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Can Consumer Responsibility Help Address Carbon Leakage Concerns? An Analysis of Participation vs. Non-participation in a Global Mitigation Regime*

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Competitiveness and carbon leakage are two central concerns in the international negotiations of a future climate policy. With more attentions given to border adjustment measures to address these concerns, it is rational to consider consumption-based national inventory to account for emissions embodied in international trade. In this work, we examine the impacts of a change in the national emissions accounting principle from producer responsibility to consumer responsibility on the national welfare, international trade, competitiveness and carbon leakage. By applying linear programming to a multi-region input-output model, we established a numerical model to analyse participation and non-participation in a global mitigation regime. Preliminary results indicate that without full participation of parties in a global mitigation regime, the international competitiveness and national welfare of the participation country will be influenced negatively. However with an emissions trading system in place, these disadvantages will be alleviated substantially. A change from producer responsibility to consumer responsibility may have potential impacts on the exports and domestic reductions in the participation country and may serve as an effective measure to restrain the trend of carbon leakage.

Keywords: carbon leakage, embodied emissions, consumer responsibility, producer responsibility, climate policy, international trade

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Introduction

The entry into force of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) divides parties of the UNFCCC into two groups by their obligations to domestic mitigation. Under the Kyoto Protocol, Annex I countries to the UNFCCC (except for the US) commit to collectively reduce 5.5% of emissions for 2008-2012 based on their 1990 emission levels. According to the principle of "common but differentiated responsibilities", non-Annex I countries (mostly developing countries) do not have binding targets.This division creates differences in the strictness of domestic climate policy.

The US did not ratify the Kyoto Protocol due mainly to the concerns of reduced international competitiveness and lack of participation from developing country (Pauwelyn, 2007). Emission reduction is costly and therefore can affect terms-of-trade. Industries in countries which implement emission reduction will face competitive disadvantage compared to their international competitors that operate in countries which do not have a quantified reduction target in place (van Asselt & Biermann, 2007). As a consequence, carbon-intensive production will be pulled to countries that have less stringent climate policies along with other economic factors. Emissions reduced in Annex I countries through offshore production and international trade will however generate elsewhere, in particular from developing countries. This potential trend of relocation has led to the concern of carbon leakage, which refers to an increase in CO_2 emissions in countries without climate policies that can be related to emission reduction in countries with climate policies in place. Reduced global competitiveness and carbon leakage can undermine the effectiveness of climate policy (Weber & Matthews, 2007; Peters & Hertwich, 2008) and have become central concerns in the debates of international trade and climate change and in domestic policy discussions in the US and the European Union (EU) (Weber & Peters, 2009; van Asselt & Brewer, 2010).

Various policy measures have been suggested to address these concerns. Among others, the foremost policy option is to commit all emitting countries to control emissions based on "common but differentiated responsibilities" and national capacity. Based on the results of the Copenhagen meeting of the Conference of the Parties of the UNFCCC, to conclude an international agreement on full participation in emission reduction will remain an intractable challenge. According to a literature review by Asselt and Brewer (2010), a strand of recent literature has focused on border adjustment measures varying from analyzing the effectiveness of border adjustment measures in achieving the stated environmental and economic objectives (Manders & Veenendaal, 2008; Reinaud, 2008; Fischer & Fox, 2009; Mckibbin & Wilcoxen, 2009) to examining the compatibility of border adjustment measures with the rules of international trade law (Biermann & Brohm, 2005; Ismer & Neuhaff, 2007; Quick, 2008; Sindico, 2008; WTO & UNEP, 2009).

A corresponding issue related to border adjustment and carbon leakage is emissions embodied in tradable goods. "Embodied emissions" refers to CO_2 emitted from each upstream stage of the supply chain of a product, which is used or consumed by the downstream stages or the consumer. On the one hand, the Stern Review (Stern, 2007) pointed out that although developing countries accounted for less than one quarter of cumulative emissions, over three quarters of future emissions growth will likely come from today's developing countries, because of more rapid population and GDP growth than developed countries, and an increasing share of energy-intensive industries. On the other hand, a large body of literature indicated that a significant portion of emissions emitted from developing countries is embodied in the consumption in rich nations.

For example, CO_2 emitted inside Japan was estimated to be 304Mt-C in 1990, while carbon embodiments in imports to Japan were 68Mt-C, surpassing those embodied in Japan's exports (46.4Mt-C) (Kondo et al., 1998). For Denmark, CO_2 trade balance changed from a surplus of 0.5Mt in 1987 to a deficit of 7Mt in 1994 (Munksgaard & Pedersen, 2001). Norwegian household consumption-induced CO_2 emitted in foreign countries represented 61% of its total indirect CO_2 emissions in 2000 (Peters & Hertwich, 2006). For the US, the overall CO_2 embodied in US imports grew from 0.5-0.8Gt-CO_2 in 1997 to 0.8-1.8Gt-CO_2 in 2004, representing 9%-14% and 13%-30% of US national emissions in 1997 and 2004, respectively (Weber & Matthews, 2007). At the multi-region level, about 13% of the total carbon emissions of six OECD countries (Canada, France, Germany, Japan, UK and USA) were embodied in their manufactured imports in mid-1980s (Wyckoff & Roop, 1994) . More recent research shows CO_2 embodied in multilateral trade of ten countries (including Japan, the US, China and other Asian countries) in 2000 accounted for 13% of their total emissions (Zhou, 2009). From the perspective of trade balance of embodied CO_2, the US had the largest trade deficit (-464Mt-CO_2), followed by Japan (-191Mt-CO_2), while China had the largest trade surplus (452Mt-CO_2). Another study (Peters & Hertwich, 2008) indicates that around 5Gt-CO_2 of 42Gt-CO_2 equivalent of global GHG emissions in 2000 were embodied in international trade of goods and services, most of which flowed from non-Annex I to Annex I countries.

Current national GHG inventory reported to the UNFCCC accounts for "all greenhouse gas emissions and removals taking place within national (including administered) territories and offshore areas over which the country has jurisdiction" (IPCC, 1996). This accounting method is based on a principle of territorial responsibility or producer responsibility (Eder & Narodoslawsky, 1999). The equity of the producer principle is arguable because the consumer who benefits from internationally traded goods produced in other countries should shoulder certain responsibility for the emissions emitted from production. In response to this argument, consumer responsibility and shared responsibility between exporting and importing countries (Eder & Narodoslawsky, 1999; Munksgaard & Pedersen, 2001; Ferng, 2003; Peters, 2008) or among upstream and downstream agents in a supply chain (Bastianoni et al., 2004; Gallego & Lenzen, 2005; Lenzen et al., 2007) are proposed to account for bothdirect emissions fromconsumption (e.g., transportation) and indirect emissions embodied in goods. If border adjustment measures will be implemented, it is rational to consider that emissions embodied in imported goods subject to tax adjustment at borders should be charged to the national inventory of importing countries (Jiang et al., 2008).

The purpose of this paper is to account for emissions embodied in international trade and examine how consumer responsibility will influence carbon leakage and international competitiveness associated with trade. Linear programming is applied to a multi-region input-output model to simulate international trade and climate policy for participation country and non-participation in a global mitigation regime. The next section explains the analytical structure, based on which a numerical model is provided in section 3. Section 4 concludes this paper and provides a future research agenda.

Analytical Structure

In this paper, linear programming (LP) is applied to a multi-region input-output (MRIO) model to simulate the impacts of setting a cap onnational emissions and a change of the accounting method from producer responsibility to consumer responsibility on international trade and emission levels.

Dantzig's pioneer work on LP in an input-output (IO) model (IO-LP) led to the *Leontief Substitution Model* (Dantzig, 1949, 1963). By using the Leontief substitution type of LP models, one can identify the substitution of alternative activities/technologies when an economy-wide or sectoral policy target (e.g., energy efficiency improvement or constraints on emissions) is set (Miyazawa, 1984; Vogstad, 2009). In particular, IO-LP models are useful in dealing with trade for open economies under the consideration of comparative competitiveness (Miyazawa, 1984). The Leontief substitution type of LP model can help examine the substitution between domestic production and imports for a nation to optimize its value-added (GDP) under given demand and import requirements among other constrains. For policy makers who concern about processing trade and its relations to national economy, IO-LP models can help determine the optimal structure for production and for exports. In addition, they can help identify the optimal spatial allocation of production and goods through international transportation under constrains of various available resources. Since 1990s, applications of LCA and process analysis in optimization models have been developed to combine economic and environmental objectives (Azapagic & Clift, 1995, 1999; Alexander et al., 2000; Bjork & Rasmuson, 2002).

In this paper, the Leontief substitution type of LP model is extended to a MRIO model to analyze the substitution between domestic production, imports and exports in order to achieve the optimal national welfare under the constraints of technologies, emission levels and given final consumption requirements. First, different climate policy instruments, i.e., a change in national inventory accounting method from producer responsibility to consumer responsibility and an introduction of multi-nation cap-and-trade system, are introduced. Second, corresponding reactions from both participation and non-participation countries in a global mitigation regime are analyzed. Third, the impacts on carbon leakage and international competitiveness (in terms of market share) are examined. The reason of selecting a MRIO model is because it can model imports and exports of both intermediates and final products systematically and identify the origin sector of imports and the destination sector of exports. In addition, a MRIO model has proved to be useful in accounting emissions embodied in international trade (Lenzen et al., 2004; Peters & Hertwich, 2008; Wiedmann et al., 2007; Zhou, 2009; Wiedmann, 2009). A MRIO model is therefore more appropriate for the purpose of this work.

For convenience, a two-country MRIO model is considered. Country r represents a participation country in a mitigation regime and therefore takes actions to fulfill its emission target. Country s represents a non-participation country without quantified reduction target. Each country has the same n industries producing n different products and each industry produces one goods. In each country, there is a given level of final consumption. Each industry sells in both countries to meet the demand of intermediate production by various industries and the final demand by households. The same industry located in two countries competes with each other in both home and foreign markets. To simplify, it is assumed that two countries trade with each other but do not trade with other countries. The equilibrium between supply, demand and bilateral trade in a MRIO model is defined as in equation (1):

$$\begin{cases} X^r = X^{rr} + X^{rs} + F^{rr} + F^{rs} \\ X^s = X^{sr} + X^{ss} + F^{sr} + F^{ss} \end{cases} \quad (1)$$

where X^r and X^s (column vectors) denote industrial outputs; two pairs, X^{rr} and X^{ss}, and F^{rr} and F^{ss}, are the sales of intermediate products and final products, respectively, by domestic industries at domestic markets; another two pairs, X^{rs} and X^{sr}, and F^{rs} and F^{sr}, are the sales of intermediate products and final products, respectively, by domestic industries at foreign markets.

Therefore, from Country *r*'s point of view, X^{rs} and F^{rs} are exports to *s*, and X^{sr} and F^{sr} are imports from *s*. The market share of industries located in each country, defined as $X^r(X^r + X^s)^{-1}$ and $X^s(X^r + X^s)^{-1}$, respectively, can represent relative industrial competitiveness.

Define $A^r = (X^{rr} + X^{sr})X^{r^{-1}}$ and $A^s = (X^{sr} + X^{ss})X^{s^{-1}}$ as the Leontief technical coefficient matrices in two countries. Technical coefficients, which are assume fixed in the model, present the production recipe of each industry and the interrelations among industries to fulfill their production. Also define S^r and S^s (diagonal matrices) as self-sufficiency ratios for domestic demand, indicating the share of domestic production in satisfying total domestic demand. For each sector, the same ratio is applied into both intermediate demand and final demand. Higher self-sufficiency in a home country indicates more competitive a domestic industry in domestic market and lower self-sufficiency in a foreign country indicates more competitive a domestic industry in foreign markets. Equation (1) is therefore re-defined as follows (see equation (2)):

$$\begin{cases} X^r = S^r A^r X^r + (1 - S^s) A^s X^s + S^r F^r + (1 - S^s) F^s \\ X^s = (1 - S^r) A^r X^r + S^s A^s X^s + (1 - S^r) F^r + S^s F^s \end{cases} \quad (2)$$

where $F^r (= F^{rr} + F^{sr})$ and $F^s (= F^{sr} + F^{ss})$ are the total final demand by households in two countries. In a consumption-driven type of input-output analysis, final consumption is given exogenously.

Each industry has a fixed ratio of value-added, denoted by vectors α^r and α^s. Different sectoral value-added ratios represent the comparative competitiveness of the same sector in different countries. The value-added, calculated as $\alpha^r X^r$ and $\alpha^s X^s$, satisfies the following relations (equation (3)). In addition, each industry operates within its production capacity (equation (4)).

$$\begin{cases} X^r = A^r X^r + \alpha^r X^r \\ X^s = A^s X^s + \alpha^s X^s \end{cases} \quad (3)$$

where *I* is an identity matrix.

$$\begin{cases} X^r \le PC^r \\ X^s \le PC^s \end{cases} \quad (4)$$

To simply reflect the non-perfect substitution of similar final products produced domestically and those imported from a foreign country, a minimum level of domestic demand for imported similar goods is introduced in equation (5).

$$\begin{cases} F^{sr} \ge \beta^r F^r \\ F^{rs} \ge \beta^s F^s \end{cases} \quad (5)$$

So far the substitution of domestic production and international trade to achieve the optimization of national welfare (defined as value-added) is modeled. Next, climate policy instruments will be introduced to the model.

First, national emissions calculated based on producer responsibility (equation (6)) and consumer responsibility (equation (6)'), respectively, are defined as follows:

$$\begin{cases} NQ^r = Q^r X^r = Q^r (X^{rr} + X^{rs} + F^{rr} + F^{rs}) \\ NQ^s = Q^s X^s = Q^r (X^{sr} + X^{ss} + F^{sr} + F^{ss}) \end{cases} \tag{6}$$

$$\begin{cases} RQ^r = Q^r (X^{rr} + F^{rr}) + Q^s (X^{sr} + F^{sr}) \\ RQ^s = Q^r (X^{rs} + F^{rs}) + Q^s (X^{ss} + F^{ss}) \end{cases} \tag{6'}$$

where Q^r and Q^s (vectors) are emission intensities, defined as emissions generated from the production of one unit output. NQ^r and NQ^s are national emissions based on producer responsibility, and RQ^r and RQ^s are national responsible emissions based on consumer responsibility. In equation (6), emissions embodied in exports are charged to exporting countries, where the production is located. In equation (6)', emissions embodied in imports are charged to importing countries, where the consumer resides.

Emission limits, denoted as CAP^r and CAP^s, are set for two countries under both producer responsibility and consumer responsibility (equation (7)). Since country s does not have a binding mitigation target and therefore there is no incentive to reduction, CAP^s is therefore infinite and R^s is zero.

$$\begin{cases} NQ^r \le CAP^r \\ NQ^s \le CAP^s \end{cases} \text{or} \begin{cases} RQ^r \le CAP^r \\ RQ^s \le CAP^s \end{cases} \tag{7}$$

Because of an emission cap set for the participation country, we also modeled relevant abatement costs. Unit abatement costs, c^r and c^s (parameters which areassumed uniform across all industries in each country), are given exogenously. The function of abatement costs is defined as $c^r {R^r}^2$ and $c^s {R^s}^2$, where R^r and R^s are abated emissions. The functions of abatement costs are convex, indicating that the total abatement costs and marginal abatement costs, i.e., $2c^r R^r$ and $2c^s R^s$, increase with the quantity of reduction. This infers that abatement is a cost which will influence national welfare.

By introducing environmental constrains to the model, a country is facing trade-offs among domestic production, imports, exports and domestic reduction. Domestic production will increase value-added but contributes to national emissions. Imports will be the costs to national welfare but can help release reduction pressure, which is also a cost to national welfare. Exports will increase revenue, however contributes to national emissions. Domestic abatement will help achieve national emission target, but is a cost to national welfare. When facing a combined objective of economy and the environment, major strategic factors provide alternatives for decision-making. A change in the accounting method will influence the reaction of the participation country to an emission cap by the trade-offs between imports of carbon-intensive products from the non-participation country and domestic abatement. This will therefore have implications for carbon leakage and international competitiveness.

In addition, emissions trading between two countries is considered. ER^r indicates emissions right bought by country *r* from *s* (or emissions credits sold by Country *s* to *r*) and ER^s indicates emissions right bought by country *s* from *r*. Given a carbon price, the balance of emissions trading (= total sales less total purchase) becomeseither a cost (negative) or an income (positive) which impacts the national welfare.

Considering domestic abatement and emissions trading, equation (7) should be modified as follows based on producer responsibility and consumer responsibility, respectively (see equation (7)’):

$$\begin{cases} NQ^r - R^r + (ER^s - ER^r) \le CAP^r \\ NQ^s - R^s + (ER^r - ER^s) \le CAP^s \end{cases} \text{or} \begin{cases} RQ^r - R^r + (ER^s - ER^r) \le CAP^r \\ RQ^s - R^s + (ER^r - ER^s) \le CAP^s \end{cases} \quad (7)’$$

Consider a linear programming model in which each countrymaximizes itsnational welfare in equation (8) under all constrains defined in equations (2)-(5), equation (6) or (6)’, and equation (7) or (7)’. National welfare is defined as total value-added minus reduction costs plus net incomefrom emissions trading.

$$\begin{cases} W^r = \alpha^r X^r - c^r {R^r}^2 + cp \times (ER^s - ER^r) \\ W^s = \alpha^s X^s - c^s {R^s}^2 + cp \times (ER^r - ER^s) \end{cases} \quad (8)$$

where *cp* represents the carbon price (given exogenously) in emissions trading. Major strategies to achieve the economic and environmental bi-objectives faced by nations in this setting include: (1) to produce at an optimal level; (2) to import and export; (3) to reduce emissions domestically; and (4) to buy the right for emissions. There are trade-offs among these strategies and a mix of these strategies implemented by the two countries will influence carbon leakage and international competitiveness.

A Numerical Model

Based on the model introduced in section 2, a two-sector two-country numerical model on international trade and climate policy is set up to examine changes in national welfare, total emission level, carbon leakage and competitiveness based on four scenarios. In the basic scenario, both countries do not have emission limit. In scenario I (*S1*), country *r* as emission limit. National emissions are accounted for based on producer responsibility. In scenario II (*S2*), both countries have emission limit with country *r* having stricter limit than *s*. An emissions trading system is established under fixed carbon price. Conditions set in Scenario III (*S3*) and IV (*S4*) are the same as in *S1* and *S2*, respectively, except for that national responsible emissions are accounted for based on consumer responsibility. Table 1 summarizes the rules for each scenario.

Table 1

Scenarios for a Two-Country MRIO-LP Model

Rule	Base scenario	*S1*	*S2*	*S3*	*S4*
Production-based national inventory	*r, s*	*r, s*	*r, s*	×	×
Consumption-based national inventory	×	×	×	*r, s*	*r, s*
Emission cap	×	*r*	*r, s*	*r*	*r, s*
Emissions trading system	×	×	✓	×	✓

Note. × means not applicable.

These parameters are set arbitrarily based on the following considerations:

(1) There are two countries, *r* and *s*. Country *r* representsparticipationand a developed country, and country *s* represents a non-participation developing country;

(2) There are two sectors, sector 1 and sector 2, located in two countries. Sector 1 is considered as a primary sector with relatively lower ratio of value-added and less emission intensity. Sector 2 is a manufacturing sector with higher ratio of value-added and more emission intensity;

(3) Country *r* has more advanced technology than *s* and therefore has lower emission intensities, in particular in the more carbon-intensive sector 2 ($q_1^r = q_1^s$, $q_2^r < q_2^s$);

(4) Country *r* is more competitive in sector 2, featured by higher ratio of value-added than that in *s* ($\alpha_2^r > \alpha_2^s$), while Country *s* is more competitive in sector 1 ($\alpha_1^s > \alpha_1^r$);

(5) Under scenarios II and IV (with a cap-and-trade system), both countries have an emission cap. Based on the principle of "common but differentiated responsibilities", endorsed by the UNFCCC, we set stricter emission limit for Country *r*, which is 5% reduction at its base level (387 × 95% = 368). While for country *s*, the limit is set the same asits base level;

(6) Country *s* has lower unit abatement cost than in *r* ($c^s < c^r$), complying with the convex function of abatement costs. In addition, with other conditions being the same, if country *r* needs to attain to the emission limit by domestic abatement, the abatement costs (= c^r × $(387 - 368)^2$) are about 10% of its national welfare in the base scenario ($0.15 \times 19^2/519 = 10.4\%$);

(7) Carbon price for emissions trading is set at a level between the unit abatement cost in country *r* and that of country *s* ($c^s < cp < c^r$);

(8) As country *r* is richer than *s*, household expenditure in country *r* is much higher than that in country *s* ($f_1^r > f_1^s$; $f_2^r > f_2^s$);

(9) Production capacity is set at the level when the country has the maximum self-sufficiency (or minimum imports) and minimum exports to satisfy the final demand in its trading partner.

To capture different features of participation and non-participation countries, different parameters are set in Table 2.

Table 2

Parameters Used in the Numerical Model

Parameter	Value	Explanation
$a_{11}^r, a_{12}^r, a_{21}^r, a_{22}^r$	0.4, 0.1, 0.3, 0.3	Technical coefficients for two industries in country *r*.
$a_{11}^s, a_{12}^s, a_{21}^s, a_{22}^s$	0.4, 0.2, 0.2, 0.3	Technical coefficients for two industries in country *s*.
α_1^r, α_2^r	0.3, 0.6	Ratio of value-added for two industries in country *r*.
α_1^s, α_2^s	0.4, 0.5	Ratio of value-added for two industries in country *s*.
f_1^r, f_2^r	150, 300	Final demand for products produced by two industries in country *r*.
f_1^s, f_2^s	100, 200	Final demand for products produced by two industries in country *s*.
q_1^r, q_2^r	0.3, 0.4	Emission intensities for two industries in country *r*.
q_1^s, q_2^s	0.3, 0.5	Emission intensities for two industries in country *s*.
pc_1^r, pc_2^r	410, 660	Production capacities for two industries in country *r*.
pc_1^s, pc_2^s	330, 430	Production capacities for two industries in country *s*.
β_1^r, β_2^r	0.04, 0.1	Minimum demand for the imports of similar products produced by two industries in country *r*.
β_1^s, β_2^s	0.05, 0.07	Minimum demand for the imports of similar products produced by two industries in country *s*.
CAP^r, CAP^s	368, 314	Emission cap for two countries.
c^r, c^s	0.15, 0.1	Unit abatement costs in two countries.
cp	0.13	Carbon price in the emissions trading system.

Applying the parameters provided in Table 2, we applied GAMS algorithms to solve the optimization problem and obtained preliminary results (Table 3 and Table 4). The simulation is one-shot and the results are much dependent on parameters. Recognizing the limitation in setting arbitrary parameters, we conducted sensitivity analysis on major parameters including: (1) carbon price (increased from 10%-100%); (2) abatement costs (increased from 10%-100%); and (3) emission cap (decreased from 2%-20%). We conducted sensitivity analysis for each parameter at an interval of 10 separately while kept other parameters the same as their base levels (see Tables 5- 9).

Table 3

Results Based on the Maximization for Country r

Item	Base scenario	*S1*	*S2*	*S3*	*S4*
X1_r	410	358	410	410	410
	(66%)	(58%)	(66%)	(66%)	(66%)
X1_s	214	263	214	214	214
	(34%)	(42%)	(34%)	(34%)	(34%)
X2_r	660	660	660	660	660
	(69%)	(70%)	(69%)	(69%)	(69%)
X2_s	291	283	291	291	291
	(31%)	(30%)	(31%)	(31%)	(31%)
V_r	519	503	519	519	519
V_s	231	247	231	231	231
E_r	207	160	147	146	146
E_s	138	107	78	77	77
R_r	×	3.3	0.4	0.6	0.4
R_s	×	×	0	×	0.0
ER_r	×	×	19	×	0.6
ER_s	×	×	0	×	0.4
Q_r	387	368	387	368.0	368.2
	(65%)	(63%)	(65%)	(62%)	(62%)
Q_s	209.6	220.4	209.6	228.0	228.0
	(35%)	(37%)	(35%)	(38%)	(38%)
Q	597	588	596	596	596
W_r	519	502	517	519	519
	(69%)	(67%)	(69%)	(69%)	(69%)
W_s	231	247	233	231	231
	(31%)	(63%)	(31%)	(31%)	(31%)
W	750	748	750	750	750

Notes. Date in brackets indicate the share of each country in the total amount of two countries for each item. × means Not applicable; *r* and *s* mean participation and non-participation countries, respectively; *X1* and *X2* mean outputs of sector 1 and 2, respectively; *V* means value-added; *E* meanstotal exports of both intermediate and final goods; *R* means domestic emission abatement; *ER* means purchase of emission credits; *Q* means national emissions based on producer responsibility under *S1* and *S2*, or responsible emissions based on consumer responsibility under *S3* and *S4*; *W* means national welfare.

On the one hand, to achieve the singe-country maximization objective of country *r* (see Table 3), the base scenario shows that *r* will fully utilize its production capacity in both sectors and maximize its exports to generate more value-added. Comparing four scenarios, most of the variables in *S1* (an emission limit set only for *r*) will be influenced. In particular, the outputs of sector 1, the total exports and national welfare of *r* will be impacted negatively, indicating that *s* is a potential winner and *r* a loser in a mitigation regime without full participation. Total emissions decreased about 1.5%, mainly attributable to reductions in *r* and adjustment in trade pattern, however emissions will increase from *s*, indicating potential carbon leakage.

By changing the accounting principle from producer responsibility to consumer responsibility (*S3* or *S4*), most of the variables will not be influenced except for the level of domestic abatement in *r* and the amount of emission credits purchased by *r*. In addition, exports from *s* are influenced negatively because the carbon intensity of production in *s* is higher than producing similar goods in *r*. Comparing with *S1* and *S2*, emissions from *s* under consumer principle will increase due mainly to the reductions in imports from *r*, which has lower carbon intensity in producing similar goods.

By introducing the emissions trading system (*S2* or *S4*), buying emission credits will be an efficient substitution to domestic abatement.

Table 4

Results Based on the Maximization for Country s

Item	Base scenario	*S1*	*S2*	*S3*	*S4*
X1_r	316	316	316	316	316
	(49%)	(49%)	(49%)	(49%)	(49%)
X1_s	330	330	330	330	330
	(51%)	(51%)	(51%)	(51%)	(51%)
X2_r	514	514	514	514	514
	(54%)	(54%)	(54%)	(54%)	(54%)
X2_s	430	430	430	430	430
	(46%)	(46%)	(46%)	(46%)	(46%)
V_r	403	403	403	403	403
V_s	347	347	347	347	347
E_r	44	44	44	44	411
E_s	91	91	91	91	458
R_r	×	5.8	5.2	14.5	5.2
R_s	×	×	0.7	×	0.7
ER_r	×	×	0.7	×	61.2
ER_s	×	×	0.0	×	0.0
Q_r	300.2	294.4	295.1	309.6	355.6
	(49%)	(48%)	(48%)	(52%)	(58%)
Q_s	314.0	314.0	313.4	290.1	252.8
	(51%)	(52%)	(52%)	(48%)	(42%)
Q	614.2	608.4	608.4	599.7	608.4
W_r	403	398	399	371	391
	(54%)	(53%)	(53%)	(52%)	(52%)
W_s	347	347	347	347	355
	(46%)	(47%)	(47%)	(48%)	(58%)
W	750	745	746	718	746

On the other hand, from the optimization perspective of country *s* (see Table 4), most of the variables will not be influenced except for domestic abatement, purchases of emissions credits and national welfare. All scenarios show that country *r* will be impacted negatively on its national welfare due mainly to the additional domestic abatement costs. In addition, *S3* and *S4* (an accounting method based on consumer responsibility) indicate an effective way to control total emissions and carbon leakage. Emissions trading system may work as an incentive to the non-participation country to mitigation and sell emissions credits.

An increase in the carbon price will mainly influence domestic abatement efforts and potential trade in emission credits sensitively (see Table 5). In particular, rising carbon price will be an incentive to the participation country to abate more domestically and to sell more emission credits by taking the comparative advantage of lower carbon intensity. On the other hand, from the non-participation country's perspective, an increase in the carbon price will also be effective to stimulate domestic abatement efforts and sell more emission credits by taking the comparative advantage of lower unit abatement costs.

Table 5

Influence of an Increase (*by 100%*) *in Carbon Price* (*cp*)

Item	*S2/r*	*S4/r*	*S2/s*	*S4/s*
R_r	100%	100%	-1%	-100%
R_s	0%	0%	100%	100%
ER_r	13%	0%	102%	1%
ER_s	1,445%	100%	10,304%	0%
W_r	0%	0%	0%	-1%
W_s	1%	0%	0%	2%
W	0%	0%	0%	1%

Notes. *S2/r* means optimizing country *r* based on Scenario 2; *S4/r* means optimizing *r* based on *S4*; *S2/s*meansoptimizing *s* based on *S2*; *S4/s* means optimizing *s* based on *S4*.

An increase in the unit abatement costs will mainly have impacts on domestic abatement and the emissions trading market. In particularly, an increase in *r*'s unit abatement costs will weaken its domestic efforts to reduce and buy more emission credits because of the relatively lower carbon price (see Table 6). On the other hand, an increase in *s*' unit abatement costs will also weaken its domestic abatement efforts and at the same time influence *r*'s demand in purchasing emission credits negatively (see Table 7).

Table 6

Influence of an Increase (*by 100%*) *in Unit Abatement Costs* (c^r)

Item	*S1/r*	*S2/r*	*S3/r*	*S4/r*
X1_r	2%	0%	0%	0%
X1_s	-2%	0%	0%	0%
V_s	1%	0%	0%	0%
E_r	3%	0%	0%	0%
E_s	1%	0%	0%	0%
R_r	-50%	-50%	0%	-50%
ER_r	0%	1%	0%	123%
Q	1%	0%	0%	0%
W_r	1%	0%	0%	0%
W_s	0%	0%	0%	0%
W	0%	0%	0%	0%

Notes. *S2/r*, *S4/r*, *S2/s* and *S4/s*, ibid; *S1/r* means optimizing *r* based on *S1*; S3/r means optimizing *r* based on *S3*; *S1/s* means optimizing *s* based on *S1*; *S3/s* means optimizing for *s* based on *S1*.

From the participation country's perspective, a tightened emission cap in *r* will influence its benefits substantially, in particular the level of production, exports, international competitiveness (indicated as the share of domestic production in the global markets) and national welfare, while at the same time it will be greatly beneficial to the non-participation country, especially when a cap-and-trade system is not in place (*S1/r* and *S3/r*) (see Table 8). Without an emissions trading system, emissions will be reduced in *r* however substantial carbon leakage will occur and the global emissions will increase. With a cap-and-trade system, such situation will change dramatically.

Table 7

Influence of an Increase (*by 100%*) *in Unit Abatement Costs* (c^s)

Item	S2/s	S4/s
R_s	-50%	-50%
ER_r	-50%	-1%

Table 8

Influence of Decrease (*by 20%*) *in the Emission Cap* (CAP^r)

Item	S1/r	S2/r	S3/r	S4/r
X1_r	-12%	0%	-23%	0%
X1_s	25%	0%	54%	0%
X2_r	-22%	0%	-21%	0%
X2_s	52%	0%	44%	0%
V_r	-20%	0%	-21%	0%
V_s	41%	0%	48%	0%
E_r	-66%	0%	-67%	0%
E_s	21%	0%	17%	0%
R_r	75%	0%	4,808%	0%
ER_r	0%	396%	0%	4,886%
ER_s	0%	0%	0%	-100%
Q_r	-19%	0%	-12%	0%
Q_s	43%	0%	26%	0%
Q	4%	0%	3%	0%
W_r	-21%	-2%	-47%	-2%
W_s	41%	4%	48%	4%
W	0%	0%	-18%	0%

On the other hand, a tightened emission cap in the non-participation country will slightly impact its national welfare and at the same time benefit the participation country (see Table 9). In addition, it will greatly decrease *r*'s demand in purchasing emission credits.

Table 9

Influence of Decrease (*by 20%*) *in the Emission Cap* (CAP^s)

Item	S2/s	S4/s
ER_r	-91%	-100%
ER_s	*L*	*L*
W_r	2%	2%
W_s	-2%	-2%

Note. *L* means a very large number, which is greater than five million.

Conclusions and Future Research Agenda

Competitiveness and carbon leakage are two central concerns in the international negotiations of a future climate regime. With more attentions given to border adjustment measure to address these concerns, it is rational to consider consumption-based national inventory to account for emissions embodied in imports, which are subject to tax adjustment at borders.

In this paper, we examine the impacts of a change in the national accounting principle from producer responsibility to consumer responsibility on the national welfare, international trade, competitiveness and carbon leakage for participation and non-participation in a global mitigation regime. In addition, a cap-and-trade system is considered. Linear programmingis applied into a multi-region input-output model and a numerical model is established for two countries and two sectors. Because of the limitations in arbitrarily given parameters, sensitivity analysis is conducted on major parameters.

Several preliminary findings come out:

(1) Without full participation of parties in a global mitigation regime, the participation country will be impacted negatively on its international competitiveness, exports and national welfare, while the non-participating country, taking the advantage of free-riding, will be a winner in a globalized economy linked with trade;

(2) A change from producer responsibility to consumer responsibility in a national inventory accounting system may have potential impacts on exports and domestic reductions in the participation country. In addition, when the emission cap for the participation country is becoming tighter, consumer responsibility can be an effective measure to restrain the trend of carbon leakage (*S1* and *S3* in Table 8);

(3) In a global mitigation regime without full participation, a cap-and-trade system between participation and non-participation can greatly help alleviate the disadvantages of the participation country (*S2* and *S4* in Table 8);

(4) Domestic abatement efforts and the emissions trading market can be influenced by carbon price and unit abatement costs sensitively.

In this study, a simple MRIO-LP model is applied. It would be interesting to compare such a model with a multi-region computable general equilibrium model, which can simulate price, tax and different agents. In addition, instead of optimizing individual country separately, one can consider to solve simultaneous equations of the reaction functions of two countries using game theory.

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