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Abstract

In this study, we develop a two-country model to examine whether border carbon adjustments (BCAs) are more effective than emission tax alone in preventing carbon leakage and decreasing global emissions with endogenous assembly locations. Specifically, we explore three policy regimes: i) emission taxes alone (no BCAs), ii) emission taxes and carbon-content tariffs (partial BCAs), and iii) emission taxes, carbon-content tariffs, and tax rebates on exports (full BCAs). We find that the effectiveness of BCAs depends on whether BCAs induce assembly relocation. If assembly relocation does not occur, BCAs prevent carbon leakage and decrease global emissions. However, if BCAs induce assembly relocation, carbon leakage may occur with partial BCAs, and global emissions may be higher with full BCAs.

Keywords: Abatement Investments; Border Carbon Adjustments; Carbon Leakage; Endogenous Assembly Locations; International Oligopoly

JEL classification: F18; H23; Q54.

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1. Introduction

A country's ambition to deal with climate change may be thwarted by the existence of carbon leakage. That is, stricter environmental regulations in a country decrease its greenhouse gas (GHG) emissions yet increase other countries' emissions (e.g., Aichele and Felbermayr, 2015). To cope with carbon leakage, policymakers are inclined toward border carbon adjustments (BCAs) in addition to domestic emission taxes. For instance, the American Clean Energy and Security Act of 2009 (also known as the Waxman-Markey Bill) proposed a cap-and-trade system requiring importers to purchase emission permits as domestic producers do. On July 14, 2021, the European Commission adopted a proposal for the carbon border adjustment mechanism, which would put a carbon price on the imports of some targeted products. Policymakers believe that emission tax, together with BCAs, can internalize the environmental costs of production across countries and, therefore, can be more effective in mitigating carbon leakage and controlling global emissions than emission tax alone. Many studies have demonstrated the effectiveness of BCAs, including Veenendaal et al. (2008), Elliott et al. (2010), Böhringer et al. (2012), and Fischer and Fox (2012). However, no study has investigated the limitations of BCAs with vertical linkages.

Vertically related markets deserve more attention when examining the effectiveness of BCAs. First, intermediate goods account for roughly 60 percent of international trade (Johnson, 2014). Second, the production of intermediate goods can be dirtier than the production of final goods, such as in the production of tires and bodyshells versus the assembly of automobiles. Third, a country may find it easier to regulate direct emissions rather than indirect emissions because of the high administration costs of data collection for emissions in each stage of production, especially when some parts are completed in foreign countries (e.g., Lockwood and Whalley, 2010; Kortum and Weisbach, 2017). Based on the latter two points, producers may escape environmental regulations through exports, FDI, or assembly relocation under BCAs.[1] For instance, a final goods producer can assemble the dirty inputs in a country with more lax environmental regulations and export the clean final goods to a country implementing BCAs, which may result in carbon leakage and more global emissions. We examine this possibility in the present study.

We build a two-country model with several intermediate goods producers and a final goods

[1]The concern about environmental tax evasions under BCAs is also mentioned in Monjon and Quirion (2010), McAusland and Najjar (2015) and Cosbey et al. (2019). For instance, McAusland and Najjar (2015) find that the pipeline decision of Canada's oil sand producers would be affected by the destination-based carbon tax. The producers export polluting oil and crude oil to unregulated overseas markets, while the stakeholders would import conventionally extracted relatively clean oil. In addition, regarding the SB 775 proposal for the California cap-and-trade program that seeks full BCAs, Meredith Fowlie argues that "*... this asymmetric treatment of what stays home and what gets sent outside of California creates an incentive to re-allocate more emission-intensive production to the export market to avoid the carbon price.*" See `https://energyathaas.wordpress.com/2017/05/22/californias-carbon-border-wall/`

producer. The final goods producer is a monopolist in the final goods market that chooses its assembly location endogenously, which is the key point of our study. The production of intermediate goods emits GHG and is subject to oligopolistic competition because some polluting industries, such as chemicals and cement, have a strong feature of oligopoly.[2] Intermediate goods producers have identical abatement technologies, and their production becomes clean after this abatement. This assumption, together with the existence of the trade costs of final goods, is meaningful in determining the timing of assembly relocation.

Countries differ in their awareness of environmental protection. Country 1, a developed country, imposes emission tax on the domestic production of dirty goods. However, country 2, a developing country, does not implement environmental regulations. To avoid carbon leakage and decrease global emissions, country 1 is inclined to implement BCAs, similar to what the EU intends to do. We specifically examine three environmental policy regimes to examine the effectiveness of BCAs: i) emission taxes alone (Regime α), ii) emission taxes and carbon-content tariffs on the imports of dirty inputs (Regime β), and iii) emission taxes, carbon-content tariffs, and rebates on the exports of dirty inputs (Regime γ).

With this model, we find that whether BCAs are effective in dealing with carbon leakage and global emissions depends on whether BCAs induce assembly relocation. If trade costs are high and (or) abatement costs are low, the assembly is located in the taxing country under BCAs. Carbon leakage is eliminated and global emissions decrease because BCAs reduce the imports of dirty inputs. In this case, BCAs are effective. However, if trade costs are low and (or) abatement costs are high, then the final goods producer relocates its assembly to the non-taxing country, which can lead to carbon leakage in Regime β and more global emissions in Regime γ. In this case, BCAs induce assembly relocation, which in turn makes them invalid. According to Article XX of GATT, the general exceptions clause, countries may impose BCAs if they are "necessary to protect human, animal or plant life or health." Our findings indicate that Regime γ may be incompatible with these related rules.

We mainly follow two strands of the literature in our study. The first strand examines the effectiveness of BCAs in preventing carbon leakage and controlling emissions (Yomogida and Tarui, 2013; Jakob et al., 2013; Eichner and Pethig, 2015; Ishikawa and Okubo, 2017; Cheng and Ishikawa, 2021). Yomogida and Tarui (2013) show that carbon leakage can occur under BCAs through the trade of dirty goods when the emissions per unit of dirty goods in the taxing country are sufficiently higher than those in the non-taxing country. Jakob et al. (2013) adopt a two-sector, two-country model to compare the effectiveness between consumption-based and production-based

[2]International oligopoly model has been extensively employed to investigate environmental issues in international trade. See Higashida and Jinji (2006), Riveiro (2008), Ishikawa and Okubo (2010), and Celik and Orbay (2011).

carbon pricing systems in mitigating carbon leakage. They show that carbon leakage can still occur through terms-of-trade effects and may even be larger under consumption-based carbon pricing (i.e., carbon pricing with full BCAs). Eichner and Pethig (2015) develop a two-period two-country general equilibrium model with fossil fuel as the production input to examine how carbon tax with full BCAs (also called a consumption-based carbon tax) affects each country's emissions in each period through changes in fossil fuel prices. They find that such tax in the first period may increase both countries' emissions as long as the income effect is sufficiently strong. In contrast to these studies, we focus on how firm relocation leads to carbon leakage under BCAs. Ishikawa and Okubo (2017) and Cheng and Ishikawa (2021) extend the footloose capital model and the strategic trade policy model to examine the same channel as ours. Ishikawa and Okubo (2017) show that BCAs do not affect firm locations while decreasing each firm's production in the non-taxing country; therefore, no carbon leakage exists under BCAs. Cheng and Ishikawa (2021) also find that firm relocation can lead to carbon leakage under BCAs; however, they do not consider vertical linkages. In contrast, we demonstrate that carbon leakage may still exist under BCAs due to assembly relocation.

The second strand concerns environmental issues in the presence of vertical linkages. Examples include Hamilton and Requate (2004), Greaker (2006), Bushnell and Mansur (2011), and Wan et al. (2018). Similar to our study, Hamilton and Requate (2004) and Wan et al. (2018) introduce an upstream industry comprising polluting producers, while Greaker (2006) considers an upstream market for environmental innovation. However, the three papers do not consider endogenous assembly locations and BCAs, and their interests are not in policy effectiveness in dealing with carbon leakage. Bushnell and Mansur (2011) discuss a BCA-equivalent policy in the upstream market, as we do, and show that such a policy can prevent carbon leakage. Their findings are based on the assumption that the downstream firm locations are fixed. By relaxing this assumption, we can investigate how the final goods producer evades BCAs through assembly relocation, which can lead to carbon leakage and more global emissions.

The remainder of this paper is organized as follows. Section 2 describes the basic components of the proposed model. Section 3 examines and compares the three policy regimes. Section 4 discusses the welfare implications and assumptions of the model. Finally, Section 5 concludes the paper.

2. Setup

The basic setup of our study is shown in Figure 1. A final goods producer, which is a monopolist, produces homogeneous final goods by assembling homogeneous inputs from countries 1 and 2. The

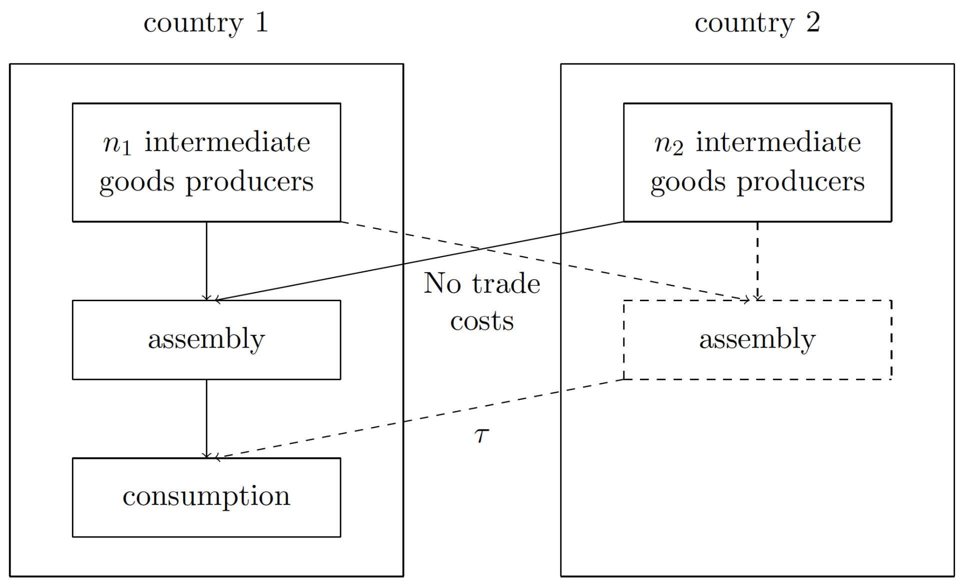

Figure 1: Basic setup of the model

assembly location is endogenous. The numbers of intermediate goods producers in countries 1 and 2 are n_1 and n_2, respectively, with $n_1 + n_2 = N$. Intermediate goods are freely traded across countries; however, each unit of the final goods incurs τ units of trade costs.[3] For simplicity, we assume that only country 1 consumes final goods and that the inverse demand function is linear.

$$P = b - X/2, \tag{1}$$

where b is a parameter measuring the market size in country 1 and is assumed to be sufficiently large; thus, trade is always positive after relocation throughout our analysis.[4]

The production of final goods is clean; however, one unit of intermediate goods emits one unit of GHG during production.[5] In order to control GHG emissions, country 1 imposes environmental regulations. We specifically explore three environmental policy regimes: Regime α, which includes solely an emission tax on the domestic production of dirty goods; Regime β, which pairs a carbon-content tariff on imports of dirty inputs with the emission tax; and Regime γ, which includes an emission tax, a carbon-content tariff, and a tax rebate on the exports of its dirty goods. The rates of the three instruments are assumed to be the same and are denoted by t.

[3]Our main findings do not change much even if each unit of the intermediate goods also incurs τ units of trade costs when transported across countries. We discuss the changes in footnotes 9 and 10.

[4]The denominator "2" in the demand function is imposed for simplicity and has no impact on our results.

[5]EU's carbon border adjustment mechanism covers the power sector and energy-intensive industrial sectors in the first phase, such as aluminum, cement, iron, steel, and electricity, which have strong features of intermediate goods. See `https://ec.europa.eu/taxation_customs/green-taxation-0/carbon-border-adjustment-mechanism_en`

For simplicity, the production costs of intermediate goods are simplified to zero. Intermediate goods producers are identical and subject to Cournot competition. They can employ abatement for clean production, which generates no emissions.[6] The unit abatement cost is denoted by c. After abatement, the producer's marginal cost becomes c. If the producers are regulated by emission tax higher than the abatement costs, then they will choose to employ abatement instead of paying the tax.

One unit of final goods requires only one unit of intermediate goods for assembly. Therefore,

$$G = \begin{cases} z_1 & \text{if } A = 1 \\ z_2 + \tau & \text{if } A = 2 \end{cases}, \tag{2}$$

where A denotes the assembly location, G is the unit cost of final goods, z_1 and z_2 are the prices of intermediate goods given the assembly in countries 1 and 2, respectively.

The model has three stages of decision-making. In the first stage, considering country 1's environmental policies as given, the final goods producer decides on its assembly location. The location decision on assembly is put in the first stage because it is a relatively long-term behavior compared to the decisions on production. In the second stage, N intermediate goods producers commit to the quantities of intermediate goods supplied to the final goods producer. In the third stage, taking the price of the intermediate goods as a given, the final goods producer decides on its monopolist price and the corresponding quantity of final goods.

Before moving on, we discuss the game-theoretic structure regarding the final goods producer. It is a price taker in the input market but a price maker in the final goods market. The assumption of this formulation can be justified if we treat the inputs as commonly used materials across a large number of industries such as steel so that any monopsony power of the final goods producer in a specific industry vanishes.[7]

As usual, we solve the game backward. In the last stage, the profit of the final goods producer is

$$\pi_F = (P - G)X. \tag{3}$$

With the inverse demand function in equation (1), the price of the monopolist is derived as $P^* =$

[6]The assumption of no emissions after abatement can be understood from two perspectives. First, some emissions remain after the abatement, but carbon emissions are captured, utilized, and stored (CCUS) with an investment cost of c. Second, we consider an example of a switch from coal to renewable electricity. We thank the associate editor for the helpful suggestions. In addition, our main results do not change, even if we assume lower yet positive emissions per unit of input production after abatement, because assembly relocation can still occur before abatement in Regimes β and γ, leading to carbon leakage and more global emissions, respectively.

[7]We would like to thank the associate editor for this very helpful suggestion. For more discussions about this assumption, refer to Ishikawa and Spencer (1999) and Ino and Matsumura (2021).

$(b+G)/2$.[8] Therefore, the equilibrium quantity of final goods is $X^* = 2(b - P^*) = b - G$. Taking the price and quantity into the equation (3), we obtain the monopolist's profit as

$$\pi_F = (b - G)^2/2. \tag{4}$$

In the second stage, the input price at the Cournot-Nash equilibrium z_A^* ($A = 1$ or 2) can be obtained from the market-clearing condition, where the demand by the final goods producer is equal to the total supply of the inputs produced by the N producers. The details are discussed in the following sections.

In the first stage, the final goods producer chooses its assembly location by comparing its profits with the assembly in countries 1 and 2. This comparison can be transformed into an equivalent comparison of the unit costs of the final goods.

$$A = \begin{cases} 1 & \text{if } z_1^* \leq z_2^* + \tau \\ 2 & \text{if } z_1^* > z_2^* + \tau \end{cases}. \tag{5}$$

Thus, the assembly is located in a country with a lower unit cost. If the final goods producer decides to locate its assembly in country 1, it saves trade costs. However, the final goods producer may be incentivized to locate its assembly in country 2 to evade environmental regulations, especially under BCAs.

3. Three Policy Regimes

3.1. Regime α: Emission Tax Alone

This section introduces the benchmark case in which country 1 imposes only emission tax on the domestic production of intermediate goods. We first analyze the behaviors of intermediate goods producers given the assembly in countries 1 and 2, respectively, and then show how the final goods producer chooses its assembly location endogenously.

Assuming that the assembly is located in country 1, the inverse demand for intermediate goods by the final goods producer can be derived from the equilibrium quantity of final goods in the last stage:

$$X^* = b - G \implies z_1^\alpha = G = b - X^* = b - \left(\sum_{i=1}^{n_1} x_{11i}^\alpha + \sum_{j=1}^{n_2} x_{21j}^\alpha \right). \tag{6}$$

[8]The asterisks denote the variables at the equilibria throughout the paper.

x^{α}_{11i} and x^{α}_{21j} are the production of intermediate goods producers i and j in countries 1 and 2, respectively, with the first number in the subscripts referring to the location of the intermediate goods producers, and the second number is the location of the assembly.[9] $X^* = \sum_{i=1}^{n_1} x^{\alpha}_{11i} + \sum_{j=1}^{n_2} x^{\alpha}_{21j}$ stems from the assumption that one unit of final goods requires one unit of intermediate goods for assembly.

For each intermediate goods producer in countries 1 and 2, the profit is

$$\pi^{\alpha}_{11i} = [z^{\alpha}_1 - \min(t, c)]x^{\alpha}_{11i}; \quad \pi^{\alpha}_{21j} = z^{\alpha}_1 x^{\alpha}_{21j}. \tag{7}$$

Producers in country 1 either choose to employ abatement or pay the emission tax directly, depending on the relative values of tax rates and abatement costs. Producers in country 2 face no environmental regulation; therefore, they neither pay the emission tax nor employ abatement.

The market outcome is obtained by a Nash equilibrium of the game in which the N intermediate goods producers compete in quantity, given the inverse demand function in equation (6). Solving the profit maximization problems, we obtain the equilibrium quantities and price of intermediate goods as follows:

$$x^{\alpha*}_{11} = \frac{b - (1 + n_2)\min(t, c)}{1 + N}; \quad x^{\alpha*}_{21} = z^{\alpha*}_1 = \frac{b + n_1 \min(t, c)}{1 + N}. \tag{8}$$

Emission tax always increases the equilibrium price when it is lower than the abatement costs but does not affect the price when it becomes higher than the abatement cost because that is when producers in country 1 employ abatement. Correspondingly, when the emission tax is lower than the abatement costs, as t increases, producers in country 1 produce less because of higher production costs. Producers in country 2 then provide more dirty inputs because they are not regulated by the emission tax, which can make them more competitive.

Assuming that the assembly is located in country 2, the inverse demand for intermediate goods is derived as:

$$z^{\alpha}_2 = b - \tau - \left(\sum_{i=1}^{n_1} x^{\alpha}_{12i} + \sum_{j=1}^{n_2} x^{\alpha}_{22j} \right). \tag{9}$$

x^{α}_{12i} and x^{α}_{22j} are the production of intermediate goods producers i and j in countries 1 and 2, respectively.

[9] Since the intermediate goods producers are identical, we suppress the letters i and j in the subscripts when there is no ambiguity.

The profits of producers are

$$\pi_{12i}^{\alpha} = [z_2^{\alpha} - \min(t, c)]x_{12i}^{\alpha}; \quad \pi_{22j}^{\alpha} = z_2^{\alpha} x_{22j}^{\alpha}. \tag{10}$$

Producers in country 1 are still regulated by the emission tax.

Analogously, we can derive the equilibrium quantities and price of intermediate goods as follows

$$x_{12}^{\alpha*} = \frac{b - \tau - (1 + n_2)\min(t, c)}{1 + N}; \quad x_{22}^{\alpha*} = z_2^{\alpha*} = \frac{b - \tau + n_1 \min(t, c)}{1 + N}. \tag{11}$$

As shown in equation (5), the final goods producer locates its assembly in the country with a lower unit cost of intermediate goods. Note that

$$G_2^{\alpha*} = z_2^{\alpha*} + \tau > z_1^{\alpha*} \tag{12}$$

always holds. Therefore, we have the following lemma.

Lemma 1: The assembly is always located in country 1 under Regime α.

The rationale behind this finding is as follows: By locating its assembly in country 1, the final goods producer can save trade costs. However, even if the assembly is located in country 2, the intermediate goods producers in country 1 still have to pay the emission tax.

We derive each country's and global emissions based on the equilibrium quantities of intermediate goods:

$$(E_1^{\alpha*},\ E_2^{\alpha*},\ E_W^{\alpha*}) = \begin{cases} \left(\frac{n_1[b - (1 + n_2)t]}{1 + N},\ \frac{n_2(b + n_1 t)}{1 + N},\ \frac{Nb - n_1 t}{1 + N}\right) & \text{if } t \leq c \\ \left(0,\ \frac{n_2(b + n_1 c)}{1 + N},\ \frac{n_2(b + n_1 c)}{1 + N}\right) & \text{if } t > c \end{cases}. \tag{13}$$

The dashed lines in Figures 2 and 3 describe the relationship between the emission tax and GHG emissions.[10] When the emission tax is not high, an increase in the tax rate decreases country 1's emissions while increasing country 2's emissions, which verifies the existence of carbon leakage. When the emission tax becomes sufficiently high, it has no impact on emissions because production in country 1 becomes clean.

[10] Figures 2, 3 and 4 are drawn with the variable values $a = 3$, $N = 1$, $n_1 = 0.3$, $n_2 = 0.7$, $c = 0.5$. Trade costs are manipulated to derive different cases: $\tau = 0.25$ in Figures 2 and 4, and $\tau = 0.4$ in Figure 3.

3.2. Regime β: Emission Tax + Carbon Tariff

In Regime β, aside from emission tax on domestic production, country 1 imposes a carbon-content tariff on imports of intermediate goods from country 2 so that all dirty goods consumed in country 1 are regulated at the same level. The final goods producer may have an incentive to escape the carbon-content tariff by locating its assembly in country 2, which would not be possible under Regime α.

Assuming that the final goods producer places its assembly in country 1, the intermediate goods producers in both countries face the same environmental regulations. The inverse demand for intermediate goods is:

$$z_1^\beta = b - \left(\sum_{i=1}^{n_1} x_{11i}^\beta + \sum_{j=1}^{n_2} x_{21j}^\beta \right). \tag{14}$$

The profit of an intermediate goods producer in countries 1 and 2 then becomes

$$\pi_{11i}^\beta = [z_1^\beta - \min(t,c)]x_{11i}^\beta; \quad \pi_{21j}^\beta = [z_1^\beta - \min(t,c)]x_{21j}^\beta. \tag{15}$$

The intermediate goods producers in country 2 also choose to either employ abatement or pay the tariff directly in Regime β.

The equilibrium quantities and price of intermediate goods are given by:

$$x_{11}^{\beta*} = x_{21}^{\beta*} = \frac{b - \min(t,c)}{1+N}; \quad z_1^{\beta*} = \frac{b + N\min(t,c)}{1+N}. \tag{16}$$

Assuming that the final goods producer locates its assembly in country 2, the analysis becomes exactly the same as that in Regime α, because only the intermediate goods producers in country 1 are regulated by the emission tax.

When deciding on the location of assembly, the final goods producer faces a trade-off between saving trade costs and avoiding the carbon-content tariff. It saves trade costs but has to pay the carbon-content tariff on the import of inputs by locating the assembly in country 1. However, it has to pay the trade costs instead of the carbon-content tariff if the assembly is located in country 2.

If trade costs are high and/or abatement costs are low, that is, $\tau \geq n_2 c/N$, then $z_2^\beta + \tau \geq z_1^\beta$ holds, and the assembly is located in country 1 because saving the high trade costs is dominant.

Each country's and global emissions at equilibrium are derived as follows:

$$\left(E_1^{\beta*},\ E_2^{\beta*},\ E_W^{\beta*}\right) = \begin{cases} \left(\dfrac{n_1(b-t)}{1+N},\ \dfrac{n_2(b-t)}{1+N},\ \dfrac{N(b-t)}{1+N}\right) & \text{if } t \le c \\ (0,\ 0,\ 0) & \text{if } t > c \end{cases}. \tag{17}$$

Carbon leakage is prevented because the dirty inputs from country 2 face a carbon-content tariff. As a result, global emissions are lower than those in Regime α.

If trade costs are low and/or abatement costs are high, that is, $\tau < n_2 c/N$, then $z_2^\beta + \tau < z_1^\beta$ holds for $t > t_1^\beta \equiv N\tau/n_2$. The final goods producer relocates its assembly to country 2 at $t = t_1^\beta$ because avoiding the carbon-content tariff becomes dominant as t increases.

Lemma 2. If $\tau < n_2 c/N$, the assembly is relocated from country 1 to country 2 as t increases in Regime β.

In this case, each country's and global emissions at equilibrium are given by:

$$\left(E_1^{\beta*\prime},\ E_2^{\beta*\prime},\ E_W^{\beta*\prime}\right) = \begin{cases} \left(\dfrac{n_1(b-t)}{1+N},\ \dfrac{n_2(b-t)}{1+N},\ \dfrac{N(b-t)}{1+N}\right) & \text{if } t \le t_1^\beta \\ \left(\dfrac{n_1[b-\tau-(1+n_2)t]}{1+N},\ \dfrac{n_2(b-\tau+n_1 t)}{1+N},\ \dfrac{N(b-\tau)-n_1 t}{1+N}\right) & \text{if } t_1^\beta < t \le c \\ \left(0,\ \dfrac{n_2(b-\tau+n_1 c)}{1+N},\ \dfrac{n_2(b-\tau+n_1 c)}{1+N}\right) & \text{if } t > c \end{cases}. \tag{18}$$

As shown in Figure 2, carbon leakage occurs for $t_1^\beta < t \le c$ because the intermediate goods producers in country 2 no longer pay the carbon tariff, which makes them more competitive. Assembly relocation invalidates Regime β's role in preventing carbon leakage. However, global emissions are still lower than those in Regime α because the existence of trade costs decreases the demand for final goods and, thus, the quantity of dirty inputs used for their production.[11]

We conclude our findings in the following proposition:[12]

Proposition 1. If $\tau \ge n_2 c/N$, Regime β is more effective than Regime α in preventing carbon leakage; however, if $\tau < n_2 c/N$, carbon leakage occurs because of assembly relocation induced by Regime β. Global emissions are always lower in Regime β than in Regime α.

[11] If we allow trade costs of intermediate goods, global emissions in Regime β can be higher than that in Regime α for $t > c$ if trade costs are low and/or abatement costs are high.

[12] Please see Appendix A for proofs of the propositions.

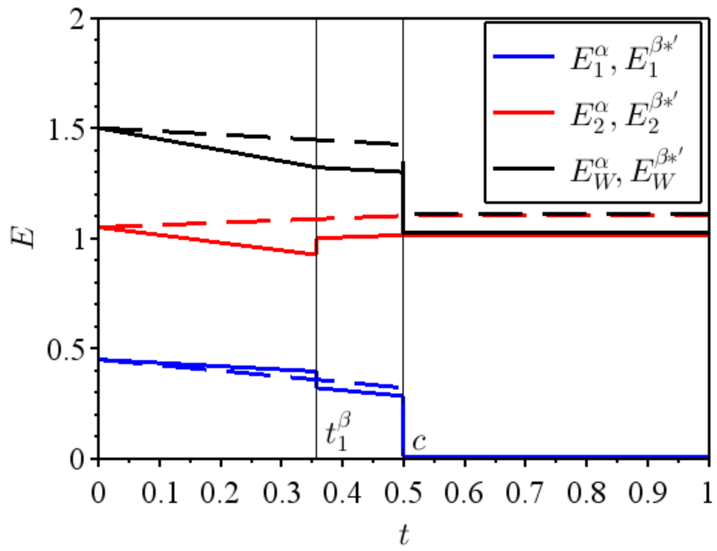

Figure 2: Comparison of the emissions under Regime β (solid lines) and Regime α (dashed lines) for $\tau \leq n_2c/N$.

3.3. Regime γ: Emission Tax + Carbon Tariff + Tax Rebate

Compared with Regime β, country 1 then imposes a tax rebate on its exports of intermediate goods to country 2 to eliminate their cost disadvantage in the foreign market. Given the assembly in country 1, the analysis becomes exactly the same as that in Regime β. When the assembly is in country 2, the inverse demand for intermediate goods becomes:

$$z_2^\gamma = b - \tau - \left(\sum_{i=1}^{n_1} x_{12i}^\gamma + \sum_{j=1}^{n_2} x_{22j}^\gamma \right). \tag{19}$$

The profits of intermediate goods producers in countries 1 and 2 are

$$\pi_{12i}^\gamma = z_2^\gamma x_{12i}^\gamma; \quad \pi_{22j}^\gamma = z_2^\gamma x_{22j}^\gamma. \tag{20}$$

The equilibrium quantities and price of intermediate goods are obtained as

$$x_{12}^{\gamma*} = x_{22}^{\gamma*} = z_2^{\gamma*} = \frac{b - \tau}{1 + N}. \tag{21}$$

The unit cost of the final goods given $A = 2$ is

$$z_2^{\gamma *} + \tau = \frac{b + N\tau}{1 + N}. \tag{22}$$

When deciding on the assembly location, the final goods producer faces a trade-off between trade costs and higher input costs due to environmental regulations. If $\tau \geq c$, then the final goods producer always locates its assembly in country 1. This is more likely to occur when abatement costs are low and/or trade costs are high. Our rationale is that the final goods producer saves trade costs greatly when they are high and benefits from lower production costs of inputs after employing abatement; producers are willing to employ abatement when abatement costs are low. In this case, each country's and global emissions at equilibrium are

$$\left(E_1^{\gamma *},\ E_2^{\gamma *},\ E_W^{\gamma *}\right) = \begin{cases} \left(\dfrac{n_1(b-t)}{1+N},\ \dfrac{n_2(b-t)}{1+N},\ \dfrac{N(b-t)}{1+N}\right) & \text{if } t \leq c \\ (0,\ 0,\ 0) & \text{if } t > c \end{cases}. \tag{23}$$

Carbon leakage is prevented and global emissions are lower in Regime γ than in Regime α.

If $\tau < c$, then the assembly is relocated to country 2 before abatement. The threshold tax rate is

$$t_2^{\gamma} = \tau. \tag{24}$$

This is more likely to occur when trade costs are low and/or abatement costs are high. In Regime γ, the final goods producer has a stronger incentive to locate the assembly in country 2 than Regime β, that is, $t_2^{\gamma} < t_1^{\beta}$, because the intermediate goods exported from country 1 are exempt from environmental regulation due to a rebate.

Lemma 3. If $\tau < c$, the final goods producer has a stronger incentive to relocate the assembly in country 2 in Regime γ than in Regime β.

In this case, each country's and global emissions at the equilibrium are

$$\left(E_1^{\gamma *\prime},\ E_2^{\gamma *\prime},\ E_W^{\gamma *\prime}\right) = \begin{cases} \left(\dfrac{n_1(b-t)}{1+N},\ \dfrac{n_2(b-t)}{1+N},\ \dfrac{N(b-t)}{1+N}\right) & \text{if } t \leq t_2^{\gamma} \\ \left(\dfrac{n_1(b-\tau)}{1+N},\ \dfrac{n_2(b-\tau)}{1+N},\ \dfrac{N(b-\tau)}{1+N}\right) & \text{if } t > t_2^{\gamma} \end{cases}. \tag{25}$$

The solid lines in Figure 3 depict the effect of Regime γ on GHG emissions when trade costs are lower than abatement costs. As the assembly is relocated to country 2, each producer's production in countries 1 and 2 does not change. Therefore, emissions do not change at the threshold tax rate, implying no carbon leakage.[13] In addition, we find that global emissions can be higher in Regime γ than in Regime α. If the emission tax rate is higher than the abatement costs, Regime γ relieves the production of intermediate goods in country 1 from environmental regulation by inducing assembly to be located in country 2. Intermediate goods producers in country 1 thus become more competitive and produce more without abatement. Therefore, Regime γ increases country 1's emissions while decreasing country 2's emissions. Consequently, global emissions may be higher if the former effect dominates. This case occurs when $b > (N\tau + n_1 n_2 c)/n_1$.

Next, we compare Regime γ with Regime β. If $\tau > c$, the assembly is always located in country 1 in both regimes. The tax rebate on exports of dirty goods to country 2 plays no role. The emissions are the same in the two regimes for a given t. If $n_2 c/N < \tau \leq c$, the assembly is always located in country 1 in Regime β, but is relocated to country 2 at $t = t_2^\gamma$ in Regime γ. Each country's emissions are the same in the two regimes for $t \leq t_2^\gamma$; however, they are higher in Regime γ for $t > t_2^\gamma$ because of assembly relocation. If $\tau < n_2 c/N$, the assembly is relocated from country 1 to country 2 at $t = t_1^\beta$ in Regime β and at $t = t_2^\gamma$ in Regime γ. As shown in Figure 4, country 1's emissions are the same in the two regimes for $t \leq \tau$ and are higher in Regime γ for $t > \tau$ because the tax rebate increases country 1's exports of intermediate goods with assembly in country 2. In contrast, country 2's emissions are the same in the two regimes for $t \leq \tau$, higher in Regime γ for $\tau < t \leq t_1^\beta$, and lower in Regime γ for $t > t_1^\beta$. Consequently, global emissions are the same in the two regimes for $t \leq \tau$; however, they are always higher in Regime γ for $t > \tau$ because of the existence of a tax rebate. Assembly relocation invalidates Regime γ's role in decreasing global emissions.

We conclude our findings in the following proposition:

Proposition 2. If $\tau \geq c$, Regime γ is more effective than Regime α in dealing with carbon leakage and global emissions. If $\tau < c$, global emissions can be higher in Regime γ than in Regimes α and β.

[13]This finding is based on the assumption that intermediate goods can be freely transported across countries. Assuming that there are trade costs for intermediate goods, carbon leakage can also occur in Regime γ.

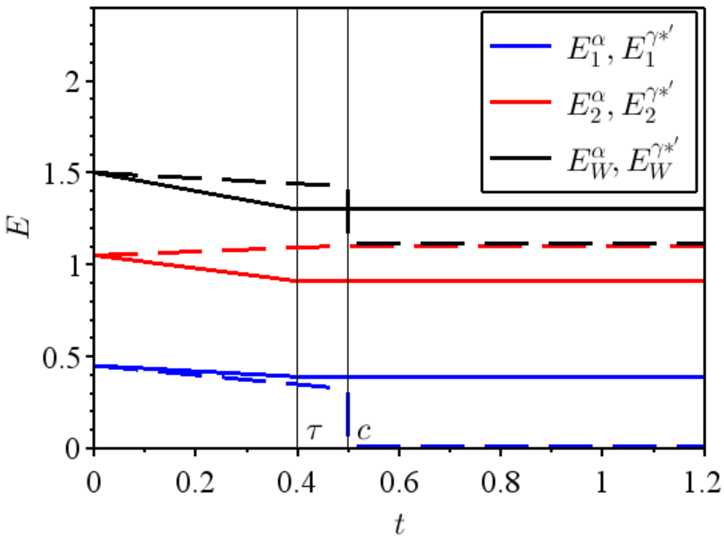

Figure 3: Comparison of the emissions under Regime γ (solid lines) and Regime α (dashed lines) for $\tau \leq c$.

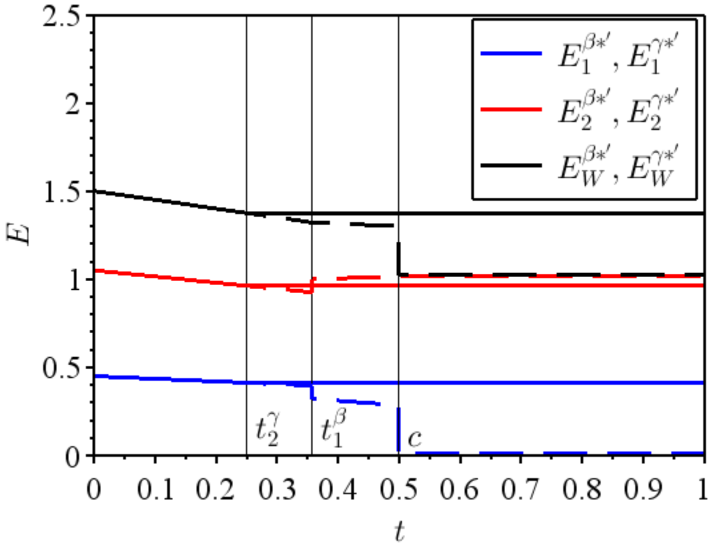

Figure 4: Comparison of the emissions under Regime γ (solid lines) and Regime β (dashed lines) for $\tau \leq n_2c/N$.

4. Discussions

4.1. Welfare Analysis

In this part, we briefly discuss how emission tax with and without BCAs affects each component of the countries' welfare.[14] We assume that country 1's welfare consists of consumer surplus, the profits of the n_1 intermediate goods producers and the final goods producer, tax revenue, and environmental damage from global warming. Country 2's welfare consists of only the profits of the n_2 intermediate goods producers and environmental damage from global warming. The analysis below implies that which policy regime is preferable strongly depends on how country 1 evaluates its environmental damage from global warming.

In Regime α, before the abatement, an increase in the emission tax harms consumers, the n_1 intermediate goods producers, and the final goods producer in country 1 while benefiting the n_2 intermediate goods producers in country 2, and the global environment. The effect on tax revenue in country 1 is ambiguous. Country 2's welfare then increases. If the positive effect from fewer emissions dominates the negative effects, country 1's and global welfare improves as well. At the point of abatement, the consumer surplus and profits of producers do not change. Tax revenue decreases to zero and global emissions decrease. The abatement improves country 2's welfare but necessarily worsens country 1's welfare if the benefits from fewer global emissions are smaller than the loss of tax revenue. Country 1 has an incentive to impose an emission tax lower than the abatement cost ($t < c$) if the environmental damage from global warming is low in country 1.

In Regime β, an increase in tax harms consumers, the n_1 intermediate goods producers, and the final goods producer before abatement regardless of whether assembly relocation occurs. In contrast, a tax increase hurts the n_2 intermediate goods producers in country 2 when the assembly is located in country 1 but benefits them before their abatement when it is located in country 2. The effect on tax revenue is ambiguous. As long as the assembly is located in country 1, the shift from Regime α to Regime β for a given tax rate is harmful to the consumers in country 1 and the n_2 intermediate goods producers in country 2 but is beneficial to the n_1 intermediate goods producers and the tax revenue (before abatement) in country 1. As global emissions decrease, the two countries may benefit from the regime shift. However, if the assembly is in country 2 under Regime β, the shift can be harmful to the n_1 intermediate goods producers and the tax revenue; for example, $t_1^\beta < t \leq c$ in Figure 2. As a result, the shift from Regime α to Regime β can worsen all welfare components except environmental quality. Country 1 has an incentive to impose Regime β when the improvement in environmental quality dominates all losses, although the regime shift would cause firm relocation and carbon leakage.

[14] Please see Appendix B for mathematical calculations on the welfare comparisons.

In Regime γ, an increase in the tax hurts the N intermediate goods producers and the final goods producer but improves the environment before assembly relocation or abatement. However, it does not affect them after the relocation and abatement. The effect on tax revenue is ambiguous. Analogously, we can investigate how the shift from Regime α to Regime γ affects welfare components. If the assembly is in country 1 under Regime γ, the effects are qualitatively the same as the shift from Regime α to Regime β. However, if the assembly is in country 2 under Regime γ, then the shift benefits the n_1 intermediate goods producers in country 1 but harms the n_2 intermediate goods producers in country 2; how the shift affects country 1's tax revenue, final goods producer's profits, and global emissions is ambiguous. If global emissions are higher in Regime γ than in Regime α and country 1 has a strong awareness of environmental protection, then country 1 has no incentive to impose Regime γ, although doing so benefits its polluting producers.

Regimes β and γ are the same when the assembly is located in country 1. If the assembly is in country 1 under Regime β but in country 2 under Regime γ (e.g., $t_2^\gamma < t \leq t_1^\beta$ in Figure 4), the shift from Regime β to Regime γ benefits consumers and all producers, but harms country 1's tax revenue and the environment. If the assembly is in country 2 under both regimes, then the regime shift harms the n_2 intermediate goods producers. The effects on the other components are qualitatively the same as in the former case, except that country 1's tax revenue is not affected for $t > c$ because they are zero under both regimes. Whether country 1 has an incentive to shift from Regime β to Regime γ depends on how much it suffers from more global emissions under Regime γ.

4.2. Existence of Country 2's Market

Although the assumption that only country 1 consumes the final goods is useful for us to focus on the trade-off between trade costs and abatement investment, as shown in equation (5), one might wonder how our results would change if country 2 also consumes the final goods. The essence of our findings still holds. That is, the effectiveness of BCAs still depends on the assembly location, as BCAs are more effective if the assembly is always located in country 1 and may not be effective if it is located in country 2. Note that whether country 2 consumes the final goods affects the timing of the assembly relocation. If the market size in country 2 is sufficiently small, then the analysis is very similar to that of the main part. If it is sufficiently large, the assembly is likely to always be located in country 2 to save trade costs in all three policy regimes. In the latter case, Regime β is the same as Regime α; however, global emissions are higher in Regime γ than in the other two regimes.

4.3. Endogenous Locations of Input Producers

In the main part of this paper, the locations of the intermediate goods producers are fixed, with n_1 producers in country 1 and n_2 producers in country 2. In this section, we discuss their relocation. That is, the number of firms in each country is determined endogenously. For simplicity, we assume that there is no relocation cost. In Regime α, all intermediate goods producers are located in country 2 to avoid emission tax. The assembly is always located in country 1 to save trade costs. Carbon leakage occurs because of the relocation of n_1 producers. In Regime β, as long as the assembly is located in country 1, all intermediate goods producers are regulated by the environmental tax wherever they are. This happens when abatement costs are low and (or) trade costs are high. The n_1 producers have no incentive to relocate to country 2, thus eliminating carbon leakage. However, when trade costs are sufficiently low, the n_1 intermediate goods producers and assembly are relocated to country 2 at a specific tax rate to evade BCAs. In this case, carbon leakage occurs and becomes even more serious than in the case of the fixed locations of input producers. The analysis of Regime γ is similar to that of the main part. The intermediate goods producers have no incentive to change their locations because they cannot avoid the environmental tax if the assembly is in country 1, and are not regulated at all if the assembly is located in country 2. However, global emissions are lower in Regime γ than in Regime α because of the trade costs of the final goods.

4.4. Bertrand Competition in the Input Market

In this section, we discuss how the results would change if we consider Bertrand competition instead of Cournot competition in the input market. In contrast to Cournot competition, the final goods producer procures intermediate goods from the country at a lower cost. In Regime α, the final goods producer always locates its assembly in country 1 and imports all the inputs from country 2 because the inputs in country 1 are regulated by the emission tax. In Regime β, if the assembly is located in country 1, the intermediate goods producers are identical because they have the same production and environmental costs. However, as the tax rate increases in country 1, the final goods producer has an incentive to relocate its assembly to country 2 before the intermediate goods producers invest in abatement, which is the same as in the case of Cournot competition. When the assembly is in country 2, the final goods producer purchases all inputs from the n_2 producers in country 2 because n_1 producers in country 1 have to pay emission tax and therefore have higher input costs. Assembly relocation thus causes carbon leakage, which becomes even worse than in the case of Cournot competition. In Regime γ, the N intermediate goods producers face the same environmental regulation, regardless of the assembly location. Assembly relocation does not lead to carbon leakage, as explained in the case of Cournot competition. Compared with

Regime α, country 1's emissions are higher, and country 2's and global emissions are lower in Regime γ.

4.5. Regulations on Final Goods and Carbon Footprint Tax

We made two critical assumptions regarding the final goods in the main part. First, the production of final goods is clean and, thus, unregulated by environmental taxes. In the following, we show how our results change if we loosen this assumption. Suppose the final goods emit GHG during their production and are taxed in the three regimes. In Regime α, the final goods producer may be incentivized to locate its assembly in country 2 to avoid emission tax on the final goods. Thus, Lemma 1 may not hold. However, in Regimes β and γ, the final goods producer's decision on assembly relocation is not incentivized by the tax avoidance of final goods. In other words, assembly relocation frees input production in country 2 from environmental regulation in Regime β and input production in both countries in Regime γ. Therefore, carbon leakage and more global emissions can still occur, even if the final goods are dirty and regulated.

Second, we assumed that environmental policies are imposed only on direct emissions, which incentivizes the final goods producer to relocate assembly to country 2. If indirect emissions were also regulated, the incentive would be eliminated, and the assembly would always be located in country 1. Therefore, a carbon footprint tax is more effective in preventing carbon leakage and decreasing global emissions in our model.[15] However, as shown in Appendix C, if we modify our model by assuming a market of final goods in country 2, a carbon footprint tax can backfire.[16] Under a carbon footprint tax, the production of inputs for the final goods consumed in country 1 is taxed, while that for the final goods consumed in country 2 is exempt from environmental regulations. Compared with production under emission tax alone, country 2's input production decreases, but country 1's input production increases. It is likely that the latter strength dominates the former, increasing global emissions. Contrastingly, we find that a carbon footprint tax eliminates carbon leakage even if it causes assembly relocation in the presence of country 2's market.

5. Concluding Remarks

We developed a simple model to examine and compare how BCAs affect production and GHG emissions in the presence of intermediate goods and endogenous assembly locations. We found

[15] Different from our result, Jakob et al. (2013) and Eichner and Pethig (2015) find that carbon leakage can still occur under a carbon footprint tax as shown in Section 1. Please refer to McAusland and Najjar (2015) for more discussions on carbon footprint taxes.

[16] Please see Appendix C for a formal analysis about the comparison of an emission tax alone and a carbon footprint tax in the presence of country 2's market of final goods.

that BCAs avoid carbon leakage and decrease global emissions by reducing the imports of dirty inputs when the assembly is located in a taxing country. However, BCAs may induce assembly relocation, which in turn invalidates BCAs. That is, carbon leakage can still occur because of assembly relocation in a regime with emission tax and a carbon-content tariff. In addition, the introduction of a tax rebate can lead to more global emissions than other regimes after assembly relocation. Our findings imply that BCAs may not be more effective in dealing with carbon leakage and controlling global emissions than emission tax alone when the assembly location is endogenous. However, as long as the assembly is located in the taxing country, BCAs become more effective. To ensure this, the taxing country can subsidize abatement activities and encourage technology transfer across countries so that production costs decline even without assembly relocation.

We conclude by discussing an important issue for future research. Although we introduce vertically related markets in our analysis, our model is still too naive to describe today's trade and environmental problems. With the development of information and communication technologies, production has entered into the era of global value chains (GVCs), where the final goods producers segment their production into parts and source them worldwide. Consequently, emissions are generated along GVCs in different countries. In particular, inputs are transported across countries multiple times before they are assembled into final goods, during which emissions are also generated from shipping. It would be worthwhile to investigate how BCAs affect the patterns of GVCs and thus the emissions from both production and transport.[17]

[17] See Cheng et al. (2021) for an example of environmental taxes in GVCs but without BCAs.

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Appendix

A: Proofs of Propositions 1 and 2

Proof of Proposition 1:

In Regime α, carbon leakage occurs for $t \leq c$. This can be verified from equation (13):

$$\frac{\partial E_1^{\alpha*}}{\partial t} = -\frac{n_1(1+n_2)}{1+N} < 0; \quad \frac{\partial E_2^{\alpha*}}{\partial t} = \frac{n_1 n_2}{1+N} > 0; \quad \frac{\partial E_W^{\alpha*}}{\partial t} = -\frac{n_1}{1+N} < 0.$$

An increase in the tax rate decreases country 1's emissions but increases country 2's emissions.

In Regime β, if $\tau \geq n_2 c/N$, the assembly is always located in country 1. From equation (17), for $t \leq c$, we have

$$\frac{\partial E_1^{\beta*}}{\partial t} = -\frac{n_1}{1+N} < 0; \quad \frac{\partial E_2^{\beta*}}{\partial t} = -\frac{n_2}{1+N} < 0; \quad \frac{\partial E_W^{\beta*}}{\partial t} = -\frac{N}{1+N} < 0.$$

An increase in the tax rate decreases country 1's, country 2's and global emissions. Carbon leakage does not occur in Regime β. Therefore, we conclude that if $\tau \geq n_2 c/N$, Regime β is more effective than Regime α in preventing carbon leakage. In this case, global emissions are lower in Regime β than in Regime α because

$$E_W^{\alpha*} - E_W^{\beta*} = \begin{cases} \dfrac{n_2 t}{1+N} > 0 & \text{if } t \leq c \\ \dfrac{n_2(b+n_1 c)}{1+N} > 0 & \text{if } t > c \end{cases}.$$

In Regime β, if $\tau < n_2 c/N$, the final goods producer relocates its assembly to country 2 at $t = N\tau/n_2 \equiv t_1^\beta$. Country 1's emissions decrease but country 2's emissions increase at $t = t_1^\beta$, which can be verified from equation (18):

$$\Delta E_1^{\beta*\prime}\Big|_{t=t_1^\beta} = -\frac{n_1(\tau + n_2 t_1^\beta)}{1+N} < 0; \quad \Delta E_2^{\beta*\prime}\Big|_{t=t_1^\beta} = \frac{n_2[(1+n_1)t_1^\beta - \tau]}{1+N} = n_1\tau > 0.$$

In addition, an increase in t decreases country 1's emissions but increases country 2's emissions for $t_1^\beta < t \leq c$ because we have the following relationships from equation (18):

$$\frac{\partial E_1^{\beta*\prime}}{\partial t} = -\frac{n_1(1+n_2)}{1+N} < 0; \quad \frac{\partial E_2^{\beta*\prime}}{\partial t} = \frac{n_1 n_2}{1+N} > 0; \quad \frac{\partial E_W^{\beta*\prime}}{\partial t} = -\frac{n_1}{1+N} < 0.$$

To conclude, if $\tau < n_2 c/N$, then carbon leakage occurs because of assembly relocation induced by

Regime β. In this case, global emissions are lower in Regime β than in Regime α because

$$E_W^{\alpha*} - E_W^{\beta*\prime} = \begin{cases} \dfrac{n_2 t}{1+N} > 0 & \text{if } t \leq t_1^\beta \\ \dfrac{N\tau}{1+N} > 0 & \text{if } t_1^\beta < t \leq c \\ \dfrac{n_2 \tau}{1+N} > 0 & \text{if } t > c \end{cases}.$$

Hence, we conclude that global emissions are *always* lower in Regime β than in Regime α.

Proof of Proposition 2:

In Regime γ, if $\tau \geq c$, the assembly is always located in country 1. From equation (23), for $t \leq c$, we have

$$\frac{\partial E_1^{\gamma*}}{\partial t} = -\frac{n_1}{1+N} < 0; \; \frac{\partial E_2^{\gamma*}}{\partial t} = -\frac{n_2}{1+N} < 0; \; \frac{\partial E_W^{\gamma*}}{\partial t} = -\frac{N}{1+N} < 0.$$

An increase in the tax rate decreases country 1's, country 2's and global emissions. Carbon leakage does not occur in Regime γ. In this case, global emissions are lower in Regime γ than in Regime α because

$$E_W^{\alpha*} - E_W^{\gamma*} = \begin{cases} \dfrac{n_2 t}{1+N} > 0 & \text{if } t \leq c \\ \dfrac{n_2(b + n_1 c)}{1+N} > 0 & \text{if } t > c \end{cases}.$$

Therefore, we conclude that if $\tau \geq c$, Regime γ is more effective than Regime α in dealing with carbon leakage and global emissions.

In Regime γ, if $\tau < c$, the final goods producer relocates its assembly to country 2 at $t = \tau$. For $t > c$, the difference of global emissions in Regime γ and Regime α is

$$E_W^{\gamma*\prime} - E_W^{\alpha*} = \frac{n_1 b - N\tau - n_1 n_2 c}{1+N}.$$

Global emissions in Regime γ can be higher than those in Regime α if $b > (N\tau + n_1 n_2 c)/n_1$.

For $t > c$, the difference of global emissions in Regime γ and Regime β is

$$E_W^{\gamma*\prime} - E_W^{\beta*} = \frac{n_1(b - \tau - n_2 c)}{1+N} > 0.$$

Global emissions in Regime γ are higher than those in Regime β.

Based on the results above, we conclude that if $\tau < c$, global emissions can be higher in Regime γ than in Regimes α and β.

B: Welfare Analysis

In this part, we briefly discuss how emission tax with and without BCAs affects each component of the countries' welfare. We assume that country 1's welfare consists of consumer surplus (CS), the profits of the n_1 intermediate goods producers ($n_1\pi_1$) and the final goods producer (π_F), tax revenue (TR), and environmental damage from global warming ($D_1(E_W)$). Country 2's welfare consists of only the profits of the n_2 intermediate goods producers ($n_1\pi_1$) and environmental damage from global warming ($D_2(E_W)$). D_1 and D_2 are increasing in E_W. The analysis below implies that which policy regime is preferable strongly depends on how country 1 evaluates its environmental damage from global warming.

In Regime α, we derive each component of the countries' welfare:

$$CS^{\alpha} = \frac{1}{4}X^{\alpha*2} = \frac{1}{4}\left(n_1 x_{11}^{\alpha*} + n_2 x_{21}^{\alpha*}\right)^2 = \frac{1}{4}\left(\frac{Nb - n_1 \min(t,c)}{1+N}\right)^2;$$

$$n_1\pi_1^{\alpha} = n_1\left(x_{11}^{\alpha*}\right)^2 = n_1\left(\frac{b-(1+n_2)\min(t,c)}{1+N}\right)^2;$$

$$\pi_F^{\alpha} = \frac{1}{2}(b-G)^2 = \frac{1}{2}\left(\frac{Nb - n_1\min(t,c)}{1+N}\right)^2;$$

$$TR^{\alpha} = tE_1^{\alpha*} = \begin{cases} \dfrac{n_1 t[b-(1+n_2)t]}{1+N}, & \text{if } t \le c \\ 0, & \text{if } t > c \end{cases};$$

$$n_2\pi_2^{\alpha} = n_2\left(x_{21}^{\alpha*}\right)^2 = n_2\left(\frac{b+n_1\min(t,c)}{1+N}\right)^2.$$

For $t \le c$,

$$\frac{\partial CS^{\alpha}}{\partial t} < 0; \ \frac{\partial n_1\pi_1^{\alpha}}{\partial t} < 0; \frac{\partial \pi_F^{\alpha}}{\partial t} < 0; \ \frac{\partial n_2\pi_2^{\alpha}}{\partial t} > 0.$$

An increase in the emission tax harms consumers, the n_1 intermediate goods producers, and the final goods producer in country 1 while benefiting the n_2 intermediate goods producers in country 2, and the global environment. Country 2's welfare increases. $\partial TR^{\alpha}/\partial t$ is positive for $t \le b/2(1+n_2)$ but negative for $t > b/2(1+n_2)$. The effect of a tax increase on tax revenue in country 1 is ambiguous. However, if the positive effect from fewer emissions dominates the negative effects, country 1's and global welfare improves as well. At the point of abatement, the consumer surplus and profits of producers do not change. Tax revenue decreases to zero and global emissions decrease. The abatement improves country 2's welfare but necessarily worsens country 1's welfare if the benefits from fewer global emissions are smaller than the loss of tax revenue. Country 1 has an incentive to impose an emission tax lower than the abatement cost ($t < c$) if the environmental damage from global warming is low in country 1.

In Regime β, if $\tau \geq n_2 c/N$, the assembly is located in country 1, the welfare components are shown as follows:

$$CS^\beta = \frac{1}{4} X^{\beta * 2} = \frac{1}{4}\left(n_1 x_{11}^{\beta *} + n_2 x_{21}^{\beta *}\right)^2 = \frac{1}{4}\left(\frac{Nb - N\min(t,c)}{1+N}\right)^2;$$

$$n_1 \pi_1^\beta = n_1 \left(x_{11}^{\beta *}\right)^2 = n_1 \left(\frac{b - \min(t,c)}{1+N}\right)^2;$$

$$\pi_F^\beta = \frac{1}{2}(b-G)^2 = \frac{1}{2}\left(\frac{Nb - N\min(t,c)}{1+N}\right)^2;$$

$$TR^\beta = t\left(E_1^{\beta *} + E_2^{\beta *}\right) = \begin{cases} \dfrac{Nt(b-t)}{1+N}, & \text{if } t \leq c \\ 0, & \text{if } t > c \end{cases};$$

$$n_2 \pi_2^\beta = n_2 \left(x_{21}^{\beta *}\right)^2 = n_2 \left(\frac{b - \min(t,c)}{1+N}\right)^2.$$

Note that $CS^\beta < CS^\alpha$, $n_1\pi_1^\beta > n_1\pi_1^\alpha$, $\pi_F^\beta < \pi_F^\alpha$, $TR^\beta > TR^\alpha$ for $t \leq c$, $n_2\pi_1^\beta < n_1\pi_2^\alpha$. The shift from Regime α to Regime β for a given tax rate is harmful to the consumers in country 1 and the n_2 intermediate goods producers in country 2, but is beneficial to the n_1 intermediate goods producers and the tax revenue (before abatement) in country 1. As global emissions decrease, the two countries may benefit from the regime shift.

If $\tau < n_2 c/N$, the final goods producer relocates its assembly to country 2 at $t = t_1^\beta$. The welfare components are

$$CS^{\beta\prime} = \begin{cases} \dfrac{1}{4}\left(\dfrac{Nb - Nt}{1+N}\right)^2 & \text{if } t \leq t_1^\beta \\ \dfrac{1}{4}\left(\dfrac{N(b-\tau) - n_1 t}{1+N}\right)^2 & \text{if } t_1^\beta < t \leq c \\ \dfrac{1}{4}\left(\dfrac{N(b-\tau) - n_1 c}{1+N}\right)^2 & \text{if } t > c \end{cases};$$

$$n_1\pi_1^{\beta\prime} = \begin{cases} n_1\left(\dfrac{b-t}{1+N}\right)^2 & \text{if } t \le t_1^\beta \\ n_1\left(\dfrac{b-\tau-(1+n_2)t}{1+N}\right)^2 & \text{if } t_1^\beta < t \le c\,; \\ n_1\left(\dfrac{b-\tau-(1+n_2)c}{1+N}\right)^2 & \text{if } t > c \end{cases}$$

$$\pi_F^{\beta\prime} = \begin{cases} \dfrac{1}{2}\left(\dfrac{Nb-Nt}{1+N}\right)^2 & \text{if } t \le t_1^\beta \\ \dfrac{1}{2}\left(\dfrac{N(b-\tau)-n_1 t}{1+N}\right)^2 & \text{if } t_1^\beta < t \le c\,; \\ \dfrac{1}{2}\left(\dfrac{N(b-\tau)-n_1 c}{1+N}\right)^2 & \text{if } t > c \end{cases}$$

$$TR^{\beta\prime} = \begin{cases} \dfrac{Nt(b-t)}{1+N} & \text{if } t \le t_1^\beta \\ \dfrac{n_1 t[b-\tau-(1+n_2)t]}{1+N} & \text{if } t_1^\beta < t \le c\,; \\ 0 & \text{if } t > c \end{cases}$$

$$n_2\pi_2^{\beta\prime} = \begin{cases} n_2\left(\dfrac{b-t}{1+N}\right)^2 & \text{if } t \le t_1^\beta \\ n_2\left(\dfrac{b-\tau+n_1 t}{1+N}\right)^2 & \text{if } t_1^\beta < t \le c\,. \\ n_2\left(\dfrac{b-\tau+n_1 c}{1+N}\right)^2 & \text{if } t > c \end{cases}$$

For $t \le t_1^\beta$, the assembly is in country 1 in both regimes. The shift from Regime α to Regime β for a given tax rate is harmful to the consumers in country 1 and the n_2 intermediate goods producers in country 2, but is beneficial to the n_1 intermediate goods producers and the tax revenue in country 1.

For $t > t_1^\beta$, the assembly is in country 1 in Regime α but in Regime β in Regime β. The shift is harmful to the n_1 intermediate goods producers because $n_1\pi_1^{\beta\prime} < n_1\pi_1^\alpha$. The shift is also harmful to the tax revenue in country 1 before abatement because $TR^{\beta\prime} < TR^\alpha$ for $t_1^\beta < t \le c$. As a result, the shift from Regime α to Regime β can worsen all welfare components except environmental quality. Country 1 has an incentive to impose Regime β when the improvement in environmental quality dominates all losses, although the regime shift would cause firm relocation and carbon leakage.

In Regime β, an increase in tax harms consumers, the n_1 intermediate goods producers, and the final goods producer before abatement regardless of whether assembly relocation occurs, i.e., for $t \le c$, $\partial CS^\beta/\partial t < 0$, $\partial CS^{\beta\prime}/\partial t < 0$, $\partial n_1\pi_1^\beta/\partial t < 0$, $\partial n_1\pi_1^{\beta\prime}/\partial t < 0$, $\partial\pi_F^\beta/\partial t < 0$, $\partial\pi_F^{\beta\prime}/\partial t < 0$. In contrast, a tax increase hurts the n_2 intermediate goods producers in country 2 when the assembly is located in country 1 but benefits them before their abatement when it is located in country 2, i.e., $\partial n_2\pi_2^\beta/\partial t < 0$ for $t \leq c$, $\partial n_2\pi_2^{\beta'}/\partial t < 0$ for $t \leq t_1^\beta$, $\partial n_2\pi_2^{\beta'}/\partial t > 0$ for $t_1^\beta < t \leq c$. The effect on tax revenue is ambiguous because the signs of $\partial TR^\beta/\partial t$ and $\partial TR^{\beta'}/\partial t$ depend on the parameter values and the tax rates.

In Regime γ, if $\tau \geq c$, the assembly is located in country 1, the welfare components are the same as those in Regime β:

$$CS^\gamma = \frac{1}{4}X^{\gamma*2} = \frac{1}{4}\left(n_1x_{11}^{\gamma*} + n_2x_{21}^{\gamma*}\right)^2 = \frac{1}{4}\left(\frac{Nb - N\min(t,c)}{1+N}\right)^2;$$

$$n_1\pi_1^\gamma = n_1\left(x_{11}^{\gamma*}\right)^2 = n_1\left(\frac{b-\min(t,c)}{1+N}\right)^2;$$

$$\pi_F^\gamma = \frac{1}{2}(b-G)^2 = \frac{1}{2}\left(\frac{Nb - N\min(t,c)}{1+N}\right)^2;$$

$$TR^\gamma = t\left(E_1^{\gamma*} + E_2^{\gamma*}\right) = \begin{cases} \dfrac{Nt(b-t)}{1+N}, & \text{if } t \leq c \\ 0, & \text{if } t > c \end{cases};$$

$$n_2\pi_2^\gamma = n_2\left(x_{21}^{\gamma*}\right)^2 = n_2\left(\frac{b-\min(t,c)}{1+N}\right)^2.$$

If $\tau < c$, the final goods producer relocates its assembly to country 2 at $t = t_2^\gamma$. The welfare components are

$$CS^{\gamma'} = \begin{cases} \dfrac{1}{4}\left(\dfrac{Nb-Nt}{1+N}\right)^2 & \text{if } t \leq t_2^\gamma \\ \dfrac{1}{4}\left(\dfrac{N(b-\tau)}{1+N}\right)^2 & \text{if } t > t_2^\gamma \end{cases};$$

$$n_1\pi_1^{\gamma'} = \begin{cases} n_1\left(\dfrac{b-t}{1+N}\right)^2 & \text{if } t \leq t_2^\gamma \\ n_1\left(\dfrac{b-\tau}{1+N}\right)^2 & \text{if } t > t_2^\gamma \end{cases};$$

$$\pi_F^{\gamma'} = \begin{cases} \dfrac{1}{2}\left(\dfrac{Nb-Nt}{1+N}\right)^2 & \text{if } t \leq t_2^\gamma \\ \dfrac{1}{2}\left(\dfrac{N(b-\tau)}{1+N}\right)^2 & \text{if } t > t_2^\gamma \end{cases};$$

$$TR^{\gamma\prime} = \begin{cases} \dfrac{Nt(b-t)}{1+N} & \text{if } t \le t_2^{\gamma} \\ 0 & \text{if } t > t_2^{\gamma} \end{cases};$$

$$n_2\pi_2^{\gamma\prime} = \begin{cases} n_2\left(\dfrac{b-t}{1+N}\right)^2 & \text{if } t \le t_2^{\gamma} \\ n_2\left(\dfrac{b-\tau}{1+N}\right)^2 & \text{if } t > t_2^{\gamma} \end{cases}.$$

In Regime γ, an increase in the tax hurts the N intermediate goods producers and the final goods producer but improves the environment before assembly relocation or abatement, i.e., for $t \le c$, $\partial n_1\pi_1^{\gamma}/\partial t < 0$, $\partial n_2\pi_2^{\gamma}/\partial t < 0$, $\partial\pi_F^{\gamma}/\partial t < 0$; for $t \le t_2^{\gamma}$, $\partial n_1\pi_1^{\gamma\prime}/\partial t < 0$, $\partial n_2\pi_2^{\gamma\prime}/\partial t < 0$, $\partial\pi_F^{\gamma\prime}/\partial t < 0$. However, it does not affect them after the relocation and abatement. The effect on tax revenue is ambiguous because the signs of $\partial TR^{\gamma}/\partial t$ and $\partial TR^{\gamma}/\partial t$ depend on the parameter values and tax rates. In the following, we can investigate how the shift from Regime α to Regime γ affects welfare components. If the assembly is in country 1 under Regime γ, the effects are qualitatively the same as the shift from Regime α to Regime β. However, if the assembly is in country 2 under Regime γ, then the shift benefits the n_1 intermediate goods producers in country 1 but harms the n_2 intermediate goods producers in country 2, i.e., $n_1\pi_1^{\gamma\prime} > n_1\pi_1^{\alpha}$, $n_2\pi_2^{\gamma\prime} > n_2\pi_2^{\alpha}$. How the shift affects country 1's tax revenue, final goods producer's profits, and global emissions is ambiguous. If global emissions are higher in Regime γ than in Regime α and country 1 has a strong awareness of environmental protection, then country 1 has no incentive to impose Regime γ, although doing so benefits its polluting producers.

Regimes β and γ are the same when the assembly is located in country 1. If the assembly is in country 1 under Regime β but in country 2 under Regime γ (e.g., $t_2^{\gamma} < t \le t_1^{\beta}$ in Figure 4), the shift from Regime β to Regime γ benefits consumers and all producers, but harms country 1's tax revenue and the environment, i.e., for $t_2^{\gamma} < t \le t_1^{\beta}$, we have $CS^{\gamma\prime} > CS^{\beta\prime}$, $\pi_F^{\gamma\prime} > \pi_F^{\beta\prime}$, $n_1\pi_1^{\gamma\prime} > n_1\pi_1^{\beta\prime}$, $n_2\pi_2^{\gamma\prime} > n_2\pi_2^{\beta\prime}$, $TR^{\gamma\prime} < TR^{\beta\prime}$. If the assembly is in country 2 under both regimes, then the regime shift harms the n_2 intermediate goods producers ($n_2\pi_2^{\gamma\prime} < n_2\pi_2^{\beta\prime}$). The effects on the other components are qualitatively the same as in the former case, except that country 1's tax revenue is not affected for $t > c$ because they are zero under both regimes, i.e., for $t > t_1^{\beta}$, we have $CS^{\gamma\prime} > CS^{\beta\prime}$, $n_1\pi_1^{\gamma\prime} > n_1\pi_1^{\beta\prime}$, $TR^{\gamma\prime} = TR^{\beta\prime} = 0$.

C: Comparison of Emission Tax and Carbon-footprint Tax

In this section, we examine and compare two policy regimes of emission tax alone (Regime ζ) and carbon footprint tax (Regime ψ) in the presence of country 2's market. The game of decision-making is the same as in the main part. For simplicity, we assume away the abatement choices of the intermediate goods producers.[18] The inverse demand functions in the two countries are

$$P_1 = b_1 - X_1/2; \quad P_2 = b_2 - X_2/2.$$

Regime ζ: emission tax alone

In Regime ζ, country 1 imposes only an emission tax on the domestic production of intermediate goods. We first analyze the behaviors of intermediate and final goods producers in the second and third stages given the assembly in countries 1 and 2, respectively, and then show how the final goods producer chooses its assembly location endogenously.

Assuming that the assembly is located in country 1, in the third stage, the final goods producer's profit is

$$\pi^{\zeta}_{F,1} = (P^{\zeta}_1 - G^{\zeta}_1)X^{\zeta}_1 + (P^{\zeta}_2 - G^{\zeta}_1 - \tau)X^{\zeta}_2.$$

G^{ζ}_1 is the unit cost of final goods consumed in country 1. The unit cost of final goods consumed in country 2 is therefore $G^{\zeta}_1 + \tau$.

Solving the profit maximization problem of the final goods producer, we can derive the equilibrium quantity of final goods consumed in country 1 and country 2:

$$X^{\zeta*}_1 = b_1 - G^{\zeta}_1; \quad X^{\zeta*}_2 = b_2 - G^{\zeta}_1 - \tau.$$

In the second stage, the inverse demand for intermediate goods by the final goods producer can be derived from the the equilibrium quantity of final goods in the last stage:

$$z^{\zeta}_1 = \frac{1}{2}\left[b_1 + b_2 - \tau - \left(\sum_{i=1}^{n_1} x^{\zeta}_{11i} + \sum_{j=1}^{n_2} x^{\zeta}_{21j}\right)\right].$$

b_1 and b_2 are assumed to be sufficiently large so that the consumption of final goods is positive in each market, i.e., $\min(b_1, b_2 - \tau) > z^{\zeta}_1$.

[18] The main finding in this section would not change even if we consider abatement. That is, global emissions can be higher under carbon footprint tax than under emission tax alone.

For each intermediate goods producer in countries 1 and 2, the profit is

$$\pi_{11i}^{\zeta} = (z_1^{\zeta} - t)x_{11i}^{\zeta}; \quad \pi_{21j}^{\zeta} = z_1^{\zeta} x_{21j}^{\zeta}.$$

The market outcome is obtained by a Nash equilibrium of the game in which the N intermediate goods producers compete in quantity given the inverse demand function. Solving the profit maximization problems, we obtain the equilibrium quantities and price of intermediate goods as

$$x_{11}^{\zeta *} = \frac{b_1 + b_2 - \tau - 2(1+n_2)t}{1+N}; \quad x_{21}^{\zeta *} = \frac{b_1 + b_2 - \tau + 2n_1 t}{1+N}; \quad z_1^{\zeta *} = \frac{b_1 + b_2 - \tau + 2n_1 t}{2(1+N)}.$$

Assuming that the assembly is located in country 2, in the third stage, the final goods producer's profit is

$$\pi_{F,2}^{\zeta} = (\hat{P}_1^{\zeta} - G_2^{\zeta} - \tau)\hat{X}_1^{\zeta} + (\hat{P}_2^{\zeta} - G_2^{\zeta})\hat{X}_2^{\zeta}.$$

G_2^{ζ} is the unit cost of final goods consumed in country 2. The unit cost of final goods consumed in country 1 is therefore $G_2^{\zeta} + \tau$.

Solving the profit maximization problem of the final goods producer, we can derive the equilibrium quantity of final goods consumed in country 1 and country 2:

$$\hat{X}_1^{\zeta *} = b_1 - G_2^{\zeta} - \tau; \quad \hat{X}_2^{\zeta *} = b_2 - G_2^{\zeta}.$$

In the second stage, the inverse demand for intermediate goods by the final goods producer can be derived from the the equilibrium quantity of final goods in the last stage:

$$z_2^{\zeta} = \frac{1}{2}\left[b_1 + b_2 - \tau - \left(\sum_{i=1}^{n_1} x_{12i}^{\zeta} + \sum_{j=1}^{n_2} x_{22j}^{\zeta}\right)\right].$$

b_1 and b_2 are assumed to be sufficiently large so that the consumption of final goods is positive in each market, i.e., $\min(b_1 - \tau, b_2) > z_2^{\zeta}$.

For each intermediate goods producer in countries 1 and 2, the profit is

$$\pi_{12i}^{\zeta} = \left(z_2^{\zeta} - t\right) x_{12i}^{\zeta}; \quad \pi_{21j}^{\zeta} = z_2^{\zeta} x_{22j}^{\zeta}.$$

Solving the profit maximization problems, we obtain the equilibrium quantities and price of intermediate goods as

$$x_{12}^{\zeta *} = \frac{b_1 + b_2 - \tau - 2(1+n_2)t}{1+N}; \quad x_{22}^{\zeta *} = \frac{b_1 + b_2 - \tau + 2n_1 t}{1+N}; \quad z_2^{\zeta *} = \frac{b_1 + b_2 - \tau + 2n_1 t}{2(1+N)}.$$

The equilibrium quantities and price of intermediate goods are the same as those when the assembly is in country 1.

In the first stage, the final goods producer decides on its assembly location by comparing the profits with the assembly in country 1 and country 2.

If the assembly is in country 1, its profit is

$$\pi_{F,1}^{\zeta*} = \frac{1}{2}\left(b_1 - z_1^{\zeta*}\right)^2 + \frac{1}{2}\left(b_2 - z_1^{\zeta*} - \tau\right)^2.$$

If the assembly is in country 2, its profit is

$$\pi_{F,2}^{\zeta*} = \frac{1}{2}\left(b_1 - z_2^{\zeta*} - \tau\right)^2 + \frac{1}{2}\left(b_2 - z_2^{\zeta*}\right)^2.$$

The profit difference is

$$\pi_{F,1}^{\zeta*} - \pi_{F,2}^{\zeta*} = (b_1 - b_2)\tau.$$

Therefore, the final goods producer will locate its assembly in the country with a larger market size to save on trade costs of final goods.

Regime ψ: carbon footprint tax

In Regime ψ, country 1 imposes an emission tax on the dirty inputs used for the final goods consumed in country 1. In our setting, if the assembly is located in country 1, the intermediate goods producers in country 1 need to pay emission tax for their production and the intermediate goods producers in country 2 must pay a carbon-content tariff for their exports to country 1. The final goods producer sells the final goods in both countries. For the final goods consumed in country 1, there are no emission taxes on them because the assembly does not generate emissions. For the final goods consumed in country 2, country 1 refunds the emission taxes paid for the emissions embedded in them. If the assembly is located in country 2, the intermediate goods producers in country 1 face a tax refund when they export the inputs to country 2. The intermediate goods producers in country 2 do not need to pay the emission tax. The final goods producer must pay a carbon-content tariff for the emissions embedded in exports to country 1. Under a carbon footprint tax, all the dirty inputs used for the final goods consumed in country 1 are regulated by a carbon tax t, but the dirty inputs used for the final goods consumed in country 2 are exempt. In the following, we first analyze the behaviors of intermediate and final goods producers in the second and third stages given the assembly in countries 1 and 2, respectively, and then show how the final goods producer chooses its assembly location endogenously.

Assuming that the assembly is located in country 1, in the third stage, the final goods producer's profit is

$$\pi_{F,1}^{\psi} = (P_1^{\psi} - G_1^{\psi})X_1^{\psi} + (P_2^{\psi} - G_1^{\psi} - \tau + t)X_2^{\psi}.$$

G_1^{ψ} is the unit cost of final goods consumed in country 1. The unit cost of final goods consumed in country 2 is therefore $G_1^{\psi} + \tau - t$.

Solving the profit maximization problem of the final goods producer, we can derive the equilibrium quantity of final goods consumed in country 1 and country 2:

$$X_1^{\psi *} = b_1 - G_1^{\psi}; \quad X_2^{\psi *} = b_2 - G_1^{\psi} - \tau + t.$$

In the second stage, the inverse demand for intermediate goods by the final goods producer can be derived from the the equilibrium quantity of final goods in the last stage:

$$z_1^{\psi} = \frac{1}{2}\left[b_1 + b_2 - \tau + t - \left(\sum_{i=1}^{n_1} x_{11i}^{\psi} + \sum_{j=1}^{n_2} x_{21j}^{\psi}\right)\right].$$

For each intermediate goods producer in countries 1 and 2, the profit is

$$\pi_{11i}^{\psi} = \left(z_1^{\psi} - t\right) x_{11i}^{\psi}; \quad \pi_{21j}^{\psi} = \left(z_1^{\psi} - t\right) x_{21j}^{\psi}.$$

Solving the profit maximization problems, we obtain the equilibrium quantities and price of intermediate goods as

$$x_{11}^{\psi *} = x_{21}^{\psi *} = \frac{b_1 + b_2 - \tau - t}{1 + N}; \quad z_1^{\psi *} = \frac{b_1 + b_2 - \tau + (1 + 2N)t}{2(1 + N)}.$$

Assuming that the assembly is located in country 2, in the third stage, the final goods producer's profit is

$$\pi_{F,2}^{\psi} = (\hat{P}_1^{\psi} - G_2^{\psi} - \tau - t)\hat{X}_1^{\psi} + (\hat{P}_2^{\psi} - G_2^{\psi})\hat{X}_2^{\psi}.$$

G_2^{ψ} is the unit cost of final goods consumed in country 2. The unit cost of final goods consumed in country 1 is therefore $G_2^{\psi} + \tau + t$.

Solving the profit maximization problem of the final goods producer, we can derive the equilibrium quantity of final goods consumed in country 1 and country 2:

$$\hat{X}_1^{\psi *} = b_1 - G_2^{\psi} - \tau - t; \quad \hat{X}_2^{\psi *} = b_2 - G_2^{\psi}.$$

In the second stage, the inverse demand for intermediate goods by the final goods producer can be derived from the the equilibrium quantity of final goods in the last stage:

$$z_2^{\psi} = \frac{1}{2}\left[b_1 + b_2 - \tau - t - \left(\sum_{i=1}^{n_1} x_{12i}^{\psi} + \sum_{j=1}^{n_2} x_{22j}^{\psi}\right)\right].$$

b_1 and b_2 are assumed to be sufficiently large so that the consumption of final goods is positive in each market, i.e., $\min(b_1 - \tau - t, b_2) > z_2^{\psi}$.

For each intermediate goods producer in countries 1 and 2, the profit is

$$\pi_{12i}^{\psi} = z_2^{\psi} x_{12i}^{\psi}; \quad \pi_{21j}^{\psi} = z_2^{\psi} x_{22j}^{\psi}.$$

Solving the profit maximization problems, we obtain the equilibrium quantities and price of intermediate goods as

$$x_{12}^{\psi*} = x_{22}^{\psi*} = \frac{b_1 + b_2 - \tau - t}{1 + N}; \quad z_2^{\psi*} = \frac{b_1 + b_2 - \tau - t}{2(1 + N)}.$$

The equilibrium quantities of intermediate goods are the same as those when the assembly is in country 1.

In the first stage, the final goods producer decides on its assembly location by comparing the profits with the assembly in country 1 and country 2.

If the assembly is in country 1, its profit is

$$\pi_{F,1}^{\psi*} = \frac{1}{2}\left(b_1 - z_1^{\psi*}\right)^2 + \frac{1}{2}\left(b_2 - z_1^{\psi*} - \tau + t\right)^2.$$

If the assembly is in country 2, its profit is

$$\pi_{F,2}^{\psi*} = \frac{1}{2}\left(b_1 - z_2^{\psi*} - \tau - t\right)^2 + \frac{1}{2}\left(b_2 - z_2^{\psi*}\right)^2.$$

The profit difference is

$$\pi_{F,1}^{\psi*} - \pi_{F,2}^{\psi*} = (b_1 - t - b_2)\tau.$$

The carbon footprint tax plays a role in shrinking the market in country 1 because only the inputs used for the production of final goods consumed in country 1 are regulated by the carbon tax. If b_1 is sufficiently large so that $b_1 - t - b_2 > 0$ always holds, then the assembly is located in country 1. If b_2 is sufficiently large so that $b_1 - t - b_2 < 0$ always holds, then the assembly is located in country 2. Assembly relocation does not occur in the above two cases. However, if $b_1 > b_2$ but the difference is small, then the assembly is located in country 1 for $t \leq b_1 - b_2$ but in country 2 for $t > b_1 - b_2$. Although assembly relocation occurs, there is no carbon leakage in this case because each intermediate goods producer's production does not change.

Comparing the global emissions in the two policy regimes, we have

$$E_W^{\psi*} - E_W^{\zeta*} = \frac{(2n_1 - N)t}{1 + N}.$$

If $n_1 > N/2$, global emissions are higher under carbon footprint tax than under emission tax alone. The intuition is as follows. Under carbon footprint tax, the production of inputs for the final goods consumed in country 1 is taxed, while that for the final goods consumed in country 2 is exempt from environmental regulations. Compared with production under emission tax alone, country 2's input production decreases ($n_2 x_{21}^{\psi*} < n_2 x_{21}^{\zeta*}$), but country 1's input production increases ($n_1 x_{11}^{\psi*} > n_1 x_{11}^{\zeta*}$). If $n_1 > N/2$, the latter strength dominates the former, increasing global emissions.

To conclude, in the presence of country 2's market, carbon footprint tax eliminates carbon leakage even if it causes assembly relocation; however, global emissions can be higher under carbon footprint tax than under emission tax alone.