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Is Environmental Tax Harmonization Desirable in Global Value Chains?

Haitao Cheng Hayato Kato Ayako Obashi

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Graduate School of Economics
Osaka University, Toyonaka, Osaka 560-0043, JAPAN

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Haitao Cheng† Hayato Kato‡ Ayako Obashi§

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Abstract

The current globalization is characterized by the spatial unbundling of parts production and assembly, leading to the dispersion of pollution. We study environmental taxes in a two-country model of global value chains in which the location of parts and assembly can differ. When unbundling costs are so high that parts and assembly must co-locate in the pre-globalized world, pollution is spatially concentrated and harmonizing environmental taxes maximizes the global welfare. By contrast, under low unbundling costs triggering the dispersion of parts and thus of pollution in the world today, the harmonization does not maximize the global welfare.

Keywords: Environmental policy; Fragmentation; International coordination.
JEL classification: F18; F23; Q56; Q58.

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†Graduate School of Economics, Hitotsubashi University, 2-1 Naka, Kunitachi, Tokyo, 186-8601, Japan. *E-mail address:* ed185013@g.hit-u.ac.jp

‡Graduate School of Economics, Osaka University, 1-7 Machikaneyama, Toyonaka, Osaka, 560-0043, Japan. *E-mail address:* hayato.kato@econ.osaka-u.ac.jp

§School of International Politics, Economics and Communication, Aoyama Gakuin University, 4-4-25 Shibuya, Shibuya-ku, Tokyo, 150-8366, Japan. *E-mail address:* obashi@sipeb.aoyama.ac.jp

1 Introduction

The current globalization since the late twentieth century is characterized by not just declining barriers to trade and factor mobility, but also by lowering costs of coordinating activities within organizations. It has fostered a fragmentation of integrated production processes (Rossi-Hansberg et al., 2009). The spatial separation of production stages, which Baldwin and Venables (2013) call the *second unbundling*, has significant implications for the environment as well as trade. The second unbundling may promote the relocation of polluting industries to countries with lax environmental standards, known as the *pollution haven hypothesis* (Markusen et al., 1995).

One measure against the harmful impact of unbundling production processes could be a harmonization of environmental standards among countries (Sterner and Köhlin, 2003). Equalizing the degree of regulations among countries does not distort the location decisions of firms and may mitigate the divergence of environmental quality. The harmonization may be, however, too naive to address individual environmental impacts given country heterogeneity.

We aim to evaluate the effectiveness of environmental tax harmonization in a two-country model of global value chains à la Baldwin and Venables (2013), where a final good is produced assembling the chain of many parts. In the pre-globalized world where all production processes co-locate, environmental taxes do nothing to improve the global environment. Setting an equal tax between countries maximizes the global welfare by not distorting efficient locations. In the globalized world where assembly and parts can be spatially unbundled, environmental taxes can reduce the global environmental damage by avoiding the concentration of polluting processes. The simple harmonization is (almost) never desirable and a more careful coordination is necessary.

Some studies have investigated the environmental impact of mobile firms, but production structure in their models is too simple to speak to fragmentation (Zeng and Zhao, 2009; Forslid et al., 2017; Voßwinkel and Birg, 2018). Only a few studies have examined environmental policies in vertically-linked sectors like ours (Wan and Wen, 2017; Wan et al., 2018). Unlike ours, however, they fix the locations of upstream and downstream firms and focus on non-cooperative policy games.

2 The model

Consider a world with two countries, N and S. The two countries have equal population with unit mass. Each individual inelastically supplies one unit of labor. There are three types of goods, a final good, a range of parts (intermediate inputs), and a numéraire good. The numéraire-good is produced using labor and is costlessly traded, which equalizes its international price. With choice of units, the wage rates in both countries are equal to unity. Each part can be produced using labor in both countries and can be internationally traded. Parts production generates local pollution and is thus taxed by the domestic government. A single final-good producer (assembler) locates in N or S and assembles the range of parts into one unit of the good. As in Baldwin and Venables (2013), the two countries differ in two ways: (i) only N consumes the final good and (ii) the average cost of producing parts is lower in S than in N.

To describe the second unbundling, we distinguish between two types of frictions. If the assembler is located in S, it must pay *trade costs* to export the final good to N. If the locations of parts and assembly are different, the assembler must pay additional *unbundling costs* to import parts from abroad. Unbundling costs include communication costs between headquarters and foreign suppliers as well as physical transportation costs.

2.1 Preferences

The utility of the representative consumer in $i \in \{N, S\}$ is

$$U_i = \widetilde{u}\mathbf{1}_i + X_i - D(e_i), \tag{1}$$

where X_i is the consumption of numéraire good, and e_i is the pollution level. $\mathbf{1}_i$ takes one if $i = N$ and zero if $i = S$. The consumer in N obtains $\widetilde{u}$ from consuming one unit of the final good. The disutility from pollution is expressed as $D(e_i) = \gamma e_i^2/2$ with $\gamma > 0$. The budget constraint is

$$p\mathbf{1}_i + X_i = 1 + t_i e_i + \overline{X}, \tag{2}$$

where p is the final good's price and t_i is the environmental tax by i per unit of pollution. The income consists of wage ($w_i = 1$), the redistribution of tax revenues ($t_i e_i$), and the initial endowment of the numéraire ($\overline{X}$). $\overline{X}$ ensures positive consumption of the numéraire. Substituting (2) into (1) gives the indirect utility V_i.

2.2 Sourcing decision

The assembler first chooses where to locate and then from which country to source parts. We here look at the assembler's sourcing decisions given his location.

Letting z be the index of parts from the set $Z = [\underline{b}, \overline{b}]$, the unit cost of any part $z \in Z$ is unity if it is produced in N. If a part $z \in Z$ is produced in S, on the other, its unit cost is $b(z) = z$ with $0 < \underline{b} < 1 < \overline{b}$. N has a comparative advantage in parts $b \in [1, \overline{b}]$, while S has it in parts $b \in [\underline{b}, 1)$. S has an average cost advantage over N, i.e., $\beta \equiv 1 - (\underline{b} + \overline{b})/2 > 0$.[1] Producing one unit of each part generates one unit of local pollution.

One unit of the final good is produced by assembling one unit of each part. When parts cross the border, additional unbundling costs θ occur. The sourcing decision is made part by part by comparing the international cost difference. Supposing the assembler is in N, a part z is there if

$$\begin{aligned}
&\underbrace{1 + t_N}_{\text{Cost in } N} < \underbrace{b(z) + \theta + t_S}_{\text{Cost in } S}, \\
&\rightarrow b(z) > b_N \equiv \min[\max\{\underline{b}, 1 - \theta + \Delta t\}, \overline{b}], \\
&\text{where} \quad \Delta t \equiv t_N - t_S.
\end{aligned}$$

The inequality is likely to hold if S's cost is high (high $b(z)$), N's tax compared with S's is low (low Δt), and unbundling costs are high (high θ).

Supposing assembler is in S, a part z is produced there if

$$\begin{aligned}
&\underbrace{1 + \theta + t_N}_{\text{Cost in } N} > \underbrace{b(z) + t_S}_{\text{Cost in } S}, \\
&\rightarrow b(z) < b_S \equiv \max[\min\{\overline{b}, 1 + \theta + \Delta t\}, \underline{b}],
\end{aligned}$$

which can be interpreted analogously.

When unbundling costs are sufficiently high, the two *unbundling thresholds* degenerate, i.e., $b_N = \underline{b}$ and $b_S = \overline{b}$, and all parts co-locate with assembly. Specifically, supposing $\theta > \overline{\theta} \equiv \max\{1 - \underline{b} + \Delta t, \overline{b} - 1 - \Delta t\}$, Fig. 1 draws such a region ($\mathcal{NS}$ in the figure) given assembly location and taxes.[2] The co-location motive of the assembler to save unbundling costs is so strong that neither comparative advantage nor environmental taxes matter. The

[1] The average cost of parts in S is $\frac{1}{\overline{b}-\underline{b}} \int_{\underline{b}}^{\overline{b}} \tilde{b} d\tilde{b} = \frac{1}{\overline{b}-\underline{b}} \cdot \frac{\overline{b}^2 - \underline{b}^2}{2} = \frac{\overline{b}+\underline{b}}{2}$, while that in N is $\frac{1}{\overline{b}-\underline{b}} \int_{\underline{b}}^{\overline{b}} 1 d\tilde{b} = 1$.

[2] Note that $b_N = \underline{b}$ holds if $\underline{b} > 1 - \theta + \Delta t$; $b_S = \overline{b}$ holds if $\overline{b} < 1 + \theta + \Delta t$. These conditions lead to $\theta > \max\{1 - \underline{b} + \Delta t, \overline{b} - 1 - \Delta t\}$, which is equivalent to $\Delta t \in (\overline{b} - \theta - 1, \underline{b} + \theta - 1)$.

parts and assembly are spatially bundled in the pre-globalization world.

When unbundling costs are low enough, the two unbundling thresholds do not degenerate. The location of some parts is dictated by comparative advantage and taxes, not by the co-location motive. Supposing $\theta < \underline{\theta} \equiv \min\{1 - \underline{b} + \Delta t, \overline{b} - 1 - \Delta t\}$, Fig. 2 draws the sourcing pattern.[3] Unlike Fig. 1, there are other two regions in Fig. 2, $\mathcal{N}$ and $\mathcal{S}$. Parts in $\mathcal{N}$, for example, are those in which N has a very strong comparative advantage, and are always produced in N. As low unbundling costs also make the assembler aware of taxes, the tax difference now matters for his sourcing decision. The spatial unbundling captures the current globalization.

In what follows, we will separately present the analysis of the two cases.

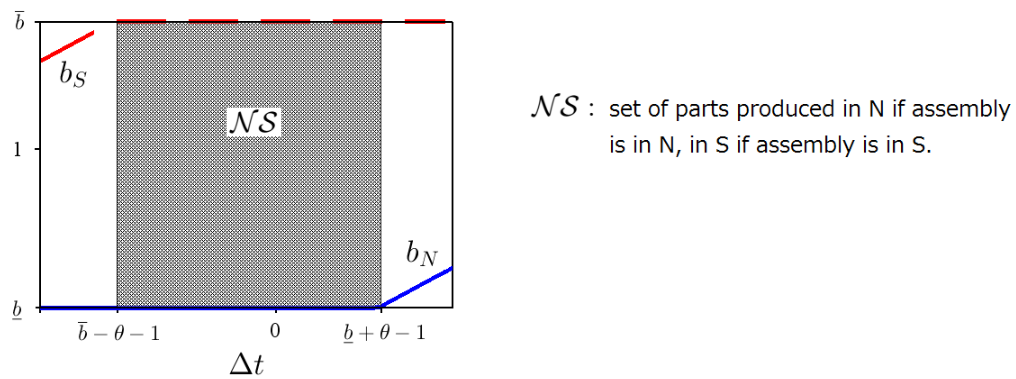

Fig. 1. Sourcing pattern under high unbundling costs.

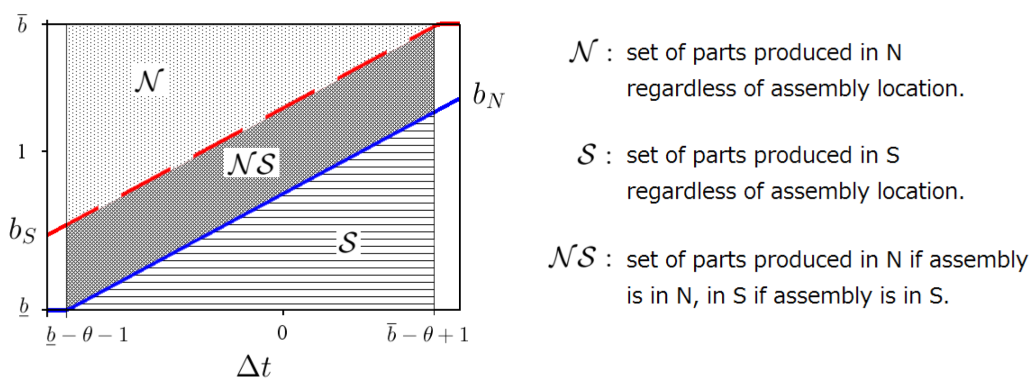

Fig. 2. Sourcing pattern under low unbundling costs.

[3]This condition is equivalent to $\Delta t \in (\underline{b} + \theta - 1, \overline{b} - \theta - 1)$.

3 High unbundling costs: co-location of parts and assembly

We consider here the case where unbundling costs are high: $\theta > \overline{\theta}$ so that parts and assembly are spatially bundled. We first characterize assembly location for given taxes and then derive the socially optimal taxes.

3.1 Assembly location

Let C_i be the total costs of producing one unit of the final good, given assembly in $i \in \{N, S\}$. Noting $b_N = \underline{b}$, we have

$$\begin{aligned} C_N &= \underbrace{\int_{\underline{b}}^{b_N} (\widetilde{b} + \theta + t_S) d\widetilde{b}}_{\text{Parts from } S} + \underbrace{\int_{b_N}^{\overline{b}} (1 + t_N) d\widetilde{b}}_{\text{Parts from } N} \\ &= (\overline{b} - \underline{b})(1 + t_N). \end{aligned} \tag{3}$$

Similarly, noting $b_S = \overline{b}$, we have

$$\begin{aligned} C_S &= \tau + \underbrace{\int_{\underline{b}}^{b_S} (\widetilde{b} + t_S) d\widetilde{b}}_{\text{Parts from } S} + \underbrace{\int_{b_S}^{\overline{b}} (1 + \theta + t_N) d\widetilde{b}}_{\text{Parts from } N} \\ &= \tau + (\overline{b} - \underline{b}) \left(\frac{\underline{b} + \overline{b}}{2} + t_S \right), \end{aligned} \tag{4}$$

where trade costs τ enter since the good crosses the border. All parts are sourced locally and thus θ does not appear here.

The assembler chooses his location that gives the lower C_i. Assembly takes place in N if

$$\begin{aligned} &\Delta C \equiv C_N - C_S = -\tau + (\overline{b} - \underline{b}) (\beta + \Delta t) \leq 0, \\ &\to \tau \geq \tau^* \equiv (\overline{b} - \underline{b}) (\beta + \Delta t), \\ &\text{where} \quad \beta \equiv 1 - (\underline{b} + \overline{b})/2, \end{aligned} \tag{5}$$

High trade costs make the assembler prefer the proximity to consumers. As seen from the switching point τ^* below which assembly takes place in S, the assembler is more likely to locate in N as N's tax gets lower (lower Δt) and/or N's parts are more costly (higher β).

This tendency is magnified by the total number of parts: $\bar{b} - \underline{b}$.

3.2 Social optimum

The social/global welfare W is the sum of each country's indirect utility V_i. Using (1), (2), (3) and (4), we have

$$W = \begin{cases} W|_{A=N} = \sum_{i=N,S} V_i|_{A=N} = u - (\bar{b} - \underline{b}) - (\gamma/2)(\bar{b} - \underline{b})^2 & \text{if } \ \tau \geq \tau^* \\ W|_{A=S} = \sum_{i=N,S} V_i|_{A=S} = u - \tau - (1/2)(\bar{b} - \underline{b})(\underline{b} + \bar{b}) - (\gamma/2)(\bar{b} - \underline{b})^2 & \text{if } \ \tau < \tau^* \end{cases},$$

$$\text{where } \ u \equiv \widetilde{u} + 2(1 + \overline{X}),$$

and where the subscript $A = i \in \{N, S\}$ indicates the assembler's location. Since all parts co-locate with assembly, the pollution level in i is $e_i = \bar{b} - \underline{b}$ if the assembler is in i and it is $e_i = 0$ otherwise.

Surprisingly, taxes do not enter in W. Higher taxes improve welfare by raising tax revenues, while they reduce welfare by raising the final-good's price. These two counteracting effects are offset each other. Taxes thus affect parts location only through changes in assembly location.

Noting that τ^* depends on the tax difference, not individual levels, the planner chooses Δt to attain $\max\{W|_{A=N}, W|_{A=S}\}$ by changing τ^*. The optimal tax difference for any trade costs turns out to be $\Delta t = 0$, as Fig. 3 shows.[4] That is, the planner should not intervene the assembler's location choice. If the location of assembly were manipulated, comparative advantage would be distorted and thus the total cost would not be minimized. In addition, assembly location affects *local* environmental damage, but does not affect *global* environmental damage, since the assembler sources all parts locally. The planner is thus unable to reduce the global damage by changing assembly location. She fully respects the cost-minimization location choice of the assembler by setting the tax difference zero. The socially optimal switching point becomes $\widehat{\tau}^* \equiv \tau^*|_{\Delta t=0} = \beta(\bar{b} - \underline{b})$.

[4] All the proofs of propositions are given in Appendix. Given τ, there may be other optimal tax differences than $\Delta t = 0$ (see Fig. A2). But only $\Delta t = 0$ maximizes the social welfare for any τ.

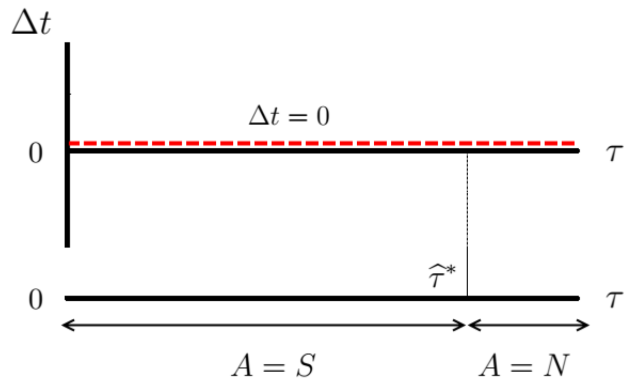

Fig. 3. Socially optimal tax harmonization (dotted line) and assembly location under high unbundling costs.

Proposition 1. *Under high unbundling costs, environmental tax harmonization, i.e., $t_N = t_S$, always maximizes the social welfare for any level of trade costs.*

4 Low unbundling costs: Separation of parts and assembly

We turn to the case where unbundling costs are low: $\theta < \underline{\theta}$. Low unbundling costs allow parts and assembly to locate in different countries, capturing the second unbundling.

4.1 Assembly location

As Fig. 2 suggests, the two unbundling thresholds are within the interval of $[\underline{b}, \overline{b}]$. The total cost of the final good in each location is respectively

$$C_N = \underbrace{\left(\theta + t_S + \frac{\underline{b} + b_N}{2}\right)(b_N - \underline{b})}_{\text{Parts from } S} + \underbrace{(1 + t_N)(\overline{b} - b_N)}_{\text{Parts from } N}, \tag{6}$$

$$C_S = \tau + \underbrace{\left(t_S + \frac{\underline{b} + b_S}{2}\right)(b_S - \underline{b})}_{\text{Parts from } S} + \underbrace{(1 + \theta + t_N)(\overline{b} - b_S)}_{\text{Parts from } N}, \tag{7}$$

where $b_N = 1 - \theta + \Delta t$ and $b_S = 1 + \theta + \Delta t$. Assembly takes place in N if

$$\Delta C \equiv C_N - C_S = -\tau + 2\theta\left(1 - \frac{\underline{b} + \overline{b}}{2} + \Delta t\right) \leq 0,$$
$$\rightarrow \tau \geq \tau^{**} \equiv 2\theta\left(\beta + \Delta t\right).$$

Unlike τ^* in (5), τ^{**} depends on θ. Higher unbundling costs make the co-location of parts and assembly more important, but do the proximity to the consumer in N less important. Thus, a higher θ increases τ^{**}, making the assembler less likely to locate in N.

4.2 Social optimum

With low unbundling costs, we use (1), (2), (6) and (7) to express the social welfare as

$$W = \begin{cases} W|_{A=S} = \sum_{i=N,S} V_i|_{A=S} & \text{if } \tau < \tau^{**} \\ W|_{A=N} = \sum_{i=N,S} V_i|_{A=N} & \text{if } \tau \geq \tau^{**} \end{cases},$$
$$W|_{A=S} = u - \left[\tau + \frac{1}{2}(\underline{b} + b_S)(b_S - \underline{b}) + (1+\theta)(\overline{b} - b_S)\right] - \frac{\gamma}{2}[(\overline{b} - b_S)^2 + (b_S - \underline{b})^2],$$
$$W|_{A=N} = u - \left[\left(\theta + \frac{\underline{b} + b_N}{2}\right)(b_N - \underline{b}) + (\overline{b} - b_N)\right] - \frac{\gamma}{2}[(\overline{b} - b_N)^2 + (b_N - \underline{b})^2].$$

Unlike the high-unbundling-cost case, the tax difference Δt affects not just the switching point τ^{**} but the unbundling thresholds b_i. The planner chooses Δt to maximize W by changing b_i as well as τ^{**}

Formally, the socially optimal tax difference is derived as follows and is illustrated in Fig. 4:[5]

$$\Delta t = \begin{cases} \Delta t|_{A=S} \equiv -\dfrac{2\gamma(\beta+\theta)}{2\gamma+1} & \text{if } \tau < \tau^a \\ \Delta\widehat{t} + \varepsilon & \text{if } \tau^a \leq \tau < \widehat{\tau}^{**} \\ \Delta\widehat{t} \equiv \dfrac{\tau}{2\theta} - \beta & \text{if } \widehat{\tau}^{**} \leq \tau < \tau^b \\ \Delta t|_{A=N} \equiv \dfrac{2\gamma(\theta-\beta)}{2\gamma+1} & \text{if } \tau \geq \tau^b \end{cases},$$
$$\text{where } \tau^a \equiv \frac{2\theta(\beta - 2\gamma\theta)}{2\gamma+1}, \quad \widehat{\tau}^{**} \equiv \frac{2\beta\theta}{2\gamma+1}, \quad \tau^b \equiv \frac{2\theta(2\gamma\theta+\beta)}{2\gamma+1},$$

[5]For τ^a to be positive, the sensitivity of environmental damage is assumed not to be too large: $\gamma < \overline{\gamma} \equiv \beta/(\overline{b} - \underline{b})$.

and $\varepsilon > 0$ is a sufficiently small constant.[6] $\widehat{\tau}^{**}$ is the socially optimal switching point.

The socially optimal tax difference would be zero if there were no environmental damage $\gamma = 0$. The planner intervenes solely for reducing the global environmental damage. Since the global damage becomes severer as pollution is more spatially concentrated, she aims to diversify the location of parts. The optimal tax difference is thus set to make the distribution of parts production more equal.[7]

As trade costs τ fall, more parts are shifted from N to S because (i) S's cost advantage starts to matter and (ii) the assembler moves from N to S. To avoid the concentration of pollution, N's tax compared with S's is set higher than before and thus the optimal tax difference decreases with τ. The simple harmonization is no longer desirable except for a special case at which the optimal tax difference coincides with zero.

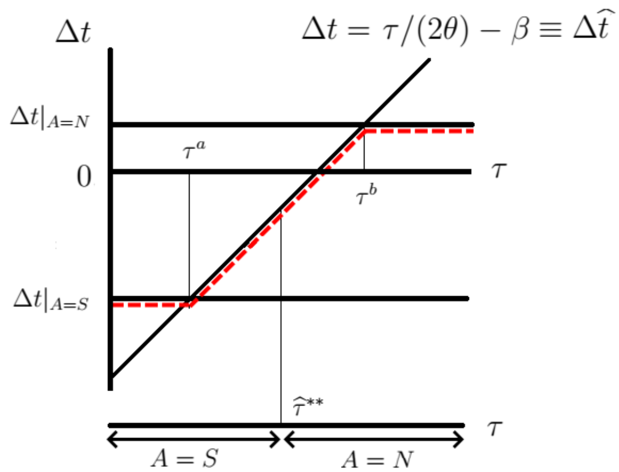

Fig. 4. Socially optimal tax difference (dotted line) and assembly location under low unbundling costs.

Proposition 2. *Under low unbundling costs, environmental tax harmonization never maximizes the social welfare except for a specific level of trade costs.*

5 Conclusion

Desirable environmental policies may drastically change before and after the current globalization characterized by the spatial unbundling of production processes. In the pre-globalized

[6]In Fig. 4, we ignore ε. $\Delta t|_{A=N}$ can be negative if θ is low enough.

[7]It can be checked that the socially optimal unbundling threshold b_i is closer to the middle-point of the range $(\underline{b} + \overline{b})/2$ than the unbundling threshold under no taxes.

world, environmental tax harmonization avoids distorting efficient location choices and maximizes the global welfare. In the globalized world, however, it leads to an excessive spatial concentration of pollution and (almost) never maximizes the global welfare. The second unbundling may call for careful international coordination beyond simple harmonization.

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Appendix to "Is Environmental Tax Harmonization Desirable in Global Value Chains?"

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A.1 Proof of Proposition 1

From (1), (2), (3) and (4), the indirect utility of the representative agent in each country is given by

$$V_N = \begin{cases} V_N|_{A=S} = \widetilde{u} - C_S + 1 + \overline{X} & \text{if } \tau < \tau^* \\ V_N|_{A=N} = \widetilde{u} - C_N + t_N(\bar{b} - \underline{b}) - (\gamma/2)(\bar{b} - \underline{b})^2 + 1 + \overline{X} & \text{if } \tau \geq \tau^* \end{cases},$$

$$V_S = \begin{cases} V_S|_{A=S} = t_S(\bar{b} - \underline{b}) - (\gamma/2)(\bar{b} - \underline{b})^2 + 1 + \overline{X} & \text{if } \tau < \tau^* \\ V_S|_{A=N} = 1 + \overline{X} & \text{if } \tau \geq \tau^* \end{cases},$$

where $\tau^* \equiv (\bar{b} - \underline{b})(\beta + \Delta t)$; $\beta \equiv 1 - (\underline{b} + \bar{b})/2$. The social welfare is defined by the sum of each country's indirect utility:

$$W = \begin{cases} W|_{A=S} = V_N|_{A=S} + V_S|_{A=S} = u - \tau - (1/2)(\bar{b} - \underline{b})(\underline{b} + \bar{b}) - (\gamma/2)(\bar{b} - \underline{b})^2 & \text{if } \tau < \tau^* \\ W|_{A=N} = V_N|_{A=N} + V_S|_{A=N} = u - (\bar{b} - \underline{b}) - (\gamma/2)(\bar{b} - \underline{b})^2 & \text{if } \tau \geq \tau^* \end{cases},$$

where $u \equiv \widetilde{u} + 2(1 + \overline{X})$,

as given in the text.

Taxes do not enter the expressions of social welfare and only affect the location decision of the assembler. The social planner thus chooses the assembly location through taxes that gives the higher social welfare. A simple comparison of welfare between the two locations reveals

$$\max\{W|_{A=N}, W|_{A=S}\} = \begin{cases} W|_{A=S} = u - \tau - (\bar{b} - \underline{b})(\underline{b} + \bar{b})/2 - (\gamma/2)(\bar{b} - \underline{b})^2 & \text{if } \tau < \widehat{\tau}^* \\ W|_{A=N} = u - (\bar{b} - \underline{b}) - (\gamma/2)(\bar{b} - \underline{b})^2 & \text{if } \tau \geq \widehat{\tau}^* \end{cases},$$

where $W|_{A=N} = W|_{A=S}$ holds at $\widehat{\tau}^* \equiv \beta(\bar{b} - \underline{b})$.

To see the results intuitively, it is helpful to illustrate the assembly location pattern in the (τ, Δ) plane, as Fig. A1 shows. The upward-sloping line is the location condition: $\tau = \tau^*$, or equivalently, $\Delta t = \tau/(\bar{b} - \underline{b}) - \beta$, which represents N's maximum tax rate that keeps assembly there. The social planner should set taxes so that the assembly locates in N if $\tau \geq \hat{\tau}^*$ and it locates in S otherwise. The optimal tax difference is thus

$$\Delta t \begin{cases} > \tau/(\bar{b} - \underline{b}) - \beta & \text{if} \quad \tau < \hat{\tau}^* \\ \leq \tau/(\bar{b} - \underline{b}) - \beta & \text{if} \quad \tau \geq \hat{\tau}^* \end{cases},$$

which is represented by the shaded area in Fig. A2. As is clear from Fig. A2, only the tax harmonization $\Delta t = 0$ (dotted line) maximizes the social welfare for any level of trade costs.

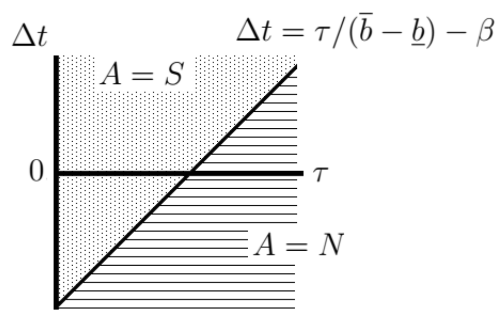

Fig. A1. Location of assembly under high unbundling costs.

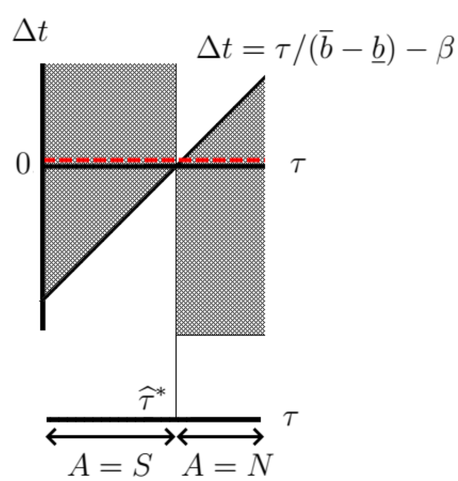

Fig. A2. Socially optimal tax difference (shaded area) and assembly location under high unbundling costs.

A.2 Proof of Proposition 2

We first derive the unconstrained socially optimal taxes given the location of assembly. With high unbundling costs, the indirect utility of the representative agent in each country is given by

$$V_N = \begin{cases} V_N|_{A=S} = \widetilde{u} - C_S + 1 + \overline{X} & \text{if } \ \tau < \tau^{**} \\ V_N|_{A=N} = \widetilde{u} - C_N + t_N(\bar{b} - \underline{b}) - (\gamma/2)(\bar{b} - \underline{b})^2 + 1 + \overline{X} & \text{if } \ \tau \geq \tau^{**} \end{cases},$$

$$V_S = \begin{cases} V_S|_{A=S} = t_S(\bar{b} - \underline{b}) - (\gamma/2)(\bar{b} - \underline{b})^2 + 1 + \overline{X} & \text{if } \ \tau < \tau^{**} \\ V_S|_{A=N} = 1 + \overline{X} & \text{if } \ \tau \geq \tau^{**} \end{cases},$$

where C_i is defined in Eqs. (6) and (7); and $\tau^{**} \equiv 2\theta(\beta + \Delta t)$; $b_N = 1 - \theta + \Delta t$; $b_S = 1 + \theta + \Delta t$. The social welfare is defined by the sum of the two country's indirect utility:

$$W = \begin{cases} W|_{A=S} = \sum_{i=N,S} V_i|_{A=S} & \text{if } \ \tau < \tau^{**} \\ W|_{A=N} = \sum_{i=N,S} V_i|_{A=N} & \text{if } \ \tau \geq \tau^{**} \end{cases},$$

$$W|_{A=S} = u - \left[\tau + \frac{1}{2}(\underline{b} + b_S)(b_S - \underline{b}) + (1+\theta)(\bar{b} - b_S)\right] - (\gamma/2)[(\bar{b} - b_S)^2 + (b_S - \underline{b})^2],$$

$$W|_{A=N} = u - \left[\left(\theta + \frac{\underline{b} + b_N}{2}\right)(b_N - \underline{b}) + (\bar{b} - b_N)\right] - (\gamma/2)[(\bar{b} - b_N)^2 + (b_N - \underline{b})^2],$$

as given in the text.

For the social welfare level at each assembly location, the first-order conditions give

$$\begin{aligned} &\frac{dW|_{A=S}}{dt_N} = -\frac{dW|_{A=S}}{dt_S} = 0, \\ &\rightarrow (t_N - t_S)|_{A=S} = -\frac{2\gamma}{2\gamma+1}(\theta + \beta) \equiv \Delta t|_{A=S}, \\ &\frac{dW|_{A=N}}{dt_N} = -\frac{dW|_{A=N}}{dt_S} = 0, \\ &\rightarrow (t_N - t_S)|_{A=N} = \frac{2\gamma}{2\gamma+1}(\theta - \beta) \equiv \Delta t|_{A=N}. \end{aligned}$$

Since $dW|_{A=i}/dt_N$ and $(-dW|_{A=i}/dt_S)$ are collinear, what matters for the social welfare maximization is the tax difference and not the absolute levels of taxes.

We then allow for endogenous assembly location and see how it affects the optimal taxes. As in Appendix A.1, it is helpful to consider in the $(\tau, \Delta t)$ plane. The upward-sloping line in Fig. A3 is the location condition: $\tau = \tau^{**}$, or equivalently, $\Delta t = \tau/(2\theta) - \beta \equiv \widehat{\Delta t}$. Putting the unconstrained maximizers derived before into the plane, we can obtain Fig. A4 and identify that there are three cases to be considered. Letting τ^a (or τ^b) be the intersection of the location condition and $\Delta t|_{A=S}$ (or $\Delta t|_{A=N}$), the three cases are characterized as follows.

Case (i) $\tau < \tau^a$. The social optimum will be either the constrained maximum with assembly in N, $W|_{A=N,\ \Delta t=\Delta\hat{t}}$, or the unconstrained maximum with assembly in S, $W|_{A=S,\ \Delta t=\Delta t|_{A=S}}$.

Case (ii) $\tau^a \leq \tau < \tau^b$. The social optimum will be either the constrained maximum with assembly in N, $W|_{A=N,\ \Delta t=\Delta\hat{t}}$, or the constrained maximum with assembly in S, $W|_{A=S,\ \Delta t=\Delta\hat{t}+\varepsilon}$.

Case (iii) $\tau \geq \tau^b$. The social optimum will be either the unconstrained maximum with assembly in N, $W|_{A=N,\ \Delta t=\Delta t|_{A=N}}$, or the constrained maximum with assembly in S, $W|_{A=S,\ \Delta t=\Delta\hat{t}+\varepsilon}$.

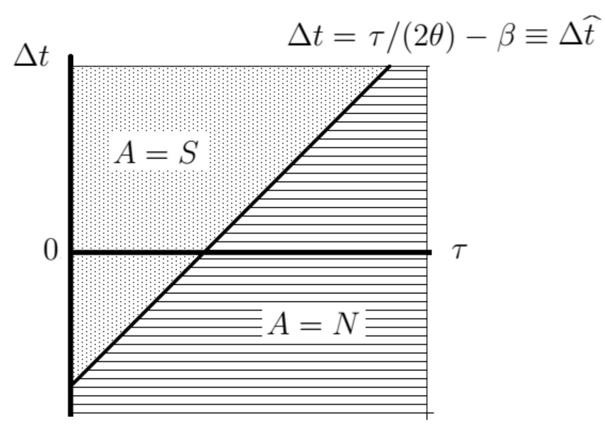

Fig. A3. Location of assembly under low unbundling costs.

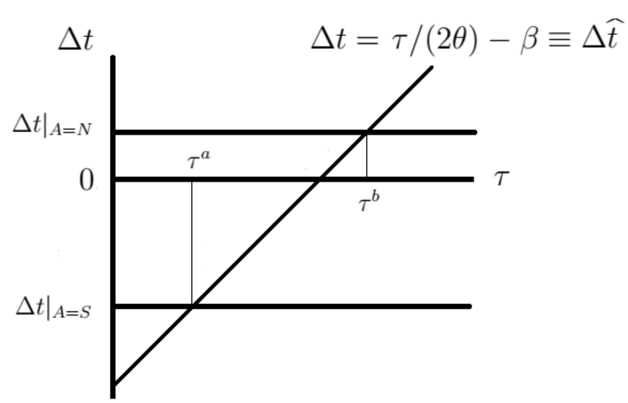

Fig. A4. Unconstrained optimal tax differences under low unbundling costs.

For the latter reference, it is informative here to compare the constrained maxima between the two locations.

$$
\begin{aligned}
W|_{A=N,\ \Delta t=\Delta\widehat{t}} - W|_{A=S,\ \Delta t=\Delta\widehat{t}+\varepsilon} &= \tau + \beta(b_N - b_S) + 2[\theta + \gamma(b_N - b_S)][1 - (b_N + b_S)/2 - \beta] \\
&= \tau(2\gamma + 1) - 2\beta\theta,
\end{aligned}
$$

noting that ε is sufficiently small. On $\Delta t = \Delta\widehat{t}$, it holds that $b_N - b_S = -2\theta$ and $b_N + b_S = 2(1 + \Delta\widehat{t})$. We thus have $W|_{A=N,\ \Delta t=\Delta\widehat{t}} \geq W|_{A=S,\ \Delta t=\Delta\widehat{t}+\varepsilon}$ if $\tau \geq \widehat{\tau}^{**} \equiv 2\beta\theta/(2\gamma + 1)$ and $W|_{A=N,\ \Delta t=\Delta\widehat{t}} < W|_{A=S,\ \Delta t=\Delta\widehat{t}+\varepsilon}$ otherwise. It can be also checked that $\tau^a < \widehat{\tau}^{**} < \tau^b$.

With these in hand, we will derive the socially optimal taxes in each case.

Case (i) $\tau < \tau^a$. In this case, we have

$$
W|_{A=S,\ \Delta t=\Delta t|_{A=S}} > W|_{A=S,\ \Delta t=\Delta\widehat{t}} > W|_{A=N,\ \Delta t=\Delta\widehat{t}}.
$$

The socially optimal outcome is the unconstrained maximum with assembly in S.

Case (ii) $\tau^a \leq \tau < \tau^b$. As $\widehat{\tau}^{**}$ is in between τ^a and τ^b, this case is further divided into two subcases.

Case (ii-a) $\tau^a \leq \tau < \widehat{\tau}^{**}$. We have

$$
W|_{A=S,\ \Delta t=\Delta\widehat{t}+\varepsilon} > W|_{A=N,\ \Delta t=\Delta\widehat{t}}.
$$

The socially optimal outcome is that assembly takes place in S and the tax difference is set at $\Delta t = \Delta\widehat{t} + \varepsilon$.

Case (ii-b) $\widehat{\tau}^{**} \leq \tau < \tau^b$. We have

$$
W|_{A=N,\ \Delta t=\Delta\widetilde{t}} \geq W|_{A=S,\ \Delta t=\Delta\widehat{t}+\varepsilon}.
$$

The socially optimal outcome is that assembly takes place in N and the tax difference is set at $\Delta t = \Delta\widehat{t}$.

Case (iii) $\tau \geq \tau^b$. In this case, we have

$$
W|_{A=N,\ \Delta t=\Delta t|_{A=N}} > W|_{A=N,\ \Delta t=\Delta\widehat{t}} > W|_{A=S,\ \Delta t=\Delta\widehat{t}+\varepsilon}.
$$

The socially optimal outcome is the unconstrained maximum with assembly in N.

In sum, the socially optimal tax difference is

$$\Delta t = \begin{cases} \Delta t|_{A=S} = -\dfrac{2\gamma(\beta+\theta)}{2\gamma+1} & \text{if } \ \tau < \tau^a \\ \Delta\widehat{t} + \varepsilon & \text{if } \ \tau^a \leq \tau < \widehat{\tau}^{**} \\ \Delta\widehat{t} = \dfrac{\tau}{2\theta} - \beta & \text{if } \ \widehat{\tau}^{**} \leq \tau < \tau^b \\ \Delta t|_{A=N} = \dfrac{2\gamma(\theta-\beta)}{1+2\gamma} & \text{if } \ \tau \geq \tau^b \end{cases},$$

$$\text{where } \ \tau^a \equiv \frac{2\theta(\beta - 2\gamma\theta)}{2\gamma+1}, \qquad \widehat{\tau}^{**} \equiv \frac{2\beta\theta}{2\gamma+1}, \qquad \tau^b \equiv \frac{2\theta(2\gamma\theta+\beta)}{2\gamma+1},$$

as given in the text.