Make and buy in a polluting industry

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Abstract

The literature paid significant attention to analyze the rationale for the make-or-buy strategy of firms. However, a related empirically relevant strategy of make-and-buy did not get much attention. We show that the presence of tax/subsidy policies, which are particularly important in the presence of environmental pollution, may create a rationale for the make-and-buy strategy of firms. Thus, we provide a new rationale for the make-and-buy strategy of firms which is different from the existing reasons, such as, uncertainty, market power of the input suppliers, moral hazard, and capacity utilization. We also discuss the implications of international harmonization and global welfare maximizing bi-sourcing.

Keywords: Bi-sourcing; Make-and-Buy; Outsourcing; Pollution; Production; Tax

JEL classifications: D21; F18; F23; H23; L12; L23; L24; Q50

1 Introduction

Empirical evidence suggests that many firms produce certain inputs in-house and purchase them from outside suppliers, i.e., adopting the Make-and-Buy strategy, which is also called bi-sourcing. Cohen and Young (2006) mentioned that several firms use a set

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of internal and external service providers in the global economy. For example, GMS, a global manufacturing and service firm, use globally decentralized internal and external resources. Nokia buys a large proportion of key electronic components such as semiconductors and microprocessors from a global network of suppliers and produces these components in its own manufacturing plants (Nokia Annual Report, 2003). There are Integrated Device Manufacturers, such as Freescale Semiconductor Inc., NXP Semiconductors and Analog Device Inc., which are also customers of Taiwan Semiconductor Manufacturing Company Ltd, which is a semiconductor dedicated foundry. Johnson (2007) mentioned that Mattel made its own die-casting molds at Malaysia and also outsourced them to Hong Kong.

Moreover, the evidence suggests that polluting firms often undertake bi-sourcing. A survey conducted by the Japanese Ministry of Economy, Trade and Industry (METI) showed that the percentage of manufacturing firms (i.e., manufacturers of production machinery, electronic parts, devices and electronic circuits, electrical machinery, equipment and supplies, general-purpose machinery, and information and communication electronics equipment) that chose bi-sourcing (firms that chose both domestic suppliers and foreign suppliers) in 2016 was 8.28%, whereas the percentage was 3.53% for non-manufacturing industries (i.e., information and communications, scientific research, professional and technical services, and the wholesale and retail trade).[1]

[1] Preliminary reports on the Basic Survey of Japanese Business Structure and Activities (*Kigyo Katsudo Kihon Chosa*) are available from the METI website (http://www.meti.go.jp/english/statistics/tyo/kikatu/index.html).

The general evidence of bi-sourcing and particularly, in polluting industries, motivates us to analyze how bi-sourcing benefits the sourcing firm and affects global environmental damage by influencing the tax/subsidy policies, which eliminate or reduce inefficiencies due to product-market imperfection as well as environmental pollution. Thus, the reason explained in this paper for bi-sourcing is different from the existing reasons, such as, uncertainty (Emons, 1996), market power of the outside input suppliers (Arya et al. 2008, Beladi and Mukherjee, 2012; Stenbacka and Tombak, 2012), moral hazard (Du et al., 2006, 2009), and capacity utilization (He and Nickerson., 2006, Puranam et al., 2013).

We consider a framework where a firm can produce a final good and the critical input that is required to produce the final good. Input production creates pollution. The firm has the option to outsource its input production completely or partially to another country, called the foreign country, where the input market is competitive. However, there is a transaction cost or transportation cost associated with input outsourcing. While the firm can outsource inputs, it must produce the final goods at home due to the high cost of relocating final goods production.[2]

In this framework, we consider three situations: (i) the benchmark case of no pollution, (ii) tax/subsidy imposed only by the home country of the final goods producer (which is appropriate if the environmental concern is not very high in the foreign country), and (iii) tax/subsidy imposed by the home and the foreign countries (which is

[2]Chen et al (2004) show that outsourcing of the final goods production requires more coordination costs and adaption costs relative to outsourcing of input.

appropriate if the environmental concern is high in both countries).

We show that bi-sourcing is not an equilibrium outcome under the benchmark case of no pollution, but it may occur in other two situations. Thus, we provide a new rationale for bi-sourcing based on the tax/subsidy policies.

In our model, the foreign country, which is exporting input, sets the environmental tax above the Pigouvian level,[3] and the introduction of environmental tax by the foreign country induces bi-sourcing even if there is no transaction or transportation cost associated with input outsourcing.

We also investigate international harmonization where the home and foreign countries set the environmental taxes cooperatively to maximize global welfare.[4] We show that international harmonization can promote bi-sourcing compared to the situation where the home and foreign countries set taxes non-cooperatively.

Finally, we consider global welfare maximizing bi-sourcing, where the taxes as well as the outsourcing decision are taken to maximize global welfare. We find that the amount of outsourcing under harmonization can be excessive compared to global welfare maximizing outsourcing. We also find that welfare is higher under global welfare maximizing case compared to harmonization but the total environmental damage can be lower under the latter case than the former case. Hence, higher welfare not necessarily

[3]In the competitive free trade model, Markusen (1975) shows that the exporting country sets an excessively high environmental tax to improve the terms of trade.

[4]The studies of international harmonization in environmental policy primarily investigate the situation in which environmental policy is distorted and argue for the need of policy coordination (Duval and Hamilton, 2002; Straume, 2006; Barcena-Ruiz and Campo, 2012).

implies lower environmental damage.

In general, our paper contributes to the literature on pollution haven hypothesis (PHH).[5] The PHH study analyzes the impact of environmental regulations on foreign direct investment (FDI), but less research has been done on the impact of environmental regulations on international outsourcing, although there are many evidences of international outsourcing in polluting industries. Lyu (2016) showed that 295.3 million tons of CO_2 were emitted by tasks offshored to China in 2010. The author found that iron and steel, nonferrous metals, chemicals, electrical machinery, and general machinery entail higher CO_2 emissions from offshoring. Michel (2013) showed that 6% to 7% of the reduction in production-related air pollution in Belgian manufacturing is due to the replacement of domestic intermediates with imported intermediates. Antonietti et al. (2017) showed that stricter environmental regulation induces international outsourcing to developing countries where regulation is less stringent.

Using Japanese firm-level data, Cole et al. (2014) found that firms belonging to the pollution-intensive industries tend to choose international outsourcing. The IPCC (2014) reported that high-income countries are net importers of carbon dioxide (CO_2) emissions whereas middle-income and low-income countries are net exporters. The

[5]PHH states that stricter environmental policies prompt firms to relocate their production to countries with more lenient environmental policies (Cole et al., 2006; Jeppesen et al., 2002; List et al., 2003). On the other hand, McConnell and Schwab (1990), Duffy-Deno (1992), Friedman et al. (1992), and Levinson (1996) found that environmental regulation had no significant, and sometimes even a positive, effect on investment.

report also stated that the share of CO_2 emissions in the production of internationally traded products is increasing. We provide a new perspective to this literature by considering bi-sourcing.

It is also worth pointing out the difference between our paper and the literature on second sourcing. Shepard (1987) and Farrell and Gallini (1988) show that an input supplier increases demand for inputs by creating competition in the input market through licensing. Kogut and Kulatilaka (1994), Rob and Vettas (2003), Choi and Davidson (2004) and Mukherjee (2008) explain why a firm serves a foreign market from its domestic and foreign plants. Schwartz and Thompson (1986), Baye et al. (1996), Yuan (1999) and Corchon and Gonzales-Maestre (2000) showed how the creation of more divisions provides strategic advantage in oligopolistic final goods markets. Unlike these papers, our focus is on the role of tax/subsidy policies in the presence of environmental pollution. Moreover, bi-sourcing in our analysis neither creates competition in the bi-sourced firm's market nor considers production in multiple plants of the bi-sourced firm.

The remainder of the paper is organized as follows. Sections 2 and 3 describe the model and derive the results. Section 4 shows a linear example of the model. Section 5 concludes.

2 The basic model

Consider a country, called the home country, with a final goods producer, firm I. We assume that production of the final goods requires a critical input, and one unit of the input is required to produce one unit of the final goods consumed in the home country. Firm I can produce the input in-house at a marginal cost of $c \geq 0$ and/or can outsource input production to a foreign country. We assume that the input market in the foreign country is competitive. For simplicity, we assume that the competitive cost of input production in the foreign country is c. We consider firm I's marginal cost of in-house input production to be equal to the competitive cost of input production in the foreign country to eliminate the incentive for outsourcing due to a lower cost of foreign input production, which is well-understood (see, e.g., Choi, 2013). We further assume that there is a per-unit transaction or transportation cost, $k > 0$, associated with the outsourcing of inputs to the foreign country. Hence, the total per-unit cost related to the outsourcing of inputs to the foreign country is $c + k > c$. We also assume that the marginal cost of final goods production is zero.

Assume that production of the input creates pollution, which is represented by an emission function $e_i(q)$, $i = h, f$ where q is the quantity of input production. We assume that this function is not identical between the home country (h) and the foreign country (f) because environmental technology in the countries are different. We also assume that $e_i'(q) > 0$ and $e_i''(q) \geq 0$, $i = h, f$. If firm I produces m fraction of the required inputs in-house and purchases $(1 - m)$ fraction of the required inputs from the foreign country where $0 \leq m \leq 1$, the total amount of pollution in the home country is $z_h = me_h(q)$, and the total amount of pollution in the foreign country is $z_f = (1-m)e_f(q)$. We define the environmental damage function as $ED_i(z_i)$, $i = 1, 2$. We assume that $\frac{\partial ED_i(z_i)}{\partial z_i} > 0$, $\frac{\partial^2 ED_i(z_i)}{\partial z_i^2} \geq 0$, which is mostly considered in the literature.

For the inverse demand function $P(q)$, we assume $P''(q)q + P'(q) < 0$ to guarantee the second order conditions for profit maximization.

We consider the following game. At stage 1, firm I determines m and writes binding contracts with the competitive foreign input suppliers specifying that it will purchase $(1-m)$ fraction of its total input demand from the input suppliers. Firm I will produce the remaining inputs, i.e., m fraction of its input demand, in-house. Firm I determines m ($(1-m)$ resp.) to maximize its profit.[6] At stage 2, the home country of firm I imposes a tax/subsidy, t, per unit of the output creating pollution in the home country. At stage 3, firm I determines the amount of final goods, and the profits are realized. We solve the game through backward induction. If both countries impose a tax/subsidy, at stage 2, the home and foreign countries simultaneously set taxes/subsidies t and τ, respectively.

The purpose of this paper, i.e., to see the effects of bi-sourcing on environmental policies, motivates the timing of the game. Hence, we consider a situation where the

[6] This modelling strategy follows Arya et al. (2008). As an alternative modelling strategy, we could consider that firm I would produce q_{IN} amount of inputs in-house and outsource q_{OUT} amount of inputs. However, our qualitative results would not be affected by the modelling choice, yet our modelling choice would make the analysis simpler.

government determines the policy after the firm's outsourcing decision, implying that the government cannot commit to the tax/subsidy policy before the firm's decision or the firm commits to its outsourcing strategy before the government's policy. No commitment by the governments allows firms to influence government policies through their actions.

As Staiger and Tabellini (1987) mentioned, governments with some degree of discretion in policy may find it difficult to commit. In our context, it can be motivated by the fact that governments may need time to establish an environmental policy, while firms can forward contract with foreign input suppliers, allowing firms to commit to bi-sourcing arrangements prior to the government's choice of tax rate. Helm et al.(2003) noted that no commitment in the energy policy arises since it is used to achieve multiple objectives such as international competitiveness, political interests, and lower energy prices.[7]

There are several papers considering non-committed government policies under environmental regulation, where they show how firm's strategies affect environmental policies. As a representative sample, one may look at Poyago-Theotoky (2007), Golombek

[7]More recently, the Australian government repealed the Clean Energy act 2011 and abolished the carbon price mechanism in order to lower the cost of domestic production and consumption (see the website of the Australian Department of the Environment http://www.environment.gov.au/). Other examples of time inconsistency problems that the past energy policies faced are shown in Helm et al (2003).

The implications of the time inconsistency problem are considered in other contexts also. See, e.g., Staiger and Tabellini (1987), Neary and Leahy (2000), and Mukherjee and Pennings (2006).

and Greaker (2010) and Hattori (2013) for the relationship between environmental investments and environmental policies, and at Eerola (2006), Dijkstra et al. (2011) and De santis and Stähler (2009) for firms' location decisions and environmental policies.[8]

We follow the literature on non-committed government policies for the timing of our game, which allows us to investigate how bi-sourcing affects environmental policy, which, in turn, affects global environmental damage. We will discuss later that if the government can commit to a tax/subsidy policy before the firm's decision, the equilibrium outcome will be either complete in-house production or complete outsourcing, but not bi-sourcing.

2.1 Tax/subsidy by the home country only

First, consider the case where only the home country of firm I imposes a tax/subsidy.

At stage 3, given m and t, firm I determines the output, q, to maximize the following expression:

$$\underset{q}{Max}\ P(q)q - cq - mte_h(q) - (1-m)kq.$$

The first order condition leads to

$$P'(q)q + P(q) - c - mte'_h - (1-m)k = 0. \tag{1}$$

[8]The non-committed government policies are also considered in papers focusing on non-polluting industries. See, e.g., Staiger and Tabellini (1987), Al-Saadon and Das (1996), Neary and Leahy (2000), Mukherjee (2000) and Mukherjee and Pennings (2006), in the context of international trade and investment.

We obtain the equilibrium output as $q = q(t, m)$. From equation (1), we obtain $\frac{\partial q(t,m)}{\partial t} = \frac{me'}{P''+2P'-mte'} < 0$ and $\frac{\partial q(t,m)}{\partial m} = \frac{te'_h - k}{P''+2P'-mte'_h}$. If $te'_h - k > 0$, in-house production increases the marginal cost of input production, which leads to $\frac{\partial q(t,m)}{\partial m} < 0$.

At stage 2, given m and internalising firm I's equilibrium output decision to be taken in stage 3, the home country government determines the tax/subsidy, t, to maximize the home country's welfare,

$$SW_h = \int_0^{q(t,m)} P(v)dv - [c + (1-m)k]q(t,m) - ED_h(z_h)$$

where $z_h = me_h(q(t,m))$.

The first order condition leads to

$$\left[P(q(t,m)) - [c + (1-m)k] - \frac{\partial ED_h(z_h)}{\partial z_h}\frac{\partial z_h}{\partial e_h}\frac{\partial e_h}{\partial q}\right]\frac{\partial q(t,m)}{\partial t} = 0. \tag{2}$$

Using equation (1), we obtain $P(q(t,m)) - c - (1-m)k = -P'(q(t,m))q + mte'_h$, and substitute it into equation (2). We obtain

$$t^*(m) = \frac{\partial ED_h(z_h)}{\partial z_h} + \frac{P'(q(t,m))q(t,m)}{me'_h}, \tag{3}$$

where $m = \frac{\partial z_h}{\partial e_h}$ and $e'_h = \frac{\partial e_h}{\partial q}$.

The tax/subsidy policy of the home country helps to control pollution as well as to reduce distortion in the product market due to imperfect competition. The first term in the right-hand side (RHS) of (3) represents the level of pollution control, which is positive, and the second term in the RHS of (3) represents the reduction of distortion in the product market, which is negative. Therefore, the tax is set below the Pigouvian tax level. If the marginal environmental damage $\frac{\partial ED_h(z_h)}{\partial z_h}$ is sufficiently low, we obtain $t^* < 0$. [9]

The equilibrium profit of firm I is $\pi^*(m) = [P(q^*) - c - (1-m)k]q^* - mt^*e_h^*$ where $q^* = q^*(t^*(m), m)$, $t^* = t^*(m)$, and $e_h^* = e_h^*(q^*)$. [10]

At stage 1, firm I determines m to maximize $\pi^*(m)$. We obtain

$$\frac{\partial \pi^*(m)}{\partial m} = kq^* - t^*e_h^* - me_h^*\frac{\partial t^*}{\partial m}. \tag{4}$$

Then, we have the following proposition.

Proposition 1. If the production of the input does not create pollution and $k > 0$, firm I chooses complete in-house production, i.e, $\frac{\partial \pi^*}{\partial m} > 0$.

From equation (4), we obtain $\frac{\partial \pi^*}{\partial m} = kq^*$ if $e_h^* = 0$. Since $k > 0$, implying that only in-house input production is the equilibrium strategy of firm I.

However, if $e_h^* > 0$, we may obtain bi-sourcing strategy in the equilibrium. We obtain from equation (4) that

[9] The sign of $\frac{\partial t^*}{\partial m}$ is given by the sign of $\frac{\partial^2 SW_h}{\partial t \partial m}$, and we obtain $\frac{\partial^2 SW_h}{\partial t \partial m} = [(P' - ED_h''(me_h')^2 - ED'me_h'')\frac{\partial q}{\partial m} + k - ED_h'e_h']\frac{\partial q}{\partial t}$. However, the sign is ambiguous.

[10] Since the RHS of equation (3) includes t, we should finally solve (3) to obtain t^*.

$$m^* = \frac{kq^* - t^* e_h^*}{e_h^* \frac{\partial t^*}{\partial m}}. \tag{5}$$

If firm I chooses bi-sourcing, the second order condition for maximization problem in (4) is negative. Therefore, using equation (4), we have $\frac{\partial \pi^*(m)}{\partial m}|_{m=0} > 0$ and $\frac{\partial \pi^*(m)}{\partial m}|_{m=1} < 0$, which leads to the following proposition.

Proposition 2. If pollution exists and if only the home country imposes environmental tax, bi-sourcing is the equilibrium strategy of firm I when $\frac{\partial \pi^*(m)}{\partial m}|_{m=0} = kq^*(0) > 0$ and $\frac{\partial \pi^*(m)}{\partial m}|_{m=1} = kq^*(1) - t^*(1)e_h^*(1) - e_h^*(1)\frac{\partial t}{\partial m}|_{m=1} < 0$.

The intuition for the above result is as follows. If $\frac{\partial \pi^*(m)}{\partial m}|_{m=0} = kq^*(0) > 0$, firm I does not choose complete outsourcing ($m = 0$) because it can avoid the variable cost of input production by $kq^*(0)$ by increasing m from $m = 0$. On the other hand, if $\frac{\partial \pi^*(m)}{\partial m}|_{m=1} = kq^*(1) - t^*(1)e_h^*(1) - e_h^*(1)\frac{\partial t}{\partial m}|_{m=1} < 0$, firm I does not choose complete in-house input production ($m = 1$). When firm I decreases m from $m = 1$, it incurs the variable cost $kq^*(1)$, whereas it can avoid the variable cost by $t^*(1)e_h^*(1) + e_h^*(1)\frac{\partial t^*}{\partial m}|_{m=1}$. Therefore, if $kq^*(1) < t^*(1)e_h^*(1) + e_h^*(1)\frac{\partial t^*}{\partial m}|_{m=1}$, firm I can lower the variable costs of input by decreasing m. As a result, when $\frac{\partial \pi^*(m)}{\partial m}|_{m=0} > 0$ and $\frac{\partial \pi^*(m)}{\partial m}|_{m=1} < 0$, firm I chooses $m^* \in (0, 1)$.

When $m^* = \frac{kq^* - t^* e_h^*}{e_h^* \frac{\partial t^*}{\partial m}} \in (0, 1)$, we have $kq^* > t^* e_h^*$, $\frac{\partial t^*}{\partial m} > 0$, and $kq^* - t^* e_h^* < e_h^* \frac{\partial t^*}{\partial m}$.[11] The reason is as follows. On one hand, $kq^* > t^* e_h^*$ implies that firm I can lower the

[11]In the bi-sourcing equilibrium, we do not have $kq^* < t^* e_h^*$ because firm I can obtain $t^* < 0$ by choosing sufficiently small m.

variable cost through in-house production (i.e., by increasing m). On the other hand, $\frac{\partial t^*}{\partial m} > 0$ implies that firm I can lower the tax rate through outsourcing (i.e., by reducing m). As a result, when $kq^* > t^* e_h^*$ and $\frac{\partial t^*}{\partial m} > 0$, firm I can receive benefits from both in-house production and outsourcing. In addition, $kq^* - t^* e_h^* < e_h^* \frac{\partial t^*}{\partial m}$ implies that firm I gets maximum benefit from bi-sourcing and not from complete in-house production or from complete outsourcing. This is an interesting result of our analysis and it suggests that even if the marginal cost of in-house input production is lower than that of outsourcing, the firm has an incentive to outsource.[12]

Bi-sourcing helps firm I to minimize its variable production cost by reducing the tax rate, $mt(m)$. Hence, it implies that if the firm chooses the bi-sourcing strategy, it can expect a lower tax rate. However, bi-sourcing simply moves the polluting activities to the other country, thus it may increase global environmental damage, as shown in Section 4.1.

Proposition 2 can be rewritten as $0 < k < \frac{e_h^*(1)}{q^*(1)}[t^*(1) + \frac{\partial t^*}{\partial m}|_{m=1}]$ where $\frac{e_h^*(1)}{q^*(1)}$ represents the pollution intensity in the home country. This condition provides a testable hypothesis. With $t^*(1) + \frac{\partial t^*}{\partial m}|_{m=1} > 0$, firms facing low transaction or transportation

[12] This is consistent with the fact that, in the polluting aviation industry (IPCC, 2007 and ICAO, 2016), Boeing signed agreements with a Japanese consortium (which is composed of Mitsubishi Heavy Industries, Kawasaki Heavy Industries LTD and Fuji Heavy Industries) whose costs are just as high as or higher than Boeing. According to the agreements, Boeing would purchase from them the 767-X fuselage during the 1990s, and then wings, together with related research and development during the 2000s (Chen, 2011).

costs and high pollution intensity in the home country tend to do bi-sourcing.[13]

Finally, we note the case where the government can commit to the tax/subsidy policies before firm I's decision. Therefore, the timing of the game is modified so that the government moves before the firm. Hence, it is intuitive that the firm's decision does not change the tax/subsidy rates; that is, $\frac{\partial t^*}{\partial m} = 0$ in equation (4). As a result, the firm chooses complete outsourcing or complete in-house production to yield a lower marginal cost of the production.

2.2 Tax/subsidy by both countries

We considered in the previous subsection that the foreign country does not impose a tax/subsidy, which may be appropriate if the foreign country is not much concerned about environmental pollution and disengaged in rent extraction following firm I's sourcing decision. The purpose of this subsection is to show how the results of the previous subsection change if both countries impose taxes/subsidies.

If the foreign country imposes a tax/subsidy following input outsourcing, the competitive per-unit input price is $c + \frac{\tau e_f}{q}$ where τ is the tax/subsidy rate imposed by the foreign country.

At stage 3, firm I determines the output, q, to maximize the following expression:

$$\underset{q}{Max}\ P(q)q - cq - mte_h(q) - (1-m)[kq + \tau e_f(q)].$$

[13]The sign of $t^*(1) + \frac{\partial t^*}{\partial m}|_{m=1}$ is ambiguous. However, when we consider the linear example in Appendix 7.1, we obtain $t^*(1) + \frac{\partial t^*}{\partial m}|_{m=1} > 0$ when $\gamma > \frac{1}{2\alpha^2}$ (see footnote 20).

The first order condition leads to

$$P'(q)q + P(q) - c - tme_h' - (1-m)[k + \tau e_f'] = 0. \tag{6}$$

From equation (6), we obtain the equilibrium output $q = q(t,\tau,m)$. We obtain $\frac{\partial q(t,\tau,m)}{\partial t} = \frac{me_h'}{P''q+2P'-tme_h''-(1-m)\tau e_f''} < 0$, $\frac{\partial q(t,\tau,m)}{\partial \tau} = \frac{(1-m)e_f'}{P''q+2P'-tme_h''-(1-m)\tau e_f''} < 0$, and $\frac{\partial q(t,\tau,m)}{\partial m} = \frac{te_h'-k-\tau e_f'}{P''q+2P'-tme_h''-(1-m)\tau e_f''}$.

First, consider the maximization problem of the home country, which determines the tax, t, to maximize the home-country welfare $SW_h = \int_0^{q(t,\tau,m)} P(v)dv - cq(t,\tau,m) - (1-m)[kq(t,\tau,m) + \tau e_f(q(t,\tau,m))] - ED_h(z_h)$ where $z_h = me_h(q(t,\tau,m))$. We obtain

$$\left[P(q(t,\tau,m)) - c - (1-m)[k + \tau\frac{\partial e_f}{\partial q}] - \frac{\partial ED_h(z_h)}{\partial z_h}\frac{\partial z_h}{\partial e_h}\frac{\partial e_h}{\partial q}\right]\frac{\partial q(t,\tau,m)}{\partial t} = 0. \tag{7}$$

In equation (10), the direct effect of outsourcing on the home country's motivation to set an environmental tax has two opposite directions. On one hand, outsourcing increases the tax rate to avoid the burdens of transaction or transportation costs and foreign taxes, which is represented by $-(1-m)[k + \tau\frac{\partial e_f}{\partial q}]\frac{\partial q(t,\tau,m)}{\partial t} > 0$. On the other hand, outsourcing decreases the tax rate because it mitigates environmental damage in the home country. This is represented by $-\frac{\partial ED_h(z_h)}{\partial z_h}m\frac{\partial e_h}{\partial q}\frac{\partial q(t,\tau,m)}{\partial t} > 0$.

Now consider the maximization problem of the foreign country, which determines the tax, τ, to maximize the foreign-country welfare $SW_f = (1-m)\tau e_f(q(t,\tau,m)) - ED_f(z_f)$ where $z_f = (1-m)e_f(q(t,\tau,m))$. We obtain

$$(1-m)e_f(q(t,\tau,m)) + (1-m)\left[\tau - \frac{\partial ED_f(z_f)}{\partial z_f}\right]\frac{\partial e_f}{\partial q}\frac{\partial q(t,\tau,m)}{\partial \tau} = 0. \tag{8}$$

The first term in equation (8) is positive, suggesting that if firm I chooses to outsource, it gives the foreign country an incentive to increase the tax rate to extract rent from firm I through increased tax revenue. Therefore, for an interior solution, the second term in (8) should be negative to satisfy equation (8), which leads to $\tau > \frac{\partial ED_f(e_f)}{\partial z_f}$. This gives the foreign country an incentive to reduce the tax rate to avoid high tax burden on firm I that affects its output decision adversely.

We obtain the Nash equilibrium simultaneously solves equations (7) and (8). Using equation (6), we have $P(q(t,\tau,m)) - c - (1-m)(k + \tau e'_f) = -P'(q(t,\tau,m))q + mte'_h$. Substituting this into equation (7) to obtain the equilibrium tax/subsidy in the home country, we get

$$t^{**}(m) = \frac{\partial ED_h(z_h)}{\partial z_h} + \frac{P'(q(t,\tau,m))q(t,\tau,m)}{me'_h}, \tag{9}$$

where $e'_h = \frac{\partial e_h}{\partial q}$ and $e'_f = \frac{\partial e_f}{\partial q}$. The tax/subsidy policy in the home country helps to control pollution as well as to reduce distortion in the product market due to imperfect competition. The first term in the RHS of (9) represents pollution control, and the second term in the RHS of (9) represents reduction of distortion in the product market, which is negative. Therefore, the tax is set below the Pigouvian level. In addition, it is set negative if the marginal environmental damage $\frac{\partial ED_h}{\partial z_h}$ is sufficiently low.

Solving equation (8) for the tax/subsidy in the foreign country, we have

$$\tau^{**}(m) = \frac{\partial ED_f(z_f)}{\partial z_f} - \frac{e_f(q(t,\tau,m))}{e'_f \frac{\partial q(t,\tau,m)}{\partial \tau}}. \tag{10}$$

The tax/subsidy policy in the foreign country helps to control pollution as well as to extract rent from firm I. The first term in the RHS of (10) represents pollution control and second term in the RHS of (10) represents rent extraction from firm I, which is positive.[14] Therefore, the tax in the foreign country is set above the Pigouvian level. Moreover, we obtain $\tau^{**} > 0$, even if the marginal environmental damage $\frac{\partial ED_f(z_f)}{\partial z_f}$ is zero.

At stage 1, firm I determines m to maximize $\pi^{**}(m) = [P(q^{**}) - c - (1-m)k]q^{**} - mt^{**}e_h^{**} - (1-m)\tau^{**}e_f^{**}$ where $q^{**} = q^{**}(t^{**}, \tau^{**}, m)$ and $e_i^{**} = e_i(q^{**})$, $i = h, f$. The first order condition is

$$\frac{\partial \pi^{**}}{\partial m} = kq^{**} + \tau^{**}e_f^{**} - t^{**}e_h^{**} - me_h^{**}\frac{\partial t^{**}}{\partial m} - (1-m)e_f^{**}\frac{\partial \tau^{**}}{\partial m} = 0, \tag{11}$$

which gives

[14]From equation (6), we obtain $\frac{\partial q(t,\tau,m)}{\partial \tau} = \frac{(1-m)e'_f}{P''q + 2P' - tme''_h - (1-m)\tau e''_f} < 0$. In addition, since we assume $e'_f > 0$, we obtain $-\frac{e_f(q(t,\tau,m))}{e'_f \frac{\partial q(t,\tau,m)}{\partial \tau}} > 0$.

$$m^{**} = \frac{kq^{**} + \tau^{**}e_f^{**} - e_f^{**}\frac{\partial \tau^{**}}{\partial m} - t^{**}e_h^{**}}{e_h^{**}\frac{\partial t^{**}}{\partial m} - e_f^{**}\frac{\partial \tau^{**}}{\partial m}}. \tag{12}$$

If firm I chooses bi-sourcing, the second order condition for the maximization problem in (11) is negative. Therefore, using equation (11), we have $\frac{\partial \pi^{**}(m)}{\partial m}|_{m=0} > 0$ and $\frac{\partial \pi^{**}(m)}{\partial m}|_{m=1} < 0$, which leads to the following proposition.

Proposition 3. If there is pollution, and both countries set environmental taxes, bi-sourcing is the equilibrium strategy of firm I when $\frac{\partial \pi^{**}(m)}{\partial m}|_{m=0} = kq^{**}(0) + e_f^{**}(0)\tau^{**}(0) - e_f^{**}(0)\frac{\partial \tau^{**}}{\partial m}|_{m=0} > 0$ and $\frac{\partial \pi^{**}(m)}{\partial m}|_{m=1} = kq^{**}(1) - t^{**}(1)e_h^{**}(1) - e_h^{**}(1)\frac{\partial t}{\partial m}|_{m=1} < 0$.

Note that we set $t^{**}(0) = 0$ and $\tau^{**}(1) = 0$ because polluting activity is not conducted in the home country when $m = 0$ and in the foreign country when $m = 1$.

When $m^{**} = \frac{kq^{**}+\tau^{**}e_f^{**}-e_f^{**}\frac{\partial \tau^{**}}{\partial m}-t^{**}e_h^{**}}{e_h^{**}\frac{\partial t^{**}}{\partial m}-e_f^{**}\frac{\partial \tau^{**}}{\partial m}} \in (0,1)$, we have $kq^{**} + \tau^{**}e_f^{**} > e_f^{**}\frac{\partial \tau^{**}}{\partial m} + t^{**}e^{**}$, $e_h^{**}\frac{\partial t^{**}}{\partial m} > e_f^{**}\frac{\partial \tau^{**}}{\partial m}$, and $kq^{**} + \tau^{**}e_f^{**} - e_f^{**}\frac{\partial \tau^{**}}{\partial m} - t^{**}e^{**} < e_h^{**}\frac{\partial t^{**}}{\partial m} - e_f^{**}\frac{\partial \tau^{**}}{\partial m}$.[15]

The reason is as follows. On one hand, $kq^{**} + \tau^{**}e_f^{**} > e_f^{**}\frac{\partial \tau^{**}}{\partial m} + t^{**}e_f^{**}$ implies that firm I can lower the variable cost through in-house production (i.e., by increasing m). On the other hand, $e_h^{**}\frac{\partial t^{**}}{\partial m} > e_f^{**}\frac{\partial \tau^{**}}{\partial m}$ implies that firm I can lower the tax payment through outsourcing (i.e., by reducing m). As a result, when $kq^{**} + \tau^{**}e_f^{**} > e_f^{**}\frac{\partial \tau^{**}}{\partial m} + t^{**}e^{**}$ and $e_h^{**}\frac{\partial t^{**}}{\partial m} > e_f^{**}\frac{\partial \tau^{**}}{\partial m}$, firm I can receive benefits from both in-house production and outsourcing.[16] In addition, $kq^{**} + \tau^{**}e_f^{**} - e_f^{**}\frac{\partial \tau^{**}}{\partial m} - t^{**}e^{**} < e_h^{**}\frac{\partial t^{**}}{\partial m} - e_f^{**}\frac{\partial \tau^{**}}{\partial m}$

[15] Also, we may have $kq^{**} + \tau^{**}e_f^{**} < e_f^{**}\frac{\partial \tau^{**}}{\partial m} + t^{**}e^{**}$, $e_h^{**}\frac{\partial t^{**}}{\partial m} < e_f^{**}\frac{\partial \tau^{**}}{\partial m}$, and $kq^{**} + \tau^{**}e_f^{**} + e_f^{**}\frac{\partial \tau^{**}}{\partial m} - t^{**}e^{**} > e_h^{**}\frac{\partial t^{**}}{\partial m} - e_f^{**}\frac{\partial \tau^{**}}{\partial m}$.

[16] We can obtain $\frac{\partial \tau^{**}}{\partial m}$ and $\frac{\partial t^{**}}{\partial m}$ by differentiating the left-hand sides of equations (7) and (8) with

implies that firm I gets maximum benefit from bi-sourcing and not from complete in-house production or from complete outsourcing.

Proposition 3 can be rewritten as $-\frac{e_f^{**}(0)}{q^{**}(0)}[\tau^{**}(0) - \frac{\partial \tau^{**}}{\partial m}|_{m=0}] < k < \frac{e_h^{**}(1)}{q^{**}(1)}[t^{**}(1) + \frac{\partial t^{**}}{\partial m}|_{m=1}]$. Like the previous section, we get a similar testable hypothesis. With $\tau^{**}(0) - \frac{\partial \tau^{**}}{\partial m}|_{m=0} > 0$ and $t^{**}(1) + \frac{\partial t^{**}}{\partial m}|_{m=1} > 0$, firms facing low transaction or transportation costs and high pollution intensity in the home country tend to do bi-sourcing.[17]

Different from Proposition 2, firm I chooses bi-sourcing even if $k = 0$ when $\tau^{**}(0) - \frac{\partial \tau^{**}}{\partial m}|_{m=0} > 0$. In Proposition 2, only the home country imposed tax. Hence, if $k = 0$, firm I has no incentive to produce inputs in-house when there is no foreign tax. However, if the foreign country imposes tax, firm I may prefer bi-sourcing even if $k = 0$, to save taxes in both countries.[18]

Bi-sourcing helps firm I to minimize its variable production cost by reducing the sum of tax rates, $mt(m) + (1 - m)\tau$. Hence, bi-sourcing may increase global environmental damage, as shown in Section 4.1.

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respect to m where $t = t^{**}(m)$ and $\tau = \tau^{**}(m)$, respectively, and solving these equations for $\frac{\partial t^{**}}{\partial m}$ and $\frac{\partial \tau^{**}}{\partial m}$. However, the signs are ambiguous.

[17]The signs of $\tau^{**}(0) - \frac{\partial \tau^{**}}{\partial m}|_{m=0}$ and $t^{**}(1) + \frac{\partial t^{**}}{\partial m}|_{m=1}$ are ambiguous. In our linear example in Appendix 7.2, we show that when pollution intensity in the home country increases, firm I tend to choose bi-sourcing.

[18]The signs of $\frac{\partial \tau^{**}}{\partial m}|_{m=0}$ and $\tau^{**}(0) - \frac{\partial \tau^{**}}{\partial m}|_{m=0}$ are ambiguous. In our linear example in Section 4.2, we obtain $\tau^{**}(0) - \frac{\partial \tau^{**}}{\partial m}|_{m=0} > 0$ when $k = 0$, and firm I does bi-sourcing even if $k = 0$.

3 International harmonization

We consider the case in which home and foreign countries determine environmental taxes cooperatively. In this case, global welfare at stage 2 is given by $GW = \int_0^{q(t,\tau,m)} P(v)dv - [c + (1-m)k]q(t,\tau,m) - ED_h(z_h) - ED_f(z_f)$. Given equation (6), we obtain the first order conditions as $\frac{\partial GW}{\partial t} = \frac{\partial GW}{\partial \tau} = -P'q + mte'_h + (1-m)\tau e'_f - mED'_h e'_h - (1-m)ED'_f e'_f = 0$. Therefore, in the equilibrium, we obtain the sum of tax rates as:

$$me'_h t^C(m) + (1-m)e'_f \tau^C(m) = mED'_h e'_h + (1-m)ED'_f e'_f + P'q^C, \tag{13}$$

where the superscript C represents the cooperative case.

When countries set environmental taxes cooperatively, the incentive for rent extraction disappears, whereas the incentive to reduce distortion due to imperfect competition and pollution remain.

At stage 1, firm I chooses m^C that maximizes $\pi^C = [P^C(q^C) - c]q^C - mte_h^C - (1-m)[kq^C + \tau^C e_f^C]$. We obtain

$$\frac{\partial \pi^C}{\partial m} = kq^C + \tau^C e_f^C - t^C e_h^C - me_h^C \frac{\partial t^C}{\partial m} - (1-m)e_f^C \frac{\partial \tau^C}{\partial m}. \tag{14}$$

Proposition 4. If there is pollution and both countries set environmental taxes cooperatively, bi-sourcing is the equilibrium strategy of firm I when $\frac{\partial \pi^C(m)}{\partial m}|_{m=0} = kq^C(0) + e_f^C(0)\tau^C(0) - e_f^C(0)\frac{\partial \tau^C}{\partial m}|_{m=0} > 0$ and $\frac{\partial \pi^C(m)}{\partial m}|_{m=1} = kq^C(1) - t^C(1)e_h^C(1) - e_h^C(1)\frac{\partial t^C}{\partial m}|_{m=1} < 0$.

Unlike Proposition 3, now the foreign government's incentive for rent extraction through tax revenue disappears (the second term in the right-hand side of equation (10) disappears). Therefore, compared to the non-cooperative case, now firm I can outsource more. In our linear example in Section 4.1, we show that the amount of outsourcing by firm I under harmonization is larger than that of under the non-cooperative case.

Note that we obtain $\frac{\partial \pi^C(m)}{\partial m}|_{m=1} = \frac{\partial \pi^*(m)}{\partial m}|_{m=1}$, since, in our analysis, the global welfare is equal to the welfare of the home country for $m = 1$, which leads to $t^C(1) = t^*(1)$. Hence, it is intuitive that the linear example in Section 4.1 shows the same range of k over which bi-sourcing occurs under both tax/subsidy imposed by the home country only and international harmonization.

Proposition 4 can be rewritten as $-\frac{e_f^C(0)}{q^C(0)}[\tau^C(0) - \frac{\partial \tau^C}{\partial m}|_{m=0}] < k < \frac{e_h^C(1)}{q^C(1)}[t^C(1) + \frac{\partial t^C}{\partial m}|_{m=1}]$. Like the previous sections, this section also provides a similar testable hypothesis, viz., with $\tau^C(0) - \frac{\partial \tau^C}{\partial m}|_{m=0} > 0$ and $t^C(1) + \frac{\partial t^C}{\partial m}|_{m=1} > 0$, firms facing low transaction or transportation costs and high pollution intensity in the home country tend to do bi-sourcing.[19]

Finally, we consider m^G that maximizes global welfare $GW^C(m) = \int_0^{q(t^C(m),\tau^C(m),m)} P^C(v)dv - [c + (1-m)k]q^C(t^C(m), \tau^C(m), m) - ED_h(z_h^C(m)) - ED_f(z_f^C(m))$. [20] Given equations

[19]The signs of $\tau^C(0) - \frac{\partial \tau^C}{\partial m}|_{m=0}$ and $t^C(1) + \frac{\partial t^C}{\partial m}|_{m=1}$ are ambiguous. In our linear example in Section 4.3, we show that when pollution intensity in the home country increases, firm I tend to choose bi-sourcing.

[20]The taxes are set in the same way as the harmonization case in equation (13), but the amount of outsourcing is determined to maximize global welfare.

(6) and (13), we obtain

$$\frac{\partial GW^C}{\partial m} = kq^C - ED'_h e_h^C + ED'_f e_f^C. \tag{15}$$

Therefore, the marginal benefit of increasing m is the reductions of transaction or transportation costs (kq^C) and the environmental damage in the foreign country ($ED'_f e_f^C$), whereas the marginal cost of increasing m is the increase of the environmental damage in the home country ($ED'_h e_h$).

From equation (15), we obtain $\frac{\partial GW^C}{\partial m}|_{m=0} = kq^C(0) + ED'_f(z_f^C(0))e_f^C(0) > 0$ and $\frac{\partial GW^C}{\partial m}|_{m=1} = kq^C(1) - ED'_h(z_h^C(1))e_h^C(1)$. Therefore, if $0 \leq k < \frac{ED'_h(z_h^C(1))e_h^C(1)}{q^C(1)}$, $m^G \in (0, 1)$ maximizes global welfare.

4 Example

We assume that the inverse demand function for the final goods is $P = 1 - q$ where P is price and q is the output. We assume $c = 0$ to simplify the analysis and $k < 1$ to ensure $q > 0$. Emission functions are $e_h = \alpha q$ and $e_f = \beta q$ where $\alpha > 0$ and $\beta > 0$ are pollution intensities in the home country and the foreign country, respectively. We also assume the environmental damage function as $ED_i = \gamma z_i^2$, $i = h, f$, where γ is the evaluation parameter for emission, and $z_h = me_h$ and $z_f = (1 - m)e_f$ are the total amount of pollution in the home country and the foreign country respectively.

	The range of bi-sourcing	The optimal m
Tax/subsidy by the home country only	$0 < k < 1$	$m^* = \frac{\sqrt{5}\sqrt{21k^2-40k+20}-10(1-k)}{10k}$
Tax/subsidy by both countries	$0 < k < 1$	$m^{**} = \frac{\sqrt{10}\sqrt{23k^2-40k+40}-20(1-k)}{20k}$
International Harmonization	$0 < k < 1$	$m^C = \frac{\sqrt{10}\sqrt{21k^2-40k+40}-20(1-k)}{20k}$
Global welfare maximization	$0 < k < \frac{20}{21}$	$m^G = \frac{k+20}{20(2-k)}$

Table 1: The main results under specific parameters, $\alpha = \beta = 1$ and $\gamma = 10$.

4.1 Results

The equilibrium values under three cases (tax/subsidy only applied by the home country, applied by both countries, and international harmonization) are shown in the Appendix. Here we only show the results under the specific parameters, $\alpha = \beta = 1$ and $\gamma = 10$. The main results are summarized in Table 1.[21]

Comparing the cases where only the home country sets the tax/subsidy and where both countries set the tax/subsidy, we get that the presence of foreign tax in the latter situation reduces the amount of bi-sourcing, since $m^* < m^{**}$. When only the home country imposes tax, firm I has the incentive to choose bi-sourcing to avoid the tax in the home country. However, the presence of the foreign tax reduces firm I's benefit

[21] For our paranmeter values, the tax rates in the bi-sourcing equilibria are positive except for the situation where only the home country sets the tax/subsidy. When only the home country sets the tax/subsidy, the tax rate is positive under complete in-house production but bi-sourcing makes it negative by reducing the importance of the environmental problem in the home country relative to the inefficiency due to product-market imperfection.

from outsourcing.

Bi-sourcing may increase global environmental damage, as pointed out in Sections 2.1 and 2.2. When only the home country sets the tax/subsidy, we obtain $ED_h(m^*) + ED_f(m^*) - ED_f(m = 0) = \frac{k^2\left(31k^2+2k(S-30)-4S+40\right)}{80(41k^2+4k(S-20)-4S+40)} - \frac{5}{2}(1-k)^2 > 0$ for $0 < k < 1$, where $ED_f(m = 0)$ is global environmental damage under complete outsourcing and $S \equiv \sqrt{5}\sqrt{21k^2 - 40k + 20}$. We also obtain $ED_h(m^*) + ED_f(m^*) - ED_h(m = 1) = \frac{k^2\left(31k^2+2k(S-30)-4S+40\right)}{80(41k^2+4k(S-20)-4S+40)} - \frac{10}{441} > 0$ for $0 < k < 1$, where $ED_h(m = 1)$ is global environmental damage under complete in-house input production. Therefore, bi-sourcing increases global environmental damage.

When both countries impose taxes/subsidies, we obtain $ED_h(m^{**}) + ED_f(m^{**}) - ED_f(m = 0) = \frac{k^2\left(2J(k-2)+43k^2-80k+80\right)}{320(2J(k-2)+33k^2-80k+80)} - \frac{5}{288}(1-k)^2 > 0$ for $0 < k < 1$, where $J \equiv \sqrt{10}\sqrt{23k^2 - 40k + 40}$. We also obtain $ED_h(m^{**}) + ED_f(m^{**}) - ED_h(m = 1) = \frac{k^2\left(2J(k-2)+43k^2-80k+80\right)}{320(2J(k-2)+33k^2-80k+80)} - \frac{10}{441} > 0$ if $0 < k < 0.271$. Therefore, bi-sourcing can increase global environmental damage.

Next, we compare firm I's incentive for bi-sourcing, global environmental damage and global welfare between international harmonization and non-cooperation (where both countries set the tax/subsidy but non-cooperatively) and obtain the following result.

Proposition 5. (i) The amount of outsourcing by firm I under harmonization is larger than that of under non-cooperation where the countries set the environmental taxes non-cooperatively, i.e., $m^C < m^{**}$.

(ii) Total environmental damage is higher under harmonization compared to the situation where the countries set the environmental taxes non-cooperatively. Global welfare can be lower under harmonization compared to the situation where the countries set the environmental taxes non-cooperatively.

Proof. (i) From Table 1, we get $m^C - m^{**} = \frac{\sqrt{21k^2-40k+40}-\sqrt{23k^2-40k+40}}{2\sqrt{10}k} < 0$. The derivations of m^{**} and m^C are shown in the Appendices 7.2 and 7.3, respectively.

(ii) We get $ED_h(m^{**}) + ED_f(m^{**}) < ED_h(m^C) + ED_f(m^C)$, since $ED_h(m^{**}) + ED_f(m^{**}) - (ED_h(m^C) + ED_f(m^C)) = \frac{k^2\left(2J(k-2)+43k^2-80k+80\right)}{320(2J(k-2)+33k^2-80k+80)} - \frac{k^2\left(41k^2+2k(R-40)-4R+80\right)}{320(31k^2+2k(R-40)-4R+80)} < 0$, where $J \equiv \sqrt{10}\sqrt{23k^2-40k+40}$ and $R \equiv \sqrt{10}\sqrt{21k^2-40k+40}$. We also get $GW^{**}(m^{**}) - GW^C(m^C) = \frac{k^2\left(24k^2+k(J-40)-2J+40\right)}{160(33k^2+2k(J-40)-4J+80)} - \frac{k^2\left(21k^2+k(R-40)-2R+40\right)}{160(31k^2+2k(R-40)-4R+80)} > 0$ when $0.71 < k < 1$. □

Under international harmonization, where countries cooperatively set environmental taxes, the incentive for rent extraction disappears. Hence, the incentive of firm I to choose outsourcing increases, which leads to $m^C < m^{**}$.

When k is large, the benefit of international harmonization that increases consumer surplus is dominated by the cost of environmental damage. Therefore, international harmonization is not preferable for global welfare when transaction or transportation costs are large.

Finally, we compare m^C with m^G where m^G maximizes global welfare and obtain the following result.

Proposition 6. (i) The amount of outsourcing by firm I under harmonization is larger than that of under global welfare maximization, i.e., $m^C < m^G$. Similarly, the range of k for which outsourcing occurs is lower under global welfare maximization.

(ii) Global welfare is higher under global welfare maximization but total environmental damage can be lower under harmonization.

Proof. (i) We obtain $\frac{\partial \pi^C}{\partial m}|_{m=m^G} = \frac{10(k-2)^3 k}{121(21k^2-40k+40)} < 0$, which leads to $m^C < m^G$. In addition, from Table 1, we obtain the range of k for which outsourcing occurs under international harmonization and global welfare maximization as $0 < k < 1$ and $0 < k < \frac{20}{21}$, respectively.

(ii) We get $ED_h(m^C)+ED_f(m^C)-(ED_h(m^G)+ED_f(m^G)) = \frac{k^2\left(41k^2+2k(R-40)-4R+80\right)}{320(31k^2+2k(R-40)-4R+80)} - \frac{221k^2+400(1-k)}{9680} < 0$, where $R \equiv \sqrt{10}\sqrt{21k^2-40k+40}$. For global welfare comparison, it is immediate from the definition that global welfare is higher under global welfare maximizing bi-sourcing compared to harmonization. □

Since firm I can affect the tax rate through its sourcing decision, its choice of in-house production is lower under harmonization compared to the global welfare maximization level. Hence, the environmental damage in the foreign (home) country is higher (lower) under harmonization compared to global welfare maximizing outsourcing. Further, the total environmental damage under harmonization is lower than that of under global welfare maximizing outsourcing.

To satisfy equation (15), governments choose m^G. Therefore, global welfare maximization requires that the marginal benefit of increasing m $(kq^C + MED'_f e_f^C)$ equals its marginal cost $(MED'_h e_h^C)$. However, firm I chooses m^C to minimize its variable production cost by reducing the sum of tax rates. As a result, the amount of outsourcing by firm I leads to $kq^C + MED'_f e_f^C > MED'_h e_h^C$. Therefore, a lower global pollution level does not necessarily mean that global welfare is maximized.

5 Conclusion

While the literature has paid significant attention to analyze the make-or-buy decisions of the firms, a related empirically relevant strategy of make-and-buy did not get much attention. Whatever effort has been devoted to analyze the rationale for the make-and-buy strategy, often called bi-sourcing, ignored the tax/subsidy policies of the governments, which are particularly important in the presence of environmental pollution. We derive the conditions for bi-sourcing, complete outsourcing and no outsourcing in the presence of tax/subsidy policies and environmental pollution.

Our paper provides a new rationale for bi-sourcing and show that even if the existing reasons for bi-sourcing, such as, uncertainty in the final goods market, market power of the input suppliers, moral hazard, capacity utilization, and internal and external scale constraints, are absent, the incentive for tax saving may be responsible for bi-sourcing. However, the incentive for outsourcing reduces in the presence of the tax/subsidy policy of the foreign country compared to the situation where only the home country imposes tax/subsidy.

We also discuss the implications of international harmonization and global welfare maximizing bi-sourcing. We find that global welfare maximizing outsourcing is less than the harmonization case, where the taxes are determined to maximize global welfare but not the outsourcing decision. We also find that welfare is higher under global welfare maximizing case compared to harmonization but the total environmental damage can be lower under the latter case than the former case. Hence, higher welfare not necessarily implies lower environmental damage.

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7 Appendix

7.1 Tax/subsidy by the home country only

At stage 3, given m and t, firm I determines the amount of the final goods, q, to maximize $\pi = (1-q)q - mt\alpha q - (1-m)kq$.

The equilibrium output and profit of firm I are $q = \frac{1-(1-m)k-m\alpha t}{2}$ and $\pi = \frac{(1-(1-m)k-m\alpha t)^2}{4}$, respectively.

At stage 2, the home country government determines the tax/subsidy to maximize welfare of the home country, $SW_h = \frac{q^2}{2} + \pi + mt\alpha q - \gamma(m\alpha q)^2$.

The equilibrium tax rate is

$$t^*(m) = \frac{(1-(1-m)k)\left(2\gamma m^2\alpha^2 - 1\right)}{2\gamma m^3\alpha^3 + m\alpha}.$$

Then, the equilibrium output and profit of firm I are $q^*(m) = \frac{1-(1-m)k}{2\gamma m^2\alpha^2+1}$ and $\pi^*(m) = \frac{(1-(1-m)k)^2}{(2\gamma m^2\alpha^2+1)^2}$.

At stage 1, firm I determines m to maximize its profit, π^*. We have

$$\frac{\partial \pi^*}{\partial m} = -\frac{2(1-(1-m)k)\left(k\left(2\gamma m^2\alpha^2 - 4\gamma m\alpha^2 - 1\right) + 4\gamma m\alpha^2\right)}{\left(2\gamma m^2\alpha^2+1\right)^3}. \tag{16}$$

As a benchmark, consider the case of no pollution, i.e., $\gamma = 0$. In this situation, we obtain $\frac{\partial \pi^*}{\partial m} = 2k(1-(1-m)k) > 0$ if $k > 0$, and firm I produces all inputs in-house.

Next, we consider the case where $\gamma > 0$, i.e., production creates pollution. In this case, we obtain that $\frac{\partial \pi^*}{\partial m}|_{m=0} = 2(1-k)k > 0$, and $\frac{\partial \pi^*}{\partial m}|_{m=1} = \frac{2\left(k-4\gamma\alpha^2+2\gamma\alpha^2 k\right)}{\left(2\gamma\alpha^2+1\right)^3} < 0$ if $k < \frac{4\gamma\alpha^2}{2\gamma\alpha^2+1} \equiv k^*$. Therefore, firm I prefers bi-sourcing, i.e., the equilibrium m, say, m^*, is between 0 and 1 if $0 < k < k^*$. Then, we have [22]

$$m^* = \frac{-4\alpha^2\gamma(1-k) + \sqrt{8\alpha^2\gamma k^2 + \left(4\alpha^2\gamma - 4\alpha^2\gamma k\right)^2}}{4\alpha^2\gamma k}.$$

Finally, we consider the effect of pollution intensity α on m. We obtain $\frac{\partial k^*}{\partial \alpha} >$

[22] Note that when $k = 0$, firm I chooses $m > 0$, which is almost zero because it can obtain the production subsidy $t^* < 0$. If we consider the lower bound of $\underline{m}$ such that $t = 0$, firm I chooses $m = \underline{m}$ if $k = 0$.

0. Therefore, pollution intensity in the home country promotes firm I's bi-sourcing strategy.[23]

7.2 Tax/subsidy by both countries

At stage 3, firm I determines the output, q, to maximize $\pi = (1-q)q - mt\alpha q - (1-m)(k+\tau\beta)q$. The equilibrium output and profit of firm I are $q = \frac{1-mt\alpha-(1-m)(k+\tau\beta)}{2}$ and $\pi = \frac{(1-mt\alpha-(1-m)(k+\tau\beta))^2}{4}$, respectively.

At stage 2, the home country determines t to maximize the home-country's welfare, $SW_h = \frac{q^2}{2} + \pi + mt\alpha q - \gamma(m\alpha q)^2$, and the foreign country determines τ to maximize the foreign-country's welfare, $SW_f = (1-m)\tau\beta q - \gamma((1-m)\beta q)^2$.

The home and the foreign countries determine the respective tax/subsidy rates simultaneously. The equilibrium taxes/subsidies are

$$t^{**}(m) = \frac{(1-k(1-m))\left(2\gamma m^2\alpha^2 - 1\right)}{\alpha m\left(2\gamma\beta^2 + 2\gamma m^2\left(\alpha^2+\beta^2\right) - 4\gamma m\beta^2 + 3\right)},$$

$$\tau^{**}(m) = \frac{2(1-k(1-m))\left(\beta^2\gamma(1-m)^2 + 1\right)}{\beta(1-m)\left(2\gamma\beta^2 + 2\gamma m^2\left(\alpha^2+\beta^2\right) - 4\gamma m\beta^2 + 3\right)}.$$

The equilibrium output and profit of firm I are $q^{**}(m) = \frac{1-(1-m)k}{2\beta^2\gamma+2\gamma m^2(\alpha^2+\beta^2)-4\beta^2\gamma m+3}$ and $\pi^{**}(m) = \frac{(1-(1-m)k)^2}{(2\beta^2\gamma+2\gamma m^2(\alpha^2+\beta^2)-4\beta^2\gamma m+3)^2}$, respectively.

At stage 1, firm I determines m to maximize π^{**}. We obtain

[23] We obtain $t^*(1) + \frac{\partial t^*}{\partial m}|_{m=0} = \frac{8\alpha^2\gamma+k\left(4\alpha^4\gamma^2-1\right)}{\alpha(2\alpha^2\gamma+1)^2} > 0$ when $\gamma > \frac{1}{2\alpha^2}$. Therefore, in such a case, as we confirmed in the general case, high pollution intensity in the home country promotes bi-sourcing.

$$\frac{\partial \pi^{**}}{\partial m} = -\frac{2(1-(1-m)k)\left(k\left(2\beta^2\gamma+2\gamma m(m-2)\left(\alpha^2+\beta^2\right)-3\right)+4\gamma\left(m\left(\alpha^2+\beta^2\right)-\beta^2\right)\right)}{\left(2\beta^2\gamma+2\gamma m^2\left(\alpha^2+\beta^2\right)-4\beta^2\gamma m+3\right)^3}. \tag{17}$$

The equilibrium m^{**} satisfies $\frac{\partial \pi^{**}}{\partial m} = 0$. Then, we obtain

$$m^{**} = \frac{\sqrt{2}\sqrt{\gamma\left(\alpha^2+\beta^2\right)\left(2\gamma\left(\alpha^2+\beta^2\right)+k^2\left(2\alpha^2\gamma+3\right)-4\alpha^2\gamma k\right)}-2\gamma(1-k)\left(\alpha^2+\beta^2\right)}{2\gamma k\left(\alpha^2+\beta^2\right)}.$$

Now, we consider the equilibrium outsourcing choice of firm I when $\gamma > 0$.[24]

We obtain from equation (17) that $\frac{\partial \pi^{**}}{\partial m}|_{m=0} = -\frac{2(1-k)\left(k\left(2\beta^2\gamma-3\right)-4\beta^2\gamma\right)}{\left(2\beta^2\gamma+3\right)^3} > 0$ for $0 \leq k < 1$, $\gamma > 0$, and $\beta > 0$. On the other hand, we obtain $\frac{\partial \pi^{**}}{\partial m}|_{m=1} = \frac{k\left(4\alpha^2\gamma+6\right)-8\alpha^2\gamma}{\left(2\alpha^2\gamma+3\right)^3} < 0$ if $k < \frac{4\alpha^2\gamma}{2\alpha^2\gamma+3} \equiv k^{**}$, implying that firm I may not want to produce all inputs in-house if the transaction/transportation cost k is small. As a result, firm I prefers bi-sourcing, i.e., the equilibrium m, say, m^{**}, is between 0 and 1 if $0 \leq k < k^{**}$.[25]

[24] If $\gamma = 0$, we get $\frac{\partial \pi^{**}}{\partial m} = \frac{2}{9}k(1-(1-m)k) > 0$, implying $m = 1$, i.e., firm I produces all inputs in-house.

[25] When $\frac{\partial \pi^{**}}{\partial m} > 0$, firm I chooses $m = 1$. However, if $m = 1$, the foreign country's welfare is zero, and only the home country determines the tax/subsidy, t. In such a case, we obtain $q^{**}(1) = \frac{1}{2\alpha^2\gamma+1}$, $\pi^{**}(1) = \frac{1}{(2\alpha^2\gamma+1)^2}$, and $t^{**}(1) = \frac{2\alpha^2\gamma-1}{2\alpha^3\gamma+\alpha}$. On the other hand, when $m = 0$, the home country does not set the tax/subsidy. In such a case, we obtain $q^{**}(0) = \frac{1-k}{2\gamma\beta^2+4}$, $\tau^{**}(0) = \frac{(1-k)\left(\gamma\beta^2+1\right)}{\beta(\gamma\beta^2+2)}$ and $\pi^{**}(0) = \frac{(1-k)^2}{(2\gamma\beta^2+4)^2}$. As a result, firm I chooses a bi-sourcing strategy if $\pi^{**}(m^*)$ is larger than $\pi^{**}(1)$ and $\pi^{**}(0)$.

Note that firm I may choose a bi-sourcing strategy even if $k = 0$ when the foreign country imposes environmental taxes. Indeed, when $k = 0$, using equation (17), we have $m^{**} = \frac{\beta^2}{\alpha^2+\beta^2}$.

Finally, we obtain $\frac{\partial k^{**}}{\partial \alpha} = \frac{24\alpha\gamma}{(2\alpha^2\gamma+3)^2} > 0$. Therefore, when pollution intensity in the home country increases, firm I tends to choose bi-sourcing.

7.3 International Harmonization

We consider the case in which both countries set environmental taxes cooperatively.

At stage 2, the home and foreign countries set the environmental taxes to maximize global welfare that is defined as $GW = SW_h + SW_f$. In this case, we obtain the sum of tax rates.

$$m\alpha t^C(m) + (1-m)\beta\tau^C(m) = \frac{(k(m-1)+1)\left(2\beta^2\gamma + 2\gamma m^2\left(\alpha^2+\beta^2\right) - 4\beta^2\gamma m - 1\right)}{\left(2\beta^2\gamma + 2\gamma m^2\left(\alpha^2+\beta^2\right) - 4\beta^2\gamma m + 1\right)}.$$

At stage 1, firm I determines m to maximize $\pi^C(m) = \frac{(k(m-1)+1)^2}{(2\beta^2\gamma+2\gamma m^2(\alpha^2+\beta^2)-4\beta^2\gamma m+1)^2}$. We obtain

$$m^C = \frac{\sqrt{2}\sqrt{\gamma\left(\alpha^2+\beta^2\right)\left(2\gamma\left(\alpha^2+\beta^2\right) + k^2\left(2\alpha^2\gamma+1\right) - 4\alpha^2\gamma k\right)} - 2\gamma(1-k)(\alpha^2+\beta^2)}{2\gamma k\left(\alpha^2+\beta^2\right)}.$$

We obtain $\frac{\partial \pi^C}{\partial m}|_{m=0} = \frac{2(k-1)\left(k\left(2\beta^2\gamma-1\right)-4\beta^2\gamma\right)}{\left(2\beta^2\gamma+1\right)^3} > 0$ for $0 \leq k < 1$, $\gamma > 0$, and $\beta > 0$. In addition, we obtain $\frac{\partial \pi^C}{\partial m}|_{m=1} = \frac{2\left(-4\alpha^2\gamma+2\alpha^2\gamma k+k\right)}{(2\alpha^2\gamma+1)^3} < 0$ if $k < \frac{4\alpha^2\gamma}{2\alpha^2\gamma+1} \equiv k^C$. Therefore, firm I prefers bi-sourcing, i.e., the equilibrium m, say, m^C, is between 0 and 1 if $0 \leq k < k^C$.

We obtain $\frac{\partial k^C}{\partial \alpha} = \frac{8\alpha\gamma}{(2\alpha^2\gamma+1)^2} > 0$. Therefore, when pollution intensity in the home country increases, firm I tends to choose bi-sourcing.

Finally, we consider m that maximizes global welfare $GW^C = \frac{(k(m-1)+1)^2}{4\beta^2\gamma+4\gamma m^2(\alpha^2+\beta^2)-8\beta^2\gamma m+2}$, and obtain $m^G \in (0,1)$ as

$$m^G = \frac{2\beta^2\gamma + k}{2\gamma(\alpha^2 + \beta^2 - \alpha^2 k)}$$

when $0 < k < \frac{2\alpha^2\gamma}{2\alpha^2\gamma+1} \equiv k^G$.[26] Therefore, a bi-sourcing strategy can maximize global welfare when $0 < k < k^G$.

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