Paris, Institut du dveloppement durable et des relations internationales.

Kossoy, A., G. Peszko, K. Oppermann, N. Prytz, N. Klein, K. Blok, L. Lan, L. Wong, and B. Borkent (2015) State and Trends of Carbon Pricing 2015. The World Bank. Available online in January 2017 at http://documents.worldbank.org/curated/en/636161467995665933/ pdf/99533-REVISED-PUB-P153405-Box393205B.pdf

Labandeira, X. and J.M. Labeaga (2002) Estimation and Control of Spanish Energy- Related CO2 Emissions: An Input-Output Approach. *Energy Policy*, 30, 597–611.

Lin, B. and X. Li (2011) The Effect of Carbon Tax on Per Capita CO2 Emissions. *Energy Policy*, 39, 5137–5146.

Lu, C., Q. Tong, and X. Liu (2010) The Impacts of Carbon Tax and Complementary Policies on Chinese Economy. *Energy Policy*, 38, 7278–7285.

Manne, A. and R. Richels (1992) CO_2 Emission Limits: An Economic Cost Analysis for the USA. *Energy Journal*, 11, 51–74.

Meng, S., M. Siriwardana, and J. McNeill (2013) The Environmental and Economic Impact of the Carbon Tax in Australia. *Environmental and Resource Economics*, 54, 313–332.

Nordhaus, W. and J. Boyer (2003) *Warming the World: Economic Models of Global Warming*. MIT Press.

Parry, I. W. (2003) Fiscal Interactions and the Case for Carbon Taxes Over Grandfathered Carbon Permits. *Oxford Review of Economic Policy*, 19, 385–399.

Parry, I. W. and R. C. Williams (2011) Moving US Climate Policy Forward: Are Carbon Taxes the Only Good Alternative? Resources for the Future Discussion Paper. Available online in January 2018 at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1767316

Parry, I. W., R. Williams III, and L. Goulder (1999) When Can Carbon Abatement Policies Increase Welfare? The Fundamental Role of Distorted Factor Markets. *Journal of Environmental Economics and Management*, 37, 52–84.

Pearson, M. and S. Smith (1991) The European Carbon Tax: An Assessment of the European Commission's Proposals. Available online in October 2017 at https://www.econstor.eu/bitstream/10419/64592/2/717296490.pdf

PwC (2013) Paying Taxes 2014: The Global Picture. Available online in January 2017 at https://www.pwc.com/gx/en/paying-taxes/assets/pwc-paying-taxes-2014.pdf

Stavins, R. N. (2007) A US Cap-and-Trade System to Address Global Climate Change. KSG Working Paper No. RWP07-052; Hamilton Project Discussion Paper No. 2007-13. Available online in January 2018 at https://www.belfercenter.org/sites/default/files/legacy/files/rwp_07_052_stavins.pdf

Timilsina, G. R. and R. M. Shrestha (2002) General Equilibrium Analysis of Economic and Environmental Effects of Carbon Tax in a Developing Country: Case of Thailand. *Environmental Economics and Policy Studies*, 5, 179–211.

Van Heerden, J., R. Gerlagh, J. Blignaut, M. Horridge, S. Hess, R. Mabugu, and M. Mabugu (2006) Searching for Triple Dividends in South Africa: Fighting CO_2 pollution and poverty while promoting growth. *Energy Journal*, 27, 113–141.

Whalley, J. and R. Wigle (1991) Cutting CO_2 Emissions: The Effects of Alternative Policy Approaches. *Energy Journal*, 12, 109–124.

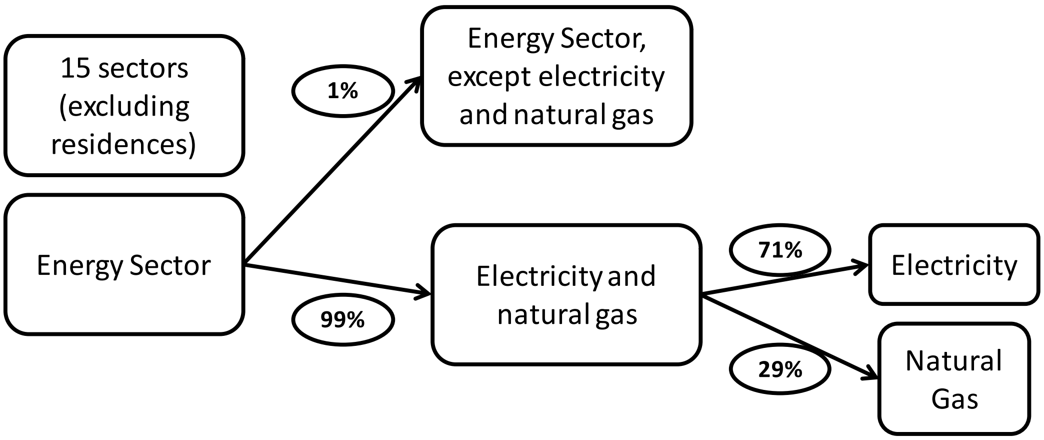
Wissema, W. and R. Dellink (2007) AGE Analysis of the Impact of a Carbon Energy Tax on the Irish Economy. *Ecological Economics*, 61, 671–683.

World Bank (2015) State and Trends of Carbon Pricing 2015. Washington, D.C., World Bank Group Climate Change.

Zhang, Z. and A. Baranzini (2004) What Do We Know About Carbon Taxes? An Inquiry into their Impacts on Competitiveness and Distribution of Income. *Energy Policy*, 32, 507–518.

Appendix 1: Matrix harmonization

Figure 1: Treating the energy balance matrix



We harmonize the dimensions of the Brazilian energy balance and the supply-use tables. The energy balance has 16 sectors, including the energy sector. We split the energy sector into two sectors: 'electricity and natural gas' and 'energy sector, except electricity and natural gas'. We use the proportions of electricity and natural gas in the use table (99% out of total).

The 'electricity and natural gas' sector is further split into 'electricity sector' and 'natural gas sector' using data from the energy balance (71% is the total consumption of electricity, and 29% natural gas). Figure 1 summarizes the steps to treat the Brazilian energy balance. Therefore, the final energy balance matrix has 18 sectors: 15 original (excluding residences), the 'energy sector, except electricity and natural gas', the 'electricity sector', and the 'natural gas sector'.

Finally, we harmonize the SUTs and the energy balance to construct the hybrid matrix (in values, US$, and TOEs). The use table has 128 lines (products) and 38 columns (intermediate consumption sectors), where the latter are aggregated into the same 18 sectors as the energy balance. The supply table presents 128 products and 68 sectors, which are also aggregated into 18 sectors. We also split the product 'Electricity and natural gas' into 'electricity' and 'natural gas' in both use and supply tables, keeping the 71%-29% proportion mentioned before. We use this final use and supply tables to estimate our results.

Table 1: Calculated CO_2 emissions coefficient (ton CO_2 / US$ million)

Sectors	CO_2 coefficient emissions by sector for intermediary consumption	CO_2 coefficient emissions by sector for final demand
Agriculture	31.7	68.3
Mining	46.1	89.8
Food and Beverages	6.6	80.8
Textile	7.2	47.3
Paper	123.4	199.4
Chemical	31.1	94.6
Non-Metallic Minerals	146.7	221.0
Iron and Steel	289.8	394.0
Non-Ferrous and Others	62.3	161.7
Other Industries	6.6	67.1
Commerce and Services	5.4	32.3
Land Transportation	399.4	479.0
Water Transportation	177.2	221.6
Air Transportation	223.4	241.9
Public Sector	6.0	22.8
Energy Sector	191.6	345.5

Table 2: Scenario 1–Impact on final demand by sector (US$ million)

	Carbon Tax	
Sector	US$ 10/tCO2e	US$ 50/tCO2e
Agriculture	-128	-639
Mining	-2	-11
Food and Beverages	-685	-3,425
Textile	-44	-219
Paper	-12	-62
Chemical	-102	-508
Non-Metallic Minerals	-7	-36
Iron and Steel	-3	-13
Non-Ferrous and Others	-31	-155
Other Industries	-624	-3,121
Commerce and Services	-307	-1,536
Ground Transportation	-210	-1,051
Water Transportation	-1	-5
Air Transportation	-1	-6
Public Sector	-11	-56
Energy Sector	-432	-2,161
Total	-2,600	-13,004

Table 3: Scenario 1–Impacts on GDP, wages and jobs (%)

	Base Year 2011	Carbon Tax	
		US$ 10/tCO2e	US$ 50/tCO2e
GDP (US$ billion)	2,227	-0.19%	-0.94%
Wages (US$ billion)	871	-0.16%	-0.79%
Number of Jobs (thousands)	99,560	-0.21%	-1.03%

Constant values in 2011; average exchange rate in 2011 of R$ 1.67/US$.

Table 4: Scenario 1–Impacts on CO_2 emissions and tax revenue

	Carbon Tax	
	US$ 10/tCO2e	US$ 50/tCO2e
CO_2 emissions (MtCO2e)	-1.2	-6.0
Tax collection		
Carbon Tax (US$ billion)	6.2	30.7
Other indirect taxes (US$ billion)	-0.9	-4.4
Total	5.3	26.3

Constant values in 2011; average exchange rate in 2011 of R$ 1.67/US$.

Table 5: Scenario 2–Impacts on tax revenue

	Tax Collection (US$ billion)
PIS/Cofins simplification + IVA	-22.4
Carbon Tax (US$ 35.68 /tons CO_2)	22.4
Other indirect taxes	3.1
Total	3.1

Constant values in 2011; average exchange rate in 2011 of R$ 1.67/US$.

Table 6: Scenario 2–Impact on final demand by sector (US$ million)

Sector	US$ million
Agriculture	366
Mining	-3
Food and Beverages	1,622
Textile	1,841
Paper	87
Chemical	-43
Non-Metallic Minerals	-6
Iron and Steel	-2
Non-Ferrous and Others	88
Other Industries	4,965
Commerce and Services	-3,427
Ground Transportation	-849
Water Transportation	-2
Air Transportation	-5
Public Sector	65
Energy Sector	2,795
Total	7,489

Table 7: Scenario 2–Impacts on GDP (US$ billion), wages (US$ billion) and jobs (number)

	Base Year 2011	Carbon Tax (US$ 35.68 /tCO2e) + PIS/Cofins simplification	
	US$ billion	US$ billion	% var.
GDP	2,227	10.4	*0.47%*
Wages	871	3.6	*0.41%*
	number	number	% var.
Jobs	99,560,000	533,000	*0.53%*

Constant values in 2011; average exchange rate in 2011 of R$ 1.67/US$.

Figure 1: Scenario 1–Reduction in emissions by sector (%)

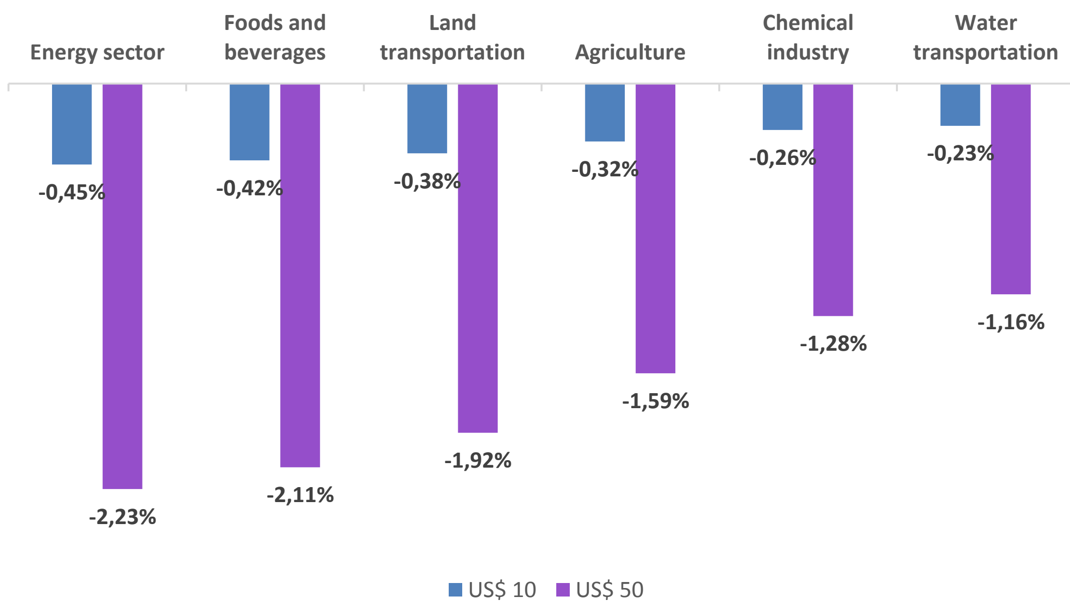


Figure 2: Scenario 2–Simplification of PIS/Cofins: effect on exports by sector (% exports value)

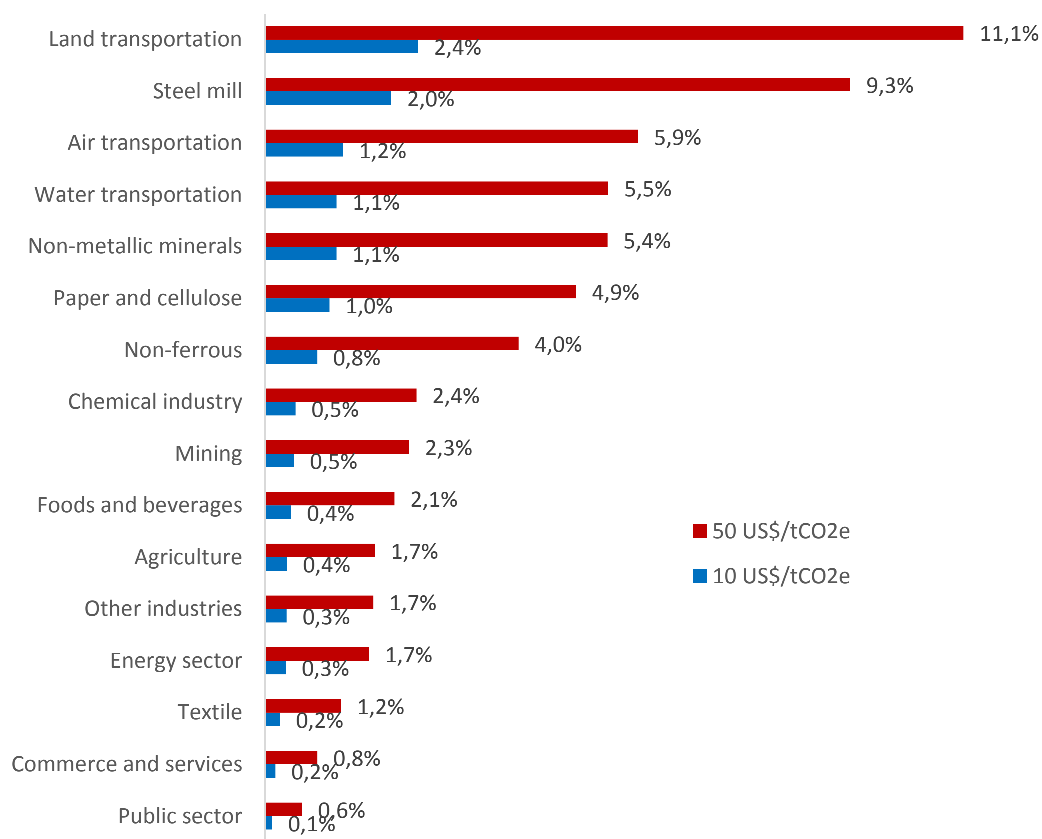


Figure 3: Scenario 2 - Effect on GDP by sector (%, US$ million 2011)

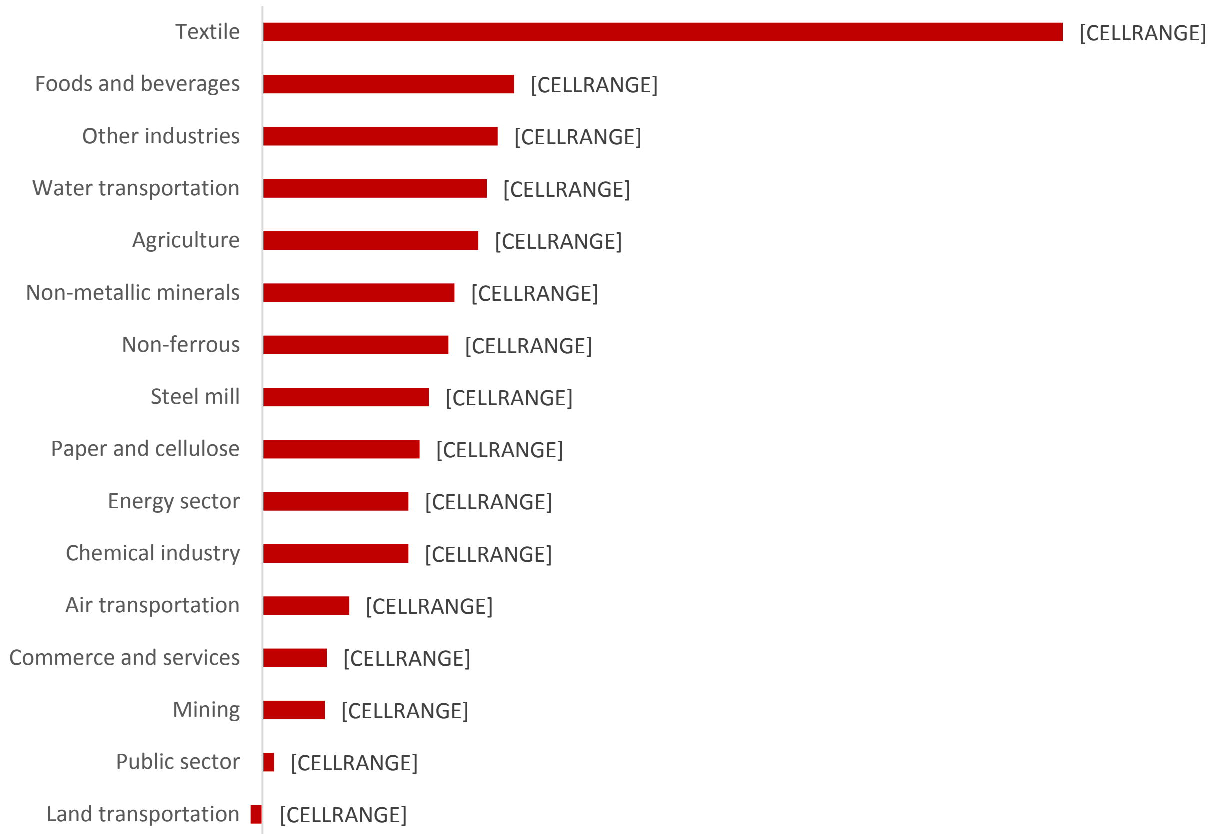


Figure 4: Scenario 2–CO_2 emissions avoided by sector (in tons.)

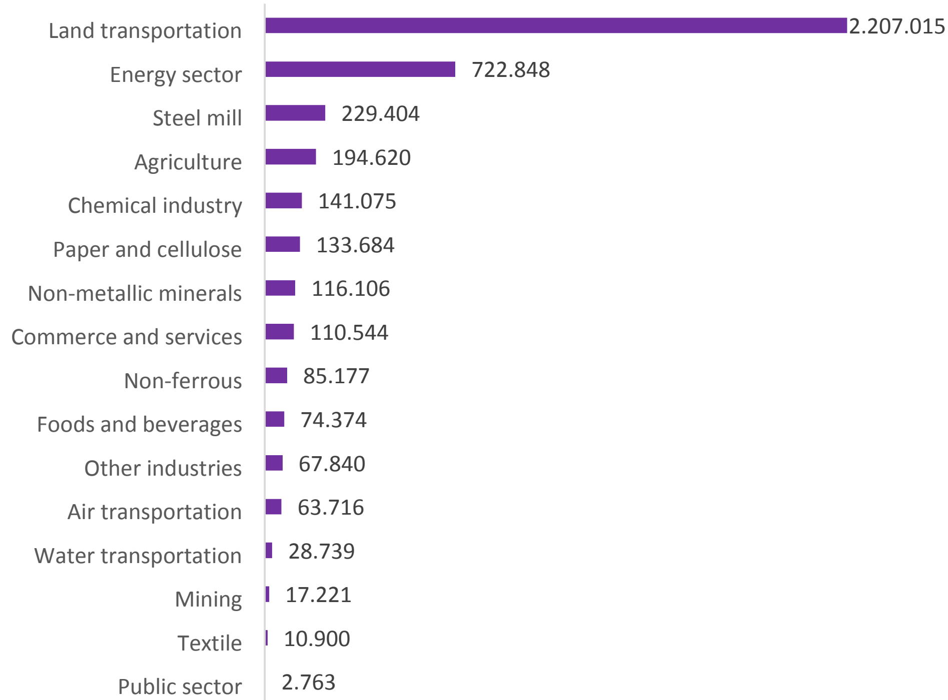


Figure 5: Scenario 2–Exemption of Carbon tax: effect on exports by sector (% exports value)

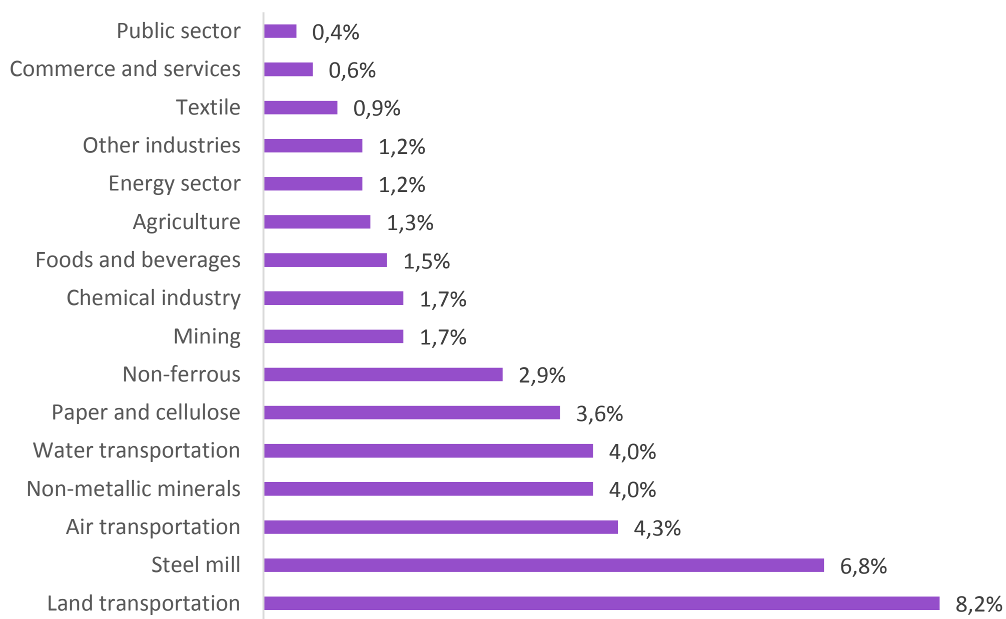


Figure 6: Scenario 2–Simplification of PIS/Cofins: effect on exports by sector (% exports value)