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Offshoring, trade and environmental policies: Effects of transboundary pollution

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Abstract

This study develops a two-country model, Home and Foreign, with offshoring and environmental spillover. A final good producer in Home can produce (homogeneous) final goods using customized inputs produced by its partner–supplier in Foreign. The intermediate input price is determined by Nash bargaining, presenting a hold-up problem. Additionally, input production causes transboundary pollution. Home and Foreign governments can set trade taxes. Moreover, the Foreign government can set the environmental standard. This model demonstrates that, under no international policy

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agreement, both the environmental standard and the quantity of the intermediate input are lower than the first-best levels. This inefficiency persists even if both governments conclude an agreement.

JEL classification: F12; F13; F18; L24; Q56

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1 Introduction

Increasingly over the last several decades, some economically developing (or emerging) countries (Brazil, Tunisia, South Africa, Vietnam, Thailand, Indonesia, Bangladesh, India, China, and so on) have received foreign direct investment (FDI) from economically developed countries. Those economically developing countries have achieved higher rates of economic growth. Industrialization in such countries has taken place against the background of increased offshoring of intermediate inputs. Offshoring is now widely recognized as a strategic weapon to survive in a global economy. Johnson and Noguera (2012, p.224) point out that "trade in intermediate inputs accounts for as much as two thirds of international trade." Levinson (2010, p.63) makes the following wise remark, which presents a crucial point related to such international trade.

International trade has environmental consequences, and environmental policy can have international trade consequences. Levinson (2010, p.63)

In facts, international environmental problems have become increasingly severe. For example, Greenhouse gas emissions from economically developing and emerging-Asian countries are estimated to become much greater.[1] As revealed by an empirical study conducted by Grether and Mathys (2013), enormous and increasing amounts of SO_2 are generated through offshoring of intermediate inputs. Furthermore, in recent years, transboundary air pollution (e.g., PM2.5 etc.) from China has become an extremely important policy issue in eastern Asian countries[2]. These transboundary pollution problems might lower consumer utility. It socially necessitates reduction of the transboundary pollution, which is harmful. Moreover, corresponding to the new era of offshoring economy, we should carefully examine the welfare impacts generated by transboundary pollution and transboundary offshoring of intermediate inputs.[3]

To study the interaction between offshoring and international environmental problems, this paper presents development of a model incorporating transboundary pollution explicitly to the offshoring model by Antras and Staiger (2012a,b). We assume two small country, Home and Foreign, and a final good

[1] For example, see OECD (2012) and Jakob and Marschinski (2013).
[2] For an explanation of transboundary pollution problems in European countries, see Barret (2003, Chapter 1).
[3] For example, see Staiger and Sykes (2011).

producer in Home can produce (homogeneous) final goods using customized inputs produced by its partner–supplier in Foreign. Production of the intermediate inputs necessarily creates transboundary pollution. In this model, while the Home government can set only trade taxes, the Foreign government can set not only trade taxes but also the environmental standard.

Three reasons exist for such modelling. The first one is that, among the existing offshoring models, only Antras and Staiger (2012a,b) specifically examine economic distortion derived through bilateral trading and examine the tax policy. The second is that many firms of economically developed countries outsourcing production processes to foreign firms that are not their own local subsidiaries.[4] The Antras and Staiger (2012a,b) offshoring model describes such circumstances well. The third one is the transboundary pollution effect. Peters *et al.* (2011) reports that recent source points of transboundary pollution have changed greatly compared with those before, although Antras and Staiger (2012a,b) do not consider transboundary pollution.

The main goal of this paper is to find the implication on international policy coordination. As described by Levinson (2010), a complicated interaction connects international trade and the global environment.[5] One reason is that although domestic environmental regulation is regarded as a trade barrier, a strategic relation exists between each country's environmental and trade policies. Policy coordination among concerned countries can be required to achieve policy goals and to improve world welfare. Under the current negotiation regime of the World Trade Organization (WTO), discussions of trade–environment rules are conducted in the Committee on Trade and Environment. With respect to such discussion of trade rules, the Bagwell and Staiger (2001) examination is useful from the viewpoint of theoretical research. Bagwell and Staiger (2001) describe the simultaneous decision-marking model of tariff and domestic policies when neither offshoring of intermediate good nor transboundary pollution is present. Their main result is that the efficient policy combination of tariff bindings and standards policies can be implemented under international negotiation about the trade volume.

In this paper, we first demonstrate that, under no international policy coordination, the sum of social

[4] Even though the model of this paper is extended to the case in which offshoring-receiving firms are subsidiary firms of the parent company, our results are fundamentally robust.

[5] See also Copeland and Taylor (1994, 1995a, 1995b), Ludema and Wooton(1994), and Antwiler *et al.* (2001).

welfare of home and foreign countries (referred as the joint welfare) cannot be maximized. Interestingly, comparative statics show that the signs of impacts of the degree of international emission spillover on the joint welfare and aggregate pollution are ambiguous. However, if the joint welfare is increasing in the degree of emission spillover, aggregate pollution must be increased.

This paper also reveals that even if home and foreign governments can negotiate over both trade taxes and the environmental standard, the joint welfare can be maximized. But this result is not surprising. Next, we examine the usefulness of the negotiation over the international trade volume of the intermediate inputs such as Bagwell and Staiger (2001) and Antras and Staiger (2012a,b). This paper shows that the negotiation over the international trade volume cannot fully eliminate the distortion if any emission spillover exists. In this case, the second-best trade volume, which maximize the joint welfare, is higher than the trade volume in the case where both governments can negotiate over all policy instruments.

This paper has two purposes. The first is to provide new and meaningful findings related to welfare impact by transboundary emissions generated by the offshoring economy. Such findings can make strong impacts on environmental economics because the seminal survey of transboundary pollution by Missfeldt (1999) does not include emissions spillover effects generated by recent increases of offshoring of intermediate goods. The second one is to incorporate the parameter of transboundary pollution explicitly into the existing offshoring model and to ascertain the welfare effects of transboundary pollution and a desirable policy mix when environmental and trade policies are determined simultaneously and endogenously. In fact, the vast bulk of the international trade literature includes descriptions of the presence of environmental externality (e.g. Conrad (1993), Barrett (1994), Walz and Wellisch (1997), Hamilton and Requate (2004), Lai and Hu (2008), Greaker (2013) and others).[6] Those papers, which are based on the Brander and Spencer strategic trade model (e.g., Brander and Spencer (1985)), examine trade and environmental policies when the behaviors of firms and governments are strategic. In contrast, recent research streams examine offshoring of production of intermediate inputs. Particularly, the offshore production model of intermediate goods by Antras and Staiger (2012a,b), Ornelas and Turner (2008), and others are bridging

[6] As survey papers of international trade and environment, see Jayadevappa and Chhatre (2000) and Sturm (2003). Esty (2001) gives excellent discussions of issues in this field.

international trade and incomplete contract theory.[7] At the same time, as Levinson (2010) notes about US firms' pollution offshoring effects, emissions in economically developing and emerging countries producing intermediate inputs might increase. The present paper explicitly incorporates the transboundary pollution generated by producing intermediate good into the Antras and Staiger (2012a,b) model, and examines the welfare effects of transboundary pollution as well as the policy mix when environmental and trade policy variables are determined endogenously and simultaneously. This paper attempts to fill a large gap separating offshoring and transboundary pollution literatures.

The remainder of this paper is organized as follows. The next section presents the model. Section 3 solves the game and gives Nash equilibrium policies. Section 4 presents consideration of free trade agreements and market access commitment, and also explains the derivation of policy implications. The final section presents conclusions and some directions for future research.

2 The Basic Model

Following Antras and Staiger (2012a), we construct a two small countries model with an offshoring economy and transboundary pollution. Its two countries, Home (H) and Foreign (F), face a fixed world price for a single homogeneous final good. Although Home is inhabited by a unit measure of final good producers, Foreign is inhabited by a unit measure of inputs suppliers. To produce the final good, final goods producers in Home must import intermediate inputs from inputs suppliers in Foreign.

A final good producer can produce final goods using a customized intermediate input x. The production function of final good producers is given as $y(x)$, with $y(0) = 0$, $y' > 0$, $y'' < 0$, $\lim_{x \to 0} y' = \infty$, and $\lim_{x \to \infty} y' = 0$. The input producer can produce the intermediate inputs with constant marginal costs. The production of each unit of the intermediate inputs gives rise to pollution. For simplification, the final good production generates no pollution. The environmental standard is denoted as $e \in [0, \bar{e}]$, which is determined by the Foreign government, under which intermediate inputs production necessarily creates pollution as a by-product e. We assume that the marginal cost of input production depends on environmental standard e, and that it is denoted by $v(e)x$, where $v' < 0$. For simplicity, it is assumed

[7] For other offshoring models, see Acemoglu *et al.* (2007), Grossman and Rossi-Hansberg (2008), and others.

that $v(e)$ is the linear function of e. Additionally, stricter environmental standard also requires higher abatement cost. More formally, the pollution abatement cost is $A(e)$, with $A(\bar{e}) = 0$, $A' < 0$, $A'' > 0$, $\lim_{e \to 0} A' = -\infty$, and $\lim_{e \to \bar{e}} A' = 0$.

The pollution does not confine itself to Foreign, where intermediate input production takes place. It therefore gives rise to a transboundary pollution problem. The degree of emissions spillover is $\theta \in [0,1]$. Home receives transboundary pollution $E_H = \theta ex$ from the input production in Foreign. The environmental damage in Foreign is $E_F = (1-\theta)ex$.[8] As the value of θ converges to 0, then the input suppliers' emissions become completely local. If $\theta = 1/2$, then the emissions are purely global.

A final good producer matches an input supplier (one-to-one matching) and imports intermediate inputs from this supplier.[9] Suppliers in the Foreign country tailor their inputs specifically to the needs of a (matched) final good producer in the Home country. For simplicity, these inputs are assumed to be useless to alternative final good producers. Additionally, no enforceable contract can be signed between suppliers and producers before the initial supplier investment decisions. Without an initial contract, the price at which each supplier in the foreign country sells its inputs to a producer in the Home country is then determined through Nash bargaining.

The utility function of a representative household in country $j \in \{H, F\}$ is

$$U_j = u(c_j) - \delta E_j,$$

where c_j is the consumption of the final goods in country $j \in \{H, L\}$, where $u' > 0$ and $u'' < 0$. The final term is the disutility from the pollution where E_j is the pollution in country j, and δ represents the marginal environmental damage.

The price of final goods is denoted by p. Because Home and Foreign are small countries, p is determined exogenously. By this assumption, the consumer surplus in Home and Foreign are determined exogenously. The model is then tractable.[10]

[8] This property, related to transboundary pollution, is also assumed by Conconi (2003, p.403) and Canton (2008, p.300).

[9] The analyses described in this paper assumes that no input supplier in the Foreign country is a subsidiary firm of a final good producer in the Home country. Furthermore, input firms are assumed to emit a single type of pollution.

[10] In Antras and Staiger (2012 a), final goods price is determined endogenously because they consider the tariff on the final goods trade.

For input goods trade, both governments can set the trade tax/subsidy. Home is an importing country of intermediate inputs. Therefore, the Home government can set the importing tax τ_H. If $\tau_H < 0$, then the Home government sets the importing taxes. Similarly, Foreign is an exporting country. The Foreign government can set the exporting taxes $\tau_F > 0$ or subsidies $\tau_F < 0$. Additionally, the Foreign government can set the environmental standard e under which the input supplier must choose e.

We can summarize the timing of events as follows.

Stage 1. The Home government selects its trade tax τ_H. The Foreign government selects its trade tax τ_F and environmental standard e.

Stage 2. The final goods producers in the Home country and inputs suppliers in the Foreign country are randomly matched, producing a unit measure of matches. Each firm decides whether to stay with the match or exit the market. In the latter case, each agent obtains an ex ante outside option (equal to zero).

Stage 3. Each supplier pays the pollution abatement costs and produces customized input (at marginal cost of $v(e)$).

Stage 4. Each producer–supplier pair bargains over the price of the intermediate input. We consider the generalized Nash bargaining solution with weights α and $1-\alpha$ for the final good producer and intermediate input supplier, where $\alpha \in [0,1]$. Weights for the final good producer α are designated as the final good producer's bargaining power.

Stage 5. Each final goods producer in the Home country imports x from its partner–supplier, produces the final goods, and payments agreed in stage 4 are settled.

Finally, to ensure the interior solution, we assume

$$v' + \delta(1-\theta)(1-\alpha) > 0. \qquad \text{(Assumption 0)}$$

The inequality presented above shows that the marginal production costs of more stringent environmental standard is lower than the marginal benefits obtained through reduction of the emission per intermediate input.

3 Nash Equilibrium Policies

The equilibrium concept in this model is the Sub-game Perfect Nash Equilibrium (SPNE) characterized using the backward induction method. First, we characterize the market equilibrium.

3.1 Market Equilibrium

In stage 5, if a final good producer uses inputs to produce the final goods, then its (post-tax) revenue is given as $py(x) - \tau x$, where $\tau = \tau_H + \tau_F$. In stage 4, as a result of the Nash bargaining game, the payoff of a final good producer is $\alpha (py(x) - \tau x)$. The payoff of the input supplier is $(1-\alpha)(py(x) - \tau x)$, where α is the bargaining power of final goods producers. We assume that the outside options of both final good producers and inputs suppliers in the Nash bargaining are 0.

In stage 3, input suppliers choose the amount of customized input x to maximize their profits. Using the Nash bargaining outcome, the profit of an input supplier is given as $(1-\alpha)(py(x) - \tau x) - v(e)x$, so the equilibrium quantity $\hat{x}$ is determined as $\hat{x} \in \arg\max (1-\alpha)(py(x) - \tau x) - v(e)x$. The first-order condition is

$$0 = (1-\alpha)(py' - \tau) - v(e). \tag{1}$$

From the concavity of $y(x)$, the equilibrium quantity of the intermediate inputs is demonstrably lower when the bargaining power of the final goods producer is higher.

With respect to comparative-static results, the impacts of each policy on $\hat{x}$ are

$$\frac{\partial \hat{x}}{\partial \tau_H} = \frac{\partial \hat{x}}{\partial \tau_F} = \frac{\partial \hat{x}}{\partial \tau} = \frac{1}{py''} < 0, \tag{2}$$

$$\frac{\partial \hat{x}}{\partial e} = \frac{v'}{(1-\alpha)py''} > 0. \tag{3}$$

Because $y'' < 0$ and $v' < 0$, (2) and (3) mean that although τ_H and τ_F have negative impacts on the production of intermediate inputs, e has a positive impact.

Intuitively, trade taxes on intermediate input trade are equivalent to production taxes, and the quantity of intermediate inputs then decreases with τ. Under the weaker environmental standard, the marginal costs of intermediate inputs are lower and the quantity is larger. Moreover, (3) shows that the positive impact of e on $\hat{x}$ is greater if the final goods producers have stronger bargaining power.

3.2 First-best Policies

To provide a benchmark, we characterize the first-best policies under which the sum of the Home and the Foreign welfare, so-called joint welfare, is maximized. To do so, we first define the welfare of Home and Foreign countries.

Home welfare is defined as

$$W_H = -\delta\theta ex + \alpha\left(py\left(x\right) - \tau x\right) + \tau_H x. \tag{4}$$

The first term of the equation above represents utility costs of the transboundary pollution. The second term is the profit of the final good producers. The third term is the tax revenue.

Note that the consumer surplus is constant because the final good price, p, is an exogenous variable. We can abstract the consumer surplus from the welfare function.

Similarly, Foreign welfare is defined as

$$W_F = -\delta\left(1-\theta\right)ex + \left(1-\alpha\right)\left(py\left(x\right) - \tau x\right) - v\left(e\right)x - A\left(e\right) + \tau_F x. \tag{5}$$

The first term is the utility costs of the pollution, whereas the second and third terms respectively denote the profit of the input suppliers. The fourth term represents the (fixed) abatement costs. The final term is the tax revenue.

Combining (4) and (5), the joint welfare function W is defined as

$$W = W_H + W_F = -\delta ex + py\left(x\right) - v\left(e\right)x - A\left(e\right). \tag{6}$$

The first term of (6) represents the sum of utility costs of the emission in Home and Foreign, whereas the second and third terms represent aggregate profit with inputs and the final goods producer. The final term represents the abatement costs. The joint welfare is an independently of the bargaining power of the input suppliers, α, and the degree of emissions spillover, θ.

The first-best outcome, which is given by the joint welfare maximization problem as $(x, e) \in \arg\max W$, can be characterized by the following lemma.

Lemma 1. *(i) The first-best outcomes, x^{1st} and e^{1st}, are given as*

$$0 = py' - \delta e^{1st} - v\left(e^{1st}\right), \tag{7}$$

$$0 = (\delta + v')\, x^{1st} + A'. \tag{8}$$

(ii) The second-order condition holds if

$$A'' > -\frac{(\delta + v')^2}{py''}. \qquad \text{(Assumption 1)}$$

Proof. See Appendix. □

Equation (7) implies that the first-best quantity of intermediate inputs equates to the marginal revenue, y', with the marginal environmental costs and fiscal, δe^{1st} and $v\left(e^{1st}\right)$. Similarly, (8) implies that the first-best environmental standard e^{1st} equates the marginal utility from an additional pollution reduction, δx^{1st}, with the marginal abatement costs, $v' x^{1st} + A'$. Furthermore, the first-best outcomes are independent of the bargaining power of the final good producer α and the degree of emissions spillover θ because the parameters affect only the distribution of the producer surplus and the pollution.

Next, we define the first-best policies which can produce the first-best outcomes. From a comparison of (1), (7), and (8), one can obtain the first-best policies as the following lemma.

Lemma 2. *The first-best policies are e^{1st} and $\tau^{1st} = \left(\alpha py' - \delta e^{1st}\right)/(1-\alpha)$.*

Proof. It is straightforward that the environmental standard must be e^{1st}. To implement $\hat{x} = x^{1st}$, using

(1) and (7), the trade tax should be set as

$$py' - \delta e^{1st} = (1-\alpha)\left(py' - \tau^{1st}\right),$$

which can be rewritten as

$$\tau^{1st} = \frac{\delta e^{1st} - \alpha py'}{1-\alpha}.$$

□

The first-best taxes on input trade depends on the bargaining power α. Moreover, if α is large, then the positive subsidy is optimal. If α is small, then the positive tax is optimal.

The model has two sources of inefficiency for the production of input. The first source is related with the hold-up problem, which reflects that an input and a final good producers bargain over the price of intermediate inputs. By this source, the equilibrium production level with $\tau = 0$ might be lower than the first-best production. The second one is the externalities of pollution, by which the equilibrium production with $\tau = 0$ might be higher than the first-best production level.

When α is high, the hold-up problem is more severe than the externality of pollution. Then governments should set negative taxes on trade to increase production. When α is small, the externality of pollution is severe. Then to reduce the production (and emission), positive taxes are socially efficient.

3.3 Nash Equilibrium

In the Nash equilibrium of the game between the Home and Foreign governments, policies are determined such as $(\tau_F, e) \in \arg\max W_F$ and $\tau_H \in \arg\max W_H$, subject to (1). Using (4) and (5), the first-order conditions are

$$\frac{\partial W_H}{\partial \tau_H} = 0 = \underbrace{(1-\alpha)\,\hat{x}}_{\text{Direct effect}} + \underbrace{\frac{\partial W_H}{\partial \hat{x}}\frac{\partial \hat{x}}{\partial \tau}}_{\text{Production effect}}, \tag{9}$$

$$\frac{\partial W_F}{\partial \tau_F} = 0 = \underbrace{\alpha\hat{x}}_{\text{Direct effect}} + \underbrace{\frac{\partial W_F}{\partial \hat{x}}\frac{\partial \hat{x}}{\partial \tau}}_{\text{Production effect}}, \tag{10}$$

$$\frac{\partial W_F}{\partial e} = 0 = \underbrace{-\delta\,(1-\theta)\,\hat{x} - v'\hat{x} - A'}_{\text{Direct effect}} + \underbrace{\frac{\partial W_F}{\partial \hat{x}}\frac{\partial \hat{x}}{\partial e}}_{\text{Production effect}}, \tag{11}$$

where

$$\frac{\partial W_H}{\partial \hat{x}} = -\delta\theta e + \tau_H + \frac{\alpha}{1-\alpha} v\,(e)\,, \tag{12}$$

$$\frac{\partial W_F}{\partial \hat{x}} = -\delta\,(1-\theta)\,e + \tau_F. \tag{13}$$

The second-order conditions hold if and only if

$$0 > (2-\alpha)\,y'' + (1-\alpha)\,\hat{x}y''', \tag{Assumption 2}$$

$$0 > (1+\alpha)\,y'' + \alpha\hat{x}y''', \tag{Assumption 3}$$

and

$$A'' > -\frac{[2\delta\,(1-\theta) + v']\,(1-\alpha)\,y'' - \alpha\hat{x}y'''v'}{(1-\alpha)^2\,p\,(y'')^2}v' - \frac{[\alpha v'\,(y'' + \hat{x}y''') - \delta\,(1-\theta)\,(1-\alpha)\,y'']^2}{[(1+\alpha)\,y'' + \alpha\hat{x}y''']\,(1-\alpha)^2\,p\,(y'')^2}. \tag{Assumption 4}$$

(see Appendix for detailed calculations.)

Equations (9), (10), and (11) imply that the effects of these policies on welfare in Home and Foreign countries are composed of the direct effect plus the production effect. The production effect is defined as an impact on welfare through changing the equilibrium quantity of the intermediate inputs $\hat{x}$.

Trade taxes τ_H and τ_F have positive direct effects on welfare in Home and Foreign countries. Intuitively, neither final goods producers nor input suppliers bear the full burden of the increase in τ_H and

τ_F if they have less than full bargaining power in their negotiations ($0 < \alpha < 1$). Therefore, the Home and Foreign governments can pass part of the cost of the import and exporting taxes on to the Foreign and Home while maintaining tax revenues. Consequently, both governments have an incentive to set positive trade taxes if the production effects are zero. Importantly, we note that both τ_H and τ_F have no direct effects on joint welfare W because the direct effects are a pure transfer between Home and Foreign countries.

The environmental standard, e, also has direct effects on Foreign welfare. Tightening local environmental regulation improves Foreign welfare through reduction of local emissions, $\delta(1-\theta)\hat{x}$, but also raises the production costs, $-v'\hat{x}$, and abatement costs, $-A'$. Using (6), the direct effects on joint welfare are $\partial W/\partial e = -\delta x - v'\hat{x} - A'$, which is smaller than the direct effects on the Foreign welfare because of the emission spillover.

Finally, the production effects might be positive or negative. Equation (12) shows the production effect on Home, by which an increase in outputs increases not only the profit of the final good producers and the tax revenue of Home but also emissions from the inputs goods production. Similarly, equation (13) shows the production effect on Foreign, by which an increase in outputs increases both the tax revenue and emissions in the Foreign country.

Using the first-order condition of the input producer's profit maximization problem (1), the reaction function of the Home government (9), the reaction functions of the Foreign government (10) and (11), and the production effects (12) and (13), one can obtain the equilibrium conditions that determine the equilibrium quantity of intermediate inputs, environmental standard, the trade taxes. The equilibrium production levels of intermediate inputs, environmental standards, and the trade taxes are denoted by x^{NE}, e^{NE}, τ_H^{NE}, and τ_F^{NE}.

First, combining (9) and (10), we derive the first equilibrium condition, which is designated as

$$0 = x^{NE} + \frac{\partial W}{\partial \hat{x}} \frac{\partial \hat{x}}{\partial \tau}, \qquad \text{(International condition)}$$

where

$$\frac{\partial W}{\partial \hat{x}} = \frac{\partial W_H}{\partial \hat{x}} + \frac{\partial W_F}{\partial \hat{x}} = py' - \delta e^{NE} - v\left(e^{NE}\right).$$

Recalling that to maximize the joint welfare, $\partial W/\partial\hat{x}$ must be zero. However, from $\partial\hat{x}/\partial\tau < 0$ (see (2)), the international condition implies that $\partial W/\partial\hat{x} > 0$. This fact suggests that given an environmental standard, the equilibrium quantity is smaller than the level under which the joint surplus is maximized. In other words, the sum of trade taxes, τ, is too high.

Next, combining (10) and (11), we derive the second equilibrium condition, which is designated as

$$0 = \delta(1-\theta)x^{NE} + v'x^{NE} + A' + \alpha x^{NE} \left.\frac{\partial e}{\partial \tau}\right|_{\Delta\hat{x}=0}, \qquad \text{(Intranational condition)}$$

where

$$\left.\frac{\partial e}{\partial \tau}\right|_{\Delta\hat{x}=0} \equiv -\frac{1-\alpha}{v'} > 0.$$

The international and intranational conditions can be rewritten as

$$0 = v' + (1-\alpha)\left[\delta(1-\theta) + \frac{A'}{x^{NE}}\right], \qquad (14)$$

$$0 = py' - \delta e^{NE} - v\left(e^{NE}\right) + x^{NE}py''. \qquad (15)$$

We summarize the discussion presented above for the Nash equilibrium as the following proposition.

Proposition 1. *The Nash quantity of intermediate inputs and environmental standard is definable by* (14) *and* (15). *The equilibrium is determined uniquely if and only if*

$$A'' > -\frac{1}{p}\left(\frac{v'}{1-\alpha} + \delta(1-\theta)\right)\frac{\delta + v'}{2y'' + x^{NE}y'''}. \qquad \text{(Assumption 5)}$$

Proof. See Appendix. □

Assumptions 1 to 5 show that if the pollution abatement cost and the production functions are sufficiently concave, then there exists a unique Nash equilibrium and the first-best outcome. In the following analysis, to ensure the existence and uniqueness, in addition to Assumption 0, we assume that Assumptions 1 to 5 hold.

The Nash equilibrium is presented in Fig. 1 as the intersection of (14) and (15). From total differen-

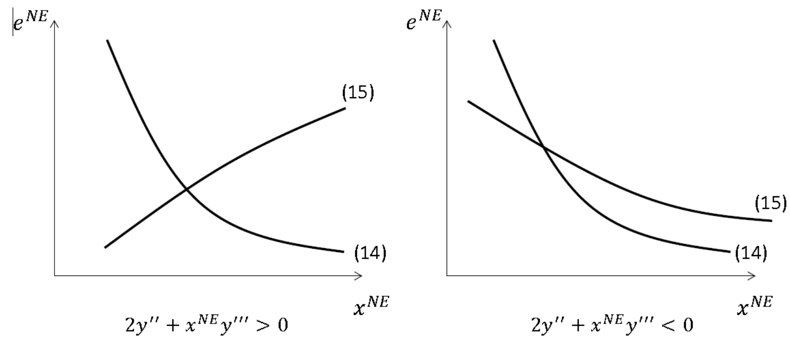

Figure 1: Nash equilibrium

tiation, it is readily shown that (14) shows a negative relation between e^{NE} and x^{NE}. Furthermore, (15) shows a positive relation between e^{NE} and x^{NE} if and only if $2y'' + x^{NE}y''' > 0$.

Comparing the first-best outcomes, (7) and (8), and the Nash equilibrium conditions, (14) and (15), it is readily demonstrable that the Nash equilibrium policies cannot yield the first-best outcomes. To clarify that intuition, we first consider the $\alpha = \theta = 0$ case in which the emission spillover and the hold-up problem are eliminated. In this case, (14) and (15) can be rewritten as

$$0 = py' - v\left(e^{NE}\right) - \delta e^{NE} + px^{NE}y'',$$
$$0 = v' + \delta + \frac{A'}{x^{NE}}.$$

The second equation implies that if $x^{NE} = x^{1st}$, the Foreign government sets the first-best environmental standard. However, recalling that $y'' < 0$, the first equation shows that even if $e^{NE} = e^{1st}$, then $x^{NE} < x^{1st}$. Consequently, both the equilibrium quantity and environmental standard are too low even if both the hold-up problem and the emission spillover are eliminated. Intuitively, (10) can be rewritten as

$$\frac{\partial W_F}{\partial \tau_F} = \frac{\partial W_F}{\partial \tau_F}\frac{\partial \hat{x}}{\partial \tau} = \left[-\delta e^{NE} + py' - \tau_H - v\left(e\right)\right]\frac{\partial \hat{x}}{\partial \tau}.$$

The equation presented above shows that the Foreign government only considers the production effects. Moreover, if $\tau_H = 0$, then $\partial W_F/\partial x = \partial W/\partial x$, which means that the Foreign government fully internalizes the effect of x on Foreign welfare, and that its taxes or subsidies will in general be efficient.

However, (9) can be rewritten as

$$\frac{\partial W_H}{\partial \tau_H} = \hat{x} + \tau_H \frac{\partial \hat{x}}{\partial \tau}.$$

The equation above implies that the Home government sets positive taxes because final good producers will be able to pass part of the cost of the tax on to input firms in their ex post bargaining. Thus, the Foreign government will not fully internalize this effect of x because a part of the benefit from the production of intermediate inputs is stolen by Home, and then the production levels of input goods are lower than the first-best production level.

Finally, we define the Nash equilibrium trade policies, which are defined by τ_H^{NE} and τ_F^{NE}. Substituting (2), (12), and (13) into (9) and (10) gives

$$\tau_H^{NE} = -(1-\alpha) p y'' x^{NE} + \delta\theta e^{NE} - \frac{\alpha}{1-\alpha} v\left(e^{NE}\right), \tag{16}$$

and

$$\tau_F^{NE} = -\alpha x^{NE} p y'' + \delta(1-\theta) e^{NE}. \tag{17}$$

Equations (16) and (17) imply that, although the sign of τ_F^{NE} must be positive, the sign of τ_H^{NE} is ambiguous. Combining (16) and (17), one can obtain

$$\tau^{NE} = -p y'' x^{NE} + \delta e^{NE} - \frac{\alpha}{1-\alpha} v\left(e^{NE}\right).$$

3.4 Comparative Statics

In this subsection, we examine the impacts of the hold-up problem and the emission spillover on the amount of pollution and the joint welfare. Preliminarily to that, the following lemma presents results of comparative statics of e^{NE} and x^{NE} with respect to θ and α.

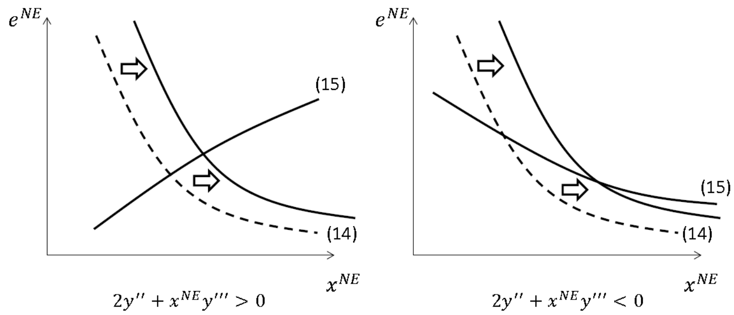

Figure 2: Inpacts of the bargaining power of final goods producers and the degree of emission spillover.

Lemma 3. *Impacts of θ on e and x are*

$$\frac{de^{NE}}{d\theta} = \frac{x^{NE}\delta}{B},$$
$$\frac{dx^{NE}}{d\theta} = \frac{x^{NE}\delta\left(\delta + v'\right)}{p\left(2y'' + x^{NE}y'''\right)B}.$$

The impacts of α on e and x are

$$\frac{de^{NE}}{d\alpha} = -\frac{v'x^{NE}}{\left(1-\alpha\right)^2 B},$$
$$\frac{dx^{NE}}{d\alpha} = -\frac{v'\left(\delta + v'\right)x^{NE}}{\left(1-\alpha\right)^2 p\left(2y'' + x^{NE}y'''\right)B},$$

where

$$B = A'' + \left(\frac{v'}{\left(1-\alpha\right)} + \delta\left(1-\theta\right)\right)\frac{\delta + v'}{p\left(2y'' + x^{NE}y'''\right)} > 0.$$

Proof. See Appendix. □

The impacts of α and θ are depicted in Fig. 2. From (14), given x^{NE}, increases in α and θ induce lower environmental standards. Intuitively, if θ is high, then the Foreign country's marginal damage from pollution is low. The Foreign government then sets the weak environmental standard. The intuition underlying $de^{NE}/d\alpha > 0$ is more complex. From (3), if α is high, then the positive effect of e on x is strong. Consequently, to maintain the production of inputs goods, the Foreign government sets a lax environmental standard.

Then the line of (14) shifts to the right. For the case in which $2y'' + x^{NE}y''' > 0$, because (15) shows the positive relation between e^{NE} and x^{NE}, both e^{NE} and x^{NE} are increased. In contrast, when $2y'' + x^{NE}y''' < 0$, although e^{NE} are increased, x^{NE} are decreased.

Next, we characterize the impacts on the amount of pollution using Lemma 3 as follows:

$$\begin{aligned}\frac{\partial e^{NE}x^{NE}}{\partial \theta} &= \frac{\partial e^{NE}}{\partial \theta}x^{NE} + \frac{\partial x^{NE}}{\partial \theta}e^{NE} \\ &= \frac{x^{NE}\delta}{B}\frac{x^{NE}p\left(2y'' + x^{NE}y'''\right) + (\delta + v')\, e^{NE}}{p\left(2y'' + x^{NE}y'''\right)},\end{aligned}$$

and

$$\begin{aligned}\frac{\partial e^{NE}x^{NE}}{\partial \alpha} &= \frac{\partial e^{NE}}{\partial \alpha}x^{NE} + \frac{\partial x^{NE}}{\partial \alpha}e^{NE} \\ &= -\frac{v'x^{NE}}{(1-\alpha)^2 B}\frac{x^{NE}p\left(2y'' + x^{NE}y'''\right) + (\delta + v')\, e^{NE}}{p\left(2y'' + x^{NE}y'''\right)}.\end{aligned}$$

Because $B > 0$ and $v' < 0$, $\partial e^{NE}x^{NE}/\partial\theta < 0$ and $\partial e^{NE}x^{NE}/\partial\alpha < 0$ if and only if

$$\frac{x^{NE}p\left(2y'' + x^{NE}y'''\right) + (\delta + v')\, e^{NE}}{p\left(2y'' + x^{NE}y'''\right)} < 0.$$

Using Assumption 0, we can show the following proposition.

Proposition 2. *Increases in the bargaining power of the final good producer and the degree of emission spillover reduce the amount of pollution only if*

$$2y'' + x^{NE}y''' < 0. \tag{18}$$

Intuitively, because $\partial e^{NE}/\partial\alpha > 0$ and $\partial e^{NE}/\partial\theta > 0$, the amount of pollution might be decreased only if the production level of intermediate inputs is decreased. From Lemma 3, increases in α and θ decrease the production level of intermediate inputs if and only if $2y'' + x^{NE}y''' < 0$. Therefore, (18) is the necessary condition of $\partial e^{NE}x^{NE}/\partial\theta < 0$ and $\partial e^{NE}x^{NE}/\partial\alpha < 0$.

Finally, the impacts on the joint welfare are summarized as the following proposition.

Proposition 3. *The bargaining power of the final good producer, α, and the emissions spillover, θ, have positive impacts on the joint welfare if*

$$\frac{3y'' + x^{NE}y'''}{2y'' + x^{NE}y'''} < 0. \tag{19}$$

Proof. See Appendix. □

Equation (19) implies that increases in α and θ have positive impacts on the joint welfare only if $2y''+x^{NE}y''' > 0$ because $2y''+x^{NE}y''' > 3y''+x^{NE}y'''$. Intuitively, from Lemma 3, only if $2y''+x^{NE}y''' > 0$, the hold-up problem and the emission spillover increase inputs goods trade volume. Consequently, if α and θ are high, then while the Foreign government sets a lax environmental standard, the intermediate input trade volume is large. Additionally, if $3y'' + x^{NE}y''' < 0$, then the positive effect of increasing intermediate input trade volume dominates the negative effect of relaxation of the environmental standard.

It is particularly interesting that, from Proposition 2, if $2y'' + x^{NE}y''' > 0$, then the amount of pollution must increase with α and θ. Consequently, increases in the degree of emission spillover and the producer's bargaining power might improve joint welfare only if these changes worsen pollution.

4 International Trade Agreements

Generally, because of the presence of supernational organizations (e.g., WTO), trade agreements are easier to achieve than international environmental agreements. In this section, we derive implications of offshoring and environmental spillover for international trade agreements and characterize the second-best trade agreements.

4.1 Free Trade Agreement

First, we consider a free trade agreement under which the Home government cannot set import taxes. Then τ_H must be zero. Moreover, the Home government has no policy instruments. The Foreign government can also not set exporting taxes and subsidies but it can freely set the environmental standard and production subsidies or taxes. The Foreign government then has same policy instruments as the basic model; its policies can be characterized by the same conditions as those in the basic model. Consequently, the equilibrium outputs and environmental standard are characterized by the first-order condition of input producers, (1), the reaction function of the Foreign government, (10) and (11), the production effect, (12) and (13), and $\tau_H = 0$.

From (2), (10) and (11), the equilibrium subsidies and environmental standard under free trade agreements, which are denoted by τ_F^{FT} and e^{FT}, are given as

$$\tau_F^{FT} = \delta (1-\theta) e^{FT} - py'' \alpha \hat{x}, \tag{20}$$

$$0 = v' + (1-\alpha) \left(\delta (1-\theta) + \frac{A'}{\hat{x}} \right). \tag{21}$$

Substituting (20) into (1), the equilibrium quantity of intermediate inputs, denoted by x^{FT}, are then yielded by

$$0 = (1-\alpha) \left(py' - \delta (1-\theta) e^{FT} + \alpha py'' x^{FT} \right) - v \left(e^{FT} \right). \tag{22}$$

Comparing with (7) and (8), one can easily show the following proposition.

Proposition 4. *If (and only if) $\alpha = \theta = 0$, then the free trade agreement leads to the first-best policies.*

It is also readily apparent that if $\alpha \neq 0$ or $\theta \neq 0$, then the free trade agreement necessarily engenders the first-best policies. Intuitively, as pointed out in the last section, the only source of distortion is trade taxes imposed by the Home government in the case $\alpha = \theta = 0$. Consequently, in this case, the free trade agreement can eliminate the distortion source perfectly and then engender first-best policies. However, if $\alpha \neq 0$ or $\theta \neq 0$, then other distortion sources exist: the hold-up problem and emission spillover. Then the joint welfare cannot be maximized solely by the free trade agreement.

4.2 Market Access Commitment

Next, we consider the market access commitment, as defined by Bagwell and Staiger (1999, 2001). Following Antras and Staiger (2012 a), we specify the market access commitment as that by which both governments first negotiate the levels of τ_H and τ_F. Subsequently, the Foreign government might make unilateral adjustments to τ_F and e so long as these adjustments do not alter the equilibrium import volume $x = x^{MAC}$ from the level implied by the agreed upon levels of τ_H and τ_F and the level of e that prevailed at the time of the negotiation. Under the market access commitment, the Home government has no policy instrument because a change in τ_H, which is only policy of the Home government, must change the intermediate input trade volume.

The equilibrium policies of the Foreign government are determined as shown below.

$$(\tau_F, e) \in \arg\max W_F \quad \text{s.t. } x^{MAC} = \hat{x}(\tau, e). \tag{23}$$

The first-order conditions are

$$\left.\frac{\partial W_F}{\partial e}\right|_{d\bar{x}=0} = 0 = -x^{MAC}\delta(1-\theta) - v'x^{MAC} - A' + \alpha\bar{x}\left.\frac{\partial \tau_F}{\partial e}\right|_{dx^{MAC}=0}.$$

Recalling that $\frac{\partial \tau_F}{\partial e}|_{dx^{MAC}=0} = -\frac{v'}{1-\alpha} > 0$, the equilibrium environmental standard, which is denoted by e^{MAC}, is therefore,

$$0 = v' + (1-\alpha)\left[\delta(1-\theta) + \frac{A'}{x^{MAC}}\right], \tag{24}$$

which is exactly identical to (14) if $x^{MAC} = x^{NE}$. Comparing (8) and (24), we have the following proposition.

Proposition 5. *If $\alpha = \theta = 0$, then the market access commitment as $x^{MAC} = x^{1st}$ can engender first-best policies. If $\alpha \neq 0$ or $\theta \neq 0$, then under the commitment as $x^{MAC} = x^{1st}$, the environmental standard is too low.*

The proposition above implies that if either a hold-up problem or emission spillover exists, then the first-best outcomes cannot be implemented by the market access commitment.

Finally, we characterize the second-best market access commitment as

$$\bar{x}^{2nd} \in \arg\max W \quad \text{s.t. } (24).$$

To do so, first it is necessary to examine the relation between the (committed) inputs trade volume and the environmental standard. Equation (24) implies that the equilibrium environmental standard is a function of x^{MAC}. From the total differentiation of (24), the impacts of committed trade volume on the environmental standard are given as shown below.

$$\frac{de^{MAC}}{dx^{MAC}} = \frac{A'}{A''x^{MAC}}$$

Recalling that $A' < 0$ and $A'' > 0$, under the high trade volume commitments, the Foreign government sets the strict environmental standard. Intuitively, the average abatement cost, A/x^{MAC}, is low if the committed trade volume is high. Then the Foreign government sets the strict environmental standard.

From the first-order condition of the optimization problem (23), the second-best trade volume is given as

$$0 = py' - v\left(e^{MAC}\right) - \delta e^{MAC} + \left(\frac{\alpha}{1-\alpha}v' - \theta\delta\right)\frac{A'}{A''}. \tag{25}$$

Comparison of (7) and (25) leads to the following proposition.

Proposition 6. *The trade volume obtained under the second-best market access commitment is greater than the first-best trade volume.*

Proof. See Appendix. □

Intuitively, the commitment for large trade volume can induce the Foreign government to a strict environmental standard. Consequently, the second-best commitment is expected to be stronger than the first-best to induce strict environmental standards.

5 Concluding Remarks

This paper presented an examination of the impacts of the interaction between offshoring and emission spillover on trade and environmental policies. Efficiency analysis revealed two sources of inefficiency associated with the unilateral policy choices of the Home and Foreign governments. First, because a government can shift some costs of trade taxes to trading partners, both governments set an overly high trade tax to redistribute surplus across countries. Second, the Foreign government sets an overly lax environmental standard because of the emissions spillover and to maintain the level of intermediate goods trade. In this model, the market access commitment, which is the commitment to an intermediate input trade level, cannot engender first-best policies. Moreover, the second-best market access commitment is a commitment to a higher level of intermediate input trade than the first-best trade level.

Finally, some directions for future research are described below. First, it is important to investigate the emissions generated by final good consumption. Emissions from consumption processes are trending upward in many countries. Second, we should add decision-making related to whether each home firm should choose a domestic intermediate good supplier or a foreign one. At stage 2 in the current model, the final good producer is assumed to be able to contract only with a foreign inputs supplier. If the final good firm can choose a domestic offshoring partner or a foreign one, then that describes more realistic circumstances.

Appendix

A.1. Proof of Lemma 1.

The first-order conditions of the joint welfare maximization problem are

$$\frac{\partial W}{\partial x} = 0 = -\delta e + py' - v\left(e\right),$$
$$\frac{\partial W}{\partial e} = 0 = -\delta x - v'x - A'.$$

The second-order conditions of the joint welfare maximization problem are satisfied as long as

$$\frac{\partial^2 W}{\partial x^2} = py'' < 0, \tag{A.1-1}$$
$$\frac{\partial^2 W}{\partial e^2} = -A'' < 0, \tag{A.1-2}$$
$$\frac{\partial^2 W}{\partial x^2}\frac{\partial^2 W}{\partial e^2} - \left(\frac{\partial^2 W}{\partial x \partial e}\right)^2 = -py''A'' - \left[\delta + v'\right]^2 > 0.$$

Because $y'' < 0$ and $A'' > 0$, conditions (A.1-1) and (A.1-2) must be satisfied. Consequently, the second-order conditions are satisfied if (and only if) $-py''A'' - \left[\delta + v'\right]^2 > 0$, which can be rewritten as $A'' > -\left[\delta + v'\right]^2 / py''$.

A.2. Proof of the second-order conditions of government problems.

Substituting (1) into (9), (10), and (11), one can obtain

$$\frac{\partial W_H}{\partial \tau_H} = 0 = (1-\alpha)\,\hat{x} + \left[-\delta e\theta + \alpha\,(py' - \tau) + \tau_H\right]\frac{\partial \hat{x}}{\partial \tau},$$
$$\frac{\partial W_F}{\partial \tau_F} = 0 = \alpha\hat{x} + \left[-\delta e\,(1-\theta) + (1-\alpha)\,(py' - \tau) - v\,(e) + \tau_F\right]\frac{\partial \hat{x}}{\partial \tau},$$
$$\frac{\partial W_F}{\partial e} = 0 = -\delta\,(1-\theta)\,\hat{x} - v'\hat{x} - A' + \left[-\delta e\,(1-\theta) + (1-\alpha)\,(py' - \tau) - v\,(e) + \tau_F\right]\frac{\partial \hat{x}}{\partial e}.$$

From second-order total differentiation of (1), we derive

$$\frac{d^2 x}{d\tau^2} = -\frac{y'''}{p^2\,(y'')^3} > 0,$$
$$\frac{d^2 x}{ded\tau} = -\frac{y''' v'}{(1-\alpha)\,p^2\,(y'')^3} < 0,$$
$$\frac{d^2 x}{de^2} = -\frac{y'''\,(v')^2}{(1-\alpha)^2\,p^2\,(y'')^3} > 0.$$

Using the equations above, (2), and (3), the second-order condition of the Home government problem is

$$\frac{\partial^2 W_H}{\partial \tau_H^2} = \frac{1}{py''}\left[2 - \alpha - \left[-\delta\theta e + \alpha\,(py' - \tau) + \tau_H\right]\frac{y'''}{p^2\,(y'')^3}\right] < 0.$$

Using (15), the second-order condition above can be rewritten as

$$0 > (2-\alpha)\,y'' + (1-\alpha)\,\hat{x}y'''.$$

Similarly, using (2) and (3), the second-order conditions of the Foreign government problem are

$$\frac{\partial^2 W_F}{\partial \tau_F^2} = \frac{(1+\alpha)\, y'' + \alpha \hat{x} y'''}{p\,(y'')^2} < 0, \tag{A.2-1}$$

$$\frac{\partial^2 W_F}{\partial e^2} = -A'' - \frac{[2\delta\,(1-\theta) + v']\,(1-\alpha)\, y'' - \alpha \hat{x} y''' v'}{(1-\alpha)^2\, p\,(y'')^2} v' < 0, \tag{A.2-2}$$

$$\frac{\partial^2 W_F}{\partial \tau_F^2}\frac{\partial^2 W_F}{\partial e^2} - \left(\frac{\partial^2 W_F}{\partial e \partial \tau_F}\right)^2 = -\frac{(1+\alpha)\, y'' + \alpha \hat{x} y'''}{p\,(y'')^2}\left(A'' + \frac{[2\delta\,(1-\theta) + v']\,(1-\alpha)\, y'' - \alpha \hat{x} y''' v'}{(1-\alpha)^2\, p\,(y'')^2} v'\right)$$
$$- \left(\frac{\alpha v'\,(y'' + \hat{x} y''') - \delta\,(1-\theta)\,(1-\alpha)\, y''}{(1-\alpha)\, p\,(y'')^2}\right)^2 > 0. \tag{A.2-3}$$

The conditions (A.2-1) and (A.2-2) can be rewritten as

$$0 > (1+\alpha)\, y'' + \alpha \hat{x} y''',$$
$$A'' > -\frac{[2\delta\,(1-\theta) + v']\,(1-\alpha)\, y'' - \alpha \hat{x} y''' v'}{(1-\alpha)^2\, p\,(y'')^2} v'.$$

If $\partial^2 W_F/\partial \tau_F^2 < 0$ (and then $0 > (1+\alpha)\, y'' + \alpha \hat{x} y'''$), then the final condition (A.2-3) can be rewritten as

$$A'' > -\frac{[2\delta\,(1-\theta) + v']\,(1-\alpha)\, y'' - \alpha \hat{x} y''' v'}{(1-\alpha)^2\, p\,(y'')^2} v' - \frac{[\alpha v'\,(y'' + \hat{x} y''') - \delta\,(1-\theta)\,(1-\alpha)\, y'']^2}{[(1+\alpha)\, y'' + \alpha \hat{x} y''']\,(1-\alpha)^2\, p\,(y'')^2}. \tag{A.2-4}$$

If $\partial^2 W_F/\partial \tau_F^2 < 0$ holds, then the sign of the final term in the right-hand-side of (A.2-4) is positive. Consequently, $\partial^2 W_F/\partial e^2 < 0$ holds if (A.2-4) holds. The second-order conditions of the Foreign government's problem can be summarized as presented below.

$$0 > (1+\alpha)\, y'' + \alpha \hat{x} y''',$$
$$A'' > -\frac{[2\delta\,(1-\theta) + v']\,(1-\alpha)\, y'' - \alpha \hat{x} y''' v'}{(1-\alpha)^2\, p\,(y'')^2} v' - \frac{[\alpha v'\,(y'' + \hat{x} y''') - \delta\,(1-\theta)\,(1-\alpha)\, y'']^2}{[(1+\alpha)\, y'' + \alpha \hat{x} y''']\,(1-\alpha)^2\, p\,(y'')^2}.$$

A.3. Proof of Proposition 1.

To show the uniqueness and existence, from (14) and (15), we define $x_1(e)$ and $x_2(e)$ as

$$x_1(e) = -\frac{py' - \delta e - v(e)}{py''}, \qquad \text{(A.3-1)}$$
$$x_2(e) = -\frac{(1-\alpha) A'}{v' + \delta(1-\alpha)(1-\theta)}.$$

Using $G(e) \equiv x_1(e) - x_2(e)$, the Nash equilibrium is definable by $G\left(e^{NE}\right) = 0$ and $x^{NE} = x_1\left(e^{NE}\right) = x_2\left(e^{NE}\right)$.

First, we show the existence. Using $\lim_{x \to 0} y' = \infty$ and $\lim_{x \to \infty} y' = 0$ for any $e \in [0, \bar{e}]$, it is straightforward to verify that $0 < x_1(e) < \infty$. Using $(Assumption 0)$, $\lim_{e \to 0} A'(e) = -\infty$, and $A'(\bar{e}) = 0$, it can be shown that $\lim_{e \to 0} x_2(e) = \infty$, and $x_2(\bar{e}) = 0$. Consequently, it is easily shown that $\lim_{e \to 0} G(e) = -\infty$ and $G(\bar{e}) > 0$. Then there exist x^{NE} and e^{NE}.

Next, we show the uniqueness. To do so, we first use (A.3-1) to derive that

$$\frac{\partial x_1(e)}{\partial e} = \frac{1}{p} \frac{\delta + v'}{2y'' + x_1(e) y'''},$$
$$\frac{\partial x_2(e)}{\partial e} = \frac{x_2(e) A''}{A'}.$$

Next, we derive $\partial G(e) / \partial e|_{e = e^{NE}} = 0$,

$$\left.\frac{\partial G(e)}{\partial e}\right|_{e = e^{NE}} = \frac{1}{p} \frac{\delta + v'}{2y'' + x^{NE} y'''} - \frac{x^{NE} A''}{A'}.$$

Substituting (14), one can obtain,

$$\left.\frac{\partial G(e)}{\partial e}\right|_{e = e^{NE}} > 0 \iff A'' > -\frac{1}{p}\left(\frac{v'}{1-\alpha} + \delta(1-\theta)\right) \frac{\delta + v'}{2y'' + x^{NE} y'''}.$$

The equilibrium is determined uniquely if the above inequality holds.

A.4. Proof of Lemma 3.

The total differentiations of (14) and (15) are derived as

$$0 = p\left(2y'' + x^{NE}y'''\right)dx^{NE} - \left(\delta + v'\right)de^{NE},$$

and

$$0 = -\left(1-\alpha\right)\frac{A'}{\left(x^{NE}\right)^2}dx^{NE} + \left(1-\alpha\right)\frac{A''}{x^{NE}}de^{NE} - \left(\delta\left(1-\theta\right) + \frac{A'}{x^{NE}}\right)d\alpha - \left(1-\alpha\right)\delta d\theta.$$

Combining the two equations above, one can ascertain the impacts of the degree of emission spillover as

$$\begin{aligned}\frac{de^{NE}}{d\theta} &= x^{NE}\delta\left[A'' - \frac{A'}{x^{NE}}\frac{\delta + v'}{p\left(2y'' + x^{NE}y'''\right)}\right]^{-1}, \\ \frac{dx^{NE}}{d\theta} &= \frac{x^{NE}\delta\left(\delta + v'\right)}{p\left(2y'' + x^{NE}y'''\right)}\left[A'' - \frac{A'}{x^{NE}}\frac{\delta + v'}{p\left(2y'' + x^{NE}y'''\right)}\right]^{-1},\end{aligned} \tag{A.4-1}$$

and the impacts of the bargaining power as

$$\begin{aligned}\frac{de^{NE}}{d\alpha} &= -\frac{x^{NE}}{1-\alpha}\left(\delta\left(1-\theta\right) + \frac{A'}{x^{NE}}\right)\left[A'' - \frac{A'}{x^{NE}}\frac{\delta + v'}{p\left(2y'' + x^{NE}y'''\right)}\right]^{-1}, \\ \frac{dx^{NE}}{d\alpha} &= -\frac{\left(\delta + v'\right)x^{NE}}{\left(1-\alpha\right)p\left(2y'' + x^{NE}y'''\right)}\left(\delta\left(1-\theta\right) + \frac{A'}{x^{NE}}\right)\left[A'' - \frac{A'}{x^{NE}}\frac{\delta + v'}{p\left(2y'' + x^{NE}y'''\right)}\right]^{-1}.\end{aligned} \tag{A.4-2}$$

Using (14), (A.4-1) and (A.4-2) can be rewritten as

$$\begin{aligned}\frac{de^{NE}}{d\theta} &= x^{NE}\delta\left[A'' + \left(\frac{v'}{\left(1-\alpha\right)} + \delta\left(1-\theta\right)\right)\frac{\delta + v'}{p\left(2y'' + x^{NE}y'''\right)}\right]^{-1}, \\ \frac{dx^{NE}}{d\theta} &= \frac{x^{NE}\delta\left(\delta + v'\right)}{p\left(2y'' + x^{NE}y'''\right)}\left[A'' + \left(\frac{v'}{\left(1-\alpha\right)} + \delta\left(1-\theta\right)\right)\frac{\delta + v'}{p\left(2y'' + x^{NE}y'''\right)}\right]^{-1},\end{aligned}$$

and

$$\frac{de^{NE}}{d\alpha} = -\frac{v'}{(1-\alpha)^2}x^{NE}\left[A'' + \left(\frac{v'}{(1-\alpha)} + \delta(1-\theta)\right)\frac{\delta + v'}{p(2y'' + x^{NE}y''')}\right]^{-1},$$
$$\frac{dx^{NE}}{d\alpha} = -\frac{v'(\delta + v')}{(1-\alpha)^2 p(2y'' + x^{NE}y''')}x^{NE}\left[A'' + \left(\frac{v'}{(1-\alpha)} + \delta(1-\theta)\right)\frac{\delta + v'}{p(2y'' + x^{NE}y''')}\right]^{-1}.$$

A.5. Proof of Proposition 3.

The impacts of θ and α on the joint welfare are

$$\frac{\partial W}{\partial \theta} = \left[-\delta e^{NE} + py' - v\left(e^{NE}\right)\right]\frac{dx^{NE}}{d\theta} + \left[-\delta x^{NE} - v'x^{NE} - A'\right]\frac{de^{NE}}{d\theta},$$
$$\frac{\partial W}{\partial \alpha} = \left[-\delta e^{NE} + py' - v\left(e^{NE}\right)\right]\frac{dx^{NE}}{d\alpha} + \left[-\delta x^{NE} - v'x^{NE} - A'\right]\frac{de^{NE}}{d\alpha}.$$

Using Lemma 3 and (15), the equations presented above can be rewritten as

$$\begin{aligned}\frac{\partial W}{\partial \theta} &= -\left(x^{NE}\right)^2\delta\left(\frac{\left(3y'' + x^{NE}y'''\right)(\delta + v')}{2y'' + x^{NE}y'''} - \frac{v'}{1-\alpha} - \delta(1-\theta)\right)\\ &\quad\times\left[A'' + \left(\frac{v'}{(1-\alpha)} + \delta(1-\theta)\right)\frac{\delta + v'}{p(2y'' + x^{NE}y''')}\right]^{-1},\end{aligned}$$

and

$$\begin{aligned}\frac{\partial W}{\partial \alpha} &= \frac{\left(x^{NE}\right)^2 v'}{(1-\alpha)^2}\left(\frac{\left(3y'' + x^{NE}y'''\right)(\delta + v')}{2y'' + x^{NE}y'''} - \frac{v'}{1-\alpha} - \delta(1-\theta)\right)\\ &\quad\times\left[A'' + \left(\frac{v'}{(1-\alpha)} + \delta(1-\theta)\right)\frac{\delta + v'}{p(2y'' + x^{NE}y''')}\right]^{-1}.\end{aligned}$$

A.6. Proof of Proposition 6.

The respective impacts of $\bar{x}$ on W are

$$\begin{aligned}\frac{\partial W}{\partial \bar{x}} &= py' - v(e) - \delta e + \left[-\delta\bar{x} - v'\bar{x} - A'\right]e'(\bar{x})\\ &= py' - v(e) - \delta e - \left(\delta + v' + \frac{A'}{\bar{x}}\right)\frac{A'}{A''}.\end{aligned}$$

The first-order condition is

$$\frac{\partial W}{\partial \bar{x}} = 0 = py' - v(e) - \delta e - \left(\delta + v' - \frac{v'}{1-\alpha} - \delta(1-\theta)\right)\frac{A'}{A''}.$$

Using (24), the first-order condition can be rewritten as

$$0 = py' - v(e) - \delta e + \left(\frac{\alpha}{1-\alpha}v' - \theta\delta\right)\frac{A'}{A''}.$$

The equation above implies that $\bar{x}^{2nd} > x^{1st}$.

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