Make and buy in a polluting industry

Received: 4 October 2018 | Accepted: 6 March 2020

DOI: 10.1111/jpet.12440

ORIGINAL ARTICLE

JOURNAL OF PUBLIC ECONOMIC THEORY WILEY

Make and buy in a polluting industry

Takeshi Iida[1] | **Arijit Mukherjee**[2]

[1]Faculty of Education and Regional Studies, University of Fukui, Fukui, Japan

[2]Nottingham University Business School, Jubilee Campus, Nottingham, UK

Correspondence
Arijit Mukherjee, Nottingham University Business School, Jubilee Campus, Wollaton Road, Nottingham NG8 1BB, UK.
Email: arijit.mukherjee@nottingham.ac.uk

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 show that international harmonization, where countries set taxes cooperatively, can promote outsourcing compared with the situation where the countries set taxes non-cooperatively. Further, global welfare maximizing outsourcing is less than the harmonization case. While global welfare is higher under global welfare maximization compared with harmonization, the total environmental damage can be lower under the latter case than the former case. Hence, higher welfare not necessarily implies lower environmental damage.

1 | INTRODUCTION

Empirical evidence suggests that many firms produce certain inputs in-house and purchase them from outside suppliers, that is, adopting the make-and-buy strategy, which is also called bisourcing. Cohen and Young (2006) mentioned that several firms use a set of internal and external service providers in the global economy. For example, GMS, a global manufacturing and service firm, uses 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 bisourcing. 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 bisourcing (firms that chose both domestic suppliers and foreign suppliers) in 2016 was 8.28%, whereas the percentage was 3.53% for nonmanufacturing industries (i.e., information and communications, scientific research, professional and technical services, and the wholesale and retail trade).[1]

The general evidence of bisourcing and particularly, in polluting industries, motivates us to analyze how bisourcing 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 bisourcing is different from the existing reasons, such as uncertainty (Emons, 1996), market power of the outside input suppliers (Arya, Mittendorf, & Sappington, 2008; Beladi & Mukherjee, 2012; Stenbacka & Tombak, 2012), moral hazard (Du, Lu, & Tao, 2006, 2009), and capacity utilization (He & Nickerson, 2006; Puranam, Gulati, & Bhattacharya, 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: (a) the benchmark case of no pollution, (b) 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 (c) tax/subsidy imposed by the home and the foreign countries (which is appropriate if the environmental concern is high in both countries).

We show that bisourcing 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 bisourcing 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 bisourcing even if there is no transaction or transportation cost associated with input outsourcing.

[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).

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

[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.

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 outsourcing compared with the situation where the home and foreign countries set taxes non-cooperatively.

Finally, we consider global welfare maximizing bisourcing, 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 with global welfare maximizing outsourcing. While global welfare is higher under global welfare maximization compared with harmonization, the total environmental damage can be lower under the latter case than the former case. Hence, higher welfare not necessarily 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 6–7% of the reduction in production-related air pollution in Belgian manufacturing is due to the replacement of domestic intermediates with imported intermediates. Antonietti, De Marchi, and DiMaria (2017) showed that stricter environmental regulation induces international outsourcing to developing countries where regulation is less stringent.

Using Japanese firm-level data, Cole, Elliott, and Okubo (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- and low-income countries are net exporters. The 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 bisourcing.

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), J. P. 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, Crocker, and Ju (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, bisourcing in our analysis neither creates competition in the bisourced firm's market nor considers production in multiple plants of the bisourced firm.

[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 (Bárcena-Ruiz & Campo, 2012; Duval & Hamilton, 2002; Straume, 2006).

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

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., T. M. 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 is 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 $ED_i(z_i)$, $i = h, f$. 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, that is, 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, that is, to see the effects of bisourcing on environmental policies, motivates the timing of the game. Hence, we consider a situation where the government determines the policy after the firm's outsourcing decision, implying that the government

[6]This modeling strategy follows Arya et al. (2008). As an alternative modeling 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 modeling choice, yet our modeling choice would make the analysis simpler.

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 bisourcing arrangements before the government's choice of tax rate. Helm, Hepburn, and Mash (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 noncommitted 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), Golmbek, Greaker, and Hoel (2010), and Hattori (2013) for the relationship between environmental investments and environmental policies, and at Eerola (2006), Dijkstra, Mathew, and Mukherjee (2011), and De Santis and Stähler (2009) for firms' location decisions and environmental policies.[8]

We follow the literature on noncommitted government policies for the timing of our game, which allows us to investigate how bisourcing 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 bisourcing.

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:

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

The first-order condition leads to

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

We obtain the equilibrium output as $q = q(t, m)$. From Equation (1), we obtain $\frac{\partial q(t,m)}{\partial t} = \frac{me_h'}{P'' + 2P' - mte_h''} < 0$ 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 $\frac{\partial q(t,m)}{\partial m} < 0$.

[7]More recently, the Australian government repealed the Clean Energy act 2011 and abolished the carbon price mechanism 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, for example, Staiger and Tabellini (1987), Neary and Leahy (2000), and Mukherjee and Pennings (2006).

[8]The noncommitted government policies are also considered in papers focusing on nonpolluting industries. See, for example, 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.

At Stage 2, given m and internalizing 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 $P(q(t,m)) - c - (1-m)k = -P'(q(t,m))q(t,m) + mte_h'(q(t,m))$, 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 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, that is,* $\frac{\partial \pi^*}{\partial m}(m) > 0$.

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

[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^*.

However, if $e_h^* > 0$, we may obtain bisourcing strategy in the equilibrium. We obtain from Equation (4) that

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

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

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

Note that we set $t^*(0) = 0$ because polluting activity is not conducted in the home country when $m = 0$.[11]

The intuition for the above result is as follows. If $\left.\frac{\partial \pi^*(m)}{\partial m}\right|_{m=0} = kq^*(0) > 0$, 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 $\left.\frac{\partial \pi^*(m)}{\partial m}\right|_{m=1} = kq^*(1) - t^*(1)e_h^*(1) - e_h^*(1)\left.\frac{\partial t^*}{\partial m}\right|_{m=1} < 0$, 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 $t^*(1)e_h^*(1) + e_h^*(1)\left.\frac{\partial t^*}{\partial m}\right|_{m=1}$. Therefore, if $kq^*(1) < t^*(1)e_h^*(1) + e_h^*(1)\left.\frac{\partial t^*}{\partial m}\right|_{m=1}$, firm I can lower the variable costs of input by decreasing m. As a result, when $\left.\frac{\partial \pi^*(m)}{\partial m}\right|_{m=0} > 0$ and $\left.\frac{\partial \pi^*(m)}{\partial m}\right|_{m=1} < 0$, 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 $kq^* - t^* e_h^* < e_h^* \frac{\partial t^*}{\partial m}$.[12] The reason is as follows. On the one hand, $kq^* > t^* e_h^*$ implies that firm I can lower the 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 bisourcing 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.[13]

---

[11]Since we assume $t^*(0) = 0$, there is a discontinuity at $m = 0$. Therefore, we need to compare the profit with $m = m^*$ to that of with $m = 0$. In our linear example in Appendix A.1, we confirm that $\pi^*(m^*) > \pi^*(0)$, suggesting that bisourcing is the equilibrium outcome.

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

[13]This is consistent with the fact that, in the polluting aviation industry (ICAO, 2016; IPCC, 2007), Boeing signed agreements with a Japanese consortium (which is composed of Mitsubishi Heavy Industries, Kawasaki Heavy

Bisourcing 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 bisourcing strategy, it can expect a lower tax rate. However, bisourcing 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 $0 < k < \frac{e_h^*(1)}{q^*(1)}\left[t^*(1) + \frac{\partial t^*}{\partial m}\Big|_{m=1}\right]$, where $\frac{e_h^*(1)}{q^*(1)}$ represents the pollution intensity in the home country. This condition provides a testable hypothesis. With $t^*(1) + \frac{\partial t^*}{\partial m}\Big|_{m=1} > 0$, firms facing low transaction or transportation costs and high pollution intensity in the home country tend to do bisourcing.[14]

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 Section 2.1 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 Section 2.1 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 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:

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

The first-order condition leads to

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

From Equation (6), we obtain the equilibrium output $q = q(t, \tau, m)$. We obtain

$$\frac{\partial q(t,\tau,m)}{\partial t} = \frac{me_h'}{P''q + 2P' - tme_h'' - (1-m)\tau e_f''} < 0,$$

$$\frac{\partial q(t,\tau,m)}{\partial \tau} = \frac{(1-m)e_f'}{P''q + 2P' - tme_h'' - (1-m)\tau e_f''} < 0,$$

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).

[14]The sign of $t^*(1) + \frac{\partial t^*}{\partial m}\Big|_{m=1}$ is ambiguous. However, when we consider the linear example in Appendix A.1, we obtain $t^*(1) + \frac{\partial t^*}{\partial m}\Big|_{m=1} > 0$ when $\gamma > \frac{1}{2\alpha^2}$ (see footnote 25).

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

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

In Equation (7), the direct effect of outsourcing on the home-country's motivation to set an environmental tax has two opposite directions. On the one hand, outsourcing increases the tax rate to avoid the burdens of transaction or transportation costs and foreign taxes, which is represented by $-(1-m)\left[k + \tau\frac{\partial e_f}{\partial q}\right]\frac{\partial q(t,\tau,m)}{\partial t} > 0$. On the other hand, outsourcing decreases the tax rate because it mitigates environmental damage in the home country. This is represented by $-\frac{\partial ED_h(z_h)}{\partial z_h}\partial \mathrm{zh}/\partial \mathrm{eh}\frac{\partial e_h}{\partial q}\frac{\partial q(t,\tau,m)}{\partial t} > 0$.

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

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

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 $P(q(t,\tau,m)) - c - (1-m)(k + \tau e_f') = -P'(q(t,\tau,m))q(\mathrm{t},\tau,m) + mte_h'(\mathrm{q}(\mathrm{t},\tau,m))$. Substituting this into Equation (7) to obtain the equilibrium tax/subsidy in the home country, we get

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

where $e_h' = \frac{\partial e_h}{\partial q}$. The tax/subsidy policy in the home country helps 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

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

where $e_f' = \frac{\partial e_f}{\partial q}$. The tax/subsidy policy in the foreign country helps 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.[15] 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 $q^{**} = q^{**}(t^{**}(m), \tau^{**}(m), m)$ and $e_i^{**} = e_i^{**}(q^{**}), i = h, f$. The first-order condition is

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

which gives

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

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

Proposition 3. *If there is pollution, and both countries set environmental taxes, bisourcing is the equilibrium strategy of firm I when*

$$\left.\frac{\partial \pi^{**}(m)}{\partial m}\right|_{m=0} = kq^{**}(0) + \tau^{**}(0)e_f^{**}(0) - e_f^{**}(0)\left.\frac{\partial \tau^{**}}{\partial m}\right|_{m=0} > 0$$

and

$$\left.\frac{\partial \pi^{**}(m)}{\partial m}\right|_{m=1} = kq^{**}(1) - t^{**}(1)e_h^{**}(1) - e_h^{**}(1)\left.\frac{\partial t^{**}}{\partial m}\right|_{m=1} < 0.$$

[15]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 $-\frac{e_f(q(t,\tau,m))}{e_f' \frac{\partial q(t,\tau,m)}{\partial \tau}} > 0$.

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 $m = 1$.[16]

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 $kq^{**} + \tau^{**}e_f^{**} > e_f^{**}\frac{\partial \tau^{**}}{\partial m} + t^{**}e_h^{**}$, $e_h^{**}\frac{\partial t^{**}}{\partial m} > e_f^{**}\frac{\partial \tau^{**}}{\partial m}$, and $kq^{**} + \tau^{**}e_f^{**} - e_f^{**}\frac{\partial \tau^{**}}{\partial m} - t^{**}e_h^{**} < e_h^{**}\frac{\partial t^{**}}{\partial m} - e_f^{**}\frac{\partial \tau^{**}}{\partial m}$.[17]

The reason is as follows. On the one hand, $kq^{**} + \tau^{**}e_f^{**} > e_f^{**}\frac{\partial \tau^{**}}{\partial m} + t^{**}e_h^{**}$ 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 $kq^{**} + \tau^{**}e_f^{**} > e_f^{**}\frac{\partial \tau^{**}}{\partial m} + t^{**}e_h^{**}$ 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.[18] In addition, $kq^{**} + \tau^{**}e_f^{**} - e_f^{**}\frac{\partial \tau^{**}}{\partial m} - t^{**}e_h^{**} < e_h^{**}\frac{\partial t^{**}}{\partial m} - e_f^{**}\frac{\partial \tau^{**}}{\partial m}$ implies that firm I gets maximum benefit from bisourcing and not from complete in-house production or from complete outsourcing.

Proposition 3 can be rewritten as $-\frac{e_f^{**}(0)}{q^{**}(0)}\left[\tau^{**}(0) - \frac{\partial \tau^{**}}{\partial m}\Big|_{m=0}\right] < k < \frac{e_h^{**}(1)}{q^{**}(1)}\left[t^{**}(1) + \frac{\partial t^{**}}{\partial m}\Big|_{m=1}\right]$. Like Section 2.1, we get a similar testable hypothesis. With $\tau^{**}(0) - \frac{\partial \tau^{**}}{\partial m}\Big|_{m=0} > 0$ and $t^{**}(1) + \frac{\partial t^{**}}{\partial m}\Big|_{m=1} > 0$, firms facing low transaction or transportation costs and high pollution intensity in the home country tend to do bisourcing.[19]

Different from Proposition 2, firm I chooses bisourcing even if $k = 0$ when $\tau^{**}(0) - \frac{\partial \tau^{**}}{\partial m}\Big|_{m=0} > 0$. 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 bisourcing even if $k = 0$, to save taxes in both countries.[20]

[16]Since we assume $t^{**}(0) = 0$ and $\tau^{**}(1) = 0$, there are discontinuities at $m = 0$ and $m = 1$. In our linear example in Appendix A.2, we confirm that the profits at $m = 0$ and at $m = 1$ with $t^{**}(0) = 0$ and $\tau^{**}(1) = 0$ respectively are less than the bisourcing profit. Therefore, firm I does bisourcing.

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

[18]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 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.

[19]The signs of $\tau^{**}(0) - \frac{\partial \tau^{**}}{\partial m}\Big|_{m=0}$ and $t^{**}(1) + \frac{\partial t^{**}}{\partial m}\Big|_{m=1}$ are ambiguous. In our linear example in Appendix A.2, we show that when pollution intensity in the home country increases, firm I tends to choose bisourcing.

[20]The signs of $\frac{\partial \tau^{**}}{\partial m}\Big|_{m=0}$ and $\tau^{**}(0) - \frac{\partial \tau^{**}}{\partial m}\Big|_{m=0}$ are ambiguous. In our linear example in Appendix A.2, we obtain $\tau^{**}(0) - \frac{\partial \tau^{**}}{\partial m}\Big|_{m=0} > 0$ when $k = 0$, and firm I does bisourcing even if $k = 0$.

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

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 $GW = SW_h + SW_f = \int_0^{q(t,\tau,m)} P(v)\, dv - [c + (1-m)k]q(t,\tau,m) - ED_h(z_h) - ED_f(z_f)$ where $z_h = me_h(q(t,\tau,m))$ and $z_f = (1-m)e_f(q(t,\tau,m))$. 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

$$me_h't^C(m) + (1-m)e_f'\tau^C(m) = mED_h'e_h' + (1-m)ED_f'e_f' + P'q(t,\tau,m), \tag{13}$$

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 remains.

At Stage 1, firm I chooses m^C that maximizes $\pi^C(m) = [P^C(q^C) - c]q^C - mt^C(m)e_h^C - (1-m)\left[kq^C + \tau^C(m)e_f^C\right]$ where $q^C = q^C(t^C(m), t^C(m), m)$ and $e_i^C = e_i^C(q^C)$, $i = h, f$. Given equation (6), we obtain

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

Proposition 4. *If there is pollution and both countries set environmental taxes cooperatively, bisourcing is the equilibrium strategy of firm I when*

$$\left.\frac{\partial \pi^C(m)}{\partial m}\right|_{m=0} = kq^C(0) + \tau^C(0)\,e_f^C(0) - e_f^C(0)\left.\frac{\partial \tau^C}{\partial m}\right|_{m=0} > 0$$

and

$$\left.\frac{\partial \pi^C(m)}{\partial m}\right|_{m=1} = kq^C(1) - t^C(1)e_h^C(1) - e_h^C(1)\left.\frac{\partial t^C}{\partial m}\right|_{m=1} < 0.$$

Unlike Proposition 3, now the foreign government's incentive for rent extraction through tax revenue disappears (the second term in the RHS of Equation 10 disappears). Therefore, compared with 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.

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

	The range of bisourcing	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	$0 < k < \frac{20}{21}$	$m^G = \frac{k+20}{20(2-k)}$

Note that we obtain $\left.\frac{\partial \pi^C(m)}{\partial m}\right|_{m=1} = \left.\frac{\partial \pi^*(m)}{\partial m}\right|_{m=1}$, 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 bisourcing occurs under both tax/subsidy imposed by the home country only and international harmonization.

Proposition 4 can be rewritten as $-\frac{e_f^C(0)}{q^C(0)}\left[\tau^C(0) - \left.\frac{\partial \tau^C}{\partial m}\right|_{m=0}\right] < k < \frac{e_h^C(1)}{q^C(1)}\left[t^C(1) + \left.\frac{\partial t^C}{\partial m}\right|_{m=1}\right]$. Like the previous sections, this section also provides a similar testable hypothesis, namely, with $\tau^C(0) - \left.\frac{\partial \tau^C}{\partial m}\right|_{m=0} > 0$ and $t^C(1) + \left.\frac{\partial t^C}{\partial m}\right|_{m=1} > 0$, firms facing low transaction or transportation costs and high pollution intensity in the home country tend to do bisourcing.[21]

Finally, we consider m^G that maximizes global welfare

$$GW^C(m) = \int_0^{q(t^C(m),\tau^C(m),m)} P^C(v)\,dv - [c + (1-m)k]q^C(t^C(m), \tau^C(m), m) - ED_h\left(z_h^C(m)\right) - ED_f\left(z_f^C(m)\right),$$

where $z_h^C(m) = me_h^C(q^C(t^C(m), \tau^C(m), m))$ and $z_f^C(m) = (1-m)e_f^C(q^C(t^C(m), \tau^C(m), m))$.[22] Given Equations (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 ($ED_h' e_h^C$).

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

[21]The signs of $\tau^C(0) - \left.\frac{\partial \tau^C}{\partial m}\right|_{m=0}$ and $t^C(1) + \left.\frac{\partial t^C}{\partial m}\right|_{m=1}$ are ambiguous. In our linear example in Appendix A.3, we show that when pollution intensity in the home country increases, firm I tends to choose bisourcing.

[22]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.

4 | EXAMPLE

We assume that the inverse demand function for the final goods is $P = 1 - q$, where P is the price and q 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.

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.[23]

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 bisourcing, since $m^* < m^{**}$. When only the home country imposes tax, firm I has the incentive to choose bisourcing to avoid the tax in the home country. However, the presence of the foreign tax reduces firm I's benefit from outsourcing.

Bisourcing 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 $ED_h^*(m^*) + ED_f^*(m^*) - ED_f^*(m = 0) = \frac{k^2(31k^2 + 2k(S - 30) - 4S + 40)}{80(41k^2 + 4k(S - 20) - 4S + 40)} - \frac{5}{2}(1 - k)^2 > 0$ 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 $ED_h^*(m^*) + ED_f^*(m^*) - ED_h^*(m = 1) = \frac{k^2(31k^2 + 2k(S - 30) - 4S + 40)}{80(41k^2 + 4k(S - 20) - 4S + 40)} - \frac{10}{441} > 0$ for $0 < k < 1$, where $ED_h^*(m = 1)$ is global environmental damage under complete in-house input production. Therefore, bisourcing increases global environmental damage.

When both countries impose taxes/subsidies, we obtain

$$ED_h^{**}(m^{**}) + ED_f^{**}(m^{**}) - ED_f^{**}(m = 0) = \frac{k^2(2J(k - 2) + 43k^2 - 80k + 80)}{320(2J(k - 2) + 33k^2 - 80k + 80)} - \frac{5}{288}(1 - k)^2 > 0$$

for $0 < k < 1$, where $J \equiv \sqrt{10}\sqrt{23k^2 - 40k + 40}$. We also obtain

[23]For our parameter values, the tax rates in the bisourcing 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 bisourcing makes it negative by reducing the importance of the environmental problem in the home country relative to the inefficiency due to product-market imperfection.

$$ED_h^{**}(m^{**}) + ED_f^{**}(m^{**}) - ED_h^{**}(m=1) = \frac{k^2(2J(k-2) + 43k^2 - 80k + 80)}{320(2J(k-2) + 33k^2 - 80k + 80)} - \frac{10}{441} > 0$$

if $0 < k < 0.271$. Therefore, bisourcing can increase global environmental damage.

Next, we compare firm I's incentive for bisourcing, 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, that is,* $m^C < m^{**}$.

(ii) *Total environmental damage is higher under harmonization compared with the situation where the countries set the environmental taxes non-cooperatively. Global welfare can be lower under harmonization compared with 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 Appendices A.2 and A.3, respectively.

(ii) We get $ED_h^{**}(m^{**}) + ED_f^{**}(m^{**}) < ED_h^C(m^C) + ED_f^C(m^C)$, since

$$\begin{aligned} &ED_h^{**}(m^{**}) + ED_f^{**}(m^{**}) - (ED_h^C(m^C) + ED_f^C(m^C)) \\ &= \frac{k^2(2J(k-2) + 43k^2 - 80k + 80)}{320(2J(k-2) + 33k^2 - 80k + 80)} \\ &\quad - \frac{k^2(41k^2 + 2k(R-40) - 4R + 80)}{320(31k^2 + 2k(R-40) - 4R + 80)} < 0, \end{aligned}$$

where $J \equiv \sqrt{10}\sqrt{23k^2 - 40k + 40}$ and $R \equiv \sqrt{10}\sqrt{21k^2 - 40k + 40}$. We also get

$$\begin{aligned} GW^{**}(m^{**}) - GW^C(m^C) = &\frac{k^2(24k^2 + k(J-40) - 2J + 40)}{160(33k^2 + 2k(J-40) - 4J + 80)} \\ &- \frac{k^2(21k^2 + k(R-40) - 2R + 40)}{160(31k^2 + 2k(R-40) - 4R + 80)} > 0 \end{aligned}$$

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, that is, $m^C < m^G$. Similarly, the range of k for which outsourcing occurs is lower under global welfare maximization.

(ii) Global welfare is higher under global welfare maximization compared with harmonization, but total environmental damage can be lower under the latter case than the former case.

Proof.

(i) We obtain $\frac{\partial \pi^C}{\partial m}(m)\Big|_{m=m^G} = \frac{10(k-2)^3 k}{121(21k^2-40k+40)} < 0$, 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

$$
\begin{aligned}
&ED_h^C(m^C) + ED_f^C(m^C) - (ED_h^G(m^G) + ED_f^G(m^G)) \\
&= \frac{k^2(41k^2 + 2k(R-40) - 4R + 80)}{320(31k^2 + 2k(R-40) - 4R + 80)} - \frac{221k^2 + 400(1-k)}{9680} < 0,
\end{aligned}
$$

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 bisourcing compared with harmonization. □

Since firm I can affect the tax rate through its sourcing decision, its choice of in-house production is lower under harmonization compared with the global welfare maximization level. Hence, the environmental damage in the foreign (home) country is higher (lower) under harmonization compared with 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 bisourcing, ignored the tax/subsidy policies of the governments, which are particularly important in the presence of environmental pollution. We derive the conditions for bisourcing, complete outsourcing, and no outsourcing in the presence of tax/subsidy policies and environmental pollution.

Our paper provides a new rationale for bisourcing and show that even if the existing reasons for bisourcing, 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 bisourcing. However, the incentive for outsourcing reduces in the presence of the tax/subsidy policy of the foreign country compared with the situation where only the home country imposes tax/subsidy.

We also discuss the implications of international harmonization and global welfare maximizing bisourcing. 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 with 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.

ACKNOWLEDGMENTS

We would like to thank an anonymous referee of this journal and the participants at the "Workshop on Energy Regulation and Global Environmental Issues," Loughborough University, UK, for helpful comments and suggestions. The usual disclaimer applies.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

ORCID

Arijit Mukherjee http://orcid.org/0000-0002-9611-2888

REFERENCES

Al-Saadon, Y., & Das, S. P. (1996). Host-country policy, transfer pricing and ownership distribution in international joint ventures: A theoretical analysis. *International Journal of Industrial Organization*, *14*, 345–364.

Antonietti, R., De Marchi, V., & DiMaria, E. (2017). Governing offshoring in a stringent environmental policy setting: Evidence from Italian manufacturing firms. *Journal of Cleaner Production*, *155*, 103–113.

Arya, A., Mittendorf, B., & Sappington, D. E. M. (2008). The make-or-buy decision in the presence of a rival: Strategic outsourcing to a common supplier. *Management Science*, *54*, 1747–1758.

Bárcena-Ruiz, J. C., & Campo, M. L. (2012). Partial cross-ownership and strategic environmental policy. *Resource and Energy Economics*, *34*, 198–210.

Baye, M., Crocker, K., & Ju, J. (1996). Licensing, franchising, and divestiture incentives in oligopoly. *The American Economic Review*, *86*, 223–236.

Beladi, H., & Mukherjee, A. (2012). Market structure and strategic bi-sourcing. *Journal of Economic Behavior and Organization*, *82*, 210–219.

Chen, T. J., Chen, H., & Ku, Y. H. (2004). Foreign direct investment and local linkages. *Journal of International Business Studies*, *35*, 320–333.

Chen, Y. (2011). Strategic sourcing for entry deterrence and tacit collusion. *Journal of Economics*, *102*, 137–156.

Choi, J. P., & Davidson, C. (2004). Strategic second sourcing by multinationals. *International Economic Review*, *45*, 579–600.

Choi, T. M. (2013). Local sourcing and fashion quick response system: The impacts of carbon footprint tax. *Transportation Research Part E*, *55*, 43–54.

Cohen, L., & Young, A. (2006). *Multisourcing: Moving beyond outsourcing to achieve growth and agility*. Boston, MA: Harvard Business School Press.

Cole, M. A., Elliot, R. J. R., & Fredriksson, P. G. (2006). Endogenous pollution havens: Does FDI influence environmental regulations? *Scandinavian Journal of Economics*, *108*, 157–178.
Cole, M. A., Elliott, R. J. R., & Okubo, T. (2014). International environmental outsourcing. *Review of World Economics*, *150*, 639–664.
Corchon, L. C., & Gonzales-Maestre, M. (2000). On the competitive effects of licensing. *Mathematical Social Sciences*, *39*, 71–79.
De Santis, A. R., & Stähler, F. (2009). Foreign direct investment and environmental taxes. *German Economic Review*, *10*, 115–135.
Dijkstra, B. R., Mathew, A. J., & Mukherjee, A. (2011). Environmental regulation: An incentive for foreign direct investment. *Review of International Economics*, *19*, 568–578.
Du, J., Lu, Y., & Tao, Z. (2006). Why do firms conduct bi-sourcing? *Economics Letters*, *92*, 245–249.
Duffy-Deno, K. T. (1992). Pollution abatement expenditures and regional manufacturing activity. *Journal of Regional Science*, *32*, 419–436.
Duval, Y., & Hamilton, S. F. (2002). Strategic environmental policy and international trade in asymmetric oligopoly markets. *International Tax and Public Finance*, *9*, 259–271.
Eerola, E. (2006). International trade agreements, environmental policy, and relocation of production. *Resource and Energy Economics*, *28*, 333–350.
Emons, W. (1996). Good times, bad times, and vertical upstream integration. *International Journal of Industrial Organization*, *14*, 465–484.
Farrell, J., & Gallini, N. (1988). Second-sourcing as commitment: Monopoly incentives to attract competition. *The Quarterly Journal of Economics*, *103*, 673–694.
Friedman, J., Gerlowski, D. A., & Silberman, J. (1992). What attracts foreign multinational corporations? Evidence from branch plant location in the United States. *Journal of Regional Science*, *32*, 403–418.
Golmbek, R., Greaker, M., & Hoel, M. (2010). Carbon taxes and innovation without commitment. *The B.E. Journal of Economic Analysis & Policy*, *10*. https://doi.org/10.2202/1935-1682.2473
Hattori, K. (2013). Environmental innovation and policy harmonization in international oligopoly. *Environment and Development Economics*, *18*, 162–183.
He, D., & Nickerson, J. (2006). Why do firms make and buy? Efficiency, appropriability, and competition in the trucking industry. *Strategic Organization*, *4*, 43–69.
Helm, D., Hepburn, C., & Mash, R. (2003). Credible carbon policy. *Oxford Review of Economic Policy*, *19*, 438–450.
ICAO. (2016). *ICAO environmental report 2016 aviation and climate change*. Montreal, Canada: The Environment Branch of the International Civil Aviation Organization (ICAO).
IPCC. (2007). Climate change 2007: Mitigation. In B. Metz, O. R. Davidson, P. R. Bosch, R. Dave & L. A. Meyer (Eds.), *Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge, United Kingdom and New York, NY: Cambridge University Press.
IPCC. (2014). Climate change 2014: Mitigation of climate change. In O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlomer, C. von Stechow, T. Zwickel & J. C. Minx (Eds.), *Contribution of working group III to the fifth assessment report of the intergovernmental panel on climate change*. Cambridge, United Kingdom and New York, NY: Cambridge University Press.
Jeppesen, T., List, J. A., & Folmer, H. (2002). Environmental regulations and new plant location decisions: Evidence from a meta-analysis. *Journal of Regional Science*, *42*, 19–49.
Johnson, E. M. (2007). Dual sourcing strategies: Operational hedging and outsourcing to reducing risk in low-cost countries. In C. Y. Lee & H. L. Lee (Eds.), *Building supply chain excellence in emerging economies*. Boston, MA: Springer-Verlag.
Kogut, B., & Kulatilaka, N. (1994). Operating flexibility, global manufacturing, and the option value of a multinational network. *Management Science*, *40*, 123–139.
Levinson, A. (1996). Environmental regulations and manufacturers' location choices: Evidence from the census of manufactures. *Journal of Public Economics*, *62*, 5–29.
List, J. A., McHone, W. W., & Millimet, D. L. (2003). Effects of air quality regulation on the destination choice of relocating plants. *Oxford Economic Papers*, *55*, 657–678.
Lyu, Y. (2016). Evaluating carbon leakage emissions in undertaking offshored production tasks: The case of China. *Journal of Cleaner Production*, *116*, 32–39.

Markusen, J. R. (1975). International externalities and optimal tax structures. *Journal of International Economics*, *5*, 15–29.
McConnell, V. D., & Schwab, R. M. (1990). The impact of environmental regulation on industry location decisions: The motor vehicle industry. *Land Economics*, *66*, 67–81.
Michel, B. (2013). Does offshoring contribute to reducing domestic air emissions? Evidence from Belgian manufacturing. *Ecological Economics*, *95*, 73–82.
Mukherjee, A. (2000). Host-country policy: Commitment or no-commitment: A theoretical analysis. *Policy Reform*, *4*, 75–89.
Mukherjee, A. (2008). Unionised labour market and strategic production decision of a multinational. *Economic Journal*, *118*, 1621–1639.
Mukherjee, A., & Pennings, E. (2006). Tariffs, licensing and market structure. *European Economic Review*, *50*, 1699–1707.
Neary, J. P., & Leahy, D. (2000). Strategic trade and industrial policy towards dynamic oligopolies. *Economic Journal*, *110*, 484–508.
Nokia Annual Report. (2003). Nokia Form 20-F 2003. Retrieved from https://www.nokia.com/system/files/files/form20-f-03-pdf.pdf
Poyago-Theotoky, J. A. (2007). The organization of R&D and environmental policy. *Journal of Economics Behavior and Organization*, *62*, 63–75.
Puranam, P., Gulati, R., & Bhattacharya, S. (2013). How much to make and how much to buy? An analysis of optimal plural sourcing strategies. *Strategic Management Journal*, *34*, 1145–1161.
Rob, R., & Vettas, N. (2003). Foreign direct investment and exports with growing demand. *Review of Economic Studies*, *69*, 1–20.
Schwartz, M., & Thompson, E. A. (1986). Divisionalization and entry deterrence. *Quarterly Journal of Economics*, *101*, 307–322.
Shepard, A. (1987). Licensing to enhance the demand for a new product. *Rand Journal of Economics*, *18*, 360–368.
Staiger, R., & Tabellini, G. (1987). Discretionary trade policy and excessive protection. *American Economic Review*, *77*, 823–837.
Stenbacka, R., & Tombak, M. (2012). Make and buy: Balancing bargaining power. *Journal of Economic Behavior and Organization*, *81*, 391–402.
Straume, O. R. (2006). Product market integration and environmental policy coordination in an international duopoly. *Environmental and Resource Economics*, *34*, 535–563.
Yuan, L. (1999). Product differentiation, strategic licensing, and persistence of monopoly. *Journal of Economics and Management Strategy*, *8*, 581–602.

How to cite this article: Iida T, Mukherjee A. Make and buy in a polluting industry. *J Public Econ Theory*. 2020;22:1852–1874. https://doi.org/10.1111/jpet.12440

APPENDIX A

A.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 $q(t, m) = \frac{1-(1-m)k-m\alpha t}{2}$ and $\pi(t, m) = \frac{(1-(1-m)k-m\alpha t)^2}{4}$, respectively.

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

The equilibrium tax rate is

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

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 $\pi^*(m) = \frac{(1-(1-m)k)^2}{(2\gamma m^2\alpha^2+1)^2}$.

Note that we set $t^*(0) = 0$ because polluting activity is not conducted in the home country when $m = 0$. In this case, we obtain $q^*(0) = \frac{1-k}{2}$ and $\pi^*(0) = \frac{1}{4}(1-k)^2$.

At Stage 1, firm I determines m to maximize its profit, $\pi^*(m)$. We have

$$\frac{\partial \pi^*}{\partial m}(m) = -\frac{2(1-(1-m)k)(k(2\gamma m^2\alpha^2 - 4\gamma m\alpha^2 - 1) + 4\gamma m\alpha^2)}{(2\gamma m^2\alpha^2+1)^3}. \tag{A1}$$

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

Next, we consider the case where $\gamma > 0$, that is, production creates pollution. In this case, we obtain that $\left.\frac{\partial \pi^*}{\partial m}(m)\right|_{m=0} = 2(1-k)k > 0$, and $\left.\frac{\partial \pi^*}{\partial m}(m)\right|_{m=1} = \frac{2(k-4\gamma\alpha^2+2\gamma\alpha^2 k)}{(2\gamma\alpha^2+1)^3} < 0$ if $k < \frac{4\gamma\alpha^2}{2\gamma\alpha^2+1} \equiv k^*$. Therefore, firm I prefers bisourcing, that is, the equilibrium m, say, m^*, is between 0 and 1 if $0 < k < k^*$. Then, we have[24]

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

Since we assume $t^*(0) = 0$, there is a discontinuity at $m = 0$. Therefore, we need to compare the profit with $m = m^*$ to that of with $m = 0$. When $\alpha = 1$ and $\gamma = 10$, we obtain $\pi^*(m^*) - \pi^*(0) = \frac{k^4}{80(41k^2 - 80k + 40 - 4(1-k)\sqrt{5}\sqrt{21k^2 - 40k + 20})} - \frac{1}{4}(1-k)^2 > 0$. This is because firm I chooses m^* that induces the optimal tax to be negative.

Finally, we consider the effect of pollution intensity α on m. We obtain $\frac{\partial k^*}{\partial \alpha} > 0$. Therefore, pollution intensity in the home country promotes firm I's bisourcing strategy.[25]

A.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 $q(t, \tau, m) = \frac{1 - mt\alpha - (1-m)(k+\tau\beta)}{2}$ and $\pi(t, \tau, m) = \frac{(1 - mt\alpha - (1-m)(k+\tau\beta))^2}{4}$, respectively.

[24] 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 $k = 0$.

[25] We obtain $t^*(1) + \left.\frac{\partial t^*}{\partial m}\right|_{m=0} = \frac{8\alpha^2\gamma + k(4\alpha^4\gamma^2 - 1)}{\alpha(2\alpha^2\gamma+1)^2} > 0$ 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 bisourcing.

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

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

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

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.

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 $m = 0$, we obtain $q^{**}(0) = \frac{1-k}{2\gamma\beta^2+4}$, $\tau^{**}(0) = \frac{(1-k)(\gamma\beta^2+1)}{\beta(\gamma\beta^2+2)}$, and $\pi^{**}(0) = \frac{(1-k)^2}{(2\gamma\beta^2+4)^2}$. In addition, when $m = 1$, we obtain $q^{**}(1) = \frac{1}{2\alpha^2\gamma+1}$, $t^{**}(1) = \frac{2\alpha^2\gamma-1}{2\alpha^3\gamma+\alpha}$, and $\pi^{**}(1) = \frac{1}{(2\alpha^2\gamma+1)^2}$.

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

$$\frac{\partial\pi^{**}}{\partial m}(m) = -\frac{2(1-(1-m)k)(k(2\beta^2\gamma + 2\gamma m(m-2)(\alpha^2+\beta^2) - 3) + 4\gamma(m(\alpha^2+\beta^2) - \beta^2))}{(2\beta^2\gamma + 2\gamma m^2(\alpha^2+\beta^2) - 4\beta^2\gamma m + 3)^3}. \tag{A2}$$

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

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

Now, we consider the equilibrium outsourcing choice of firm I when $\gamma > 0$.[26]

We obtain from Equation (A2) that $\left.\frac{\partial\pi^{**}}{\partial m}(m)\right|_{m=0} = -\frac{2(1-k)(k(2\beta^2\gamma-3) - 4\beta^2\gamma)}{(2\beta^2\gamma+3)^3} > 0$ for $0 < k < 1$, $\gamma > 0$, and $\beta > 0$. On the other hand, we obtain

$$\left.\frac{\partial\pi^{**}}{\partial m}(m)\right|_{m=1} = \frac{k(4\alpha^2\gamma+6) - 8\alpha^2\gamma}{(2\alpha^2\gamma+3)^3} < 0$$

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

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 bisourcing, that is, the equilibrium m, say, m^{**}, is between 0 and 1 if $0 < k < k^{**}$.

Since we assume $t^{**}(0) = 0$ and $\tau^{**}(1) = 0$, there are discontinuities at $m = 0$ and $m = 1$. When $\alpha = \beta = 1$ and $\gamma = 10$, we obtain $\pi^{**}(m^{**}) - \pi^{**}(0) > 0$ and $\pi^{**}(m^{**}) - \pi^{**}(1) > 0$, for $0 < k < k^{**}$, where $\pi^{**}(m^{**}) = \frac{k^4}{160(33k^2+80(1-k)-2(2-k)\sqrt{10}\sqrt{23k^2-40k+40})}$, $\pi^{**}(0) = \frac{1}{576}(1-k)^2$, and $\pi^{**}(1) = \frac{1}{441}$. Therefore, in this case, firm I does bisourcing.

Note that firm I may choose a bisourcing strategy even if $k = 0$ when the foreign country imposes environmental taxes. Indeed, when $k = 0$, using Equation (A2), we have $m^{**} = \frac{\beta^2}{\alpha^2+\beta^2}$. When $\alpha = \beta = 1$ and $\gamma = 10$, we obtain $\pi^{**}(\frac{1}{2}) - \pi^{**}(0) = \frac{1}{169} - \frac{1}{576} > 0$ and $\pi^{**}(\frac{1}{2}) - \pi^{**}(1) = \frac{1}{169} - \frac{1}{441} > 0$, for $k = 0$, which means that firm I does bisourcing.

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 bisourcing.

A.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.

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

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

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

We obtain $\frac{\partial \pi^C}{\partial m}(m)\Big|_{m=0} = \frac{2(k-1)(k(2\beta^2\gamma-1)-4\beta^2\gamma)}{(2\beta^2\gamma+1)^3} > 0$ for $0 < k < 1, \gamma > 0$, and $\beta > 0$. In addition, we obtain

$$\frac{\partial \pi^C}{\partial m}(m)\Bigg|_{m=1} = \frac{2(-4\alpha^2\gamma + 2\alpha^2\gamma k + k)}{(2\alpha^2\gamma+1)^3} < 0$$

if $k < \frac{4\alpha^2\gamma}{2\alpha^2\gamma+1} \equiv k^C$. Therefore, firm I prefers bisourcing, that is, the equilibrium m, say, m^C, is between 0 and 1 if $0 < k < k^C$.

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 bisourcing.

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 $0 < k < \frac{2\alpha^2\gamma}{2\alpha^2\gamma + 1} \equiv k^G$.[27] Therefore, a bisourcing strategy can maximize global welfare when $0 < k < k^G$.

[27]When $k \geq \frac{2\alpha^2\gamma}{2\alpha^2\gamma+1}$, $m = 1$ maximizes global welfare.