Environmental Taxation in Global Value Chains

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Abstract

The current globalization is characterized by the spatial unbundling of production processes. As unbundling costs for parts remote from assembly decline, parts production and the associated pollution are spatially diversified. This paper studies environmental policies in a two-country model of global value chains in which the location of parts and assembly can differ. Parts production generates local pollution and is taxed by each country. When unbundling costs are so high that parts and assembly must co-locate in the pre-globalized world, pollution is spatially concentrated. In this case, harmonizing the environmental tax rates leads to the highest global welfare. By contrast, under low unbundling costs triggering the spatial dispersion of parts production and thus of pollution in the world today, environmental tax harmonization does not maximize the global welfare.

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1. Introduction

The current globalization since the late twentieth century is characterized by not just declining barriers to international trade and factor mobility, but also by lowering costs of coordinating activities within organizations. Before the 1990s, firms had tended to locate different production processes and stages in close proximity to enhance communication between stages for, say, adjusting production schedule. Since then, the development of information and communication technology has allowed each stages to coordinate complex activities while operating in different locations.

The spatial separation of production stages, which Baldwin (2016) calls "second unbundling," has significant implications on environment as well as trade. As a result of increasing trade in intermediate inputs, more than thirty percent of global CO$_2$ emissions is from those generated when manufacturing traded goods in 2004 (Davis et al., 2011). A growing concern is that production fragmentation may exacerbate the "pollution haven" effect, meaning that firms relocate to countries with lax regulations. The increased mobility of firms may pronounce international differences in regulations, resulting in a more unequal world distribution of pollution. The concern is in fact justified by some empirical studies (Arce González et al., 2012; Koźluk and Timiliotis, 2016; Zhang et al., 2017).

One measure against the environmental impact of mobile firms could be a harmonization of environmental regulations, which has been intensively discussed within the EU member countries (Sterner and Köhlin, 2003). Equalizing the degree of regulations among countries, such as carbon tax rates and product standards, may correct the location decision of firms and mitigate the divergence of environmental quality. In addition, the harmonization may also level the playing field and enhance the competitiveness of firms. There is a counterargument, on the other hand, that the simple harmonization could not address the regional environmental impact given the heterogeneity between countries. There seems little agreement on whether environmental policy harmonization is desirable. In the EU, the supranational body has been seeking to harmonization, especially in energy taxation, but has still a long way to go (Rosenstock et al., 2014).
To evaluate the effectiveness of environmental policy harmonization in global value chains, we focus on environmental taxation in a North-South model à la Baldwin and Venables (2013). South has a comparative advantage in parts production and only North consumes a final good. Value chains mean that the final good is produced using many parts. Before the second unbundling, the final-good assembler locally sources all parts due to substantial unbundling costs that include trade and communication barriers between the assembler and the suppliers. Environmental damage caused by parts production also remains local. After the second unbundling, value chains can be global in the sense that the assembler can locate in a different location than the suppliers. Associated with the evolution of global value chains, environmental damage has also spread across countries. In addition, the assembler and the suppliers become sensitive to the international difference in environmental regulation. We characterize the environmental tax on suppliers that maximizes the global welfare both before and after the second unbundling. We then use it to evaluate a simple tax harmonization policy where two countries set equal taxes.

Our findings show that the consequence of environmental tax harmonization significantly changes before and after the second unbundling. When unbundling costs are so high that parts and assembly must co-locate, the tax harmonization leads to the highest global welfare. As all parts are produced in the country hosting the assembly plant, environmental damage occurs only there. Environmental taxes cause just change which country suffers damage by causing the assembler’s relocation. Setting equal taxes in both countries is desirable because it does not generate distortions in the assembler’s location choice that brings the lowest production costs.

When unbundling costs are so low that parts and assembly can locate separately, such a simple tax harmonization does not contribute to the global welfare. As parts and the associated environmental damage move between borders without assembly relocation, environmental taxes can now affect how much damage each country suffers as well as which country does. Considering the increasing influence of taxes on reducing the global damage, the simple tax harmonization is not a good idea because it fails to correct the location decision of the assembler who ignores its environmental impact. The socially optimal taxes
are different between countries and depend on various conditions such as unbundling costs and trade costs of shipping the final good. Amid the progress of global value chains, more careful policy coordination is called for among countries.

Our study is positioned in the literature that examines environmental policies in international trade models with endogenous firm location. The earliest study by Markusen et al. (1993) finds that a small change in environmental taxes may lead to a discontinuous change in a regional welfare and pollution due to firm relocation. Markusen et al. (1995) and Pflüger (2001) consider environmental policy competition between countries, resulting in inefficiently lax regulations. Zeng and Zhao (2009), Forslid et al. (2017), and a series of studies by Ishikawa and Okubo (Ishikawa and Okubo, 2011, 2016, 2017) examine how agglomeration of firms is shaped by different environmental policies such as tax/subsidy, quota, and product standards. These studies ask which force, the degree of regulations or the market size of a country, determines the location of firms. Unlike ours, however, all of them assume away vertical linkages between sectors and are thus unable to discuss global value chains.

A new strand of international-trade literature has proposed models of global value chains (Antràs et al., 2012; Baldwin and Venables, 2013; Costinot et al., 2012; Antràs and Chor, 2013; Lee and Yi, 2018). These models involve not only vertical linkages between sectors but also each sector entailing many production processes. Global value chains are modeled as the spatial fragmentation of processes. We specifically choose the model by Baldwin and Venables (2013) among others as a base one because it is tractable to obtain analytical results yet rich enough to speak to fragmentation. There are several studies examining trade policies in this context. Using the framework of Baldwin and Venables (2013), Obashi (2017, 2018) characterize combinations of trade instruments including export/import tax/subsidy that maximize the global welfare. She finds that reciprocal reductions in import tariffs, which are thought to be the best policy in traditional trade models, is not enough to achieve

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1For earlier contributions on trade and environment, see a survey by Copeland and Taylor (2004).
2More recent studies investigate the interaction between environment and agglomeration in cities (Borck and Pflüger, 2015; Borck and Tabuchi, 2018).
3See Chor (2018) for a survey.
global efficiency. Although environmental issues are outside scope of Obashi’s studies, our study and hers should be seen as complements. Both emphasize that the evolution of global value chains significantly changes how optimal policies should be designed.

Only a few theoretical studies have investigated environmental issues in vertical market structure (Hamilton and Requate, 2004; Wan and Wen, 2017; Wan et al., 2018). Wan et al. (2018), for example, examine how trade liberalization in a final-good sector affects environmental taxes on an intermediate-good sector, chosen by local governments. These studies consider only one type of input and trade barriers in either of the two sectors. By contrast, to model production fragmentation, we consider multiple types of inputs and differentiate between trade costs in final goods and unbundling costs in inputs. In addition, countries are typically assumed to be symmetric in their models. We believe our North-South setting is better suited to highlight the effectiveness of environmental policy harmonization.

The rest of the paper is organized as follows. The next section develops the model and characterizes the location of different intermediate inputs given the assembly location and the environmental taxes. Main results on the assembly location, pollution, and socially optimal taxes are presented in Sections 3 and 4. Sections 3 and 4 deal with an economy before and after the second unbundling, respectively. Final section concludes.

2. The model

Consider a world with two countries, called $N$ 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 parts are produced using labor in both countries and are internationally traded. Parts production generates local pollution and is thus taxed by the domestic country. A single final-good producer (assembler) locates in $N$ or $S$ and assembles the range of parts into one unit of the final good. The production technology of assembly is the same between countries, while that of parts is not. We assume that $N$ has a higher average cost of parts (which will be defined shortly) than $S$. We also assume that the final good is consumed only
in $N$. These two assumptions allow us to interpret $N$ (or $S$) as a developed (or developing) country.

There are two types of international frictions. 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. If the assembler is located in $S$, it must pay *trade costs* to export the final good to $N$.

The numéraire-good is produced using labor. Costless trade of the good equalizes its international price. With choice of units, the wage rates in both countries are equal to unity.

2.1. Preferences

The representative consumer in $i \in \{N, S\}$ has the following quasi-linear function:

$$U_i = u1_i + X_i - D(e_i),$$  \hspace{1cm} (1)

where $X_i$ is the consumption of numéraire good, and $e_i$ is the aggregate production of parts. $1_i$ is an indicator function that takes one if $i = N$ and zero if $i = S$. That is, only the consumer in $N$ obtains $u$ by consuming one unit of the final good. The disutility from environmental damage $D(\cdot)$ is expressed as a strictly convex function of $e_i$, i.e., $D' > 0$ and $D'' > 0$. For simplicity, we specify it as $D(e_i) = \beta e_i^2/2$ with $\beta > 0$. The budget constraint is given by

$$p1_i + X_i = 1 + t_i e_i + \bar{X},$$  \hspace{1cm} (2)

where $p$ is the final good’s price and $t_i$ is the environmental tax by $i$ on each unit of parts produced there. The income consists of wage ($w_i = 1$), the redistribution of tax revenues ($t_i e_i$), and the initial endowment of the numéraire ($\bar{X}$). $\bar{X}$ is assumed to be large enough to ensure positive consumption of the numéraire. Substituting this into the utility function gives the indirect utility function $V_i$. 
2.2. Sourcing decision

The assembler simultaneously chooses (i) the location of assembly and (ii) the location of parts. It prefers the country which gives the least cost. Here we look at the sourcing locations given the location of assembly, which will be examined in the next section.

Letting $z$ be the index of parts from the set $Z = [\underline{b}, \bar{b}]$, the unit production 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 hand, its unit production cost is $b(z) = z$ with $0 < \underline{b} < 1 < \bar{b}$. $N$ has a comparative advantage over parts $b \in [1, \bar{b}]$, while $S$ has it over parts $b \in [\underline{b}, 1)$. In addition, we assume that $S$ has an average cost advantage in parts production over $N$, i.e., $(\bar{b} + \underline{b})/2 < 1$.

One unit of the final good is produced by assembling one unit of each part. When parts cross the border, additional unbundling costs of $\theta > 0$ occur. The assembler decides the sourcing country part by part by comparing the international cost difference. Supposing the assembler is in $N$, a part $z$ is produced in $N$ if

$$\frac{1 + t_N}{\text{Cost in } N} < \frac{b(z) + \theta + t_S}{\text{Cost in } S},$$

$$\rightarrow b(z) > b_N \equiv \min[\max\{\underline{b}, 1 - \theta + \Delta t\}, \bar{b}], \quad (3)$$

where $\Delta t \equiv t_N - t_S$, noting that the unit cost in $S$ includes unbundling costs $\theta$ since the part is assembled in $N$.

Intuitively, the inequality is likely to hold if $S$’s comparative advantage is weak (high $b(z)$), $N$’s (or $S$’s) tax rate is low (or high), and unbundling costs are high (high $\theta$).

Supposing the assembler is in $S$, a part $z$ is produced in $S$ if

$$\frac{1 + \theta + t_N}{\text{Cost in } N} > \frac{b(z) + t_S}{\text{Cost in } S},$$

$$\rightarrow b(z) < b_S \equiv \max[\min\{\bar{b}, 1 + \theta + \Delta t\}, \underline{b}], \quad (4)$$

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The average production cost of parts in $S$ is given by $\frac{1}{\bar{b} - \underline{b}} \int_{\underline{b}}^{\bar{b}} b \, db = \frac{1}{\bar{b} - \underline{b}} \frac{\bar{b}^{\bar{b}} - \underline{b}^{\underline{b}}}{2} = \frac{\bar{b} + \underline{b}}{2}$, while that in $N$ is given by $\frac{1}{\bar{b} - \underline{b}} \int_{\underline{b}}^{\bar{b}} \frac{1}{\bar{b}} \, db = 1$. 

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which is likely to hold if S’s comparative advantage is strong (low $b(z)$), N’s (or S’s) tax rate is high (or low), and unbundling costs are high (high $\theta$). Regardless of the assembler’s location, higher unbundling costs lead parts to co-locate with assembly.

There are three possible regions of the set of parts. (i) Parts in region $\mathcal{N}$ where $b(z) \in (b_S, \overline{b})$ are produced in $N$ regardless of assembly location. (ii) Parts in region $\mathcal{S}$ where $b(z) \in [\underline{b}, b_N)$ are produced in $S$ regardless of assembly location. (iii) Parts in region $\mathcal{NS}$ where $b(z) \in (b_N, b_S)$ are produced in the country where the assembler is located.

When unbundling costs are sufficiently high, the two ”unbundling thresholds” degenerate, i.e., $b_N = \overline{b}$ and $b_S = \underline{b}$, and only region $\mathcal{NS}$ emerges. Supposing $\theta > \overline{\theta} \equiv \max\{1-\overline{b}+\Delta t, \overline{b}-1-\Delta t\}$, Fig. 1 draws the region in the $(\Delta t, b(z))$-plane given assembly location and taxes.\(^5\)

The co-location motive of the assembler to save unbundling costs is so strong that neither comparative advantage nor environmental taxes matter. The spatial bundling of parts and assembly can be thought of as the pre-globalization world.

When unbundling costs are low enough but positive, all three regions emerge. Analogously, supposing $\theta < \underline{\theta}$ where $\underline{\theta} \equiv \min\{1-\underline{b}+\Delta t, \underline{b}-1-\Delta t\}$, the sourcing pattern is shown in Fig. 2.\(^6\) Low unbundling costs make the assembler aware of comparative advantage and taxes. A lower tax in $N$, for example, expands region $\mathcal{N}$. If there were no unbundling costs, the region of co-location, $\mathcal{NS}$, disappears.\(^7\) The situation of spatial unbundling captures the current globalization.

These findings are stated as follows:

**Proposition 1.** Suppose the location of assembly and environmental taxes are exogenously given. The effect of taxes on parts’ location differs depending on unbundling costs.

(i) Suppose unbundling costs are high such that $\theta > \overline{\theta}$. Taxes do not affect location of parts.

\(^5\)Note that $b_N = \overline{b}$ holds if $\overline{b} > 1-\theta + \Delta t$; $b_S = \underline{b}$ holds if $\underline{b} < 1+\theta + \Delta t$. These conditions lead to $\theta > \max\{1-\overline{b}+\Delta t, \overline{b}-1-\Delta t\}$, which is equivalent to $\Delta t \in (\overline{b}-\theta-1, \underline{b}+\theta-1)$. The interval is nonempty because of $\theta > (\overline{b}-\underline{b})/2$, which is implied by $\theta > \overline{\theta}$.

\(^6\)This condition is equivalent to $\Delta t \in (\underline{b}+\theta-1, \overline{b}-\theta-1)$. The interval is nonempty because of $\theta < (\overline{b}-\underline{b})/2$, which is implied by $\theta < \underline{\theta}$.

\(^7\)At $\theta = 0$, the two unbundling thresholds coincide with each other, i.e., $b_N = b_S$. 


(ii) Suppose unbundling costs are low such that $\theta < \theta$. As the international tax between $N$ and $S$ (larger $\Delta t = t_N - t_S$) increases, more parts move from $N$ to $S$.

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

Fig. 1. Sourcing pattern when unbundling costs are high.

Fig. 2. Sourcing pattern when unbundling costs are low.
3. High unbundling costs: Co-location of parts and assembly

We consider here the case where unbundling costs are high such that \( \theta > \bar{\theta} \). Parts and assembly are spatially bundled, capturing the pre-globalization world.

3.1. Assembly location

The assembler chooses its production location to minimize total costs. Let \( C_i \) be the total costs of producing one unit of the final good, given that assembly is in \( i \in \{N, S\} \). Noting that \( b_N = \bar{b} \), \( C_N \) is given by

\[
C_N = \int_{\bar{b}}^{\tilde{b} N} (\tilde{b} + \theta + t_S) d\tilde{b} + \int_{\tilde{b} N}^{\bar{b}} (1 + t_N) d\tilde{b} = (\bar{b} - \bar{b})(1 + t_N). \tag{5}
\]

Similarly, noting that \( b_S = \bar{b} \), \( C_S \) is given by

\[
C_S = \tau + \int_{\bar{b}}^{\tilde{b} S} (\tilde{b} + t_S) d\tilde{b} + \int_{\tilde{b} S}^{\bar{b}} (1 + \theta + t_N) d\tilde{b} = \tau + (\bar{b} - \bar{b}) \left( \frac{\bar{b} + \bar{b}}{2} + t_S \right), \tag{6}
\]

which includes trade costs \( \tau \) for shipping the final good. Since any parts do not cross the border, \( \theta \) does not appear in both \( C_N \) and \( C_S \).

Assembly takes place in \( N \) if

\[
\Delta C \equiv C_N - C_S = -\tau + (\bar{b} - \bar{b}) \left( 1 - \frac{\bar{b} + \bar{b}}{2} + \Delta t \right) \leq 0,
\]

\[
\rightarrow \tau \geq \tau^* \equiv (\bar{b} - \bar{b}) \left( 1 - \frac{\bar{b} + \bar{b}}{2} + \Delta t \right). \tag{7}
\]

High trade costs make the assembler prefers the proximity to consumers. The switching point \( \tau^* \) is increasing in the tax difference \( \Delta t \), meaning that the assembler tends to locate
in a low tax country. At $\Delta t = 0$, it is also increasing in the total number of parts $(\bar{b} - b)$ and the average cost advantage of $S$ $(1 - (b + \bar{b})/2)$. The assembler is less likely to choose $N$ when $S$ offers cheaper parts on average. As the total number of parts is larger, the cost advantage of $S$ is more pronounced.

**Lemma 1.** Suppose unbundling costs are high and thus parts and assembly must co-locate. The assembler locates in $N$ if trade costs are high enough, i.e., $\tau \geq \tau^*$. It is less likely to do so, as the tax difference between $N$ and $S$ increases.

### 3.2. Pollution

Producing one unit of each part gives one unit of local pollution. As all parts with $b(z) \in [\bar{b}, \overline{b}]$ co-locate with assembly, pollution is concentrated in the country where the assembler is located. Pollution in each country is given by

$$
\begin{align*}
    e_N &= \begin{cases} 
    \bar{b} - b & \text{if } \tau \geq \tau^*, \\
    0 & \text{if } \tau < \tau^*
    \end{cases}, \\
    e_S &= \begin{cases} 
    0 & \text{if } \tau \geq \tau^*, \\
    \bar{b} - b & \text{if } \tau < \tau^*
    \end{cases},
\end{align*}
$$

which are independent of taxes. Taxes affect pollution only through changes in the switching point $\tau^*$. This observation implies that the assembler along with polluting parts producers does not necessarily move to the country with lax regulation. To induce the assembler to change its location from $N$ to $S$, for example, the tax in $N$ is sufficiently higher than that in $S$.\(^8\) Otherwise, it does not have any impact on pollution. In an economy where parts and assembly locate together, the pollution haven effect emerges only if the difference of environmental tax is large enough.

### 3.3. Social optimum

We have so far assumed taxes are exogenous. This subsection considers a social planner that maximizes global welfare and endogenously determine social optimal taxes. The social

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\(^8\)Using (7), we see that the assembler locates in $S$ if $\Delta t \geq \tau/(\overline{b} - \bar{b}) - [1 - (\overline{b} + \bar{b})/2]$. 

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welfare is defined as the sum of the each country’s welfare:

\[ W = \begin{cases} 
W|_{L=N} \equiv V_N|_{L=N} + V_S|_{L=N} & \text{if } \tau \geq \tau^* \\
W|_{L=S} \equiv V_N|_{L=S} + V_S|_{L=S} & \text{if } \tau < \tau^*,
\end{cases} \]

where the subscript \( L = i \in \{N, S\} \) indicates the assembler’s location. Since both parts and final-good producers make zero profits, the welfare is represented by the indirect utility \( V_i \).

From Eqs. (1) and (2), \( V_i \) is derived as

\[ V_N = \begin{cases} 
V_N|_{L=N} = u - C_N + t_N(\bar{b} - \bar{b}) - \frac{\beta}{2}(\bar{b} - \bar{b})^2 + 1 + \bar{X} & \text{if } \tau \geq \tau^* \\
V_N|_{L=S} = u - C_S + 1 + \bar{X} & \text{if } \tau < \tau^*,
\end{cases} \]

\[ V_S = \begin{cases} 
V_S|_{L=N} = 1 + \bar{X} & \text{if } \tau \geq \tau^* \\
V_S|_{L=S} = t_S(\bar{b} - \bar{b}) - \frac{\beta}{2}(\bar{b} - \bar{b})^2 + 1 + \bar{X} & \text{if } \tau < \tau^*,
\end{cases} \]

where \( C_N \) and \( C_S \) are respectively the unit costs of final good in \( N \) and \( S \) and are defined in Eqs. (5) and (6). We note that "1" is the wage income and \( \bar{X} \) is the initial endowment of the numéraire.

The social welfare is re-expressed as

\[ W = \begin{cases} 
W|_{L=N} = \tilde{u} - C^O_N - \frac{\beta}{2}(\bar{b} - \bar{b})^2 & \text{if } \tau \geq \tau^* \\
W|_{L=S} = \tilde{u} - C^O_S - \frac{\beta}{2}(\bar{b} - \bar{b})^2 & \text{if } \tau < \tau^*,
\end{cases} \]

where \( C^O_N \equiv C_N|_{t_N=t_S=0} = \bar{b} - \bar{b} \),

\[ C^O_S \equiv C_S|_{t_N=t_S=0} = \tau + \frac{1}{2}(\bar{b} - \bar{b})(\bar{b} + \bar{b}), \]

and \( \tilde{u} \equiv u + 2(1+\bar{X}) \). \( C^O_i \) is the unit cost of final good in \( i \in \{N, S\} \) evaluated at zero taxes. Surprisingly, taxes do not enter in the social welfare. An increase in taxes improves welfare by raising tax revenues, while it reduces welfare by raising the final-good’s price. These two counter effects are offset each other. Moreover, all parts are produced in the country hosting
the assembler. The location of parts is thus affected by taxes only though changes in the assembler’s location.

Noting that \( \tau^* \) depends on \( \Delta t \), rather than \( t_N \) and \( t_S \), the planner chooses \( \Delta t \) to attain \( \max\{W|_{L=N}, W|_{L=S}\} \) by changing \( \tau^* \). It is verified that the optimal tax difference becomes \( \Delta t = 0 \). In words, the planner should not intervene the location choice of the assembler. If the location were manipulated, comparative advantage would be distorted and thus the unit total cost would not be minimized. If \( t_N \) were set extremely higher than \( t_S \), for example, the assembler would locate in \( S \) and have to export even at very high trade costs. In addition, the location of assembly affects local environmental damage perceived by residents in each country, but does not affect global environmental damage. That is, the planner is indifferent to the assembler’s location in terms of environmental damage. As both the assembler and the planner seek only cost minimization, the assembler’s location choice at zero taxes coincides with the social optimal one.

The switching point evaluated at the socially optimal taxes is given by

\[
\hat{\tau}^* \equiv \tau^*|_{\Delta t=0} = (\bar{b} - \bar{b}) \left(1 - \frac{\bar{b} + \bar{b}}{2}\right). 
\] (8)

Fig. 3 illustrates the socially optimal tax difference and the location of assembly for different levels of trade costs.

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9A simple comparison of welfare between the two cases reveals

\[
\max\{W|_{L=N}, W|_{L=S}\} = \begin{cases} 
W|_{L=N} = \tilde{u} - (\bar{b} - \bar{b}) - \frac{\beta}{2}(\bar{b} - \bar{b})^2 & \text{if } \tau \geq \hat{\tau}^* \\
W|_{L=S} = \tilde{u} - \tau - \frac{\bar{b}}{2}(\bar{b} - \bar{b})(\bar{b} + \bar{b}) - \frac{\beta}{2}(\bar{b} - \bar{b})^2 & \text{if } \tau < \hat{\tau}^* \end{cases}
\]

where \( W|_{L=N} = W|_{L=S} \) holds at \( \hat{\tau}^* \equiv (\bar{b} - \bar{b})[1 - (\bar{b} + \bar{b})/2] \). \( \hat{\tau}^* \) coincides with \( \tau^* \) at \( \Delta t = 0 \).
These findings are summarized as follows:

**Proposition 2.** Under high unbundling costs, environmental tax harmonization, i.e., \( t_N = t_S \), maximizes the social welfare.

4. Low unbundling costs: Separation of parts and assembly

We now turn to the case where unbundling costs are low such that \( \theta < \bar{\theta} \). Low unbundling costs allow parts and assembly to locate in different countries, characterizing the current globalization.
4.1. Assembly location

As Fig. 2 suggests, the two unbundling thresholds are within the interval of \([b, \bar{b}]\). As with Eqs. (5) and (6), we obtain the total costs depending on assembly location:

\[
C_N = \left( \theta + t_N \frac{\bar{b} + b_N}{2} \right) (b_N - \bar{b}) + (1 + t_N)(\bar{b} - b_N), \tag{9}
\]

\[
C_S = \tau + \left( t_S + \frac{\bar{b} + b_S}{2} \right) (b_S - \bar{b}) + (1 + \theta + t_N)(\bar{b} - b_S). \tag{10}
\]

Using \(b_N = 1 - \theta + \Delta t\) and \(b_S = 1 + \theta + \Delta t\), the condition under which assembly takes place in \(N\) is derived as

\[
\Delta C \equiv C_N - C_S = -\tau + 2\theta \left( 1 - \frac{\bar{b} + \bar{b}}{2} + \Delta t \right) \leq 0,
\]

\[
\Rightarrow \tau \geq \tau^{**} \equiv 2\theta \left( 1 - \frac{\bar{b} + \bar{b}}{2} + \Delta t \right), \tag{11}
\]

As in the case of high unbundling costs, \(N\) is likely to be chosen as trade costs are higher. The switching point \(\tau^{**}\) is also similar to the one under high-unbundling costs, \(\tau^*\), defined in (7). Unlike \(\tau^*\), however, \(\tau^{**}\) depends on unbundling costs \(\theta\). As \(\theta\) declines further, the co-location of assembly and parts becomes less important, while the proximity to consumer more important. Thus, lower \(\theta\) reduces \(\tau^{**}\), increasing the possibility that the assembler locates in \(N\). Another difference is that given taxes \(\tau^{**}\) is smaller than \(\tau^*\). When spatial unbundling occurs, the assembler are more sensitive to trade costs and is more likely to locate nearby consumers.

\textbf{Lemma 2.} Suppose unbundling costs are low and thus parts and assembly can locate in different countries. The assembler locates in \(N\) if trade costs are high enough, i.e., \(\tau \geq \tau^{**}\). As with the switching point \(\tau^*\) under high unbundling costs, \(\tau^{**}\) is increasing in the tax difference \(\Delta t\), but it is smaller than \(\tau^*\).
4.2. Pollution

When spatial separation of parts and assembly is allowed, the domestic environmental policy affects pollution in the foreign country through two ways: (i) changes in the location of the assembler and (ii) those in the location of parts.

Pollution in each country is given by

\[ e_N = \begin{cases} \\
\bar{b} - b_N & \text{if } \tau \geq \tau^{**} \\
\bar{b} - b_S & \text{if } \tau < \tau^{**} 
\end{cases}, \quad e_S = \begin{cases} \\
b_N - \bar{b} & \text{if } \tau \geq \tau^{**} \\
b_S - \bar{b} & \text{if } \tau < \tau^{**} 
\end{cases}, \]

where \( b_N = 1 - \theta + \Delta t; \) \( b_S = 1 + \theta + \Delta t. \) As \( t_N \) increases, some parts are moved from \( N \) to \( S \) (larger \( b_i \)) and pollution in \( N \) decreases. Moreover, supposing the assembler is in \( N, \) increasing \( t_N \) may cause an assembly relocation to \( S, \) resulting in a discontinuous reduction in pollution (from \( \bar{b} - b_N \) to \( \bar{b} - b_S \)). As each part changes their location responding continuously to tax difference, the pollution haven effect is observed more often under low unbundling costs than under high unbundling costs.\(^{10}\)

4.3. Social optimum

Here we analyze socially optimal taxes. As in the previous section, we first derive the indirect utility in each country as follows:

\[ V_N = \begin{cases} \\
V_{N|L=N} = u - C_N + t_N(\bar{b} - b_N) - \frac{\beta}{2} (\bar{b} - b_N)^2 + 1 + \overline{X} & \text{if } \tau \geq \tau^{**} \\
V_{N|L=S} = u - C_S + t_N(\bar{b} - b_S) - \frac{\beta}{2} (\bar{b} - b_S)^2 + 1 + \overline{X} & \text{if } \tau < \tau^{**} 
\end{cases}, \]

\[ V_S = \begin{cases} \\
V_{S|L=N} = t_S(b_N - \bar{b}) - \frac{\beta}{2} (b_N - \bar{b})^2 + 1 + \overline{X} & \text{if } \tau \geq \tau^{**} \\
V_{S|L=S} = t_S(b_S - \bar{b}) - \frac{\beta}{2} (b_S - \bar{b})^2 + 1 + \overline{X} & \text{if } \tau < \tau^{**} 
\end{cases}, \]

\(^{10}\)However, the country with a lower tax does not necessarily receive more pollution. Since \( S \) has a cost advantage in parts production, more pollution may occur in \( S \) than in \( N \) (i.e., \( e_S > e_N \)) even when \( t_S > t_N \) holds.
where \( b_N = 1 - \theta + \Delta t \); \( b_S = 1 + \theta + \Delta t \). \( C_N \) and \( C_S \) are respectively defined in Eqs. (9) and (10). The sum of the two gives social welfare:

\[
W = \begin{cases} 
W|_{L=N} = \tilde{u} - C^O_N - \frac{\beta}{2}(\bar{b} - b_N)^2 - \frac{\beta}{2}(b_N - \bar{b})^2 & \text{if } \tau \geq \tau^{**} \\
W|_{L=S} = \tilde{u} - C^O_S - \frac{\beta}{2}(\bar{b} - b_S)^2 - \frac{\beta}{2}(b_S - \bar{b})^2 & \text{if } \tau < \tau^{**} 
\end{cases}
\]

where \( C^O_N \equiv C_N|_{t_N=t_S=0} = \left( \theta + \frac{b + b_N}{2} \right)(b_N - \bar{b}) + (\bar{b} - b_N) \),

\( C^O_S \equiv C_S|_{t_N=t_S=0} = \tau + \frac{1}{2}(b + b_S)(b_S - \bar{b}) + (1 + \theta)(\bar{b} - b_S) \),

and \( \tilde{u} \equiv u + 2(1 + X) \). As with the case under high-unbundling costs, only tax difference, not individual one, appears in the expression since a rise in final good’s price and that in tax revenues are canceled out. In contrast to the previous case, however, the tax difference affects the unbundling thresholds \( b_i \) as well as the switching point \( \tau^{**} \).

The planner chooses the tax difference to maximize the social welfare while considering the assembler’s location determined by \( \tau^{**} \). Let us look at the two polar cases where trade costs are extremely high or low. At very high trade costs, the assembler puts a more emphasis on trade-cost saving than on international tax difference. It thus tends to locate in \( N \) even if the tax in \( N \) is relatively high. As the assembler is not sensitive to taxes, the planner can choose the tax difference to achieve the unconstrained optimum given the assembler in \( N \), i.e., \( \Delta t|_{L=N} \equiv \arg\max_{\Delta t} W|_{L=N} \). Analogously, at very low trade costs, the assembler emphasizes unbundling-cost saving rather than tax difference and is eager to locate in \( S \). In such a case, the tax difference is chosen so as to achieve the unconstrained optimum given the assembler in \( S \), i.e., \( \Delta t|_{L=S} \equiv \arg\max_{\Delta t} W|_{L=S} \).

At intermediate trade costs, however, the assembler is sensitive to tax difference when deciding its location. The planner carefully sets the tax difference to adjust the switching point in a way that makes the assembler choose the socially optimal location.
Formally, we derive the socially optimal tax difference as follows:\(^\text{11}\)

\[
\Delta t = \begin{cases} 
\Delta t|_{L=N} = \frac{2\beta}{1+2\beta} \left[ \theta - \left(1 - \frac{b+\bar{b}}{2} \right) \right] & \text{if } \tau > \tau^a \\
\Delta t_0 = \frac{\tau}{2\theta} - \left(1 - \frac{b+\bar{b}}{2} \right) & \text{if } \hat{\tau}^{**} \leq \tau \leq \tau^a \\
\Delta t_0 - \varepsilon & \text{if } \tau^b < \tau < \hat{\tau}^{**} \\
\Delta t|_{L=S} = -\frac{2\beta}{1+2\beta} \left[ \theta + \left(1 - \frac{b+\bar{b}}{2} \right) \right] & \text{if } \tau \leq \tau^b
\end{cases}
\]

where \(\tau^a = \frac{2\theta}{1+2\beta} \left[ 2\beta\theta + \left(1 - \frac{b+\bar{b}}{2} \right) \right], \quad \tau^b = -\frac{2\theta}{1+2\beta} \left[ 2\beta\theta - \left(1 - \frac{b+\bar{b}}{2} \right) \right].\)

and \(\varepsilon > 0\) is a sufficiently small constant. \(\hat{\tau}^{**}\) is the socially optimal switching point:

\[
\hat{\tau}^{**} = \frac{2\theta}{1+2\beta} \left(1 - \frac{b+\bar{b}}{2} \right), \quad (12)
\]

That is, assembly takes place in \(N\) if \(\tau \geq \hat{\tau}^{**}\). \(\hat{\tau}^{**}\) is smaller than the counterpart in the case of high unbundling costs, i.e., \(\hat{\tau}^*\) in (8), meaning that under low unbundling costs the assembler is more likely to locate in \(N\). Thanks to cross-border unbundling, the assembler can access to parts produced in \(S\) while staying in \(N\). The socially optimal outcomes are illustrated in Fig. 4.\(^\text{12}\)

As the above expression shows, the tax difference in each range of trade costs moves towards negative by the difference between \(N\)'s average cost of producing and \(S\)'s: \(-[1 - (b+\bar{b})/2] < 0\). Due to its cost advantage, \(S\) tends to produce more parts and receive more pollution. The more spatially concentrated pollution is, the severer the global environmental damage becomes. To reduce the damage, the planner aims to diversify the location of parts.\(^\text{13}\)

As Fig. 4 suggests, the tax difference weakly decreases as trade costs decline. Lower trade costs make the assembler aware of the cost of parts and thus source more parts from \(S\).

\(^{11}\)For \(\tau^b\) to be positive, we assume that the sensitivity of environmental damage is not too large: \(\beta < \bar{\beta} = [1 - (b+\bar{b})/2]/(\bar{b} - b).\)

\(^{12}\)In Fig. 4, we ignore \(\varepsilon\). \(\Delta t|_{L=N}\) is not necessarily positive. If \(\theta\) is low enough, it can be negative.

\(^{13}\)If the planner cared exclusively about environmental damage (\(\beta \rightarrow \infty\)), she would set taxes that equalizes the range of parts in each country: \(b_N = b_S = (b+\bar{b})/2\).
To avoid the concentration of pollution, the planner adjusts the tax difference so that $S$ becomes more stringent. This implies that environmental tax harmonization is no longer desirable except for a specific trade costs at which the optimal tax difference happens to be zero. In fact, the assembler is more likely to locate in $S$ under policy harmonization than it is under the socially optimal policy.\footnote{The socially optimal switching point $\hat{\tau}^{**}$ in (12) is smaller than $\tau^{**}$ in (11) evaluated at equal taxes $(\tau^{**}\mid \Delta t=0 = 2\theta[1 - (b + \bar{b})/2])$.} As a result, policy harmonization leads to severer global environmental damage than the socially optimal policy.

![Fig. 4. Socially optimal outcomes when unbundling costs are low: tax difference (top) and location of assembly (bottom).](image)

These findings are summarized as follows:

**Proposition 3.** Under low unbundling costs, the socially optimal tax difference moves towards negative as trade costs decline. Compared with the optimal policy, environmental tax
harmonization brings severe environmental damage and never maximizes the social welfare except for a negligible case.

5. Conclusion

Globalization characterized by the spatial unbundling of production processes has important implications for how to shape environment policies. This paper studies socially optimal environmental taxes both in a pre-globalized economy and in a globalized one. In an economy before globalization, parts and assembly must co-locate in one country. This implies that pollution generated by parts production is concentrated in a country where assembly takes place. Environmental taxes just affect the location of assembly and are thus unable to reduce global environmental damage. Both developed and developing countries should set equal taxes because such a tax harmonization respects the assembler’s location choice that minimizes consumption good’s price.

By contrast, in an economy after globalization, parts and assembly can locate separately. Environmental taxes do affect the location of parts as well as that of assembly. To reduce the global environmental damage, countries should set different taxes to diversify pollution further. Socially optimal taxes should correct the location choice of producers that do not care about its environmental impact. The tax harmonization would lead to excessive production of parts and assembly and the associated pollution in developing countries. Globalization may increase the benefit of international coordination of environmental policies, but require fine tuning beyond simple tax harmonization.

References


