Brazilian competitiveness of energy-intensive and trade-exposed industrial sectors vis-à-vis the adoption of border carbon adjustments by the EU: an approach using the GTAP-EP model

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Abstract

This paper aims to explain how Brazilian environmental vulnerability can affect its industrial competitiveness in a scenario where the European Union would adopt BCAs. A modified version of the GTAP-E (Global Trade Analysis Project – Energy) model is used here to simulate the application by the EU of BCAs to carbon-intensive products that come from countries which do not carry out similar policies to mitigate CO_2 emissions. A novelty in the present analysis is that the model takes into account the industrial process emissions of three main sectors (chemicals, iron &steel and non-metallic minerals), as well as the indirect costs associated with carbon taxes levied on the energy industries (the induced increase of electricity and gas prices). The main results suggest that BCAs are an effective instrument in curbing carbon leakage, especially when industrial process emissions are taken into account. Regarding Brazilian industrial competitiveness, BCAs would negatively affect some sectors' exports to the EU, namely non-metallic minerals and iron & steel. When it comes to the other BRICS, Brazil would lose competitiveness relative to China and India in the iron & steel sector.

Keywords

GTAP-EP, border carbon adjustments (BCA), Brazilian industry, CO2 emissions, BRICS.

Resumo

O objetivo deste artigo é explicar como a vulnerabilidade ambiental brasileira pode afetar a competitividade da sua indústria brasileira em um cenário no qual a União Europeia (EU) venha adotar BCAs (Border Carbon Adjustments, na sigla em inglês). Foi utilizada uma versão modificada do modelo GTAP-E (Global Trade Analysis Project – Energy) para simular a aplicação de BCAs pela UE aos produtos intensivos em emissão de CO2 importados de países que não adotam políticas similares de abatimento de emissão de CO2. A inovação na presente análise é que o modelo leva em consideração as emissões geradas pelos processos industriais de três principais setores (químico, ferro e aço e minerais não metálicos), assim como os custos indiretos relacionados com os impostos de carbono aplicados nas indústrias de energia (o aumento induzido nos preços do gás e eletricidade). Os principais resultados apontam que os BCAs são instrumentos efetivos para reduzir o escape de carbono, especialmente quando as emissões dos processos industriais são levadas em conta. No que diz respeito à competitividade da indústria brasileira, os BCAs afetariam negativamente a exportação de alguns setores para a UE, principalmente os de minerais não metálicos e de ferro e aço. No que se refere aos BRICS, o Brasil perderia competitividade para China e Índia no setor de ferro e aço.

Palavras-chave

GTAP-EP, ajustamentos de fronteira (BCA), indústria brasileira, emissões de CO2, BRICS.

Classificação JEL: F11, F13, F18.

Área 7: Economia Internacional

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1. Introduction

It's well known that the unilateral or sub-global adoption of environmental policies to curb climate change can create carbon emission leakage to non-adopting countries[3], and can also decrease the adopting countries' foreign trade competitive advantages vis-à-vis the non-adhering emerging economies.[4] In order to restore the competitive equilibrium and to reduce carbon leakage, some policy instruments have been proposed.[5]Among them, Border Carbon Adjustments (BCAs)[6] have been gaining prominence since the mechanism was incorporated into the Waxman/Markey bill – "The American Clean Energy and Security Act".[7] Likewise, this instrument has also gained ground in Europe as an option in the absence of a major international agreement to cap greenhouse gas (GHG)[8] emissions.[9]In this context, border adjustment measures are mentioned in the EU ETS Directive in paragraph 25 describing a system in which importers would need to surrender allowances and that any action taken should comply with the UNFCCC principles, especially the principle of common but differentiated responsibilities and respective capabilities as well as with international obligations of the EU, including the obligations under WTO agreement.[10]

Despite the fact that BCAs have been theoretically assessed as an attractive instrument to improve the global cost-effectiveness of the unilateral abatement emissions and to avoid the leakage[11], it's still a second-best policy. Indeed, the first-best would be the commitment of the countries subjected to such tariffs to reduce their own emissions, since the abatement costs tend to be significantly lower in countries where there is no emission control. Among BCAs limitations, one can mention: i) they can be challenged by the World Trade Organization (WTO)[12]; ii) non-adopting countries can impose trade sanctions in response to carbon tariffs; and iii) their effectiveness can be considerably reduced once exporting countries can manage to find alternative unregulated importing markets to sell their carbon-intensive products.[13]

Additionally, imposing BCAs on developing countries is a way of transferring a significant part of the coalition countries' costs of abatement to non-abating countries (burden-shifting effects) and, therefore, the EU pioneering role in assuming

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[3] See e.g. Hoel, 1991; Felder and Rutherford, 1993; Burniaux and Oliveira Martins, 2000; Kuik and Gerlagh, 2003; Böhringer*et al*., 2010.

[4] See Boltho, 1996; Carbon Trust, 2004; OECD, 2006; Quirion, 2010; Böhringer *et al*., 2012.

[5]The main anti-leakage policy measures are Border Carbon Adjustments (BCAs), industry exemptions and output-based allowance allocation. A full BCA combines import tariffs with rebates to exporters. For more, see Hoel, 1996; OECD, 2006; Quirion, 2009; Monjon and Quirion, 2010.

[6] Border Carbon Adjustment measures can take two forms: carbon tariffs and a mandatory requirement for importers to hold emissions allowances. In the first case, the object of our study, the BCAs work as embodied carbon tariffs that are applied in imports from countries without similar environmental taxation.

[7]The Waxman-Markey bill proposes that the US introduces a cap-and-trade scheme. The aim is to achieve a 20 percent reduction in greenhouse gas emissions by 2020 (considering 2005 emissions level).

[8] This paper uses the terms "GHG emissions" and "CO_2 emissions" as synonyms, despite the fact that the former includes the release of other gases, such as methane (CH_4) and nitrous oxide (N_2O).

[9] Actually, the idea of applying BCAs was first floated in EU in response to the US withdrawal from the Kyoto Protocol (Zhang, 2012, p.31).

[10]EC, Directive 29/2009/EC, 2009, p.67, paragraph 25.

[11] See Markusen, 1975; Hoel, 1996; Kuik and Hofkes, 2010; Böhringer *et al*., 2012; Bednar-Friedl *et al*., 2012; Fischer and Fox, 2012.

[12] For more details of a legal view on BCAs, see Medina and Lazo (2011).

[13] The so-called demand-side leakage (Copeland and Taylor, 2004).

environmental costs in order to get subsequent cooperation can be questioned. Böhringer *et al*. (2012) state that BCAs *"fare poorly when our welfare measures account for even a modest degree of inequality-aversion and there is no mechanism in place to compensate losers under the border-tax-adjustment regime"* (p.209).

But while the international trade community is dealing with these environmental dilemmas, Brazil's industry is struggling to maintain its export share in the global market, especially regarding high value added and technological products (Coutinho, 1997; Gonçalves, 2001; Laplane and Sarti, 2006). The fact is that Brazilian industry lacks competitiveness, and despite the fact that a process of trade liberalization started in the 1980s, Brazil is still one of the most closed countries in the world when it comes to international trade,[14] situated far behind the other economies of the so-called BRICS.[15] According to Canuto *et al*. (2015), this "closedness" to trade is at the core of the Brazilian industry's lack of dynamism, and *"opening up and moving towards integration into global value chains could produce efficiency gains and help Brazil address its productivity and competitiveness challenges, which have recently come into sharper focus"* (p.12).

IMF (2009) forecasts put China, India and Brazil among the top five largest world economies in 2050 thereby also placing them among the main GHG emitters – in 2008, their emissions represented 31% of the global energy use and 35% of the CO_2 emissions from fuel combustion (IEA, 2008). Brazil is an important contributor to climate change due to its emissions derived from land-use changes, and the expansion of agricultural frontiers, mainly in the Amazon region, is considered the main source of CO_2 emissions.[16] Nowadays, the Brazilian energy sector is the third largest GHG emitter in the country, mainly because hydropower and renewable biomass still play an important role as energy suppliers. But, there are those who believe this can change in the near future. According to La Rovere *et al*. (2013), if additional mitigation actions aren't taken, emissions derived from the energy sector will increase, mostly because of population and economic growth.[17]

Taking this into account, it's reasonable to wonder how the EU's potential adoption of BCA measures would affect Brazilian industry and its competitiveness, especially regarding its energy-intensive sectors. Similar analyses have been done for China and India [18], but to the best of our knowledge not yet for Brazil. For the Brazilian economy, revealing the role of its environmental vulnerability can bring a more strategic stance to industrial development and the adoption of (environmental) measures that could minimize the potential losses in foreign trade.

This paper aims to explain how Brazilian environmental vulnerability can affect its industrial competitiveness in a scenario where the European Union would adopt BCAs. More specifically, it attempts to answer the following questions: i) would a BCA be an

[14] According to World Bank data (WTI, 2013), the measure of trade penetration (share of exports plus imports in the GPD) put Brazil, in 2012, as the second most closed country in the world, among 179 nations. First position was held by Sudan.

[15] Acronym for the association of the five major emerging economies of the world – Brazil, Russia, India, China and South Africa.

[16] Brazil has been making a significant effort to limit its GHG emissions curbing Amazon deforestation (La Rovere *et al*., 2013).

[17] From 1990 to 2005, the GHG emissions derived from energy use and industrial processes increased 68% and 39%, respectively, resulting together in an 18% share among the other sources(BRASIL, 2009).

[18] See Das (2012) for India and Li *et al*. (2013) for China.

effective tool in avoiding or diminishing carbon leakage? ii) will Brazilian foreign trade competitiveness be affected by the border carbon adjustments? iii) how will the BCAs affect the competitiveness of the Brazilian energy-intensive and trade-exposed sectors vis-à-vis those of the other BRICS?

A modified version of the GTAP-E model is used here to simulate the application by the EU of BCAs to carbon-intensive products that come from countries which do not carry out similar policies to mitigate CO_2 emissions. A novelty in the present analysis is that the model takes into account industrial process emissions of three main sectors (chemicals, iron &steel and non-metallic minerals), as well as the indirect costs associated with carbon taxes levied on energy industries (the induced increase of electricity and gas prices).

The main results suggest that BCAs are an effective instrument in curbing carbon leakage, especially when industrial process emissions are taken into account. Regarding Brazilian industry competitiveness, BCAs would negatively affect some sectors' exports to EU, namely non-metallic minerals, iron & steel and non-ferrous metals. When it comes to the other BRICS, Brazil would lose competitiveness relative to China and India in the iron & steel sector.

The remainder of this paper is organized as follows. Section 2 provides an overview of Brazilian industry evolution as well as a description of the most emission-intensive industrial sectors and their mitigation potential. Section 3 presents a non-technical description of the GTAP-E model and its main modifications for the present study. Section 4 presents the results and conclusions are laid out in Section 5.

2. The main Brazilian industrial process CO_2 emitters

As a whole, Brazilian industrial energy consumption is largely based on renewable resources – electricity[19] (20.5%), sugar cane bagasse (19.5%), firewood (8.7%) and charcoal (4.1%) (MME-BEN, 2015).[20] However, some sectors still generate considerable CO_2 emissions. According to the GTAP database, the Brazilian industrial sectors that combine intensive CO_2 emissions and a high level of international trade exposure are non-ferrous metals, non-metallic minerals, iron & steel, petroleum & coke, iron ore, oil and chemicals (Table 1).

Bednar-Friedl *et al*. (2012) state that *"while the lion's share of carbon dioxide emissions arises in fossil fuel combustion, some 10% of global production CO_2 emissions are related to industrial processes. 10% might seem negligible, but it is not in the analysis of carbon leakage (...)"*(p. 168). And this is because process emissions mainly arise from three sectors that are export-oriented and under heavy international competition – iron & steel, clinker and chemicals. In many countries, process emissions account for approximately half of CO_2 emissions in the iron & steel and cement industries, and for a fifth in the chemical sector. The three sectors that not only generate

[19] Hydroelectric power is responsible for about 90% of electricity generation.
[20] 2013 database.

CO_2 emissions from fuel combustion, but also from their industrial processes – iron & steel, non-metallic minerals (cement), and chemicals are highlighted below.[21]

Table 1
Brazilian exports shares for selected sectors and their emissions intensity

Sectors	**Exports to the world (share in %)**	**Exports to EU (share in %)**	**Emissions intensity (CO_2 ton/USD million)**
Non-metallic minerals	1.5	0.8	552.8
Non-ferrous metals	4.1	4.6	544.6
Iron &steel	5.6	4.4	451.0
Petroleum &coke	1.5	0.8	267.5
Other mining (iron ore)	13.0	14.1	225.0
Refined oil products	5.4	3.8	177.8
Chemicals	7.3	5.6	113.2
Paper &paper products	2.9	3.9	68.0
Sugar	3.2	0.3	35.1
Other meats	4.5	4.6	24.6
Cattle meat	2.3	2.7	21.6
Other food	2.3	2.3	19.5
Vegetable oils	2.7	5.1	18.6
Leather	2.7	4.5	12.6
Other machinery &equipments	8.6	5.7	5.8
Electronic equipments	2.0	0.8	5.2
Lumber	2.8	4.2	2.9
Other transport equipments	3.3	2.6	2.1
Motor vehicles	9.6	6.0	1.0
Other	14.6	23.2	-
Total	100	100	-

Source: GTAP database 8.1.

Due to government policies for the promotion of infrastructure along with the automobile sector, the iron & steel industry quickly expanded during the 1970's. To produce iron and steel, the industry uses pyrometallurgical, electrolytic and mechanical processes. The two main production routes are the reduction of iron ore and scrap iron in blast furnaces (by burning coke or coal), and the direct reduction in electric ovens. The pig iron production (coke plant, sintering and blast furnace) consumes 60 to 70% of the total energy consumed in integrated plants, mainly due to coke usage as a reducing agent. In Brazil, the main production process input is mineral coal coke, which represented about 45% of the energy consumption in 2013 (Table 2) (BEN, 2015). Other important inputs are vegetal coal (18.6%), electricity (10.4%), and natural gas (6.3%). Total energy consumption in this sector has systematically gone up throughout

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[21] Bednar-Friedl*et al*. (2012, p.170) demonstrate that these three sectors, together, account for almost all of the CO_2 emissions derived from industrial processes.

the years following the production increase.[22] However, the so-called specific consumption (consumption/production) has remained relatively steady, which denotes no technological improvements towards a better energy efficiency level (Henriques Júnior, 2010).

Similarly to the iron & steel industry, the cement sector largely benefited from the extraordinary Brazilian economic growth during the 1970s, which boosted the construction industry. The cement industry is a significant contributor to GHG emissions because CO_2 is a natural byproduct of the chemical process used to convert limestone into clinker, the primary ingredient of cement. In Brazil, the energy demand of the cement industry has followed production, but the type of energy used has changed over the years.[23] During the 1970s, fuel oil was the main source of energy (around 90%). In the following decade, the industry started to use mineral coal (around 45%), and from 1990 on, petroleum coke. Nowadays, this energy input accounts for about 70% of total demand, followed by electricity use (13.2%).[24] Regarding CO_2 emissions, from 1990 to 2005 the amount of carbon dioxide emitted by this sector increased by around 30% (MCT, 2010).

Table 2
Energy consumption in industrial processes

Sector	Energy inputs mainly used in productive processes(%)	Average specific consumption (GJ/t)	Best available technology(GJ/t)
Iron & steel	1º)Mineral coal coke – 44.9 2º) Charcoal – 18.6 3º) Electricity – 10.4	20.8	13.5
Non-metallic minerals (cement)	1º) Petroleum coke – 69.5 2º) Electricity – 13.2 3º) Coal – 2.5	3.7	2.8
Chemicals	1º) Natural gas – 29.2 2º) Electricity – 28.1 3º) Fuel oil – 6.1	Petrochemical: 15 – 50	12.5
		Fertilizers (ammonia): 36	28

Source: SNIC (2008), EPE (2008), WORREL *et al*. (2008), ABM (2008), IEA (2007), DE BEER *et al*. (2001) *apud* Henriques Júnior (2010).

When it comes to the chemical industry, Brazil is among the ten largest world producers, in a group lead by the USA followed by China and Japan. As in the case of the previous two sectors, the Brazilian chemical industry has been changing its energy consumption profile over the years. During the 1970s, fuel oil was the main source of energy (70% in 1976). Over the next decade, firewood, coal and electricity gradually started to be used. In recent years, natural gas (29.2% in 2013), electricity (28.1%) and other secondary oil sources have been substituted for other energetic inputs (BEN, 2015). Concerning the energy consumption level, this industry ranks fourth (6,986 x 10^3 toe in 2013) on the list of the most energy-intensive sectors in Brazil, since some specific segments such as petrochemical, fertilizers and chlor-alkali are highly energy

[22]This sector ranks second (16,275 x 10^3 toe in 2013) on the list of the most energy-intensive ones in Brazil.
[23]This sector ranks sixth (5,315 x 10^3 toe in 2013) on the list of the most energy-intensive ones in Brazil.
[24] BEN (2015).

demanding. Together, these three segments account for about 70% of the chemical industry's energy consumption.

2.1. Challenges and opportunities for a "green" transition

In Brazil, when it comes to emissions mitigation, forests and land-use tend to occupy the center of the discussions. However, as shown before, industry plays an important role in this context, especially because of its intensive use of fossil fuels. And particularly regarding the aforementioned sectors (whose emission levels derived from their production processes are considerably high), one can say that they represent Brazilian biggest challenges in the field, but also offer the main opportunities.

The main challenge for Brazilian industry is to build a sustainable future combining good levels of productivity and competitiveness, without succumbing to cheaper energy sources that can, in the end, increase CO_2 emissions. The problem is that, as mentioned before, Brazil is still one of the most closed nations in the world, even when compared to the other BRICS countries.[25]And its economic structure, reliant on domestic value chain integration, makes it difficult for the industry to incorporate cleaner and more efficient production technologies.[26]

The good news is that given the production processes diversity, there are many technical possibilities for reducing energy consumption and emissions. This can be achieved, for example, through the implementation of energy efficiency projects, the increase in the use of cleaner energy sources (such as natural gas and charcoal originated from planted forests), and through switches in production technology.[27]

In this sense, the use of modern, higher-yield burners and their proper regulation can reduce the heat loss significantly. Besides that, heat recovery processes can be applied to several industrial segments and, according to Worrel *et al*. (2009), can generate savings up to 40%. Henriques Júnior (2010) states that among the aforesaid industrial sectors, iron-steel is the one which presents the greatest potential to reduce emissions (44%), given its high consumption of fossil fuels and charcoal derived from deforestation.[28]

Unfortunately, in many cases, the wide variety of technical solutions available to decrease GHG emissions is not enough to overcome the barriers. In Brazil, industrial sectors have to deal, for example, with the absence of a widespread natural gas

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[25]Brazil's trade penetration is around 27%, against at least 50% for the other BRICS countries (Canuto *et al*., 2015).

[26] It no coincidence that Brazil presents, among the BRICS, the highest share of processes emissions in the total of the CO_2 released by their respective industries. According to the United Nations Framework Convention on Climate Change (UNFCCC) database, processes emissions in Brazil account for around 17% of its total industry emissions (2005). For the other BRICS countries, calculations show 11% in Russia (2007), 9% in China (2005) and South Africa (1994), and 7% in India (2000).

[27] There are several options to mitigate emissions – recycling and material saving, inter-energetic replacement, use of renewable energy, biomass disposal of deforestation and co-generation (HENRIQUES JÚNIOR, 2010).

[28]In order to reduce iron-steel sector emissions, Martin *et al*. (2000) and IEA (2008a) suggest: turning off obsolete, small capacity and low efficiency furnaces; the deployment of dry advanced wet coke-ovens; the installation of pressure recovery turbines; and the usage of natural gas as an aid in the reduction process of iron ore, among other measures.

distribution network, which is fundamental to disseminate the use of this energy source. In addition, there is a lack of technological training for new technology suppliers and users, as well as a lack of international partnerships that could boost scientific-technological trainings for the gradual abandonment of fossil energy. Moreover, one can argue that the existing governmental incentives to leverage low emission energy projects aren't enough, hampering the adoption of some renewable and cleaner sources such as solar energy whose high short-term costs can make it economically unfeasible.

The high costs still involved in the course of emissions abatement continue to be the main reason why developing countries avoid taking part in international binding commitments. Even so, it seems to be clear that the transition to a "green" industry can take these countries to a leadership position among their counterparts. According to Hochstetler and Viola (2012), China is already adopting legal measures in order to reduce energy consumption and increase the use of renewable sources, aimed at continuing and sustaining its rapid growth. India wrote a non-binding National Action Plan on Climate Change in 2008 that set a strategy for reducing emissions (Hallding *et al*., 2011 *apud* Hochstetler and Viola, 2012).In South Africa, even the adoption of carbon taxes has been under consideration.

Actually, in absolute terms, Brazil's voluntary mitigation goal for 2020 (reducing GHG emissions by 36% to 39% compared to 1990 levels)is far more ambitious than the voluntary goals pledged by other emerging economies. However, non-governmental agencies are now indicating a clear reversion of the former emissions decrease path. Unfortunately, the significant shrinkage of CO_2 release levels between 2004 and 2012, resulted mainly from an impressive drop in deforestation rates, has been supplanted by the increase of emissions in other sectors – energy, transportation, agribusiness, industry and solid waste (Observatório do Clima, 2014).[29]

Thereby, the imminent adoption by Europe of BCAs could force Brazil and other nations to pay more attention to their industry's environmental vulnerability. If Brazil manages to quickly promote the necessary changes and adopts the right measures to transform its emission-intensive sectors into sustainable players on the world market, BCAs may be seen not as a threat, but as an opportunity to a "green" industry transition, which can bring competitive advantages over China, India and other emerging economies.

3. Methodology

In order to achieve the objectives of this paper, a computable general equilibrium (CGE) model is used. What is presented here is a modified version of the GTAP-E model (Burniaux and Truong, 2002), from now on called GTAP-EP (energy and process), that allows the simulation of the EU's application of BCAs to carbon-intensive products imported from countries that do not employ comparable policy actions to mitigate CO_2 emissions. As is common in this kind of analysis, the EU's Emission Trading System (EU ETS) is represented by a carbon tax that is equivalent to the EU ETS carbon allowance price.[30] Besides that, it also innovates by inserting a module which takes into

[29] The most dramatic increase occurred in the energy sector – emissions have increased more than 30% in the period (from 335 to 440 megatons). And between 1990 and 2012, the sector has increased its emissions by 125% (Observatório do Clima, 2014).

[30] Theoretically, without uncertainty, a carbon tax and a cap and trade system are perfectly equivalent (Weitzman 1974; Goulder and Schein 2013).

account industrial processes emissions of three important sectors (chemicals, iron & steel and non-metallic minerals),[31] as well as the indirect costs derived from the inclusion of energy industries in the EU ETS.[32]

GTAP-EP, is a static comparative, multi-region, multi-sector CGE model of the world economy that links all economies in the world through bilateral trade relationships. The accounting relationships of the model ensure the balance of receipts and expenditures for every agent identified in the economy, whereas the behavioral equations specify the behavior of optimizing agents in the economy (producers, consumers, and government) based on microeconomic theory (Brockmeier, 2001). The GTAP-EP model assumes perfectly competitive markets, constant returns to scale technology, a non-homothetic private demand system and a foreign trade structure characterized by the Armington (1969) assumption. Assuming weak separability, the production system is set up as a series of nested constant elasticity of substitution (CES) functions. The GTAP-EP model includes a detailed representation of energy use in production and consumption and its associated carbon emissions.

In the GTAP-EP model, the variable BCA is determined endogenously and comprised of two different components – direct and indirect costs. Direct costs, d, are associated to carbon taxes that are levied on European emission-intensive industries.[33] In order to calculate them, carbon dioxide emissions intensities, π,are multiplied by the carbon tax applied to EU sectors, $\emptyset^{EU}$ (eq.1).

$$d_{j,r} = \pi_{j,r}.\emptyset^{EU} \qquad (eq.1)$$

In turn, carbon dioxide emissions intensities (eq.2) are calculated considering the origin principle by dividing one j sector's total carbon dioxide emissions (USD million/ton CO_2) by its total production at agent's price, γ, in each region r, where total carbon dioxide emissions encompass the ones generated by the use of domestic, C^D, and imported intermediate inputs, C^M , and by the industrial processes of chemicals, iron & steel and non-metallic minerals, C^P.

$$\pi_{j,r} = \frac{\sum_i C^D_{i,j,r} + \sum_i C^M_{i,j,r} + C^P_{j,r}}{\gamma_{j,r}} \qquad (eq.2)$$

Indirect costs, id^{EU},to sector j (eq.3) arise as a market response to carbon taxes applied to EU energy sectors, since taxes' immediate effect is the increase of electricity and gas costs,ΔE^{EU} and ΔG^{EU}, respectively.

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[31] Concerning the database, a new header (CO2PF) is included to consider the emissions generated by the industrial processes of these three specific sectors.

[32] According to the European Commission (2014), an increase in the energy price is an important political concern, once it can bring additional costs to households and industries, affecting investment decisions and Europe's global competitiveness. In recent years, regarding gas and electricity prices, the differential between EU and its main economic partners has been increasing. As a consequence, some energy-intensive industries have been moving towards other countries where rules aren't so strict and energy costs are lower.

[33] This paper assumes the equivalent of a carbon tax of USD 40 per ton of CO_2 emitted.

$$id_j^{EU} = \Delta E_j^{EU} + \Delta G_j^{EU} \qquad (eq. 3)$$

In order to find the costs increase, value purchases of electricity, ε, and gas, σ, are multiplied by the variation of their respective prices, p_ε and p_σ (eqs. 4 and 5).

$$\Delta E_j^{EU} = \varepsilon . p_\varepsilon \qquad (eq. 4)$$

$$\Delta G_j^{EU} = \sigma . p_\sigma \qquad (eq. 5)$$

Ad valorem taxes, α, are calculated by taking into account both direct and indirect costs (eq.6).

$$\alpha_{j,r} = d_{j,r} + id_j^{EU} \qquad (eq. 6)$$

And as a final step, border carbon adjustment applied by the EU to sector *j* in region *r*, β, arise from the sum of direct and indirect costs adjusted by a factor, f.[34]

$$\beta_{j,r}^{EU} = \frac{\alpha_{j,r}}{f_{j,r}} \qquad (eq. 7)$$

Regarding the leakage rates, *LR*, they are also determined endogenously in percent and calculated by dividing the increase of CO_2 emissions in the rest of world, δC^{ROW}, by the decrease of CO_2 emissions in the EU, δC^{EU} (in module).

$$LR = \left| \frac{\delta C^{ROW}}{\delta C^{EU}} \right| . 100 \qquad (eq. 8)$$

The regional aggregation is strategically set to analyze and compare Brazilian industrial competitiveness vis-à-vis the other BRICS. From the sectorial point of view, high levels of industrial process emissions and participation in international trade are the criteria for disaggregation.[35]

In this model, five scenarios are constructed aiming to capture the impacts of BCAs, industrial process emissions, and indirect costs.[36] With the aid of three dummies in the model, it's possible to choose to apply BCAs(or not) either considering (or not) process emissions and indirect costs.

- **REF-NOPROC (reference, no industrial process emissions)**: EU doesn't apply BCAs and industrial process emissions aren't taken into account;
- **REF-PROC (reference, industrial process emissions)**: EU doesn't apply BCAs, but the industrial process emissions are taken into account;

[34] The adjustment factor is used to convert the import prices into the appropriated c.i.f. (cost, insurance, freight) concept, once BCAs are levied at the point of importation (see more in Kuik and Hofkes, 2010).
[35] For a more detailed description of the aggregation, see Box 2 in Appendix.
[36] Scenarios are constructed using the 8.1 GTAP database version, which describes the world economy in 2007 (latest version available).

- **BCA-NOPROC (BCA, no industrial process emissions)**: EU applies BCAs, but industrial process emissions aren't taken into account;
- **BCA-PROC**: (**BCA, industrial process emissions**): both BCAs and industrial processes emissions are considered, but indirect costs are not;
- **BCA-PROC-P**: (**BCA, industrial process emissions and indirect costs**): all the new aspects are considered – BCAs, industrial process emissions and the indirect costs caused by the policy-induced increase of gas and electricity prices.

4. Results and discussion

4.1. BCAs effectiveness and EU welfare

The purpose of this section is to analyze the effectiveness and the importance of considering BCAs to reduce carbon leakage. As can be seen from Table 3, LR is very sensitive to BCA and process emissions. When comparing REF-NOPROC to REF-PROC, or in other words, when processes emissions are considered, the leakage rate increases by 3.6%-points. This outcome shows the relevance of taking industrial process emissions into account when assessing carbon leakage, and thus confirms the results found by Bednar-Friedl *et al*. (2012). The authors argue that carbon leakage is higher when process emissions are correctly accounted for, which means that the leakage rate tends to be underestimated when models ignore this variable. According to the present simulations, the underestimation is around 25%.

Table 3
Leakage rate and EU welfare
EU carbon tax = USD40

Scenarios / Variables	REF-NOPROC	REF-PROC	BCA-NOPROC	BCA-PROC	BCA-PROC-P
LR (in %)	10.92	14.51	5.94	5.19	4.99
EV*-EU(in USD bi)	-48.34	-50.26	-42.35	-42.32	-41.03

* Equivalent variation (EV).[37]

The simulations also show that imposing BCAs on imports from outside the EU can result in a considerable decrease in the rate of leakage. When comparing the REF-PROC and BCA-PROC scenarios, the leakage rate drops by 9.3%-points; in the BCA-PROC-P scenario the leakage rate drops by 9.5 %-point compared to REF-PROC.[38]

[37] The equivalent variation (EV), a proxy for the economic welfare associated with a disturbance in the GTAP model, is equal to the difference between the expenditure required for the new level of utility (after simulation) at initial prices (YEV) and the level of utility available on initial balance (Y), i.e., EV = YEV-Y (McDougall, 2002). It can be broken down into three components: allocative effects, terms of trade and investment-savings balance.

[38] It's important to notice that this is a global analysis, which doesn't consider individual sectors. But there is evidence that the result can be quite different for sectoral investigations. Kuik and Hofkes (2010) show that leakage rates tend to be higher for more emission-intensive sectors.

Regarding the welfare effects, the comparison between REF-NOPROC and REF-PROC shows that economic welfare losses are smaller when processes emissions aren't considered, reinforcing the idea that models that ignore this variable tend to underestimate carbon taxes effects for the EU economy. The USD 2 billion difference in Equivalent Variation (EV) comes mainly from a better allocation of domestic resources (allocative effect) (USD 1.3 billion) and a positive terms-of-trade effect (USD 0.6 billion).

Finally, BCAs soften welfare losses (cf. REF-PROC and BCA-PROC), but even more so if border carbon adjustments also include the effects of indirect costs (cf. REF-PROC and BCA-PROC-P).Both comparisons confirm BCAs strong positive effects on the EU's terms-of-trade.[39]

4.2. Brazil's industry competitiveness and welfare

Considering that BCAs can be effective to curb carbon leakage, it's important to explore their effects on the competitiveness of Brazilian industrial exports. According to the simulations, in the presence of BCAs the most negatively affected sectors are non-metallic minerals (cement), iron & steel and non-ferrous metals (Table 4 and Figure 1).[40] Comparing REF-PROC and BCA-PROC-P, exports from these sectors change from positive values to highly negative ones, and this can be concomitantly explained by their intense use of energy and associated CO_2 emissions and their high level of international trade exposure (see Table 1).

Note that the non-ferrous metals sector differs from the other two when it comes to process emissions, because it cannot be classified as a high industrial process emitter. Nevertheless, the application of border carbon adjustments (BCA-PROC scenario) brings a 14%-point decrease in Brazilian exports to the EU and a 2%-point drop in its production (Table 4).

[39]Böhringer and Rutherford (2002) show that these terms of trade effects can dominate the overall economic impacts for unilaterally acting countries and likewise induce substantial losses or gains to countries without abatements action.

[40] The chemical sector is not strongly affected by the employment of BCAs because of its lower use of energy in comparison to non-metallic minerals, iron & steel and non-ferrous metals (see Table 1).

Table 4
Brazilian exports to EU and production for selected sectors (in % change)
EU carbon tax = USD 40

Scenarios / Selected Sectors	REF-NOPROC		REF-PROC		BCA-NOPROC		BCA-PROC		BCA-PROC-P	
	Exp	**Prod**	**Exp**	**Prod**	**Exp**	**Prod**	**Exp**	**Prod**	**Exp**	**Prod**
Food industry	-1.9	-0.24	-2.4	-0.28	-1.1	-0.21	-1.3	-0.23	-1.5	-0.24
Refined oil products	-8.8	0.15	-9.0	0.17	-10.2	0.13	-10.4	0.14	-10.5	0.14
Other mining	-1.4	-0.31	-1.8	-0.29	-1.3	-0.33	-1.3	-0.32	-1.3	-0.34
Chemicals	-0.4	-0.18	-0.2	-0.18	-0.6	-0.10	-0.1	-0.06	-1.3	-0.05
Non-metallic minerals	3.4	0.11	11.9	0.44	-3.6	0.06	-10.2	0.19	-11.6	0.19
Iron &steel	4.0	0.17	8.3	0.52	-2.0	0.07	-15.1	-0.2	-17.3	-0.24
Non-ferrous metals	0.8	-0.29	0.4	-0.41	-14.0	-1.97	-14.1	-1.95	-16.1	-2.15
Motor vehicles	-2.7	-0.07	-3.0	-0.10	-1.4	0.10	-1.3	0.16	-1.3	0.21
Metal products	-3.0	0.05	-3.1	0.07	-1.2	0.14	-0.4	0.18	-0.4	0.21
Electronics & machinery	-4.1	-0.05	-4.6	-0.08	-2.7	0.16	-2.7	0.22	-2.6	0.28
Paper	-1.3	-0.13	-2.0	-0.18	-1.2	-0.9	-1.5	-0.10	-2.9	-0.14
Textile& leather	-2.8	-0.34	-3.4	-0.39	-1.5	-0.26	-1.7	-0.26	-1.9	-0.26
Other manufactures	-3.5	0.21	-4.1	0.22	-2.2	0.21	-2.3	0.22	-2.0	0.22

Comparing the REF-PROC and BCA-PROC-P scenarios, Figure 1 shows a significant decrease in the contribution of these Brazilian sectors to the European import basket – a 22.6% drop for Brazil's iron & steel sector, 18.4% for non-metallic minerals, and 15.9% for non-ferrous metals.[41]

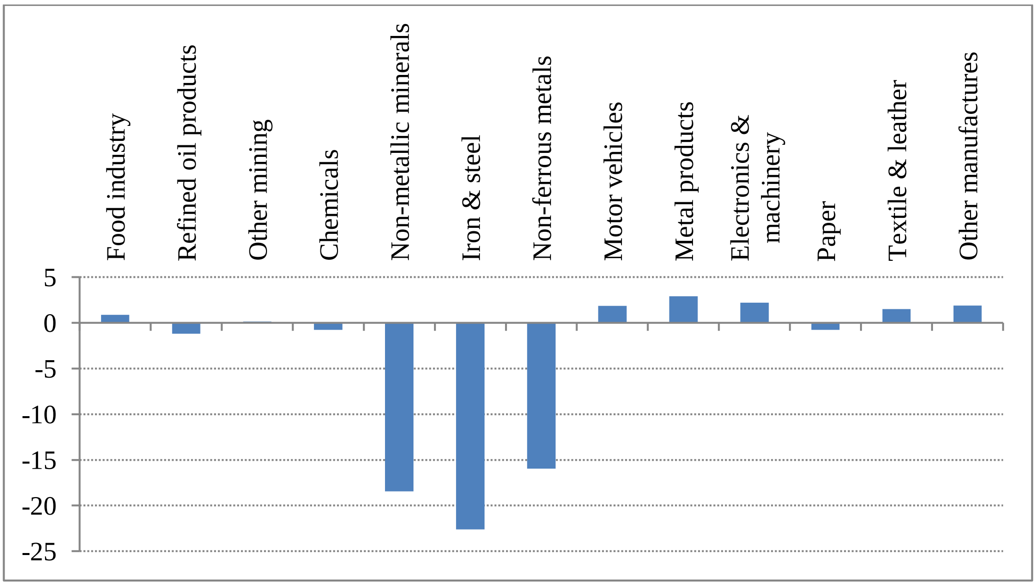
Specifically regarding the role of the industrial process emissions on Brazilian exports competitiveness, the comparison between BCA-NOPROC and BCA-PROC shows significant impacts on non-metallic minerals (cement) and iron & steel. As can be seen in Table 4, non-metallic minerals exports drop from -3.6% to -10.2%, and iron & steel exports drop from -2% to -15.1%. These results, which reflect the high level of process emissions of both sectors, reinforce the importance of taking into consideration the CO_2 released due to industrial processes.

Examining the results for the non-metallic minerals sector (cement),we notice that in the presence of BCAs its production level is not affected, despite the great negative impact on its exports to the EU. Actually, scenarios considering both BCAs and processes emissions (BCA-PROC and BCA-PROC-P) even show a little increase in its production. These results can be explained by a reorientation of its exports to "BCA-

[41]Before simulations their share in the European import market were 0.94%, 0.49% and 0.98% in the iron and steel , non-metallic minerals and non-ferrous metals , respectively.

free" countries– simulation for the BCA-PROC-P scenario, for example, shows a 2.4% increase in non-metallic minerals exports to the US.

Figure 1
Variations in the EU import basket share for Brazilian selected sectors (in %)



This outcome supports the so-called demand-side leakage (Copeland and Taylor, 2004),since BCA's effectiveness is reduced due to the existence of unregulated importing markets. However, it doesn't mean that the sector is immune to BCA effects. According to MCTI (2013), its CO_2 emissions have increased around 30% since 1990, mostly because the sector uses petroleum coke as its main source of energy (see Table 2). Therefore, in the case of BCAs being adopted by other developed countries, the sector could be strongly affected.

Concerning iron & steel, the application of BCAs negatively affects both exports and production, and this can be explained by its high level of industrial process emissions. As can be seen in Table 5,when process emissions are taken into account, the BCA *ad valorem* tariff for Brazilian iron & steel products entering the EU market is higher than the ones for the same products from China and India. In other words, in the market where Brazil plays an important role, the imposition of BCAs exposes its environmental vulnerability. And this vulnerability, as section 2 showed, is strongly connected to the fact that its production process technology still lags behind the best practices already available.

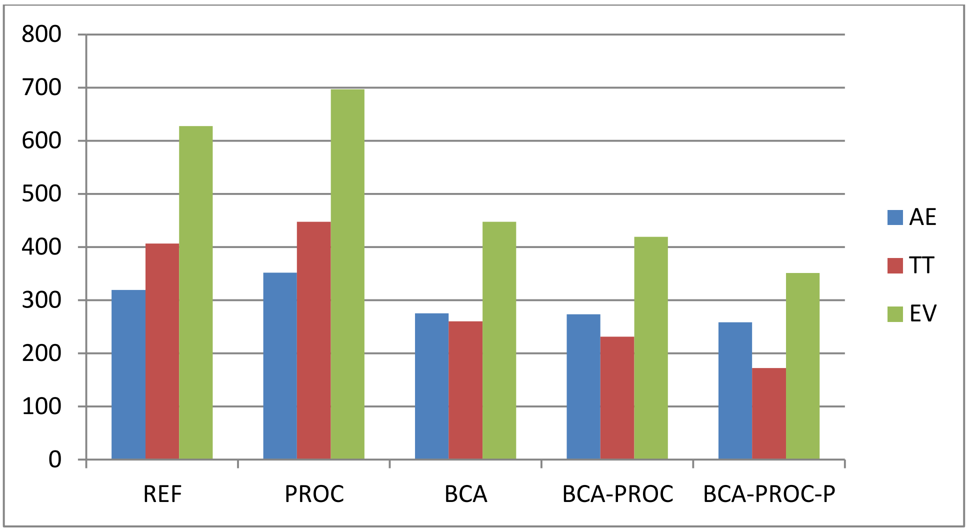
Table 5
Border carbon adjustments to BRICS (*ad valorem* tariff in %)
EU carbon tax = USD 40

Countries	Sectors	BCA-NOPROC	BCA-PROC	BCA-PROC-P
Brazil	Chemicals	0.44	0.49	0.83
	Non-metallic minerals	2.05	5.53	5.97
	Iron&steel	1.81	5.75	6.45
Russia	Chemicals	1.73	2.91	3.27
	Non-metallic minerals	3.69	11.75	12.24
	Iron & steel	2.70	9.78	10.52
India	Chemicals	1.00	1.59	1.97
	Non-metallic minerals	6.08	12.96	13.46
	Iron & steel	4.51	4.73	5.46
China	Chemicals	0.98	1.04	1.39
	Non-metallic minerals	4.95	12.02	12.50
	Iron & steel	2.44	2.85	3.52
South Africa	Chemicals	0.44	0.65	0.99
	Non-metallic minerals	3.25	6.37	6.83
	Iron & steel	3.22	7.45	8.13

In the presence of BCAs, simulations show that all BRICS countries lose welfare (measured by EV).[42]Specifically regarding Brazil, this happens also through allocative effects, but mainly through terms of trade(Figure 2). Note that for all the BCA scenarios, the losses of terms of trade overcome the losses of allocative effects. These results show that even if Brazil doesn't impose any carbon taxes on its industry, it's indirectly charged by the BCAs, since border adjustments work as a burden-shifting mechanism, transferring part of EU abatement costs to non-abating countries through changes in the terms of trade in the most affected sectors.[43]

[42]Actually, the carbon taxes applied by EU on its own industry cause an overall welfare gain to Brazil, China, India and South Africa, but the BCAs drop them significantly. Besides this, the total world welfare decrease in all scenarios, especially in the BCAs ones.
[43]Böhringer *et al*. (2012) state that BCAs can, at the same time, be effective to reduce carbon leakage and exacerbate regional inequality.

Figure 2
Brazil's welfare (in USD million)



Note: Allocative effects (AE); Terms of trade (TT); Equivalent variation (EV).

Supporting this argument, simulations also show that the EU itself is the most benefited region after the imposition of BCAs. Regarding non-metallic minerals and iron & steel, for example, the participation of European industries in its own market increases by 8%-points and 5 %-points respectively (REF-PROC versus BCA-PROC-P).[44] So, BCAs end up playing a twofold role –they manage to decrease emissions leakage and, at the same time, they protect the most energy-intensive and trade-exposed European sectors.

5. Conclusion

Simulations show that BCAs are effective in decreasing emissions leakage and also in leveling the playing field, protecting the most energy-intensive and trade-exposed European sectors. But as a side-effect, the EU ends up transferring part of the abatement costs to regions which do not employ similar environmental policies. This result, the so-called "burden-shifting" effect, is evidenced by the welfare decrease experienced by most countries and also by the significant increase of the European participation in its own market.

Regarding Brazil, the three most affected sectors in the presence of BCAs are non-metallic minerals, iron & steel and non-ferrous metals. What they all have in common is that they are, at the same time, export-oriented sectors and large CO_2 emitters, and the combination of these two features is fundamental to determine their BCA vulnerability.

Among the BRIC countries, Brazil would particularly lose competitiveness in its iron & steel sectors relative to China and India.

The threat of border adjustments can simultaneously bring challenges and opportunities to the Brazilian industry. Brazil's biggest challenge is to maintain its world export market share while finding, at the same time, an environmentally sustainable path. The point is that Brazil is by far one of the most closed countries in the world, and its

[44] It's important to highlight that the domestic participation in these two sectors was already significant even before the employment of BCAs (PROC scenario) – 74% and 72% respectively.

economic structure, reliant on domestic value chain integration, makes it difficult for industry to incorporate the most production efficient technologies.

But if the country manages to overcome these barriers by opening up its economy and moving towards integration with global value chains, there are good opportunities, especially among the non energy related emitting industrial sectors, since they can promote changes in their inputs basket (making it "greener"), increase their energy efficiency, and also switch their production technology.

Appendix

Box2– Aggregation

Regional dimension	Sectoral dimension
1. USA (United States)	1.Agr (Primary Agric., Forestry and Fishing)
2. EU27 (European Union 27)	2. Food ind (Food industry)
3. EEFSU (Annex I Eastern Europe and FSU)	3. Coal (Coal mining)
4. JPN (Japan)	4. Oil (Crude Oil)
5. RoA1 (Other Annex 1 countries)	5. Gas (Natural gas extraction)
6. EEx (Net Energy Exporters)	6. Oil_pcts (Refined oil products)
7. BRA (Brazil)	7. Electricity (Electricity)
8. RUS (Russian Federation)	8. Othermin (Other mining)
9. IND (India)	9. Cherub (Chemical ruber, plastic products)
10. CHI (China)	10. Non met_min (Non-metallic minerals)
11. SAF (South Africa)	11. Iron steel (Iron & steel)
12. MER (Rest of Mercosur)	12. Non_fer_Met (Non-ferrous metals)
13. ROW (Rest of the world)	13. Mot_veic (Motor vehicles and parts and other transport equipment)
	14. Met_prod (metal products)
	15. Elec_maq (electronic, maquinery and other equipment)
	16. Paper (paper products, publishing)
	17. Tex_Leather (Textil, Wearing and leather products)
	18. Oth_manuf (Other manucfatures products)
	19. Oth_ind_ser (Other industries and other ind. and services)

Source: GTAP database 8.1.

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