Direct versus embodied emissions: Criteria for determining the carbon coverage for border carbon adjustment

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Abstract:

For effective and practical implementation of border carbon adjustment, it is crucial to determine the carbon content of imports/exports. In this paper we discussed two criteria. One is direct carbon emissions, which accounts for direct emissions generated from production. The other is embodied emissions which accounts for the total emissions generated directly and indirectly in the supply chain. By simulating Japan's carbon tax policy and three border tax adjustment measures, we found that Japan's carbon tax policy cannot effectively address domestic mitigation, nor create real threats to carbon leakage and international competitiveness. To design effective and WTO-compatible carbon adjustment measures, it is important to ensure that the emissions criteria are identical to the carbon coverage defined by domestic carbon policy.

Key terms

Carbon tax: A carbon tax policy was introduced in Japan from October, 2012, to achieve the country's medium and long-term mitigation goals.

Border carbon adjustment: Aimed to address competitiveness concerns and carbon leakage concerns that are created by unilateral implementation of domestic carbon pricing policies, border carbon adjustment

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has been received much political attention and included in many legislative proposals for domestic mitigation policies, in particular in the EU and the US.

Direct emissions: Direct emissions refer to the carbon emissions that generated directly from production.

Embodied emissions: Embodied emissions refer to the total carbon emissions generated directly and indirectly from electricity generation and all upstream productions in the supply chain.

International competitiveness: A carbon pricing policy implemented unilaterally can inevitably increase the carbon costs of production and therefore create inequality in the playing field which will be in favour of foreign competitors and impact adversely on the international competitiveness of domestic industries.

Carbon leakage: Associated with the competitiveness concerns over unilateral implementation of domestic carbon pricing policy are the concerns over carbon leakage, which refers to an increase in the emissions from un-regulating countries due to the emissions reductions in the regulating countries. A higher carbon leakage will impair the environmental integrity in achieving global mitigation goals.

Japan: Japan is selected as the focus country in our study for two reasons. One is that Japan introduced a carbon tax policy in October, 2012, which has caused great concerns from politicians and the business sector, in particular under current situation of economic downturn. Another one is that Japan depends heavily on both imports and exports. Emissions embodied in the country's imports are considerably large which are relevant for the discussions of direct vs. embodied emissions criteria for determining the carbon contents of imports/exports for border carbon adjustment.

1. Introduction

There have been many proposals to address the competitiveness and carbon leakage concerns due to the asymmetric international arrangement for the mitigation of global greenhouse gas (GHG) emissions [1-4]. Carbon adjustment at the border has received particular attention. Depending on the nature of domestic carbon pricing policies, border carbon adjustment (BCA) measures can take two different forms. One is border tax adjustment (BTA), taking the forms of a carbon tariff on imports to address the competitiveness issue at domestic markets, export rebates to address the competitiveness issue at foreign markets, or using both to address both domestic markets and overseas markets. Another form of BCA is to require importers to surrender allowances under a cap-and-trade system.

Aside from the political concerns and legal issues such as WTO compatibility, there are several practical issues related to the implementation of BCA measures [1-2]. In particular for the design of a BTA, the issue of how to determine the carbon content has received special attention [5-6]. Böhriger and his colleagues [7] summarized three dimensions in designing the carbon tariffs: (i) embodied carbon coverage; (ii) sector coverage; and (iii) tariff rate differentiation. To complement their discussions, this paper focused on direct vs. embodied emissions as criteria to determine the carbon content of products subject to carbon adjustment at border. Direct emissions refer to emissions directly emitted on-site from the production of products. Embodied emissions refer to all emissions emitted directly or indirectly from upstream productions and electricity generation that are required for the production of the products at issue.

The objective of the BTA is to level the playing field between domestic regulated industries and foreign unregulated industries. Theoretically, an ideal BTA is to maintain the same competitive terms for relevant domestic and overseas products before and after the unilateral carbon pricing policy is introduced. Under a carbon pricing policy, the structure of carbon costs of industries includes three components: (i) direct carbon costs due to the direct emissions emitted from production; (ii) indirect carbon costs due to the consumption of electricity in production (electricity carbon costs); and (iii) indirect carbon costs due to the use of intermediate inputs (upstream carbon costs). Corresponding to these are direct emissions, indirect emissions from electricity generation and indirect emissions from upstream productions. Embodied emissions include all three types of emissions. Depending on the design of the carbon pricing policy and whether industries will pass through their carbon costs to downstream customers, the actual carbon costs of industries will include full or partial of direct, electricity and upstream carbon costs. For different industries, the impacts can vary greatly based on their individual cost structure. For the design of an effective BTA, it is therefore important to ensure that the carbon coverage of the tariff is the same as the coverage of the carbon costs per se under the carbon pricing policy. If the carbon pricing policy will de facto generate a full carbon cost to the industries, covering direct, electricity and all upstream emissions, a BTA designed based on the direct emissions criteria will not be considered effective because it can only address part of the total carbon costs. This is particular relevant for industries such as aluminum, which electricity-related emissions accounts for most of its carbon costs. If the carbon pricing policy covers only partial of the full carbon costs, such as by free allocation of emission permits under a cap-and-trade system, a carbon tariff designed based on embodied emissions criteria will be considered over-regulation on imports, which can be challenged by the WTO rule of national treatment and suspected by the motivation of using the BTA as protectionism purpose.

From practical viewpoint, defining in detail the carbon content of each individual category of goods is difficult, especially when imported goods are produced from a supply chain which is completed through global cooperation and specialisation [8]. Tracing the carbon emissions of all upstream suppliers (both direct and indirect) along the global supply chain is almost impossible, in particular when firms in third countries do not have proper monitoring and reporting system in place.

Given the importance of this issue, the aim of this paper is to examine the impacts of direct vs. embodied emissions criteria used for determining the carbon coverage on the effectiveness of BTA measures in addressing the carbon leakage and competitiveness concerns. We applied a multi-region computable general equilibrium (CGE) model for the analysis. Except for a few studies [6-7, 9-10], most literature on the quantitative assessment of the economic and environmental effectiveness of BCA measures consider either direct emissions or partial indirect emissions from electricity generation. For a review of current studies, please see Zhou, et al.[11].

Our country focus is Japan and its major trading partners in developing Asia, including Republic of Korea, China, India and ASEAN countries. The USA is also included because of its importance as a trading partner of Japan and as a counterpart which has similar technology level and carbon intensity of industries. Japan promised to reduce 6% of GHG emissions from the 1990 levels for the Kyoto Protocol first commitment period (2008-2012). For post-Kyoto process, Japan announced 25% reductions in GHGs from the 1990 level by 2020 and 80% reductions by 2050. To achieve these goals, the Japanese Government introduced a carbon tax on the use of fossil fuels (coal, gas and oil) from October, 2012. The ultimate tax rate is JPY289/t-CO_2 (approximately USD3/t-CO_2), which will be reached in three steps: JPY95 from October, 2012 to March, 2014; JPY190 from April, 2014 to March, 2016; and JPY289 from April, 2016 onwards. The introduction of the carbon tax policy will increase the production costs in Japan and have caused political concerns on losing international competitiveness of Japanese industries, which will result in demand shift to less expensive imports and loss of market share in foreign markets [101]. If Japan imports more from countries which production are more carbon intensive than in Japan, carbon leakage will happen and global GHG emissions will increase. ¥

The Ministry of Finance of Japan raised this issue at the Research Group on Environment and Tariff Policies and discussed several BCA measures such as a carbon tariff on imported products, free allocation of emission allowances, and carbon tax exemption for domestic producers [102]. In this work, we simulated the carbon tax at the rate of JPY289/t-CO_2 on the use of fossil fuels in Japan and three different BAT measures: (i) carbon tariff on the imports of EITE sectors; (ii) export rebate for Japan's EITE sectors; and (iii) both carbon tariff and export rebate for EITE sectors. We compared the impacts of using direct vs. embodied criteria for determining the carbon coverage and use the levels of emissions based on the country of origin.

The structure of the paper is arranged as follows: Section 2 explains the methodologies, including model description, scenario setting and explanations on data. Section 3 presents the results with discussions. Section 4 summarizes the conclusions, followed by an executive summary in Section 5 and the future perspectives in Section 6.

2. Methodology

In this paper, we assessed the competitiveness impacts and environmental effectiveness of the carbon tax policy and the carbon tax policy with a BTA measure in Japan. Competitiveness impacts are measured by the output change and change in the global market share of industries. Environmental effectiveness is indicated by the changes in both domestic emissions and global emissions. Only CO_2 emitted from fossil fuel combustion are considered. The significance of carbon leakage is examined by carbon leakage rate, defined as the ratio of the amount of emissions increased elsewhere to the amount of domestic reductions. If the leakage rate is greater than 1, the global emissions will increase and the environmental integrity of domestic carbon policy will be damaged. For BTA measures, we simulated (i) a carbon tariff adjustment; (ii) an export rebate adjustment; and (iii) both a carbon tariff and an export rebate. We assumed that the carbon tariff rate and the rebate rate are the same as domestic carbon tax rate, which is JPY289/t-CO_2 to be implemented from 2012 onward.

2.1 Model description

In this study, a multi-region computable general equilibrium (CGE) model, GTAP6inGAMS [103], is applied. Similar to other CGE models, a Leontief-constant elasticity of substitution (CES) nested function is employed as the production function. Intermediate goods and a composite of value added are defined by Leontief production function. Value added is aggregated by a CES function of the production factors including unskilled labor, skilled labor, capital stock, land and natural resources. Allocation between domestic and imported intermediate goods follows the Armington approach [12].

A representative household maximizes her utility, expressed in a CES function of energy commodities and non-energy commodities. Energy and non-energy commodities are aggregated by the Cobb-Douglas function. Their allocations follow the Armington approach. Different from the GTAP6inGAMS model, household behavior is formulated by using per capita variables. Government behavior is formulated by the Leontief function. Revenues from the carbon tax and border carbon tariffs will become governmental revenue and are not transferred to households. Investment is treated as exogenous variable. The dynamics of the model is determined by exogenous paths for production factors and population growth. Since investment is exogenously given, the long-term impacts on competitiveness and carbon leakage through the channel of investment and relocation cannot be reflected.

To calculate the emissions embodied in imports, we use a multi-region input-output (MRIO) model to trace the total emissions embodied in (see **Equations** 1-4). The MRIO model is constructed for seven regions (Japan, Korea, China, India, ASEAN, USA, and the rest of the world) based on the GTAP (Global Trade Analysis Project) Database Version 7 ([13]) and following the same method of Peters, et al. ([14]).

$$x = Ax + f \qquad \textbf{Equation 1}$$

$$x = (I - A)^{-1} f = Lf \qquad \textbf{Equation 2}$$

$$c \otimes x = c \otimes Lf$$ **Equation 3**

$$e_j^s = \sum_t \left[\left(\sum_r \sum_i c_i^r l_{ij}^{rt} \right) f_j^{ts} \right]$$ **Equation 4**

x is a vector of output, A is the matrix of input coefficients representing intermediate inputs per unit output, and f is a vector of final demand. **Equation 1** presents the equilibrium between supply and demand. I is an identity matrix and L is the Leontief inverse matrix representing total inputs per unit final demand. **Equation 2** represents outputs that driven by the final demand via Leontief multiplier effects. c is a vector of the intensity of direct emissions generated from the production, and $\otimes$ is element multiplication (**Equation 3**).

In **Equation 4**, e_j^s is the total emissions embodied in the final consumption of product *j* in region *s*. c_i^r is the direct emissions from sector *i* in region *r* and l_{ij}^{rt} is the outputs of upstream production *i* in region *r* that is driven by producing one unit final product of sector *j* in region *t*. $c_i^r l_{ij}^{rt}$ is therefore the associated emissions from upstream production *i* in region *r* that is driven by producing one unit final product of sector *j* in region *s*. Summation over upstream production sectors and their source regions, $\sum_r \sum_i c_i^r l_{ij}^{rt}$ presents the total emissions from all upstream productions in all regions driven by producing one unit final product of sector *j* in region *t*. f_j^{ts} is the final consumption of product *j* in region *s* that is supplied by region *t*, and $(\sum_r \sum_i c_i^r l_{ij}^{rt}) f_j^{rs}$ indicates the total upstream emissions that are driven by the final consumption of product *j* in region *s* which is provided by region *t*. By adding up regions, *t*, we have $\sum_t \left[\left(\sum_r \sum_i c_i^r l_{ij}^{rt} \right) f_j^{ts} \right]$, which is the total emissions embodied in the final consumption of product *j* in region *s*, e_j^s.

2.2 Data and assumptions

For the construction of the multi-region CGE model and the MRIO model, GTAP Database Version 7 (base year is 2004) is employed. GTAP Database Version 7 divides the world into 113 regions and each economy is categorized into fifty-seven sectors. In this study, we re-categorized 113 regions into seven and sectors into thirty-nine. Of the thirty-nine sectors, there are three energy sectors (petroleum and coal products, electricity, and gas manufacturing and distribution) and thirty-six non-energy sectors, of which six are defined as EITE sectors. Based on other studies [1-2, 15, 104], we defined paper products and printing (ppp), chemical, rubber and plastic products (crp), non-metallic minerals (nmm), iron and steel (i_s), non-ferrous metals (nfm) and fabricated metal products (fmp) as EITE sectors. They are selected because either the production itself is carbon-intensive, or they use substantial electricity in their production (such as aluminum production in the non-ferrous metals sector), or they use substantial carbon-intensive intermediate products as inputs (such as fabricated metal products). The former case will generate direct carbon costs and the latter two cases will generate indirect carbon costs to industries. In addition, most of them are exposed to trade competitions either in terms of imports or exports. Region and sector definitions are shown in Appendix I and Appendix II. For emissions data, we used the GTAP-E database, which is included in the package of GTAP Database Version 7.

Key parameters of the multi-region CGE model such as elasticity of substitution are taken from GTAP Database Version 7. Following Rutherford and Paltsev [16], the elasticity of substitution between energy and non-energy goods in household consumption is set as 0.5.

Similar to Lau et al. [105], a reference path is designed for future projection. Using the World Bank's Global Economic Prospects [17] as the reference, the growth rates of endogenous quantity and price variables are assumed at 3%. The future paths for other exogenous variables such as supply of production factors and population growth follow the forecast developed by the GTAP.

2.3 Simulation scenarios

As explained before, Japan introduced a carbon tax on the use of fossil fuels in 2012, which will be added to both the output price and import price of fossil fuels. In this study, fossil fuels include coal (sector coa), gas (sector gas), and oil (sector oil) and petroleum and coal products (sector p_c). Carbon tax is introduced from 2012 onwards at the rate of JPY289/t-CO_2 (USD2.67/t-CO_2, based on the exchange rate of JPY108.2/USD in 2004). The reference year is 2004 (the same reference year of the GTAP Database Version 7) with projections up to 2020.

Regarding the BTA measures, import tariff only, export rebate only, and both carbon tariff and export rebate adjustment are employed. The three BTA measures are applied only to the EITE sectors based on the country-specific carbon content.

In addition, we distinguished two criteria in determining the carbon content of imports/exports to be adjusted at the border. One is direct emissions coefficients calculated as emissions generated directly from the sector divided by the total outputs of the sector. Another is embodied emissions coefficients, or the carbon footprints, calculated as total emissions directly and indirectly from all upstream productions in the supply chain of the finished products. In our study, the embodied emissions coefficients are calculated using a MRIO model of seven regions (Eq. (1)-(4)). There are eight scenarios in total (see Table 1).

<Insert Table 1>

3. Results and discussions

3.1 Description of EITE sectors

The description of EITE sectors in Japan in 2004 is presented in Table 2. Chemical, rubber and plastic products, iron and steel, fabricated metal products, non-ferrous metals and non-metallic minerals are important exporting sectors, while chemical, rubber and plastic products, and non-ferrous metals are also dependent on imports. From environmental perspective, all six EITE sectors have much more embodied emissions than direct emission. Relatively speaking, direct emissions account for more shares for paper products and printing, chemical, rubber and plastic products, non-metallic minerals and iron and steel, while non-ferrous metals and fabricated metal products are attributable more to the indirect emissions embodied in their products. The impacts of direct carbon costs in total outputs are very small, ranging from 0.003% to 0.08%. Non-metallic minerals will be influenced the most (0.08%), followed by iron and steel (0.067%), while fabricated metal products (0.003%) and non-ferrous metals (0.013%) will be influenced the least. According to Reinaud ([1]), international transportation costs can function as a trade barrier to protect domestic products from imports of like products. Higher international transportation costs of imports will protect domestic competitiveness of like products. To check this mechanism, we examine the share of the international transportation costs in total value of imports (the higher the more protective from import competition) and the ratio of equivalent direct carbon costs of imports to international transportation costs (the higher the more vulnerable to competitiveness loss). We found that non-metallic minerals and fabricated metal products, with the share of international transportation costs as of 16.5% and 10.7%, respectively, are more protective from import competition. Since the ratios of the equivalent direct carbon costs of imports to the international transportation costs for all sectors are very small, ranging from 0.0003 for fabricated metal products to 0.0159 for iron and steel sector, there is no strong evidence that these EITE sectors would be vulnerable to competitiveness loss due to the introduction of the carbon tax.

<Insert Table 2>

Table 3 presents direct emissions coefficients and embodied emissions coefficients for each sector, which are used for the calculations of the carbon content of imports and exports based on the direct emissions and embodied emissions criteria, respectively. The embodied emissions coefficients, reflecting the total environmental impacts of the supply chain, can be much higher than the corresponding direct emissions coefficients, which can be as much as sixty-two times higher (such as the sector of other transport equipment in Japan).

<Insert Table 3>

3.2 Impacts on international competitiveness

International competitiveness of EITE sectors is measured by output change. Tables 4 and 5 present the output change of EITE sectors in Japan under different scenarios. We compared the differences between the carbon tax case (CTax) and the BAU case and between each of the three BTA cases and the BAU case. Table 4 shows the results of using direct emissions as the criteria for three BTA measures. Table 5 shows the results of using embodied emissions as the criteria for BTAs. It should be noted that the carbon tax levied on the use of fossil fuels in Japan can per se generate a full carbon costs to all sectors under the assumption that each sector will pass through their carbon costs to downstream customers. BTAs based on direct emissions criteria can only address direct carbon costs of each sector and BTAs based on embodied emissions criteria can reflect the full carbon costs of sectors. Therefore BTAs based on embodied emissions criteria can be considered more similar to domestic carbon tax.

<Insert Table 4>

Table 4 indicates that when Japan implements the carbon tax (CTax), the outputs of EITE sectors will be impacted negatively, however the impacts are trivial, ranging from -0.0001% (paper products and printing sector in 2012) to -0.01% (non-ferrous metals in 2020). These negative impacts can be strengthened dramatically with time. The non-ferrous metal sector will be influenced the most followed by iron and steel sector and paper products and printing will be influenced the least among six EITE sectors. Based on direct emissions criteria, the effectiveness of three BTAs in alleviating the negative impacts of the carbon tax policy on the international competitiveness of EITE sectors is different. Except for fabricated metal products, three BTAs can effectively reduce the competitiveness loss due to the carbon tax in most cases, and in many cases they can even help EITE sectors gain more competitiveness compared with the BAU case. The main reason is because the carbon intensity based on direct emissions of EITE sectors in Japan is generally much less than that of the corresponding sectors in other countries, in particular developing Asian countries (China, India and ASEAN countries) (see Table 3). By implementing carbon adjustment using the same rate as domestic carbon tax, the carbon costs per unit value of the EITE sectors that are produced from Japan will be much less than those produced from overseas. This will give EITE sectors in Japan competitive advantages. As a result, competitiveness gained though outstanding performance in the carbon intensity of most sectors in Japan can outweigh the competitiveness loss due to indirect carbon costs that are not addressed by the BTAs which are based on direct emissions criteria.

For fabricated metal products, the BTA measures can worsen the competitiveness of the sector and the BTA using both import tariff and export rebate is the worst case followed by the case of export rebate. The major difference of this sector from other EITE sectors is that the indirect carbon costs are much higher than its direct carbon costs (more than 30 times, see Table 3). Therefore BTAs based on direct emissions criteria can address only a small portion of the full costs of the sector. Based on the CGE model, more capital and labors will be allocated to other EITE sectors because they gain more competitiveness under BTAs than the BAU case. As a result, less capital and labors will be available for the sector of fabricated metal products, which will influence its output negatively.

Except for fabricated metal products, a BTA using both import tariff and export rebate can be considered the most effective in addressing output loss. In addition, import tariff will be more effective for paper products and printing, non-metallic metals and non-ferrous metals from a short-term perspective, and export rebate will be more effective for chemical, rubber and plastic products, iron and steel and for paper products and printing, non-metallic metals and non-ferrous metals in a longer term (in 2020).

In contrast to Table 4, embodied emissions coefficients are used for the calculation of the carbon content for imports/exports subject to BTAs in Table 5. Since BTAs based on this criterion can address the full carbon costs, they are more effective than the BTAs based on direct emissions. Even for fabricated metal products, all three BTAs can properly address the competitiveness issue. In addition, BTAs based on embodied emissions criteria can help all EITE sectors to gain more competitiveness than the BAU case, in particular for non-ferrous metals, which embodied emissions coefficients are much lower than those in other countries (Korea, China, India and ROW).

<Insert Table 5>

3.3 Impacts on carbon leakage

To test carbon leakage effects of different policy scenarios, we compared Japan's national emissions with those in the rest of the world (Tables 6 and 7). The carbon tax policy can reduce domestic emissions but at very minor levels, up to -0.0016% reductions compared with the BAU case. With the introduction of BTAs, Japan's domestic emissions will increase, however the impacts are also very small, up to 0.0165% when using the direct emissions criteria and 0.069% when using the embodied emissions criteria under the scenario of applying both import tariff and export rebates compared with the BAU case. Non-metallic minerals will increase the most, followed by chemical, rubber and plastic products. Among three BTAs, the BTA which imposes both carbon tariff and export rebate will have the largest impacts and import tariff will have the least impacts. The reason for such increase is because under BTAs, most of Japan's industries will gain more competitiveness due to their outstanding performance in terms of carbon intensity, which will increase the outputs compared with the BAU cases. Output increase will in turn increase national emissions. With respect to the criteria determining the carbon content of imports/exports for BTAs, embodied emissions-based BTAs will have exert more impacts on the increase of Japan's national emissions than BTAs based on direct emissions.

<Insert Table 6>

For other regions, changes in emissions due to the introduction of different climate policies in Japan show opposite trends as in Japan. In the case of CTax, emissions from the rest of the world will increase, indicating the phenomenon of carbon leakage triggered by the mechanisms of output loss in Japan. The carbon leakage rate can be as high as 180% in 2012 when the carbon tax policy was just introduced. Compared with other studies, the extremely high leakage rate in our study is due mainly to the large differences (as much as more than ten times for some sectors) in the carbon intensity of industries that are located in Japan and in other regions (see Table 3). This can be caused by data quality or sector aggregation, however to examine the data quality is beyond the scope this study.

From individual country's perspective, except for the rest of the world (ROW), China is the major destination of carbon leakage, followed by India and the USA (see Table 8). From global emissions perspective, global emissions will increase, indicating damage to the global integrity in addressing emissions by the climate policy implemented unilaterally in Japan. With BTA measures in place, emissions from other regions will decrease, indicating the effectiveness of BTAs in addressing emissions reductions in other regions. Though emissions from Japan will increase, global emissions will decrease, indicating the effectiveness of BTAs as instruments to achieve global reductions. Among three BTAs, the BTA using both import tariff and export rebate will be the most effective to address emissions reductions in other regions while the import tariff is the least effective. For the criteria used to determine the carbon content, embodied emissions criteria-based BTAs will be more effective than direct emissions-based BTAs.

<Insert Table 7>

<Insert Table 8>

4. Conclusions

In this paper we examined the impacts of using direct emissions vs. embodied emissions as criteria for determining the carbon coverage of imports/exports on the effectiveness of BTAs in addressing international competitiveness and carbon leakage concerns. By simulating a carbon tax policy introduced in Japan with three BTAs, i.e. import tariff, export rebate and both import tariff and export rebate at the same time, we summarized several conclusions for the case of Japan as follows (see also Table 9).

<Insert Table 9>

i) Based on our simulations, a carbon tax policy introduced in Japan cannot demonstrate effective to address domestic emissions. Though the carbon tax policy will trigger the carbon leakage mechanisms which can undesirably result in an increase in global emissions, the impacts are very small. Though we conducted sensitivity analysis by increasing the carbon tax rate by 10 times (about USD30/t-CO_2), the impacts of the carbon tax policy on domestic reductions and on carbon leakage are still very small.

ii) The carbon tax policy in Japan can impact domestic industries adversely on both EITE sectors and the economy as a whole. However, the impacts are very small. At sectoral level, non-ferrous metals will be influenced the most and paper products and printing sector will be influenced the least among six EITE sectors.

iii) In general, three BTA measures can effectively address the competitiveness loss of EITE sectors, however, for addressing economy-wide competitiveness loss, export rebate will be more effective than import tariff. In addition, three BTA measures can be considered effective to address carbon leakage and global reductions, with the BTA using both import tariff and export rebate being the most effective.

iv) For the case of Japan, since the carbon tax policy can generate a full carbon costs to industries, embodied emissions-based BTAs can be more effective to address both competitiveness concerns and carbon leakage concerns than direct emissions criteria-based BTAs.

Based on our empirical analysis for Japan, we raise several points as follows which we think that should be considered by the policy makers when designing a BCA measure.

First, it is important to have an effective domestic climate policy in place, which should be the fundamental basis and solid justification for introducing any BCA measures. Considering the legality of BCA measures to be judged by the WTO law, in particular based on GATT Article XX, it is necessary to demonstrate the necessity of the trade measure in achieving the environmental objective related to Article XX (b) and (g), and substantial link between the trade measure and the stated climate change policy objective. In the case of Japan, our analysis indicated that the carbon tax policy can generate only marginal impacts on domestic mitigation and global carbon leakage, which cannot be justified as necessary to require a trade measure in achieving the stated mitigation objectives.

Second, it is also important to ensure that a BCA measure designed will not infringe the non-discrimination principle, i.e. national treatment and the most-favoured-nation treatment, provided under GATT (Articles I, II and III). Based on economic theory, the inequality in the playing field between domestic and overseas industries before and after the implementation of domestic climate policy is the main reason for carbon leakage. Therefore an effective BCA measure should be designed to ensure that it will best address the inequality in the carbon costs of industries. In this regard, the direct vs. embodied emissions criteria for determining the carbon coverage of BCA measures is relevant. If the emissions criteria selected can address only part of the carbon costs per se that are created by domestic climate policy, the effectiveness of a BCA measure in addressing the inequality in the carbon costs and related carbon leakage cannot be ensured. If emissions criteria selected are stricter than the carbon coverage of domestic climate policy, the motivation of the introduction of a BCA for trade protectionism and the violation of national treatment clause of GATT can be suspected. In the case of Japan, BTAs based on direct emissions criteria are shown ineffective for sectors, such as non-ferrous metals and fabricated metal products, which are characterised as more indirect carbon costs in their cost structure. In addition, since Japan's industries generally have much less carbon intensity compared with overseas competitors, in particular those in developing countries, the selection of the emissions levels based on either the regulating country or the origin countries is also an important issue. Based on our empirical study for Japan, the selection of the emissions levels based on the origin countries will create an unequal play field in favour of Japan's industries. Under such condition, the national treatment and the most-favoured-nation treatment rules cannot be followed.

Last, but not least, in practice how to determine the carbon contents of each individual category of goods is difficult, time-consuming and costly in terms of administrative costs, in particular when embodied emissions criteria is applied. Many factors can influence the carbon intensity of production substantially, such as technologies used, energy efficiency obtained per same technology, energy sources, type of feedstock and price variations. It is more equitable to assess embodied emissions for imported goods at the border on a case-by-case product basis. However it is nearly impossible to implement without the assistance of fairly rigorous emissions monitoring and reporting in the country of origin, which require great efforts from international collaborations. Some literature discussed this issue [2, 7], however, we would like to include this in the future research agenda.

5. Executive summary

- Introduction. We raised the practical issue of how to determine the carbon coverage for border carbon adjustment and described the linkages between direct vs. embodied emissions criteria and the three components of the carbon costs of industries due to the introduction of a carbon pricing policy. The three components include: (i) direct carbon costs; (ii) indirect electricity carbon costs; and (iii) indirect upstream carbon costs.
- Methodology. We explained the method of using a multi-region CGE model (GTAP6inGAMS) for policy simulations and the method of using a multi-region input-output (MRIO) model for the calculations of embodied emissions coefficients. We designed three policy options, the business as usual case, the carbon tax policy, and border tax adjustment. For BTA, we designed three measures: carbon tariff, export rebate and both carbon tariff and export rebate. In addition, we designed two criteria for determining the carbon contents of imports/exports. One is direct carbon emissions and the other is embodied emissions.
- Results and discussions. We presented the results of policy impacts of different scenarios on international competitiveness (indicated by output change) and carbon leakage. For the competitiveness impacts, our focus is on carbon-intensive and export-exposed (EITE) sectors.
- Conclusions. We summarized the results in one table and we drew five conclusions on the impacts of each policy on international competitiveness and carbon leakage. We found that embodied emissions criteria-based BTAs can be more effective to address both competitiveness

concerns and carbon leakage concerns, however, to select which criteria should depend on the carbon coverage per se of domestic carbon pricing policy.

6. Future perspective

First, as we mentioned in the concluding section, for practical implementation of BCA, how to determine the carbon contents of each individual category of goods is a big challenge. Given the importance of this issue to ensure a fair and effective BCA measure, it should be taken up as an important topic in the future research agenda.

Second, under the presence of border carbon adjustment arrange, there will be a hidden inequality in accounting for trade-related emissions by using the national greenhouse gas inventory approach in the presence of border carbon adjustment. Under a domestic carbon pricing policy, producers pay for the carbon costs in exchange for the right to emit. Under a border carbon adjustment measure, the exporting country pays for the carbon costs of their exports to the importing country, however, they are not given any emissions credits. As a result, the emissions related to trade will be counted in the national inventory of the exporting country. We discussed this issue in another paper [18].

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Table 1. Simulation Scenarios

Scenarios	Direct emissions criteria	Embodied emissions criteria
BAU		
CTax		
BTA1	IMA_Dir	IMA_Emb
BTA2	EXA_Dir	EXA_Emb
BTA3	IMEX_Dir	IMEX_Emb

Note: BAU is the case of business as usual under which no carbon tax policy is introduced in Japan. CTax is the carbon tax scenario, and IMA, EXA and IMEX are three BAT measures, i.e. import tariff, export rebate, and both import tariff and export rebate. Each of three BTAs will be implemented with the carbon tax policy.

Table 2. Description of EITE sectors in Japan

EITE code	International trade		Carbon intensity		Carbon costs		International transportation costs vs. total value of imports		Equivalent carbon costs vs. international transportation costs of imports	
	Exports (million USD)	Imports (million USD)	Direct emissions coefficients (kg CO_2/ USD)	Embodied emissions coefficients (kg CO_2/ USD)	Direct carbon costs (million USD)	Share of direct carbon costs in total outputs	International transportation costs of imports (million USD)	Share of international transportation costs in total value of imports (%)	Equivalent direct carbon costs of imports (million USD)	Ratio of equivalent direct carbon costs of imports to international transportation costs of imports
ppp	3831.6 (18)	5373.5 (26)	0.076 (14)	0.395 (14)	36.8	0.020%	489.40	6.3%	1.57	0.0032
crp	69499.7 (4)	42234.9 (5)	0.171 (10)	0.608 (11)	177.4	0.046%	2184.80	5.6%	17.78	0.0081
nmm	6255.7 (14)	4065.6 (29)	0.298 (6)	0.725 (7)	60.3	0.080%	494.00	16.5%	2.38	0.0048
i_s	20203.4 (5)	5204.9 (28)	0.253 (7)	1.009 (3)	117.1	0.067%	331.00	4.2%	5.26	0.0159
nfm	8611.7 (10)	15109.3 (12)	0.048 (15)	0.746 (6)	7.4	0.013%	342.60	2.8%	1.56	0.0046
fmp	9630.9 (9)	6294.3 (24)	0.013 (25)	0.409 (12)	4.2	0.003%	475.80	10.7%	0.15	0.0003

Note: 1. USD is the value in 2004. 2. Numbers in brackets is the rank among thirty-nine sectors in each country. 3. Carbon costs are calculated based on Japan's carbon tax on fossil fuels, which is JPY289 /t-CO_2 (USD 2.67/t-CO_2). 4. Sector code: ppp (paper products and printing), p_c (chemical, rubber and plastic products), nmm (non-metallic minerals), i_s (iron and steel), nfm (non-ferrous metals) and fmp (fabricated metal products).

Table 3. Direct emission coefficients vs. embodied emission coefficients (in kg CO_2/ u$ of 2004 value)

Sector Code	JPN		KOR		CHN		IND		ASEAN		USA		ROW	
	Direct emissions	Embodied emissions	Direct emissions	Embodied emissions	Direct emissions	Embodied emissions	Direct emissions	Embodied emissions	Direct emissions	Embodied emissions	Direct emissions	Embodied emissions	Direct emissions	Embodied emissions
pdr	0.116	0.279	0.170	0.406	0.332	1.374	0.000	0.196	0.031	0.192	0.797	1.167	0.145	0.450
ocrp	0.217	0.393	0.164	0.425	0.380	1.581	0.001	1.351	0.132	0.325	0.279	0.570	0.180	0.527
lvst	0.015	0.280	0.232	0.796	0.170	1.093	0.004	0.632	0.054	0.409	0.107	0.590	0.114	0.521
frs	0.168	0.286	0.103	0.418	0.252	0.963	0.001	0.161	0.143	0.314	0.097	0.262	0.176	0.477
fsh	0.881	1.095	1.099	1.570	0.546	1.596	0.001	0.241	0.864	1.194	0.657	0.895	0.332	0.701
coa	0.003	0.166	0.175	0.539	1.730	3.781	0.337	0.820	0.192	0.361	0.029	0.578	0.146	0.910
oil	0.000	0.086	0.002	0.486	0.902	2.666	0.357	0.621	0.188	0.321	0.318	0.585	0.181	0.401
gas	0.000	0.092	0.000	0.000	4.513	16.495	1.107	1.430	0.028	0.150	0.160	0.500	0.899	1.197
omn	0.200	0.630	0.118	0.462	0.376	2.590	0.557	2.108	0.570	1.184	0.011	0.935	0.305	1.006
fdpro	0.031	0.283	0.064	0.578	0.281	1.740	0.284	1.056	0.122	0.687	0.106	0.619	0.061	0.526
clo	0.009	0.398	0.134	0.983	0.152	1.797	0.093	1.196	0.099	0.873	0.055	0.596	0.041	0.513
lum	0.005	0.241	0.077	0.693	0.154	1.566	0.031	1.202	0.052	0.582	0.052	0.513	0.036	0.536
ppp	0.076	0.395	0.149	0.882	0.504	2.834	0.933	4.078	0.389	1.361	0.189	0.800	0.110	0.686
p_c	0.142	0.676	0.000	0.280	0.033	2.577	0.201	0.703	0.847	1.278	0.630	1.331	0.646	1.292
crp	0.171	0.608	0.073	0.876	0.656	3.615	0.598	2.519	0.374	1.315	0.237	0.983	0.257	0.930
nmm	0.298	0.725	0.825	1.766	3.965	7.158	3.581	5.816	3.150	4.675	0.656	1.456	0.621	1.369
i_s	0.253	1.009	0.236	1.659	1.193	4.843	1.279	3.982	0.860	2.998	0.402	1.435	0.592	1.782
nfm	0.048	0.746	0.050	1.222	0.538	5.072	0.281	4.409	0.196	1.701	0.189	1.443	0.207	1.453
fmp	0.013	0.409	0.020	0.858	0.103	3.063	0.085	2.585	0.124	1.468	0.040	0.663	0.052	0.738
mvh	0.000	0.288	0.021	0.644	0.123	2.137	0.006	1.609	0.018	0.687	0.026	0.601	0.011	0.502
otn	0.005	0.314	0.091	0.725	0.102	2.034	0.005	1.342	0.045	0.715	0.028	0.435	0.022	0.484
ele	0.012	0.324	0.004	0.507	0.023	1.270	0.025	1.574	0.020	0.683	0.015	0.583	0.023	0.478
ome	0.008	0.321	0.009	0.613	0.106	2.236	0.043	1.946	0.068	0.874	0.022	0.456	0.025	0.544
omf	0.032	0.375	0.034	0.635	0.027	1.301	0.051	1.880	0.241	1.210	0.022	0.512	0.072	0.584
ely	2.585	2.867	6.144	6.699	21.464	25.178	11.778	13.606	8.634	9.590	8.146	8.894	6.050	6.750
gdt	0.020	0.134	0.076	0.281	21.686	31.107	0.651	0.886	1.029	1.338	0.404	0.742	0.575	1.021
wtr	0.005	0.233	0.231	1.059	0.096	3.830	0.030	2.192	0.369	1.577	0.208	0.760	0.184	1.015
cns	0.018	0.256	0.017	0.555	0.065	2.368	0.010	1.375	0.068	1.191	0.011	0.333	0.028	0.528
trd	0.014	0.142	0.075	0.411	0.138	1.208	0.057	0.816	0.098	0.611	0.029	0.320	0.038	0.348
otp	0.470	0.643	1.330	1.640	0.881	1.910	0.896	1.641	1.735	2.500	1.490	2.127	0.993	1.532
wtp	0.351	0.759	1.019	1.979	1.818	3.062	1.026	1.798	1.655	2.613	0.695	1.142	0.857	1.525
atp	0.421	0.800	1.201	1.831	1.043	2.033	1.023	1.792	2.375	3.187	2.294	3.004	1.135	1.722
cmn	0.008	0.121	0.016	0.250	0.031	1.010	0.005	0.974	0.057	0.439	0.004	0.177	0.029	0.264
ofi	0.005	0.074	0.016	0.150	0.036	0.506	0.001	0.353	0.061	0.468	0.008	0.141	0.015	0.234
isr	0.006	0.104	0.015	0.228	0.047	1.077	0.010	0.593	0.019	0.393	0.002	0.118	0.014	0.219
obs	0.027	0.164	0.090	0.379	0.087	1.078	0.108	1.327	0.041	0.584	0.010	0.196	0.024	0.215
ros	0.037	0.185	0.057	0.508	0.193	1.318	0.106	1.317	0.101	0.861	0.033	0.688	0.040	0.308
osg	0.037	0.175	0.046	0.299	0.162	1.306	0.002	0.342	0.091	0.684	0.031	0.262	0.035	0.244
dwe	0.000	0.022	0.000	0.082	0.001	0.356	0.000	0.077	0.000	0.056	0.000	0.032	0.000	0.056

Table 4. Output change (in %) of EITE sectors in Japan by using direct emissions coefficients

	ppp				crp			
	CTax	IMA_Dir	EXA_Dir	IMEX_Dir	CTax	IMA_Dir	EXA_Dir	IMEX_Dir
2012	-0.0001	0.0013	0.0010	0.0024	-0.0005	0.0034	0.0185	0.0224
2015	-0.0003	0.0023	0.0022	0.0048	-0.0019	0.0055	0.0384	0.0458
2020	-0.0011	0.0021	0.0038	0.0070	-0.0060	0.0042	0.0609	0.0711
	nmm				i_s			
	CTax	IMA_Dir	EXA_Dir	IMEX_Dir	CTax	IMA_Dir	EXA_Dir	IMEX_Dir
2012	-0.0003	0.0160	0.0122	0.0286	-0.0008	0.0014	0.0169	0.0191
2015	-0.0013	0.0178	0.0309	0.0501	-0.0029	0.0007	0.0363	0.0399
2020	-0.0046	0.0083	0.0656	0.0785	-0.0089	-0.0050	0.0599	0.0637
	nfm				fmp			
	CTax	IMA_Dir	EXA_Dir	IMEX_Dir	CTax	IMA_Dir	EXA_Dir	IMEX_Dir
2012	-0.0010	0.0019	-0.0005	0.0024	-0.0004	-0.0018	-0.0024	-0.0037
2015	-0.0039	-0.0015	-0.0015	0.0009	-0.0016	-0.0040	-0.0063	-0.0087
2020	-0.0124	-0.0143	-0.0043	-0.0062	-0.0056	-0.0093	-0.0152	-0.0188

Note: For output change, the change rate (in %) is calculated compared with the BAU case.

Table 5. Output change (in %) of EITE sectors in Japan by using embodied emissions coefficients

	ppp				crp			
	CTax	IMA_Emb	EXA_Emb	IMEX_Emb	CTax	IMA_Emb	EXA_Emb	IMEX_Emb
2012	-0.0001	0.0067	0.0050	0.0118	-0.0005	0.0164	0.0648	0.0818
2015	-0.0003	0.0123	0.0111	0.0237	-0.0019	0.0284	0.1362	0.1664
2020	-0.0011	0.0147	0.0205	0.0363	-0.0060	0.0336	0.2217	0.2611
	nmm				i_s			
	CTax	IMA_Emb	EXA_Emb	IMEX_Emb	CTax	IMA_Emb	EXA_Emb	IMEX_Emb
2012	-0.0003	0.0263	0.0277	0.0544	-0.0008	0.0088	0.0719	0.0814
2015	-0.0013	0.0288	0.0707	0.1008	-0.0029	0.0121	0.1571	0.1720
2020	-0.0046	0.0146	0.1524	0.1715	-0.0089	0.0065	0.2690	0.2843
	nfm				fmp			
	CTax	IMA_Emb	EXA_Emb	IMEX_Emb	CTax	IMA_Emb	EXA_Emb	IMEX_Emb
2012	-0.0010	0.0406	0.0862	0.1278	-0.0004	0.0112	0.0092	0.0208
2015	-0.0039	0.0428	0.2175	0.2636	-0.0016	0.0170	0.0180	0.0366
2020	-0.0124	0.0012	0.4324	0.4450	-0.0056	0.0073	0.0262	0.0391

Note: For output change, the change rate (in %) is calculated compared with the BAU case.

Table 6. National emissions change (in %) in Japan

	CTax	Direct emissions coefficients			Embodied emissions coefficients		
		IMA_Dir	EXA_Dir	IMEX_Dir	IMA_Emb	EXA_ Emb	IMEX_ Emb
2012	-0.0001	0.0009	0.0035	0.0046	0.0032	0.0140	0.0174
2015	-0.0005	0.0010	0.0080	0.0095	0.0047	0.0325	0.0377
2020	-0.0016	0.0000	0.0149	0.0165	0.0038	0.0640	0.0694

Note: For national emissions change, the change rate (in %) is calculated compared with the BAU case.

Table 7. Emissions change (in %) in the rest of the world

	CTax	Direct emissions coefficients			Embodied emissions coefficients		
		IMA_Dir	EXA_Dir	IMEX_Dir	IMA_Emb	EXA_ Emb	IMEX_ Emb
2012	0.00001	-0.0002	-0.0003	-0.0005	-0.0007	-0.0011	-0.0018
2015	0.00003	-0.0001	-0.0005	-0.0006	-0.0005	-0.0021	-0.0026
2020	0.00011	0.0000	-0.0008	-0.0010	-0.0003	-0.0038	-0.0042

Note: For national emissions change, the change rate (in %) is calculated compared with the BAU case.

Table 8. Change in national emissions when Japan introduced the carbon tax policy

	Change in national emissions (Mt-CO_2)					
	KOR	CHN	IND	ASA	USA	ROW
2012	0.00004	0.00126	0.00026	0.00006	0.00026	0.00075
2015	0.00015	0.00382	0.00082	0.00025	0.00065	0.00322
2020	0.00078	0.01163	0.00146	0.00127	0.00177	0.01249

Note: KOR-Korea, CHN-China, IND-India, ASA-ASEAN countries, USA-USA, ROW-Rest of the world. The change in amount is calculated compared with the BAU case.

Table 9. Summary of policy impacts on international competitiveness and carbon leakage

Policy scenario	Environmental effectiveness				Competitiveness Effects	
	Domestic reductions	Reductions in ROW	Global reductions	Carbon leakage	EITE sectors	Economy-wide effects
CTax	+	-	-	√	-	-
IMA_Dir	-	+	+	×	+*	-
EXA_Dir	-	+	+	×	+*	+
IMEX_Dir	-	+	+	×	+*	-
IMA_Emb	-	+	+	×	+	-
EXA_Emb	-	+	+	×	+	+
IMEX_Emb	-	+	+	×	+	+

Note: + indicates positive impacts; – indicates negative impacts; √ indicates yes; × indicates no. * means except for the sector of fabricated metal products.

Appendix I Region classification

Region	Code	Description
Japan	JPN	
South Korea	KOR	
China	CHN	
India	IND	
ASEAN	ASA	Including Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam
United States	USA	
Rest of the world	ROW	Including other regions than the six countries/regions of the 113 regions in the GTAP Database Version 7

Appendix II Sector Classification

No.	Sector Code		Corresponding GTAP Sector	
	Code	Description	Code	Description
1	pdr	Paddy rice	pdr	Paddy rice
2	ocrp	Other crops	wht	Wheat
			gro	Other cereal grains
			v_f	Vegetables, fruit, nuts
			osd	Oil seeds
			c_b	Sugar cane, sugar beet
			pfb	Plant-based fibers
			ocr	Other crops
3	lvst	Livestock	ctl	Cattle, sheep, goats, horses
			oap	Other animal products
			rmk	Raw milk
			wol	Wool, silk-worm cocoons
4	frs	Forestry	frs	Forestry
5	fsh	Fishing	fsh	Fishing
6	coa	Coal	coa	Coal
7	oil	Oil	oil	Oil
8	gas	Gas	gas	Gas
9	omn	Other minerals (metal ores, uranium, gems, etc.)	omn	Other minerals (metal ores, uranium, gems, etc.)
10	fdpro	Food products	cmt	Meat: cattle, sheep, goats, horse
			omt	Other meat products
			vol	Vegetable oils and fats
			mil	Dairy products
			pcr	Processed rice
			sgr	Sugar
			ofd	Other food products
			b_t	Beverages and tobacco products
11	clo	Textile and leather products	tex	Textiles
			wap	Wearing apparel
			lea	Leather products
12	lum	Wood products	lum	Wood products
13	ppp	Paper products, publishing	ppp	Paper products, publishing
14	p_c	Petroleum, coal products	p_c	Petroleum, coal products
15	crp	Chemical, rubber, plastic products	crp	Chemical, rubber, plastic products
16	nmm	Non-metallic minerals (cement, lime, concrete, etc.)	nmm	Non-metallic minerals (cement, lime, concrete, etc.)
17	i_s	Ferrous metals (iron and steel)	i_s	Ferrous metals (iron and steel)
18	nfm	Non-ferrous metals (copper, aluminum, zinc, lead, etc.)	nfm	Non-ferrous metals (copper, aluminum, zinc, lead, etc.)
19	fmp	Fabricated metal products	fmp	Fabricated metal products
20	mvh	Motor vehicles and parts	mvh	Motor vehicles and parts
21	otn	Other transport equipment	otn	Other transport equipment
22	ele	Electronic equipment	ele	Electronic equipment
23	ome	Other machinery and equipment	ome	Other machinery and equipment
24	omf	Other manufactures	omf	Other manufactures
25	ely	Electricity	ely	Electricity
26	gdt	Gas manufacture, distribution	gdt	Gas manufacture, distribution
27	wtr	Water	wtr	Water
28	cns	Construction	cns	Construction
29	trd	Trade	trd	Trade
30	otp	Other transport (road, rail, pipelines, etc.)	otp	Other transport (road, rail, pipelines, etc.)
31	wtp	Sea transport	wtp	Sea transport
32	atp	Air transport	atp	Air transport
33	cmn	Communication	cmn	Communication
34	ofi	Other financial services	ofi	Other financial services
35	isr	Insurance	isr	Insurance
36	obs	Other business services	obs	Other business services
37	ros	Recreation and other services	ros	Recreation and other services
38	osg	Public administration, defense, health care and education	osg	Public administration, defense, health care and education
39	dwe	Dwellings	dwe	Dwellings