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Abstract

We explore the effects of environmental and trade policies with negative consumption externalities when a domestic firm and a foreign rival produce imperfect substitutes and compete in the domestic market. Consumption of the foreign product generates more emissions than that of the domestic product. Emission taxes reduce emissions, harm the foreign firm, but may benefit the domestic firm. Tariffs could mitigate externalities more "effectively" than emission taxes. Consumption subsidies provided to the domestic product may raise emissions and worsen domestic welfare. Stringent environmental policies may induce the foreign firm to produce an environmentally friendly good, though environmental damages may increase.

Key words: environmental policies, trade policies, consumption externalities, international oligopoly, differentiated products

JEL classification numbers: F13, F18

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1 Introduction

Environmental deterioration is now worldwide concerns. To cope with the concerns, various environmental policies have been employed all over the world. Some economists including Professor Kojima argue that a certain supranational regime is necessary to deal with global environmental problems.[1] However, such a regime has not been established except for the Kyoto Protocol. Basically, each country tackles various problems non-cooperatively.

Some countries (mainly, developed countries) are concerned about environmental damages more seriously than some others (mainly, developing countries).[2] The former tend to actively adopt environmental policies resulting in production and consumption of more environmentally friendly products. For instance, purchases of hybrid cars and/or electric cars are subsidized or are subject to tax reductions in a number of developed countries. Exhaust emission and fuel consumption regulations are more stringent in developed countries than in developing countries.

Not only environmental policies but also trade policies are used to protect environment. For instance, trade restrictions are authorized under multilateral environmental agreements (MEAs) such as the Montreal Protocol on Substances that Deplete the Ozone Layer to protect environment and to encourage non-signatories of the MEAs to change their environmental policies. However, trade policies are sometimes used to protect domestic producers under a pretext for environmental protection, which is called "disguised protection".[3] Examples include the US ban on imports of yellowfin tuna and their related processed products from Mexico based on the Marine Mammal Protection Act.

The purpose of this paper is to explore the effects of environmental and trade policies on the economy in the framework of international oligopoly. We are particularly concerned with the effects of policies aimed to protect environment on environment and producers. Economic activities could damage environment at various stages: production, transportation, and consumption stages. Since production externalities have been paid considerable attention in the literature, we focus on negative externalities associated with consumption (including disposal) such as emissions of carbon dioxide, sulfur oxide and

[1] For example, see Kojima (2000).

[2] A typical argument is the environmental Kuznets Curve. See Grossman and Krueger (1993), for example.

[3] Environmental policies could also create trade barriers. In particular, this is the case if it is difficult for foreign firms to comply with domestic environmental regulations, standards, rules, etc.

nitrogen oxide through driving cars.[4] Thus, environmental and trade policies are directly related to consumption. In the case of environmental tax, for example, we consider taxes on consumption.

In our model, a domestic firm and a foreign rival produce slightly differentiated products and compete in the domestic market. Both domestic and foreign products generate negative externalities during consumption. We consider a situation in which the foreign product results in more externalities than the domestic product. For example, foreign cars (say, gasoline cars) emit more carbon dioxide than domestic cars (say, hybrid cars).

We explore two kinds of policies: taxes/subsidies and standards. Specifically, we consider discriminative policies, because the degrees of externalities are different between the two goods. In the case of environmental taxes, the tax is heavier for the consumption of the foreign good than the domestic good. We also examine tariffs and compare them with environmental taxes. It is shown that tariffs could reduce externalities more "effectively" than environmental taxes. With respect to subsidies, we consider consumption subsidies provided to the domestic good, i.e., the product generating less negative externalities. We show that such a subsidy may worsen environment.

In the analysis of standards, we focus on a specific case in which the foreign good does not meet domestic standards. It is often observed that governments prohibit firms from selling those products that do not achieve certain standards.[5] When domestic standards are prohibitive for foreign firms, however, they may have an incentive to circumvent them. Foreign producers may engage in R&D to develop products meeting the standards.[6] We show that although the foreign firm may be led to produce an environmentally friendly good, prohibitive standards do not guarantee an improvement in environment.

In the framework of international oligopoly, many studies have focused on strategic interactions between governments with production externalities.[7] However, relatively

[4] For those studies that analyze various policies with production externalities in the context of international trade, see Furusawa et al. (2004), Ishikawa and Kiyono (2006), Ishikawa and Kuroda (2007), Ishikawa and Okubo (2008), and Ishikawa et al. (2010), among others. See also footnote 7.

[5] In addition to the above-mentioned US bans on imports of yellowfin tuna and their related processed products, Venezuelan-refined gas was forced to meet the same reformulation standards as U.S. in 1994. The EU prohibited the use of chrysotile asbestos products and banned their imports from Canada in 1998. In 2002, China introduced the China Compulsory Certification, under which foreign firms cannot export to China without implementing certain standards.

[6] Ishikawa and Okubo (2010) examines licensing from the domestic firm to the foreign firm as well as R&D.

[7] See Barret (1994), Kennedy (1994), Conrad (1996,2001), Ulph (1996), Tanguay (2001), and Kiyono

little attention has been paid to environmental and trade policies with consumption externalities.[8] By using a simple international duopoly model, Lai (2004) considers the effects of trade liberalization on an environmental tax when externalities are associated with consumption.[9] Kayalica and Kayalica (2005) and Kayalica and Yilmaz (2006) analyze reciprocal dumping in the presence of consumption externalities. Fischer and Serra (2000) explore minimum standards on a good produced by a domestic firm and a foreign competitor when the consumption causes local damage. They consider optimal standards and examine whether they are protectionist. Abe et al. (2001) investigate eco-labelling programs under consumption externalities as well as production externalities. They analyze the effects on the domestic economy of the introduction of eco-labelling and the domestic recognition of foreign eco-labels. Tian (2003) also studies eco-labelling schemes in an international duopoly model.

The above studies (except for Tian, 2003) basically consider homogeneous products under Cournot competition.[10] In contrast, we deal with differentiated products and examine both Cournot and Bertrand competition. In the case of a homogeneous product, environmental policies affect both domestic and foreign producers symmetrically. For example, both producers face the identical environmental tax. However, this is not necessarily the case when the goods are differentiated. Some of our analyses and results crucially depend on product differentiation. For instance, an environmental tax could benefit the domestic firm even if it must pay the tax.

The rest of the paper is organized as follow. In section 2, we present a basic model which is an international Cournot duopoly model. As consumption externalities, we consider a situation under which consumption generates "emissions" that deteriorate environment. Then we examine emission taxes, tariffs, and consumption subsidies in section 3 and emission standards in section 4. Section 5 concludes. In the appendix, we show that the main results obtained with Cournot competition would not change with Bertrand competition.

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and Ishikawa (2004), among others.

[8] For those studies which consider consumption externalities in open economies under perfect competition, see Krutilla (1991) and Copeland and Taylor (1995), among others. For studies under monopolistic competition, see Haupt (2000) and Ishikawa and Okubo (2009), for example.

[9] Ohori (2006) and Wang et al. (2007) have extended Lai's (2004) analysis.

[10] Tian (2003) considers Bertrand competition with differentiated products. However, his focus is on eco-labelling scheme and hence differs from ours.

2 Basic Model

We consider two goods X and Y, which are imperfect substitutes. Good X is produced by a foreign firm (firm f), that exports the good to the domestic country. In the domestic country, a domestic firm (firm d) produces good Y. The two firms engage in Cournot competition in the domestic market. We assume that emissions are generated through consumption of the products. By an appropriate choice of units, one unit of consumption of good X generates one unit of emissions and that of good Y results in $0 < k < 1$ units of emissions. The emissions cause negative externalities.

Demands are characterized by a representative consumer that consumes goods X and Y as well as a numéraire good. The numéraire good is competitively produced and freely traded between countries, and generates no externalities. We assume the following utility function:

$$U = \alpha x + \beta y - \frac{(x)^2 + (y)^2}{2} - \phi xy + m - V,$$

where x, y and m are, respectively, the consumption of goods X and Y and the numéraire good, $V(> 0)$ is externalities, α and β are parameters, and $0 < \phi < 1$ is a parameter indicating the degree of substitutability between goods X and Y. Following Fischer and Serra (2000) and Lai (2004), we assume that the representative consumer ignores the negative externalities when making the consumption decisions.[11]

Then the inverse demands for the imperfectly substitutable goods X and Y are, respectively, given by

$$p_x = \alpha - x - \phi y, \tag{1a}$$

$$p_y = \beta - y - \phi x, \tag{1b}$$

where p_x and p_y are the consumer prices of goods X and Y. Consumer surplus (CS) is given by

$$CS = \alpha x + \beta y - \frac{(x)^2 + (y)^2}{2} - \phi xy - (p_x x + p_y y) = \frac{(x)^2 + (y)^2}{2} + \phi xy \tag{2}$$

The domestic government may impose an emission tax, τ, per unit of emission; may impose a specific tariff, t, on good X; or may provide a consumption subsidy, ς, to per unit of consumption of good Y.[12] The profits of firms f and d can be written respectively

[11] There is another modelling in which consumers care about environmental damage when making the consumption decisions. For example, in Moraga-Gonzalez and Padron-Fumero (2002), consumers differ in their willingness-to-pay for goods due to different environmental awareness.

[12] In our model, consumption subsidies to good Y are equivalent to production subsidies to good Y.

as

$$\pi^f = (p_x - c_x - \tau - t)x,$$
$$\pi^d = (p_y - c_y - k\tau + \varsigma)y,$$

where c_j $(j = x, y)$ is the constant marginal cost (MC) to produce good j. Then the first order conditions (FOCs) for profit maximization are:

$$\frac{d\pi^f}{dx} = -x + p_x - c_x - \tau - t = 0,$$
$$\frac{d\pi^d}{dy} = -y + p_y - c_y - k\tau + \varsigma = 0.$$

In the laissez-faire equilibrium denoted by subscript 0, we have

$$x_0 = \frac{2A - \phi B}{4 - \phi^2}, y_0 = \frac{2B - \phi A}{4 - \phi^2},$$

where $A \equiv \alpha - c_x$ and $B \equiv \beta - c_y$. We focus on interior solutions (except for section 4). Thus, we assume

$$2B - \phi A > 0, 2A - \phi B > 0. \tag{3}$$

The total emissions are

$$e_0 = x_0 + ky_0 = \frac{A(2 - k\phi) + B(2k - \phi)}{4 - \phi^2}$$

By using the FOCs, the profits of firms f and d are

$$\pi_0^f = (x_0)^2, \pi_0^d = (y_0)^2. \tag{4}$$

Thus, the following lemma is immediate. It should be noted that the lemma is valid even if taxes/subsidies exist.

Lemma 1 *The profits increase if and only if the output rises.*

In the laissez-faire equilibrium, domestic welfare W is measured by the sum of CS, the profits of firm d, and the value of environmental damage. The total emissions cause environmental damage, $V(e)$, with $V'(e) > 0$. From Lemma 1 and (2), we have

$$W_0 = CS_0 + \pi_0^d - V(e_0)$$
$$= \frac{(x_0)^2 + 3(y_0)^2}{2} + \phi x_0 y_0 - V(e_0).$$

3 Effects of Taxes and Subsidies

In this section, we consider the effects of emission taxes, tariffs, and consumption subsidies to good Y. We also compare emission taxes against tariffs.

3.1 Emission Taxes

Suppose that an emission tax, τ, per unit of emission is imposed. Since $k > 0$, both goods are subject to the tax. The outputs are

$$x_\tau = \frac{2(A-\tau) - \phi(B-k\tau)}{4-\phi^2}, y_\tau = \frac{2(B-k\tau) - \phi(A-\tau)}{4-\phi^2},$$

where subscript τ denotes the equilibrium with an emission tax. The effects of a change in the emission tax on the outputs of firms f and d are given by

$$\frac{dx_\tau}{d\tau} = \frac{\phi k - 2}{4-\phi^2} < 0, \frac{dy_\tau}{d\tau} = \frac{\phi - 2k}{4-\phi^2}.$$

The output of firm f necessarily decreases, but that of firm d decreases if and only if $\phi < 2k$. Since Lemma 1 is still valid here, the effects on the profits are straightforward. Interestingly, although the consumption of both goods is subject to the tax, firm d could benefit from the tax. This result stems from the difference in the tax rate per unit of consumption. An emission tax generates two opposing effects on the outputs. An emission tax decreases the output of each firm, which in turn increases the output of its rival with strategic substitutes. Since the former effect is stronger for firm f than firm d, the latter effect is stronger for firm d than firm f. If k is relatively small, that is, if the tax rate of consuming good X is relatively small, the latter effect could dominate the former for firm d.

The total emissions, $e(\equiv x + ky)$, are

$$e_\tau = \frac{2\tau - 2A + B\phi + 2k^2\tau - 2Bk + Ak\phi - 2k\tau\phi}{\phi^2 - 4}.$$

The effect of a change in the emission tax on the total emissions is given by

$$\frac{de_\tau}{d\tau} = \frac{2k(\phi - k) - 2}{4-\phi^2} < 0, \tag{5}$$

which implies that the total emissions fall and hence emission taxes are effective to reduce the total emissions.

Consumer surplus (CS) is

$$\begin{aligned} CS_\tau &= \frac{(x_\tau)^2 + (y_\tau)^2}{2} + \phi x_\tau y_\tau \\ &= \frac{\left(\begin{array}{c} -3A^2\phi^2 + 4A^2 + 2AB\phi^3 - 2Ak\tau\phi^3 + 6A\tau\phi^2 - 8A\tau - 3B^2\phi^2 + 4B^2 \\ +6Bk\tau\phi^2 - 8Bk\tau - 2B\tau\phi^3 - 3k^2\tau^2\phi^2 + 4k^2\tau^2 + 2k\tau^2\phi^3 - 3\tau^2\phi^2 + 4\tau^2 \end{array} \right)}{2\left(\phi^2 - 4\right)^2} \end{aligned}$$

Differentiating CS with respect to τ and evaluating it at $\tau = 0$, we have the effect of an introduction of a small emission tax on CS as follows:

$$\left.\frac{\partial CS_\tau}{\partial \tau}\right|_{\tau=0} = -\frac{4A - 3A\phi^2 + B\phi^3 + 4Bk + Ak\phi^3 - 3Bk\phi^2}{(\phi-2)^2(\phi+2)^2} < 0.$$

Thus, a small emission tax decreases CS.

We next consider the effect on domestic welfare which now includes tax revenues.

$$\begin{aligned} W_\tau &= CS_\tau + \pi_\tau^d + \tau e_\tau - V(e_\tau) \\ &= \frac{(x_\tau)^2 + 3(y_\tau)^2}{2} + \phi x_\tau y_\tau + \tau(x_\tau + k y_\tau) - V(e_\tau). \end{aligned}$$

Here we examine the welfare effect of introducing a small emission tax. Differentiating domestic welfare with respect to τ and evaluating it at $\tau = 0$, we have

$$\left.\frac{\partial W_\tau}{\partial \tau}\right|_{\tau=0} = \frac{A - Bk}{4 - \phi^2} - V'(e_\tau)\frac{2k(\phi - k) - 2}{4 - \phi^2}.$$

If $A - Bk \geq 0$, $\partial W/\partial\tau|_{\tau=0} > 0$ holds, that is, a small emission tax raises domestic welfare. $A - Bk \geq 0$ is likely to hold when B and/or k are relatively small. A relatively small B implies a relatively small demand for good Y.[13] A relatively small k means that firm d's per unit emissions are small. Thus, when B and/or k are relatively small, the detrimental effect on the domestic producer and consumers led by a tax is relatively small.

Therefore, we obtain

Proposition 1 *An emission tax decreases the total emissions. Firm f necessarily loses from an emission tax, while firm d loses if and only if $\phi < 2k$. When an emission tax is introduced at a marginally small rate, CS necessarily decreases and domestic welfare improves if $A - Bk \geq 0$.*

[13] Since $B \equiv \beta - c_y$, B becomes smaller as β becomes smaller and/or c_y becomes larger. One may expect that $\alpha \approx \beta$ holds when ϕ is sufficiently close to 1. However, $\alpha \approx \beta$ does not necessarily imply $A \approx B$.

3.2 Tariffs

We now suppose that a tariff is introduced instead of an emission tax. The outputs under a tariff are given by

$$x_t = \frac{2(A-t)-\phi B}{4-\phi^2}, y_t = \frac{2B-\phi(A-t)}{4-\phi^2},$$

where subscript t denotes the tariff equilibrium. The changes in the outputs of firms f and d are, respectively, given by

$$\frac{dx_t}{dt} = -\frac{2}{4-\phi^2} < 0, \frac{dy_t}{dt} = \frac{\phi}{4-\phi^2} > 0.$$

The output of firm f decreases, while that of firm d increases. The total emissions are

$$e_t = \frac{2t-2A+B\phi-2Bk+Ak\phi-kt\phi}{\phi^2-4}.$$

Thus, the effect of a tariff on the total emissions is given by

$$\frac{de_t}{dt} = \frac{k\phi-2}{4-\phi^2} < 0, \tag{6}$$

which implies that a tariff decreases the total emissions. As expected, a tariff harms firm f, benefits firm d and reduces the emissions.

CS is

$$CS_t = \frac{-3A^2\phi^2+4A^2+2AB\phi^3+6At\phi^2-8At-3B^2\phi^2+4B^2-2Bt\phi^3-3t^2\phi^2+4t^2}{2\left(\phi^2-4\right)^2}.$$

The introduction of a small tariff decreases CS, because the following holds:

$$\left.\frac{\partial CS_t}{\partial t}\right|_{t=0} = -\frac{4A-3A\phi^2+B\phi^3}{(\phi-2)^2(\phi+2)^2} < 0$$

Although consumers lose, a small tariff always enhances domestic welfare

$$\begin{aligned} W_t &= CS_t + \pi_t^d + tx_t - V(e_t) \\ &= \frac{(x_t)^2+3(y_t)^2}{2} + \phi x_t y_t + tx_\tau - V(e_\tau) \end{aligned}$$

by reducing the emissions and shifting rent from abroad:

$$\left.\frac{\partial W_t}{\partial t}\right|_{t=0} = \frac{A}{4-\phi^2} - V'(e_t)\frac{k\phi-2}{4-\phi^2} > 0.$$

Thus, the following proposition is established.

Proposition 2 *A tariff harms firm f, benefits firm d, and decreases the total emissions. When a tariff is introduced at a marginally small rate, CS falls but domestic welfare improves.*

Next we compare emission taxes with tariffs. We specifically make a comparison when both taxes and tariffs result in the same emission levels. From (5) and (6), the total emissions are the same if the tariff rate satisfies the following condition:

$$t = \frac{2k(\phi - k) - 2}{\phi k - 2}\tau(\equiv \bar{t}). \tag{7}$$

Thus, $t \gtreqless \tau$ if and only if $\phi \lesseqgtr 2k$. To put it differently, when the emission tax rate and the tariff rate are the same, the total emissions are less under an emission tax if and only if $\phi < 2k$.

We obtain

$$(W_t - W_\tau)|_{t=\bar{t}} = -k\tau \frac{\begin{pmatrix} \left(k^3\phi^2 - 12k^3 - 2k^2\phi^3 + 20k^2\phi - k\phi^2 - 20k + 4\phi\right)\tau \\ -2\left(k\phi - 2\right)\left(2B - A\phi + 2Ak - Bk\phi\right) \end{pmatrix}}{2\left(\phi - 2\right)\left(\phi + 2\right)\left(k\phi - 2\right)^2},$$

Noting $-2\left(k\phi - 2\right)\left(2B - A\phi + 2Ak - Bk\phi\right) > 0$, $(W_t - W_\tau)|_{t=\bar{t}} > 0$ holds as long as τ and hence t are sufficiently small. Thus, a tariff that satisfies (7) leads to higher welfare. Also we should recall that tariffs always enhance welfare, while emission taxes may worsen welfare. This implies that tariffs could be more attractive measures than emission taxes.

We obtain:

Proposition 3 *Suppose that the emission level under an emission tax is the same with that under a tariff. Then the tariff rate is higher than the emission tax rate if and only if $\phi < 2k$. Domestic welfare under the tariff is higher than under the emission tax if the tax rates are sufficiently small.*

3.3 Consumption Subsidies

We consider consumption subsidies provided to good Y. The effects of a consumption subsidy are similar to those of a tariff. As in the case of tariffs, a subsidy decreases the output of firm f and increases the output of firm d:

$$x_\varsigma = \frac{2A - \phi(B + \varsigma)}{4 - \phi^2}, y_\varsigma = \frac{2(B + \varsigma) - \phi A}{4 - \phi^2},$$

where subscript ς denotes the equilibrium with a subsidy. The changes in the outputs of firms f and d are, respectively, given by

$$\frac{dx_\varsigma}{d\varsigma} = -\frac{\phi}{4-\phi^2} < 0, \frac{dy_\varsigma}{d\varsigma} = \frac{2}{4-\phi^2} > 0.$$

The total emissions are

$$e_\varsigma = \frac{B\phi - 2A - 2k\varsigma + \varsigma\phi - 2Bk + Ak\phi}{\phi^2 - 4}$$

and hence the effect on the total emissions is given by

$$\frac{de_\varsigma}{d\varsigma} = \frac{2k-\phi}{4-\phi^2},$$

A subsidy increases the total emissions if and only if $\phi < 2k$. Since a subsidy increases the consumption of good Y more than a tariff, the total emissions rise unless k is small.

CS is

$$CS_\varsigma = \frac{-3A^2\phi^2 + 4A^2 + 2AB\phi^3 + 2A\varsigma\phi^3 - 3B^2\phi^2 + 4B^2 - 6B\varsigma\phi^2 + 8B\varsigma - 3\varsigma^2\phi^2 + 4\varsigma^2}{2\left(\phi^2-4\right)^2}.$$

The change in CS is

$$\left.\frac{\partial CS_\varsigma}{\partial\varsigma}\right|_{\varsigma=0} = \frac{4B + A\phi^3 - 3B\phi^2}{(\phi-2)^2(\phi+2)^2} > 0.$$

Although a consumption subsidy decreases the consumption of good X, a small subsidy raises CS. The welfare effect of a small subsidy is generally ambiguous:

$$\begin{aligned} W_\varsigma &= CS_\varsigma + \pi_\varsigma^d - \varsigma y_\varsigma - V(e_\varsigma) \\ &= \frac{(x_\varsigma^f)^2 + 3(y_\varsigma^d)^2}{2} + \phi x_\varsigma^f y_\varsigma^d - \varsigma y_\varsigma^d - V(e_\varsigma) \\ \left.\frac{\partial W}{\partial\varsigma}\right|_{\varsigma=0} &= \frac{B}{4-\phi^2} - V'(e_\varsigma)\frac{2k-\phi}{4-\phi^2}. \end{aligned} \tag{8}$$

If $2k \leq \phi$, then a small subsidy does not increase the emissions and raises domestic welfare. Conversely, a small subsidy could increase the emissions and decrease domestic welfare. This is likely to occur when B (i.e., the market for good Y) is relatively small and k is relatively large. When B is relatively small, the increases in both CS and the domestic profits are relatively small. Thus, (8) could become negative. In this case, a consumption tax on good Y rather than a subsidy could be justified from the viewpoint of both welfare enhancement and emission reduction. We should mention that domestic welfare deteriorates only if the total emissions increase (i.e.$2k > \phi$).

Thus, we obtain the following result.

Proposition 4 *A consumption subsidy to good Y decreases the total emissions if and only if $2k < \phi$. Firm d gains from consumption subsidy, while firm f loses. When a consumption subsidy ς is introduced at a marginally small rate, CS necessarily increases and domestic welfare improves if $\phi \geq 2k$.*

4 Effects of Standards

In this section, we consider the effects of emission standards. The domestic government introduces an emission standard, λ, which sets a maximum amount of emissions per unit of product consumption. If a product does not satisfy the standard, its sale is prohibited in the domestic country. In our analysis, we specifically consider an emission standard with $\lambda = k$ and hence good X does not satisfy it but good Y does. In the presence of the standard, firm f has to give up exporting to the domestic country.

4.1 Monopoly

The standard leads firm d to be a monopolist in the market. In the equilibrium denoted by subscript M, the output and price are, respectively, given by

$$y_M = \frac{B}{2}, p_M = \frac{B}{2} + c_y. \tag{9}$$

In view of (3), we can easily verify that $y_M > y_0$ and $y_M < x_0 + y_0$. As expected, therefore, the standard benefits the domestic firm and reduces emissions. The change in CS is

$$\Delta CS_M \equiv CS_M - CS_0 = \frac{\left(8A + 4B\phi - 6A\phi^2 + B\phi^3\right)(B\phi - 2A)}{8(\phi+2)^2(\phi-2)^2} < 0.$$

Since $2A - \phi B > 0$, CS falls. Thus, the welfare effect is generally ambiguous.

4.2 R&D

In the presence of the emission standard, firm f cannot serve the domestic market. Hence firm f may have an incentive to produce a good which meets the standard. In the following analysis, we assume for simplicity that firm f produces good Y to serve the domestic market.[14] We also assume that firm f can produce good Y by engaging in R&D, the cost of which is fixed costs, F.

[14] Even if the good produced by firm f is still differentiated from good Y, the essence of our main result, Proposition 5, would not change.

As long as firm f can make a positive profit from R&D, it has an incentive to invest in R&D. Since there is only good Y in the market, the inverse demand is:

$$p = \beta - (y^f + y^d),$$

where y^i is the output of firm i $(i = d, f)$. The profits of firms f and d are:

$$\begin{aligned} \pi^f &= (p - c_y^f)y^f - F, \\ \pi^d &= (p - c_y)y^d, \end{aligned}$$

where c_y^f is the constant MC of firm f to produce good Y. In the R&D equilibrium denoted by subscript R, we obtain:

$$y_R^f = \frac{B - 2\delta}{3}, y_R^d = \frac{B + \delta}{3},$$

where $\delta \equiv c_y^f - c_y$. We assume both $B > \max\{2\delta, -\delta\}$ and $0 < \pi_R^f (= (B - 2\delta)^2/9 - F) < \pi_0^f$.[15]

We compare the R&D equilibrium with the initial laissez-faire equilibrium. We first consider whether firm d gains from the standard. Noting that Lemma 1 is still valid for firm d, we check whether the output rises:

$$\begin{aligned} \Delta y_R &\equiv y_R^d - y_0^d = \frac{B + \delta}{3} - \frac{2B - \phi A}{4 - \phi^2} \\ &= \frac{3A\phi - 2B - B\phi^2 + \delta(4 - \phi^2)}{3(4 - \phi^2)}. \end{aligned}$$

Thus, the R&D under the standard benefits firm d if and only if $\Omega \equiv 3A\phi - 2B - B\phi^2 + \delta(4 - \phi^2) > 0$. This condition is likely to be satisfied when A is large relative to B, and δ and ϕ are large. A relatively large A implies relatively large demand for good X, and hence the prohibitive standard causes a relatively large demand shift to good Y. A large δ implies that firm d is much more efficient in production of good Y than firm f. Thus, the entry of firm f into the good-Y market does not decrease the output of firm d much. A large ϕ implies that goods X and Y are close substitutes. Thus, the entry of firm f into the good-Y market caused by the elimination of good X does not affect the output of firm d much.

[15] If $\pi_R^f > \pi_0^f$, firm f has no incentive to produce good X even without standards.

The change in CS is given by

$$\begin{aligned}\Delta CS_R &\equiv CS_R - CS_0 = \frac{(y_R^f + y_R^d)^2}{2} - \left(\frac{(x_0^f)^2 + (y_0^d)^2}{2} + \phi x_0^f y_0^d\right) \\ &= \frac{\left(\begin{array}{c} 28B^2 - 36A^2 - 18AB\phi^3 + 27A^2\phi^2 - 5B^2\phi^2 + 4B^2\phi^4 \\ +\delta(\phi-2)^2(\phi+2)^2(\delta - 4B)\end{array}\right)}{18(\phi+2)^2(\phi-2)^2}.\end{aligned}$$

In general, the sign of ΔCS_R is ambiguous. $\Delta CS_R > 0$ is likely to hold when when A is small relative to B. With $\Delta CS_R > 0$, a negative effect due to the decrease in variety is dominated by a positive effect due to the increase in good Y.

The change in emissions is given by

$$\Delta e_R \equiv k(y_R^f + y_R^d) - (x_0 + ky_0) = (k\frac{2B-\delta}{3}) - (\frac{2A - \phi B}{4-\phi^2} + k\frac{2B - \phi A}{4-\phi^2}).$$

If k is sufficiently small, then $\Delta e_R < 0$, that is, the emission standard decreases the total emissions. However, if k is close to 1, the total emissions may increase. Evaluating Δe_R at $k = 1$, we have

$$\begin{aligned}\Delta e_R|_{k=1} &= (\frac{2B-\delta}{3}) - (\frac{2A-\phi B}{4-\phi^2} + \frac{2B-\phi A}{4-\phi^2}) \\ &= \frac{B - 3A + 2B\phi - \delta(\phi+2)}{3(\phi+2)}.\end{aligned}$$

From the continuity argument, the total emissions increase if $\Psi \equiv B - 3A + 2B\phi - \delta(\phi+2) > 0$ and k is sufficiently close to 1. This condition is likely to be satisfied when A is small relative to B, δ is small and ϕ is large. A prohibitive standard eliminates the consumption of good X, but increases that of good Y through the foreign R&D. Although the emission per unit of consumption of good Y is lower than that of good X, this could be dominated by the increase in the total consumption of good Y and hence the total emissions could rise. A small A, a small δ and a large ϕ tend to increase the output of good Y relative to the laissez-faire equilibrium when a prohibitive standard induces firm f to enter the good Y-market.

Again, the welfare effect is generally ambiguous. If $A = B$ and $\delta = 0$, for example, then $\Delta y_R < 0$, $\Delta CS_R < 0$ and $\Delta e_R < 0$ holds, that is, the profits of firm d and CS decrease but the environmental damage is mitigated. Thus, if the mitigation of environmental damage is large (small), domestic welfare could improve (deteriorate).

The above analysis establishes the following proposition:

Proposition 5 *Suppose that an emission standard leads firm f to incur fixed R&D costs to develop good Y. By comparing the R&D equilibrium with the equilibrium without the standard, there exists a range of parameterization under which the total emissions increase. Firm d gains from the standard if and only if $\Omega > 0$. Domestic welfare may or may not improve.*

5 Concluding Remarks

Using an international duopoly model with differentiated products, we have analyzed the effects of environmental and trade policies in the presence of consumption externalities. Both domestic and foreign products generate emissions during consumption, but the foreign product results in more damage to environment than the domestic product.

Emission taxes reduce negative externalities. The foreign firm necessarily loses from such taxes, while the domestic firm could gain. Tariffs also reduce negative externalities. Interestingly, however, tariffs could reduce externalities more effectively than taxes. This is because tariffs directly impact on the foreign good alone which is environmentally less friendly. A small tariff always enhances domestic welfare, while a small emission tax may worsen welfare. Consumption subsidies provided to the domestic good may raise the total emissions and lower domestic welfare. This implies that under some situation, consumption subsidies to environmentally friendly goods such as hybrid and electric cars should be abolished or replaced by taxes.

Stringent environmental policies may induce the foreign firm to supply an environmentally friendly good through R&D. Such policies may not reduce the externalities. We should mention that the analysis of R&D can be applied to the case with production externalities.

We have explored non-cooperative environmental and trade policies in this paper. As Professor Kojima argues, however, a certain supranational regime may be required to handle global environmental issues. Designing such a regime is an important research topic left for us.

Appendix

We have assumed Cournot competition in the above analysis. In the appendix, we show that the essence of the main results obtained with Cournot competition would not change with Bertrand competition.

From (1a) and (1b), demands become

$$
\begin{aligned}
x &= \frac{(\alpha - \phi\beta) - p_x + \phi p_y}{1-\phi^2}, \\
y &= \frac{(\beta - \phi\alpha) - p_y + \phi p_x}{1-\phi^2}.
\end{aligned}
$$

Then the FOCs for profit maximization under Bertrand competition are:

$$
\begin{aligned}
\frac{d\pi^f}{dp_x} &= \frac{\alpha - p_x - \phi(\beta - p_y) - p_x + (c_x + \tau + t)}{1-\phi^2} = 0, \\
\frac{d\pi^d}{dp_y} &= \frac{\beta - p_y - \phi(\alpha - p_x) - p_y + (c_y + k\tau - \varsigma)}{1-\phi^2} = 0.
\end{aligned}
$$

In the laissez-faire Bertrand equilibrium, we have

$$
\begin{aligned}
p_{x0}^B &= \frac{2(\alpha + c_x) - \alpha\phi^2 - \phi B}{4-\phi^2}, p_{y0}^B = \frac{2(\beta + c_y) - \beta\phi^2 - \phi A}{4-\phi^2}, \\
x_0^B &= \frac{(2-\phi^2)A - \phi B}{(1-\phi^2)(4-\phi^2)}, y_0^B = \frac{(2-\phi^2)B - \phi A}{(1-\phi^2)(4-\phi^2)}.
\end{aligned}
$$

where superscript B stands for Bertrand competition. The total emissions are

$$
e_0^B = \frac{(2-\phi^2 - k\phi)A + (2k - \phi^2 k - \phi)B}{(1-\phi^2)(4-\phi^2)}.
$$

By using the FOCs, the profits of firms f and d are

$$
\pi_0^{fB} = \frac{(p_{x0} - c_x)^2}{1-\phi^2} = (z_0)^2(1-\phi^2), \pi_0^{dB} = \frac{(p_{y0} - c_y)^2}{1-\phi^2} = (y_0)^2(1-\phi^2).
$$

When an emission tax is introduced, the equilibrium is given by

$$
\begin{aligned}
p_{x\tau}^B &= \frac{2(\alpha + c_x + \tau) - \alpha\phi^2 - \phi(B - k\tau)}{4-\phi^2}, p_{y\tau}^B = \frac{2(\beta + c_y + k\tau) - \beta\phi^2 - \phi(A - \tau)}{4-\phi^2}, \\
x_\tau^B &= \frac{(2-\phi^2)(A-\tau) - \phi(B - k\tau)}{(1-\phi^2)(4-\phi^2)}, y_\tau^B = \frac{(2-\phi^2)(B - k\tau) - \phi(A-\tau)}{(1-\phi^2)(4-\phi^2)}.
\end{aligned}
$$

Thus, we have

$$
\begin{aligned}
\frac{\partial p_{x\tau}^B}{\partial \tau} &= \frac{2 + \phi k}{4-\phi^2} > 0, \frac{\partial p_{y\tau}^B}{\partial \tau} = \frac{2k + \phi}{4-\phi^2} > 0, \\
\frac{\partial x_\tau^B}{\partial \tau} &= \frac{\phi k - (2-\phi^2)}{(1-\phi^2)(4-\phi^2)} < 0, \frac{\partial y_\tau^B}{\partial \tau} = \frac{\phi - k(2-\phi^2)}{(1-\phi^2)(4-\phi^2)}.
\end{aligned}
$$

The profits of firms f and d with an emission tax are

$$
\pi_\tau^{fB} = \frac{(p_{x\tau} - c_x - \tau)^2}{1-\phi^2} = (x_\tau)^2(1-\phi^2), \pi_\tau^{dB} = \frac{(p_{y\tau} - c_y - k\tau)^2}{1-\phi^2} = (y_\tau)^2(1-\phi^2).
$$

Thus, firm f always loses from the tax, but firm d loses if and only if $\phi < k(2-\phi^2)$.

The total emissions are

$$e_\tau^B = x_\tau + ky_\tau.$$

The change in the total emissions is

$$\frac{\partial e_\tau^B}{\partial \tau} = \frac{\phi k - (2-\phi^2) + \{\phi - k(2-\phi^2)\}k}{(1-\phi^2)(4-\phi^2)}.$$

We can prove $\partial e_\tau^B/\partial\tau < 0$ as follows. Since the denominator is positive, we show the numerator is negative. First, by fixing ϕ, the numerator becomes a function of k:

$$f(k) \equiv -(2-\phi^2)k^2 + 2\phi k - (2-\phi^2).$$

$f(k) < 0$ holds as long as $0 < \phi < 1$, because $-(2-\phi^2) < 0$ holds and $f(k) = 0$ does not have real number solutions, which can be confirmed by $\phi^2 - (2-\phi^2)^2 = -(\phi-1)(\phi-2)(\phi+2)(\phi+1) < 0$. Next, by fixing k, the the numerator becomes a function of ϕ:

$$h(\phi) \equiv (1+k^2)\phi^2 + 2k\phi - 2 - 2k^2.$$

$h(\phi) = 0$ holds at $-(k \pm \sqrt{5k^2 + 2k^4 + 2})/(k^2+1)$. Since $-(k - \sqrt{5k^2+2k^4+2})/(k^2+1) \geq 1$ holds for any k (equality holds at $k = 1$), $h(\phi) < 0$ for $0 < \phi < 1$. Therefore, the numerator is negative if $0 < \phi < 1$ and $0 < k < 1$ hold.

Domestic welfare is

$$\begin{aligned} W_\tau^B &\equiv CS_\tau^B + \pi_\tau^{dB} + \tau e_\tau^B - V(e_\tau^B) \\ &= \frac{(x_\tau^B)^2 + (3-\phi^2)(y_\tau^B)^2}{2} + \phi x_\tau^B y_\tau^B + \tau(x_\tau^B + k y_\tau^B) - V(e_\tau^B). \end{aligned}$$

Differentiating domestic welfare with respect to τ and evaluating it at $\tau = 0$, we have

$$\left.\frac{\partial W_\tau^B}{\partial \tau}\right|_{\tau=0} = \frac{A - Bk}{4-\phi^2} - V'(e_\tau^B)\frac{\phi k - (2-\phi^2) + \{\phi - k(2-\phi^2)\}k}{(1-\phi^2)(4-\phi^2)}.$$

Therefore, if $A - Bk \geq 0$, domestic welfare improves by introducing a small emission tax.

When a tariff is introduced, we have

$$\begin{aligned} p_{xt}^B &= \frac{2(\alpha + c_x + t) - \alpha\phi^2 - \phi B}{4-\phi^2}, p_{yt}^B = \frac{2(\beta + c_y) - \beta\phi^2 - \phi(A-t)}{4-\phi^2}, \\ x_t^B &= \frac{(2-\phi^2)(A-t) - \phi B}{(1-\phi^2)(4-\phi^2)}, y_t^B = \frac{(2-\phi^2)B - \phi(A-t)}{(1-\phi^2)(4-\phi^2)}. \end{aligned}$$

Hence,

$$\begin{aligned}\frac{\partial p_{xt}^B}{\partial t} &= \frac{2}{4-\phi^2} > 0, \frac{\partial p_{yt}^B}{\partial t} = \frac{\phi}{4-\phi^2} > 0, \\ \frac{\partial x_t^B}{\partial t} &= \frac{-(2-\phi^2)}{(1-\phi^2)(4-\phi^2)} < 0, \frac{\partial y_t^B}{\partial t} = \frac{\phi}{(1-\phi^2)(4-\phi^2)} > 0.\end{aligned}$$

The profits of firms f and d with a tariff are

$$\pi_t^{fB} = \frac{(p_{zt}^B - c_z - t)^2}{1-\phi^2} = (x_t^B)^2(1-\phi^2), \pi_t^{dB} = \frac{(p_{yt}^B - c_y)^2}{1-\phi^2} = (y_t^B)^2(1-\phi^2).$$

Thus, firm f loses from a tariff, while firm d gains. The total emissions are

$$e_t^B = x_t^B + ky_t^B.$$

An increase in the tariff decreases the total emissions, because

$$\frac{\partial e_t^B}{\partial t} = \frac{k\phi - (2-\phi^2)}{(1-\phi^2)(4-\phi^2)} < 0.$$

Domestic welfare is

$$\begin{aligned}W_t^B &\equiv CS_t^B + \pi_t^{dB} + tx_t^B - V(e_t^B) \\ &= \frac{(x_t^B)^2 + (3-\phi^2)(y_t^B)^2}{2} + \phi x_t^B y_t^B + tx_t - V(e_t^B).\end{aligned}$$

Differentiating domestic welfare with respect to t and evaluating it at $t = 0$, we have

$$\left.\frac{\partial W_t^B}{\partial t}\right|_{t=0} = \frac{A}{4-\phi^2} - V'(e_t^B)\frac{\phi^2-2}{(1-\phi^2)(4-\phi^2)} > 0.$$

Thus, a small tariff improves domestic welfare.

Now we compare tariffs with emission taxes. If the tariff rate satisfies the following condition:

$$t = \tau\frac{k^2\phi^2 + 2k\phi + \phi^2 - 2k^2 - 2}{k\phi + \phi^2 - 2}(\equiv \bar{t}^B),$$

then the total emissions are the same. Using this, we obtain

$$\begin{aligned}&(W_t - W_\tau)|_{t=\bar{t}^B} \\ = \ & k\tau\frac{\begin{pmatrix}\left(-20k + 4\phi - 8k^2\phi^3 + 9k^3\phi^2 - 2k^3\phi^4 - 2\phi^3 + 15k\phi^2 + 20k^2\phi - 4k\phi^4 - 12k^3\right)\tau \\ +2\left(k\phi + \phi^2 - 2\right)\{(2-\phi^2)B - A\phi + k[(2-\phi^2)A - B\phi]\}\end{pmatrix}}{2\left(\phi^2 - 4\right)\left(\phi^2 + k\phi - 2\right)^2}.\end{aligned}$$

Noting $2\left(k\phi + \phi^2 - 2\right)\{(2-\phi^2)B - A\phi + k[(2-\phi^2)A - B\phi]\} < 0$, the tariff results in the higher welfare providing τ is sufficiently small and $t = \bar{t}^B$ holds, When a consumption subsidy is introduced, we obtain

$$\begin{aligned} p^B_{x\varsigma} &= \frac{2(\alpha + c_x) - \alpha\phi^2 - \phi(B+\varsigma)}{4-\phi^2}, p^B_{y\varsigma} = \frac{2(\beta + c_y - \varsigma) - \beta\phi^2 - \phi A}{4-\phi^2}, \\ x^B_\varsigma &= \frac{(2-\phi^2)A - \phi(B+\varsigma)}{(1-\phi^2)(4-\phi^2)}, y^B_\varsigma = \frac{(2-\phi^2)(B+\varsigma) - \phi A}{(1-\phi^2)(4-\phi^2)}. \end{aligned}$$

Thus,

$$\begin{aligned} \frac{\partial p^B_{x\varsigma}}{\partial\varsigma} &= -\frac{\phi}{4-\phi^2} < 0, \frac{\partial p^B_{y\varsigma}}{\partial\varsigma} = -\frac{2\varsigma}{4-\phi^2} < 0, \\ \frac{\partial x^B_\varsigma}{\partial\varsigma} &= -\frac{\phi}{(1-\phi^2)(4-\phi^2)} < 0, \frac{\partial y^B_\varsigma}{\partial\varsigma} = \frac{2-\phi^2}{(1-\phi^2)(4-\phi^2)} > 0. \end{aligned}$$

The profits of firms f and d with a subsidy are

$$\pi^{fB}_\varsigma = \frac{(p^B_{x\varsigma} - c_x)^2}{1-\phi^2} = (x^B_\varsigma)^2(1-\phi^2), \pi^{dB}_\varsigma = \frac{(p^B_{y\varsigma} - c_y + \varsigma)^2}{1-\phi^2} = (y^B_\varsigma)^2(1-\phi^2).$$

Thus, firm f loses from the subsidy, while firm d gains. The total emissions are

$$e^B_\varsigma = x^B_\varsigma + k y^B_\varsigma.$$

The change in the total emissions is

$$\frac{\partial e^B_\varsigma}{\partial\varsigma} = \frac{k(2-\phi^2) - \phi}{(1-\phi^2)(4-\phi^2)},$$

which is negative if and only if $k(2-\phi^2) < \phi$. Domestic welfare is

$$\begin{aligned} W^B_\varsigma &\equiv CS^B_\varsigma + \pi^{dB}_\varsigma - \varsigma y^B_\varsigma - V(e^B_\varsigma) \\ &= \frac{(x^B_\varsigma)^2 + (3-2\phi^2)(y^B_\varsigma)^2}{2} + \phi x^B_\varsigma y^B_\varsigma - \varsigma y_\varsigma - V(e^B_\varsigma). \end{aligned}$$

Differentiating domestic welfare with respect to ς and evaluating it at $\varsigma = 0$, we have

$$\left.\frac{\partial W^B_\varsigma}{\partial\varsigma}\right|_{\varsigma=0} = \frac{B}{4-\phi^2} - V'(e^B_\varsigma)\frac{k(2-\phi^2) - \phi}{(1-\phi^2)(4-\phi^2)},$$

which is positive if $k(2-\phi^2) - \phi \leq 0$.

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