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Low tariff on dirty goods—Environmental negligence or environmental concern?

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Abstract
Shapiro (*Quarterly Journal of Economics*, 2021) conducts an in-depth empirical analysis to show that dirtier upstream goods face lower import tariffs than cleaner downstream goods. Inspired by that paper, we examine how the welfare maximizing tariffs on the final goods will differ depending on the dirtiness and the extent of cross border pollution. We show that countries concerned about controlling pollution but maximizing own welfare would be encouraged toward relatively unfettered import of dirtier final goods if pollution is mainly generated through domestic production. We discuss the implications of global welfare maximizing tariff protection, pollution taxes, and multiple tradable products.

KEYWORDS
pollution, tariff, welfare

JEL CLASSIFICATION
F13, F18, Q58

1 | INTRODUCTION

Shapiro (2021) pointed out in an extensive empirical study that dirtier upstream goods enjoy lower import tariffs than cleaner downstream goods, where an industry's dirtiness is defined by its carbon dioxide (CO_2) emissions per dollar of output. The reasoning in that paper goes as follows. More-upstream industries have greater pollution, and firms may lobby for higher tariffs on their own products but lower tariffs on their inputs for reducing their costs of production. As a result, the politicians give lower protection to the dirtier upstream industry and higher protection to the cleaner downstream industry. Shapiro (2021) describes it as trade policy's environmental bias.

Inspired by Shapiro (2021), we examine how the welfare maximizing tariffs on the final goods will differ depending on their varied dirtiness and the extent of cross border pollution.[1] We show in an international duopoly that an importing country would impose lower (higher) tariffs on the dirtier final goods if the cross border pollution is not high (high).

Our reason goes as follows. If the countries choose tariffs to maximize own welfare, whenever pollution is generated mainly through domestic production, controlling pollution must imply lower import tariffs on dirtier goods. Lower tariffs on dirtier goods will discourage domestic production and will encourage foreign production of those goods, thus allowing the importing country to increase its welfare by shifting pollution from the domestic country to the foreign country. Hence, if cross border pollution is not high and the countries are choosing tariffs to maximize own welfare, lower import tariffs on dirtier goods acts like a tax on local productions of dirtier goods and implicit subsidies on foreign productions of polluting products. However, if either cross border pollution is high or the countries choose tariffs to maximize world welfare or there is tariff harmonization, higher import tariffs on the dirtier goods seem to be the optimal policy, since now the countries want to reduce global polluting activities. Our model clearly shows the mechanisms by which both sets of policies are quite plausible.

Popular views about climate change rightly call for penalizing production of dirtier goods. However, the problem is to bring the national interest in line with the global interest. Our analysis shows that the source of pollution matters in designing optimal trade policies.

Our result for high cross border pollution, suggesting higher tariffs on the dirtier goods, is in line with the popular views that calls for penalizing production of dirtier goods. This also shares the sentiment of Shapiro (2021) and is consistent with the policies recently proposed by the United Kingdom and the European Union, which want to impose tariffs on the high-carbon goods (steel, cement, fertilizers, aluminum, and electricity) that may create significant cross border pollution.[2] As the French finance minister Bruno Le Maire said, "It's a major step forward in the fight against climate change" (Euronews, 16 March, 2022). Hence, the proposed policy reform recognizes the environmental bias as adequate tariffs were not issued on the polluting imports creating significant cross border pollution.

If the importing countries choose tariffs to maximize their own welfare and the cross border pollution is low, which may happen for large distance between the trading countries[3] and for the pollutants affecting mainly local conditions, tariffs will be lower on dirtier goods, since it reduce domestic outputs and domestic pollution but increase foreign outputs and foreign pollution. This is different from the suggestion of Shapiro (2021), which is understandable as this part is talking about pollutants affecting mainly local conditions. However, it is consistent with Kuik and Gerlagh (2003), which showed empirically that import tariff reduction increases the rate of carbon leakage, suggesting that tariff reduction by a country shifts production and pollution emission to the country with which it is trading, and energy-intensive products contribute substantially to the increase in carbon leakage.[4] Although the national interest in this situation is not in line with the global interest for reducing pollution, such a policy can be a natural choice for an importing country that is interested to maximize its own welfare. Cooperative tariff policies of the countries can solve this problem.

Shapiro (2021), which considers *protection to industries across the vertical supply chain*, can be regarded as a path breaking empirical work in the area that hammers the point that more or less all countries across the world are lenient toward dirty goods creating CO_2 emissions. To the best of our knowledge, there is no companion empirical work analyzing *protection to different final goods industries* depending on their dirtiness and the extent of cross border pollution, which is the topic of our theoretical investigation.[5]

Our paper refers to different kinds of pollution, and not only CO_2 emissions. The extent of cross border pollution may depend on the type of pollution as well as on the distance between the trading countries. While CO_2 emission in a country pollutes the country of its trading partner through cross border pollution, it follows from Fu et al. (2022) that the effect of cross border pollution reduces as the distance between the production plant and the country of its trading partner increases. Further, there are many other disamenities of the industrial sites, such as noise, odor, visual intrusion, perceived health risk to local residents and the effects on existing land use (Powe & Willis, 1998), which may not create cross border pollution. Our results suggest that further empirical works with disaggregated data are required to examine the tariff policies on the final goods with varied dirtiness and cross border pollution.

There is an old theoretical literature examining how tariffs imposed by importing countries control pollution in a general equilibrium framework (see, e.g. Copeland, 1996; Markusen, 1975). In contrast to those papers, we focus on imperfectly competitive markets, thus capturing strategic effects among firms, and emphasize that lower import tariffs on dirtier goods can very well be a reflection of environmental concern. In this respect, we show the implications of several factors, such as domestic versus cross border pollution, trade policy harmonization, pollution taxes, and multiple tradable products.[6]

Our paper falls in the general area of environment and international trade, investment and outsourcing. Grossman and Krueger (1993), Copeland and Taylor (1994), and Levinson (2009) show how international trade affects pollution through scale, composition and technique effects. Antweiler et al. (2001) and Copeland and Taylor (2003) show that two sources of comparative advantage—capital abundance and pollution policy—work against each other to determine the pattern of international trade. Managi et al. (2009) measure how international trade varies with pollutants and between OECD and non-OECD countries. Copeland (2011) deals with theory and measurements regarding environmental impact of international trade. Antweiler (1996), Frankel and Rose (2005), Fowlie et al. (2016), and Shapiro and Walker (2018) also measure the effects of international trade or environmental regulation on pollution.[7] Marjit et al. (2007) provide a theoretical explanation for providing excessive protection to agriculture, which is a relatively clean sector. Considering consumption pollution, Lai and Hu (2008) examine trade agreement between two countries that takes the distortion arising from their non-coordinated environmental policies into consideration. One may refer to Brunnermeier and Levinson (2004), Copeland and Taylor (2003, 2004), Levinson (2010), Copeland (2011, 2020), Cherniwchan et al. (2017), Dechezleprêtre and Sato (2017), and Marjit and Yu (2020) for reviews of this literature.[8]

The well-known pollution haven hypothesis suggests that stricter environmental regulations encourage firms to relocate to countries with lenient environmental regulations. However, the evidence is mixed. For example, Copeland and Taylor (2003), List et al. (2003), Cole and Elliott (2005) found strong evidence in favor of the hypothesis, while Eskeland and Harrison (2003) and Javorcik and Wei (2004) found that environmental regulation did not influence the location decision. McConnell and Schwab (1990), Duffy-Deno (1992), Friedman et al. (1992) and Levinson (1996) found no significant effect or a positive effect between environmental regulation and investment. Dean et al. (2009) found mixed evidence. Dijkstra et al. (2011) provide a theoretical explanation for this phenomenon.[9] In contrast to this literature, which is interested to see how pollution shifted due to firms' location choices,[10] we show how tariff policies help to shift pollution to the exporting countries depending on the dirtiness of the product and the extent of cross border pollution.

The remainder of the paper is organized as follows. Section 2 describes the model and shows the results. Section 3 provides some extensions of the basic model. Section 4 concludes. We do the analysis with a general demand function for the basic model in the Appendices A, B and C.

2 | THE MODEL AND THE RESULTS

Assume that there are two countries—domestic and foreign. Assume that there is a firm in each country—firm D is in the domestic country and firm F is in the foreign country. Both firms face the same marginal cost of production c.

2.1 | One way trade

We consider in this subsection that firms D and F compete in the domestic country like Cournot duopolists. Firm F exports its output to the domestic country and pays a per-unit tariff t (gets subsidy if t is negative).

We consider pollution is a by-product of production. Assume that one unit of output crates one unit of emission, and the environmental damage in the domestic country due to pollution is given by $\alpha\left(q_d + \lambda q_f\right)^2$, where q_d and q_f are the outputs of firms D and F, $\lambda \in [0, 1]$ shows the extent of cross border pollution and $\alpha > 0$ shows the intensity of environmental damage. If $\lambda = 0$ ($\lambda = 1$), there is no (complete) cross border pollution. As α increases, it increases environmental damage and suggests a dirtier product.

The quadratic damage function is widely used in the literature (see, e.g. Dijkstra et al., 2011; Falk & Mendelsohn, 1993; Karp & Zhang, 2006; Tarui & Polasky, 2005; Van der Ploeg & De Zeeuw, 1992; Weitzman, 2010; Xu et al., 2016, to name a few). The empirical studies also justify the use of a quadratic damage function. For example, Howard and Sterner (2017) and the papers therein show a convex relationship between temperature and climate damage. However, we will also show the implications of a linear damage function.

We consider the following game in this subsection. At stage 1, the domestic country sets a per-unit tariff. At stage 2, firms D and F determine their outputs simultaneously and the profits are realized. We solve the game through backward induction.

For the ease of exposition, we consider an inverse linear demand function, $P = a - q$, where P is price, q is the total output and $a > (c + t)$. We show in Appendix A that our results hold under a general demand function.

Throughout our analysis, we would focus on those parameter values which create positive outputs for all firms. This will help to convey our points in the simplest way. As we go on, we will mention the restrictions on the parameters for positive equilibrium outputs. If no restriction are mentioned, it will imply that the equilibrium outputs are positive for all feasible parameter values.

Given the demand and cost functions, firms D and F maximize $(a - q - c)q_d$ and $(a - q - c - t)q_f$ respectively to determine their outputs, where $q = q_d + q_f$. The equilibrium outputs of firms D and F can be found respectively as $q_d^* = \frac{a-c+t}{3}$ and $q_f^* = \frac{a-c-2t}{3}$. The second-order conditions are satisfied.

The domestic government maximizes the following expression to determine the tariff rate:

$$\underset{t}{Max}\underbrace{\left(\frac{a-c+t}{3}\right)^2}_{\text{Profit of firm D}}+\underbrace{\frac{1}{2}\left(\frac{2a-2c-t}{3}\right)^2}_{\text{Domestic consumer surplus}}+\underbrace{t\left(\frac{a-c-2t}{3}\right)}_{\text{Domestic tariff revenue}}-\underbrace{\alpha\left(\frac{a-c+t}{3}+\frac{\lambda(a-c-2t)}{3}\right)^2}_{\text{Domestic environmental damage}}.$$

The equilibrium tariff rate can be found as $t^*=\frac{(a-c)\left(3+2\alpha\left(-1+\lambda+2\lambda^2\right)\right)}{9+2\alpha(1-2\lambda)^2}$. The second-order condition is satisfied.

First consider the case of no cross border pollution, that is, $\lambda=0$. We get $t^*|_{\lambda=0}=\frac{(a-c)(3-2\alpha)}{9+2\alpha}<(>)0$ for $\alpha>(<)\frac{3}{2}$. Hence, if there is no cross border pollution and the products are sufficiently dirty, that is, $\alpha>\frac{3}{2}$, the equilibrium policy is import subsidy.

Now consider the case of complete cross border pollution, that is, $\lambda=1$. We get $t^*|_{\lambda=1}=\frac{(a-c)(3+4\alpha)}{9+2\alpha}>0$, implying that if there is complete cross border pollution, the equilibrium policy is import tariff.[11]

The following result follows from the above discussion.

Proposition 1. *(a) If there is no cross border pollution, that is, $\lambda=0$, and the product is sufficiently dirty, that is, $\alpha>\frac{3}{2}$, the equilibrium policy is import subsidy.*

(b) If there is complete cross border pollution, that is, $\lambda=1$, the equilibrium policy is import tariff regardless of the extent of dirtiness.

Tariff protection in our analysis serves two purposes. On one hand, like standard literature on international trade in oligopolistic industry, it helps to extract rent from the foreign firm. However, there is a new effect in our analysis. Tariff helps to affect pollution by affecting outputs.

If there is no cross border pollution, a lower tariff protection helps to reduce domestic pollution by reducing the output of the domestic firm. Hence, the rent extraction effect encourages the domestic country to impose import tariff, while the pollution reducing effect encourages it to provide import subsidy. If the products are sufficiently dirty, the pollution reducing effect dominates the rent extraction effect and the domestic government provides import subsidy.

If there is complete cross border pollution, the tariff policy also needs to take into account the damage created by the output of the foreign firm. On the one hand, the motive to reduce domestic pollution creates the incentive for import subsidy, but on the other hand, the motive to reduce foreign pollution creates the incentive for import tariff. Since the direct effect of tariff on the foreign firm's output, $q_f^*=\frac{a-c-2t^*}{3}$, is higher than the indirect effect of tariff on the domestic firm's output, $q_d^*=\frac{a-c+t^*}{3}$, a tariff helps to reduce the total output of the firms, which is $q^*=\frac{2(a-c)-t^*}{3}$. If $\lambda=1$, the tariff rate is $t^*(\lambda=1)=\frac{(a-c)(3+4\alpha)}{9+2\alpha}$ and the total output is $q^*=\frac{2(a-c)-t^*}{3}=\frac{5(a-c)}{9+2\alpha}$, which reduces with α. Hence, both the rent extraction effect and the foreign pollution reducing effect dominate the domestic pollution reducing effect and encourages the domestic country to impose import tariff in this situation.

We further get $\frac{\partial t^*}{\partial\alpha}=\frac{6(a-c)(4+\lambda)(-1+2\lambda)}{\left(9+2\alpha(1-2\lambda)^2\right)^2}$. If there is no cross border pollution, we get $\left.\frac{\partial t^*}{\partial\alpha}\right|_{\lambda=0}=-\frac{24(a-c)}{(9+2\alpha)^2}<0$, that is, the tariff rate decreases (or the subsidy rate increases) as the products get dirtier. On the other hand, if there is complete cross border pollution, we get $\left.\frac{\partial t^*}{\partial\alpha}\right|_{\lambda=1}=\frac{30(a-c)}{(9+2\alpha)^2}>0$, that is, the tariff rate increases as the products get dirtier.

Since $\frac{\partial t^*}{\partial\alpha}=\frac{6(a-c)(4+\lambda)(-1+2\lambda)}{\left(9+2\alpha(1-2\lambda)^2\right)^2}<(>)0$ for $\lambda<(>)\frac{1}{2}$, the above discussion gives the following result immediately.

Proposition 2. A higher environmental damage increases *(*decreases*)* the tariff rate if the cross border pollution is significant *(*not significant*)*, that is, $\lambda > (<)\frac{1}{2}$.

If the products get dirtier, the importing country has a lower incentive to impose import tariff (or a higher incentive to provide import subsidy) when cross border pollution is negligible, since it helps to shift pollution from the domestic country to the foreign country by reducing domestic production and increasing foreign production.

However, if there is significant cross border pollution, the importing country has a higher incentive to impose import tariff as the products get dirtier, since a higher tariff helps to reduce the total outputs and therefore, total pollution.

Cross border pollution can be considered as a general interpretation of the possible polluting impact of the imported dirty goods. Higher environmental cost would call for higher tariffs if such cross border effect is significant, which is the source of popular perception. If cross border pollution is insignificant, it is the local production that does the damage and hence less production locally is better. That leads to lower tariff naturally. As shown above, if the tariff is exclusively used to maximize domestic welfare, it is better to even provide import subsidy if the good is sufficiently dirty when the cross border pollution is not significant, since the country will try to minimize its local production. For the cleaner good, more the merrier and hence, tariff is higher.

We find the equilibrium domestic and foreign outputs as $q_d^* = \frac{2(a-c)(2+\alpha\lambda(-1+2\lambda))}{9+2\alpha(1-2\lambda)^2}$ and $q_f^* = \frac{(a-c)(1+\alpha(2-4\lambda))}{9+2\alpha(1-2\lambda)^2}$, with $\frac{\partial q_d^*}{\partial \alpha} = \frac{2(a-c)(4+\lambda)(-1+2\lambda)}{\left(9+2\alpha(1-2\lambda)^2\right)^2} < 0$ and $\frac{\partial q_f^*}{\partial \alpha} = \frac{4(a-c)(4+\lambda)(1-2\lambda)}{\left(9+2\alpha(1-2\lambda)^2\right)^2} > 0$ for $\lambda < \frac{1}{2}$. Hence, if cross border pollution is not significant, as the goods get dirtier, the outputs of the domestic firm reduce and the outputs of the foreign firm increase due to lower import tariffs, implying that carbon leakage increases as the goods get dirtier. This explains the result of Kuik and Gerlagh (2003), where energy-intensive products contributed substantially to the increase in carbon leakage following an import tariff reduction.

We considered a single product in this subsection and showed how the tariff rate changed as the product gets dirtier. We discuss a situation with two goods—one clean and one dirty—in Section 3.1.

Like many other papers examining the effects of environmental pollution, we considered a quadratic damage function. However, our results hold even under a linear damage function $\alpha\left(q_d + \lambda q_f\right)$. See Appendix B for the calculations.

2.2 | Two way trade

Now we show in this subsection that the results derived in Section 2.1 holds under a two way trade where the firms compete in both countries.

Assume that the markets are segmented and the demand in each country is symmetric and is given by $P = a - q$. We show in Appendix C that our results hold under a general demand function.

The environmental concern in both countries is given by α and the extent of cross border pollution is also symmetric and is given by λ.

We consider the following game in this subsection. At stage 1, both countries set per-unit tariff rates simultaneously. At stage 2, firms D and F determine their outputs simultaneously and the profits are realized. We solve the game through backward induction.

Assume that t is the tariff rate set by the domestic country and s is the tariff rate set by the foreign country, where negative values of t and s imply subsidies, and $a > (c+t)$ and $a > (c+s)$.

Given the demand and cost functions, firms D and F maximize $(a - q_d - c)\, q_{dd} + \left(a - q_f - c - s\right) q_{df}$ and $\left(a - q_f - c\right) q_{ff} + (a - q_d - c - t)\, q_{fd}$ respectively to determine their outputs, where $q_d = q_{dd} + q_{fd}$ and $q_f = q_{ff} + q_{df}$. The equilibrium outputs of firms D and F can be found respectively as $q^*_{dd} = \frac{a-c+t}{3}$, $q^*_{df} = \frac{a-c-2s}{3}$, $q^*_{ff} = \frac{a-c+s}{3}$ and $q^*_{fd} = \frac{a-c-2t}{3}$. The second-order conditions are satisfied.

The domestic and foreign governments maximize the following expressions to determine the respective tariff rates:

$$\underset{t}{Max}\underbrace{\left(\frac{a-c+t}{3}\right)^2 + \left(\frac{a-c-2s}{3}\right)^2}_{\text{Profits of firm D}} + \underbrace{\frac{1}{2}\left(\frac{2a-2c-t}{3}\right)^2}_{\text{Domestic consumer surplus}} + \underbrace{t\left(\frac{a-c-2t}{3}\right)}_{\text{Domestic tariff revenue}}$$
$$-\underbrace{\alpha\left(\frac{a-c+t}{3} + \frac{a-c-2s}{3} + \lambda\left(\frac{a-c-2t}{3} + \frac{a-c+s}{3}\right)\right)^2}_{\text{Environmental damage in the domestic country}} \quad (1)$$

$$\underset{s}{Max}\underbrace{\left(\frac{a-c-2t}{3}\right)^2 + \left(\frac{a-c+s}{3}\right)^2}_{\text{Profits of firm F}} + \underbrace{\frac{1}{2}\left(\frac{2a-2c-s}{3}\right)^2}_{\text{Foreign consumer surplus}} + \underbrace{s\left(\frac{a-c-2s}{3}\right)}_{\text{Foreign tariff revenue}}$$
$$-\underbrace{\alpha\left(\frac{a-c-2t}{3} + \frac{a-c+s}{3} + \lambda\left(\frac{a-c+t}{3} + \frac{a-c-2s}{3}\right)\right)^2}_{\text{Environmental damage in the foreign country}}. \quad (2)$$

The symmetric equilibrium tariff rates can be found as $t^* = s^* = \frac{(a-c)\left(3-4\alpha+4\alpha\lambda+8\alpha\lambda^2\right)}{9-2\alpha+2\alpha\lambda+4\alpha\lambda^2}$. The second-order conditions are satisfied.

If there is no cross border pollution, that is, $\lambda = 0$, we get $t^*|_{\lambda=0} = \frac{(a-c)(3-4\alpha)}{9-2\alpha} < (>)0$ for $\alpha > (<)\frac{3}{4}$.[12] Hence, if there is no cross border pollution and the products are sufficiently dirty, that is, $\alpha > \frac{3}{4}$, the equilibrium policy is import subsidy.

Now consider the case of complete cross border pollution, that is, $\lambda = 1$. We get $t^*|_{\lambda=1} = \frac{(a-c)(3+8\alpha)}{9+4\alpha} > 0$, implying that if there is complete cross border pollution, the equilibrium policy is import tariff.

Proposition 3. *(*a*)* If there is no cross border pollution, that is, $\lambda = 0$, and the product is sufficiently dirty, that is, $\alpha > \frac{3}{4}$, the equilibrium policy is import subsidy.

*(*b*)* If there is complete cross border pollution, that is, $\lambda = 1$, the equilibrium policy is import tariff whether or not the product is dirty.

The intuition is similar to that of Proposition 1.

We further get $\frac{\partial t^*}{\partial \alpha} = \frac{\partial s^*}{\partial \alpha} = \frac{30(a-c)\left(-1+\lambda+2\lambda^2\right)}{\left(9+2\alpha\left(-1+\lambda+2\lambda^2\right)\right)^2}$. If there is no cross border pollution, we get $\left.\frac{\partial t^*}{\partial \alpha}\right|_{\lambda=0} = \left.\frac{\partial s^*}{\partial \alpha}\right|_{\lambda=0} = -\frac{30(a-c)}{(9-2\alpha)^2} < 0$, that is, the tariff rate decreases (or the subsidy rate increases) as the products get dirtier. On the other hand, if there is complete cross border pollution, we get $\left.\frac{\partial t^*}{\partial \alpha}\right|_{\lambda=1} = \left.\frac{\partial s^*}{\partial \alpha}\right|_{\lambda=1} = \frac{60(a-c)}{(9+4\alpha)^2} > 0$, that is, the tariff rate increases as the products get dirtier.

Since $\frac{\partial t^*}{\partial \alpha} = \frac{\partial s^*}{\partial \alpha} = \frac{30(a-c)\left(-1+\lambda+2\lambda^2\right)}{\left(9+2\alpha\left(-1+\lambda+2\lambda^2\right)\right)^2} < (>)0$ for $\lambda < (>)\frac{1}{2}$, the above discussion gives the following result immediately.

Proposition 4. A higher environmental damage increases (decreases) the tariff rate if the cross border pollution is significant (not significant), that is, $\lambda > (<)\frac{1}{2}$.

The intuition is similar to that of Proposition 2.

If we have considered a linear damage function, we could get the equilibrium tariff rates as $t^* = s^* = \frac{1}{3}(a - c + \alpha(-1 + 2\lambda))$, and $t^*|_{\lambda=0} = s^*|_{\lambda=0} = \frac{1}{3}(a - c - \alpha) < (>) 0$ for $\alpha > (<)(a - c)$.[13] Hence, if there is no cross border pollution and the products are sufficiently dirty, that is, $\alpha > (a - c)$, the equilibrium policy is import subsidy. If $\lambda = 1$, we get $t^*|_{\lambda=1} = s^*|_{\lambda=1} = \frac{1}{3}(a - c + \alpha) > 0$, implying that if there is complete cross border pollution, the equilibrium policy is import tariff. We further get $\frac{\partial t^*}{\partial \alpha} = \frac{\partial s^*}{\partial \alpha} = \frac{1}{3}(-1 + 2\lambda) < (>) 0$ for $\lambda < (>)\frac{1}{2}$, implying that the tariff rate decreases (increases) as the product gets dirtier if there is low (high) cross border pollution. The critical conditions shown here, such as $\alpha > (a - c)$ and $\lambda < (>)\frac{1}{2}$, are similar to the case of one-way trade, since under a linear damage function, the tariff rate imposed by the other country does not affect a country's first order condition for welfare maximization.

3 | EXTENSIONS

3.1 | The implications of two goods

Although our basic arguments on the relationship between dirtier goods and import tariff can be found from the above analysis with a single product, we show in this subsection that similar arguments follow even if there is a dirty good and a clean good. However, we show that in the presence of two goods, the importing country may provide import subsidy to both goods or to the dirty good only depending on how dirty the product is.

We consider in this section that there are two goods—one dirty and one clean. These goods are imperfect substitutes and each of them is produced by one domestic firm and one foreign firm. Assume that the dirty product is produced by the domestic firm D_1 and the foreign firm F_1, and the clean product is produced by the domestic firm D_2 and the foreign firm F_2. The products of D_1 and F_1 as well the products of D_2 and F_2 are perfect substitutes. Assume that each firm faces the same marginal cost c.

Assume that the firms compete in the domestic market only. Assume that the inverse demand functions faced by D_1 and F_1 are $P_{d1} = a - (q_{d1} + q_{f1}) - \gamma (q_{d2} + q_{f2})$ and $P_{f1} = a - (q_{d1} + q_{f1}) - \gamma (q_{d2} + q_{f2})$ respectively, and the inverse demand functions faced by D_2 and F_2 are $P_{d2} = a - (q_{d2} + q_{f2}) - \gamma (q_{d1} + q_{f1})$ and $P_{f2} = a - (q_{d2} + q_{f2}) - \gamma (q_{d1} + q_{f1})$ respectively, where $\gamma \in [0, 1]$ shows the degree of product differentiation between the dirty product produced by D_1 and F_1, and the clean product produced by D_2 and F_2. These demand functions are generated from the utility function $U = a (q_{d1} + q_{f1} + q_{d2} + q_{f2}) - \frac{1}{2}\left[(q_{d1} + q_{f1})^2 + (q_{d2} + q_{f2})^2 + 2\gamma (q_{d1} + q_{f1})(q_{d2} + q_{f2})\right]$. The dirty and clean products are isolated if $\gamma = 0$ and they are perfect substitutes if $\gamma = 1$. If $\gamma = 1$, it implies that four firms are producing a homogeneous product while D_1 and F_1 are using dirty technologies, and D_2 and F_2 are using clean technologies.

Assume that the domestic government imposes tariff t on the output of F_1 and imposes tariff τ on the output of F_2, where negative t and τ imply subsidies. We assume that $a > (c + t)$ and $a > (c + \tau)$.

Given the demand and cost functions, D_1, F_1, D_2, and F_2 maximize $(P_{d1} - c) q_{d1}$, $(P_{f1} - c - t) q_{f1}$, $(P_{d2} - c) q_{d2}$, and $(P_{f2} - c - \tau) q_{f2}$ respectively to determine their outputs.

The equilibrium outputs can be found respectively as $q_{d1}^* = \frac{a(3-2\gamma)+\gamma(2c-2t\gamma+\tau)-3c+3t}{9-4\gamma^2}$, $q_{f1}^* = \frac{a(3-2\gamma)+\gamma(2c+2t\gamma+\tau)-3(c+2t)}{9-4\gamma^2}$, $q_{d2}^* = \frac{a(3-2\gamma)+3\tau+\gamma(2c+t-2\gamma\tau)-3c}{9-4\gamma^2}$, and $q_{f2}^* = \frac{a(3-2\gamma)+\gamma(2c+t+2\gamma\tau)-3(c+2\tau)}{9-4\gamma^2}$. The second-order conditions are satisfied.

The government of the domestic country maximizes domestic welfare with respect to t and τ. Hence, the domestic government maximizes:

$$\underset{t,\tau}{Max}\underbrace{\left(U^* - P_{d1}^* q_{d1}^* - P_{f1}^* q_{f1}^* - P_{d2}^* q_{d2}^* - P_{f2}^* q_{f2}^*\right)}_{\text{Domestic consumer surplus}} + \underbrace{\pi_{d1}^* + \pi_{d2}^*}_{\text{Total domestic profit}} + \underbrace{tq_{f1}^* + \tau q_{f2}^*}_{\text{Total domestic tariff revenue}} - \underbrace{\alpha\left(q_{d1}^* + \lambda q_{f1}^*\right)^2}_{\text{Environmental damage in the domestic country}},$$

where U^* is the utility at the equilibrium outputs, $\pi_{d1}^* = \left(\frac{a(3-2\gamma)+\gamma(2c-2t\gamma+\tau)-3c+3t}{9-4\gamma^2}\right)^2$ and $\pi_{d2}^* = \left(\frac{a(3-2\gamma)+3\tau+\gamma(2c+t-2\gamma\tau)-3c}{9-4\gamma^2}\right)^2$.

The equilibrium tariff rates can be found as

$$t^* = \frac{(a-c)((-3+\gamma)(-3+2\gamma)(3+2\gamma) + 2\alpha(1+\lambda)(-9+\gamma(5+2(-2+\gamma)\gamma(-1+\lambda)-10\lambda)+18\lambda))}{81-45\gamma^2+4\gamma^4+2\alpha\left(9(1-2\lambda)^2+2\gamma^4(-1+\lambda)^2+\gamma^2(-7+(28-19\lambda)\lambda)\right)}$$

$$\tau^* = \frac{(a-c)\left((-3+\gamma)(-3+2\gamma)(3+2\gamma)+2\alpha\begin{pmatrix} 3(1-2\lambda)^2+2\gamma^3(-1+\lambda)^2 \\ -3\gamma(3+(-2+\lambda)\lambda)+\gamma^2\left(2+8\lambda-6\lambda^2\right)\end{pmatrix}\right)}{81-45\gamma^2+4\gamma^4+2\alpha\left(9(1-2\lambda)^2+2\gamma^4(-1+\lambda)^2+\gamma^2(-7+(28-19\lambda)\lambda)\right)}.$$

The second-order conditions are satisfied.

If there is no cross border pollution, that is, $\lambda = 0$, we get $t^*|_{\lambda=0} = -\frac{(a-c)\left(9(-3+\gamma)-4(-3+\gamma)\gamma^2+2\alpha(9+\gamma(-5+2(-2+\gamma)\gamma))\right)}{9(9+2\alpha)-(45+14\alpha)\gamma^2+4(1+\alpha)\gamma^4} < (>)0$ for $\alpha > (<)\frac{(3-\gamma)(3-2\gamma)(3+2\gamma)}{2\left(9-5\gamma-4\gamma^2+2\gamma^3\right)} \equiv \alpha^*$, and $\tau^*|_{\lambda=0} = \frac{(a-c)\left((3-\gamma)(3-2\gamma)(3+2\gamma)+2\alpha\left(3-9\gamma+2\gamma^2+2\gamma^3\right)\right)}{81-45\gamma^2+4\gamma^4+2\alpha\left(9-7\gamma^2+2\gamma^4\right)} < (>)0$ for $\alpha > (<)\frac{(3-\gamma)(3-2\gamma)(3+2\gamma)}{2\gamma(9-2\gamma(1+\gamma))-6} \equiv \alpha^{**}$.

We find $\tau^*|_{\lambda=0} - t^*|_{\lambda=0} = \frac{4(a-c)\alpha(1-\gamma)(2+\gamma)(3-2\gamma)}{9(9+2\alpha)-(45+14\alpha)\gamma^2+4(1+\alpha)\gamma^4} > 0$, implying that if there is no cross border pollution, the domestic government imposes higher tariff rate on the clean product than on the dirty product. Further, since $\alpha^* < \alpha^{**}$, the domestic government provides import subsidy to both goods if the dirty good is very dirty (i.e. $\alpha^{**} < \alpha$), provides import subsidy to the dirty good but imposes import tariff on the clean good if the dirty good is moderately dirty (i.e. $\alpha^* < \alpha < \alpha^{**}$), and imposes import tariff on both goods if the dirty good is not very dirty (i.e. $\alpha < \alpha^*$). The domestic government behaves in this way since it prefers the dirty product to be produced in the foreign country, and it can make the domestic dirty good producer less competitive by providing import subsidy to the foreign dirty good producer and if required, by providing import subsidy also to the foreign clean good producer. If the dirty product is not very dirty, it imposes import tariff to extract rents from the foreign firms.

It is worth noting that $\tau^*|_{\lambda=0} = \frac{(a-c)(27+6\alpha)}{81+18\alpha}$ is always positive if the products are isolated, that is, if $\gamma = 0$. If the products are isolated, import subsidy on the clean product does not help to reduce the output of the domestic firm producing the dirty product. Hence, there is no incentive to give subsidy to the clean product when $\gamma = 0$.

Now consider the case of complete cross border pollution, that is, $\lambda = 1$. We get $t^*|_{\lambda=1} = \frac{(a-c)(4\alpha(9-5\gamma)+(3-\gamma)(3-2\gamma)(3+2\gamma))}{9(9+2\alpha)+(-45+4\alpha)\gamma^2+4\gamma^4} > 0$ and $\tau^*|_{\lambda=1} = \frac{(a-c)\left((3-\gamma)(3-2\gamma)(3+2\gamma)+2\alpha\left(3-6\gamma+4\gamma^2\right)\right)}{81-45\gamma^2+4\gamma^4+2\alpha\left(9+2\gamma^2\right)} > 0.$[14]

We find $\tau^*|_{\lambda=1} - t^*|_{\lambda=1} = \frac{2(a-c)\alpha(-3+2\gamma)(5+2\gamma)}{9(9+2\alpha)+(-45+4\alpha)\gamma^2+4\gamma^4} < 0$. Hence, if there is complete cross border pollution, the domestic government imposes import tariff on both products and it imposes higher tariff on the dirty product than on the clean product. The domestic government behaves in this way since it wants to extract rents from both products but also wants to reduce the total output of the dirty product. Hence, it imposes import tariff on both products due to the rent extraction motive but it imposes higher tariff on the dirty product since it wants to reduce the total output of the dirty product.

We summarize the above discussion in the following proposition.

Proposition 5. *(a) If there is no cross border pollution, the domestic government provides import subsidy to both goods if the dirty good is very dirty, provides import subsidy to the dirty good but imposes import tariff on the clean good if the dirty good is moderately dirty, and imposes import tariff on both goods if the dirty good is not very dirty. The tariff rate is higher on the clean product than on the dirty product.*

(b) If there is complete cross border pollution, the domestic government imposes import tariff on both products and it imposes higher tariff on the dirty product than on the clean product.

The above result focuses on two extreme situations of no cross border pollution and complete cross border pollution. Now we want to use some examples to show how t^* and τ^* change with respect to different degrees of cross border pollution. Figure 1 plots $\frac{t^*}{(a-c)}$ and $\frac{\tau^*}{(a-c)}$ for $\alpha = 0.25$, $\lambda \in [0, 1]$, and $\gamma = 0.9$ (Figure 1a), $\gamma = 0.5$ (Figure 1b), $\gamma = 0.1$ (Figure 1c). Figure 2 plots $\frac{t^*}{(a-c)}$ and $\frac{\tau^*}{(a-c)}$ for $\alpha = 0.4$, $\lambda \in [0, 1]$, and $\gamma = 0.4$(Figure 2a), $\gamma = 0.3$ (Figure 2b), $\gamma = 0.1$ (Figure 2c). All figures show that $t^* < (>) \tau^*$ for lower (higher) values of λ.

3.2 | The implications of environmental taxes

To show the effects of environmental pollution on optimal tariff, we assumed away endogenous environmental taxation to eliminate further strategic effects of taxation. Endogenous environmental taxes not only help to tackle environmental pollution, they also help to reduce the product market distortion due to imperfect competition and rent extraction from the foreign firm. While the pollution reducing role helps to create the environmental taxes positive, the output market distortion reducing effect and the rent extraction effect tend to make them negative (implying subsidies). Although we ignored endogenous environmental taxes, our model can capture the existence of exogenously given environmental tax by redefining the marginal costs as environmental tax inclusive marginal cost.

Now we consider a single product and one way trade like Section 2.1 to show the implications of endogenous environmental tax in determining the relationship between environmental damage and tariff.[15]

Assume that the linear demand function is $P = a - q$, with $a > (c + t + r)$ and $a > (c+w)$, where w and r are the environmental taxes (subsidies, if negative) imposed by the domestic and foreign countries on firm D and firm F respectively.

Given the demand and cost functions, firms D and F maximize $(a - q - c - w)q_d$ and $(a - q - c - t - r)q_f$ respectively to determine their outputs. The equilibrium outputs of firms D and

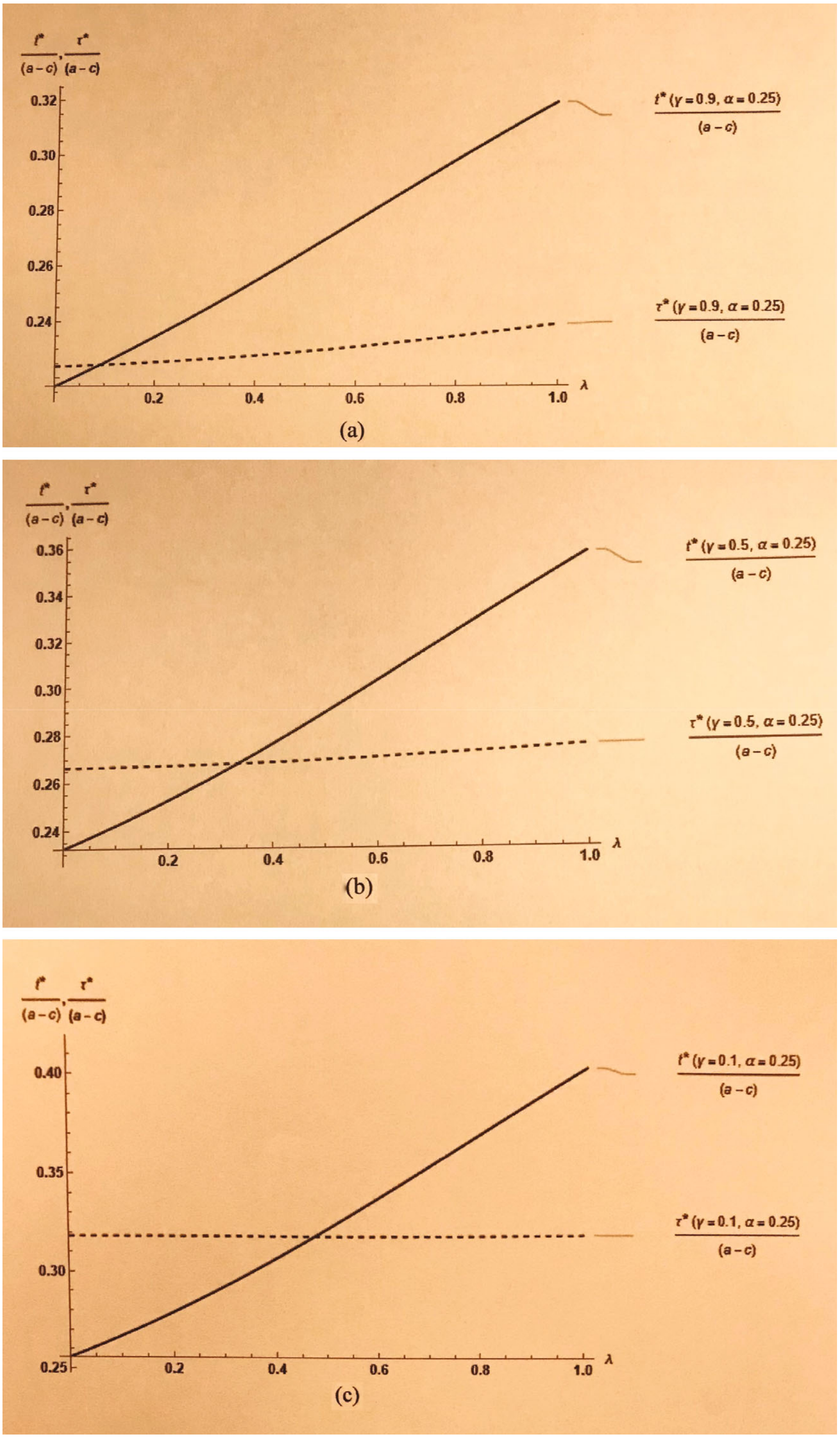

FIGURE 1 (a) The effects of λ on t^* and τ^* for $\alpha = 0.25$, $\lambda \in [0, 1]$, and $\gamma = 0.9$. (b) The effects of λ on t^* and τ^* for $\alpha = 0.25$, $\lambda \in [0, 1]$, and $\gamma = 0.5$. (c) The effects of λ on t^* and τ^* for $\alpha = 0.25$, $\lambda \in [0, 1]$, and $\gamma = 0.1$. [Colour figure can be viewed at wileyonlinelibrary.com]

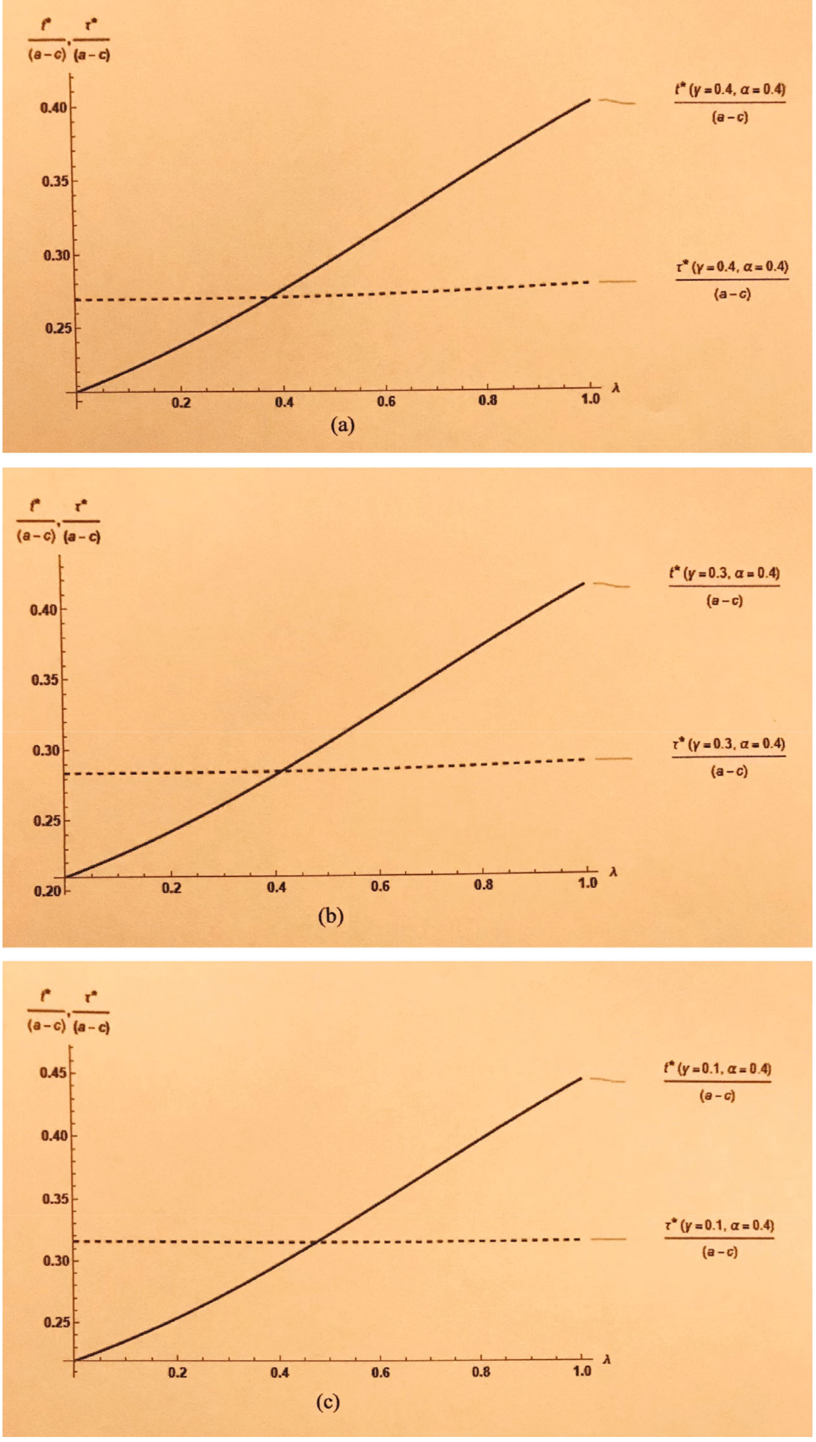

FIGURE 2 (a) The effects of λ on t^* and τ^* for $\alpha = 0.4$, $\lambda \in [0, 1]$, and $\gamma = 0.4$. (b) The effects of λ on t^* and τ^* for $\alpha = 0.4$, $\lambda \in [0, 1]$, and $\gamma = 0.3$. (c) The effects of λ on t^* and τ^* for $\alpha = 0.4$, $\lambda \in [0, 1]$, and $\gamma = 0.1$. [Colour figure can be viewed at wileyonlinelibrary.com]

F can be found respectively as $q_d^* = \frac{a-c+r+t-2w}{3}$ and $q_f^* = \frac{a-c-2r-2t+w}{3}$. The second-order conditions are satisfied.

The domestic and foreign countries maximize the following expressions to determine the tariff rate and the environmental taxes:

$$\underset{t,w}{Max} \underbrace{\left(\frac{a-c+r+t-2w}{3}\right)^2}_{\text{Profits of firm D}} + \underbrace{\frac{1}{2}\left(\frac{2a-2c-r-t-w}{3}\right)^2}_{\text{Domestic consumer surplus}}$$

$$+ \underbrace{t\left(\frac{a-c-2r-2t+w}{3}\right) + w\left(\frac{a-c+r+t-2w}{3}\right)}_{\text{Domestic tariff and tax revenue}}$$

$$- \underbrace{\alpha\left(\frac{a-c+r+t-2w}{3} + \lambda\left(\frac{a-c-2r-2t+w}{3}\right)\right)^2}_{\text{Environmental damage in the domestic country}}$$

$$\underset{r}{Max} \underbrace{\left(\frac{a-c-2r-2t+w}{3}\right)^2}_{\text{Profits of firm F}} + \underbrace{r\left(\frac{a-c-2r-2t+w}{3}\right)}_{\text{Foreign tax revenue}}$$

$$- \underbrace{\alpha\left(\frac{a-c-2r-2t+w}{3} + \lambda\left(\frac{a-c+r+t-2w}{3}\right)\right)^2}_{\text{Environmental damage in the foreign country}}.$$

The equilibrium tariff and the environmental taxes can be found as

$$t^* = \frac{2(a-c)\alpha(2+(-1+\lambda)\lambda(1+2\alpha(-2+\lambda)(1+\lambda)))}{3+2\alpha(7+2\alpha(-2+\lambda)(-1+\lambda)(1+\lambda)+\lambda(-7+3\lambda))}$$

$$w^* = \frac{(a-c)(-3+2\alpha(1+(3-2\lambda)\lambda+2\alpha(-2+\lambda)(-1+\lambda)(1+\lambda)))}{3+2\alpha(7+2\alpha(-2+\lambda)(-1+\lambda)(1+\lambda)+\lambda(-7+3\lambda))}$$

$$r^* = -\frac{2(a-c)\alpha\left(1+2\alpha(-2+\lambda)(-1+\lambda)^2(1+\lambda)+\lambda(-5+2\lambda)\right)}{3+2\alpha(7+2\alpha(-2+\lambda)(-1+\lambda)(1+\lambda)+\lambda(-7+3\lambda))}.$$

The second-order conditions are satisfied.

If $\lambda = 0$, we get $t^*|_{\lambda=0} = \frac{4(a-c)\alpha}{3+2\alpha(7+4\alpha)}$, $w^*|_{\lambda=0} = \frac{(a-c)(-3+2\alpha(1+4\alpha))}{3+2\alpha(7+4\alpha)}$ and $r^*|_{\lambda=0} = -\frac{2(a-c)(1-4\alpha)\alpha}{3+2\alpha(7+4\alpha)}$. The environmental taxes help to tackle environmental pollution, product market distortion due to imperfect competition and rent extraction from the foreign firm. While the first aspect tends to make the environmental taxes positive, the second and third aspects tend to make them negative. Hence, if the environmental damage is low, that is, α is low, we get $w^* < 0$ and $r^* < 0$ negative. Hence, to make the environmental issues significant, it may worth considering higher values of α.

We find that if the governments have other instruments like environmental taxes to control pollution along with import tariff, the rent extraction motive of import tariff becomes the important factor and the domestic government imposes import tariff even if there is no cross border pollution. However, as shown below, if the products are sufficiently dirty, the import tariff reduces as the products get dirtier, since the government wants to reduce pollution also by reducing the competitiveness of the domestic firm.

We get $\frac{\partial t^*|_{\lambda=0}}{\partial \alpha} = -\frac{4(a-c)(-3+8\alpha^2)}{(3+14\alpha+8\alpha^2)^2} < 0$ for $\alpha > \sqrt{\frac{3}{8}}$. Hence, if the environmental problem is not insignificant, a higher environmental damage decreases the tariff rate in the absence of a cross border pollution.

Now consider the case of maximum cross border pollution that provides positive outputs for all firms. Here the requirement for positive output is $\lambda < (2-\sqrt{2})$. The use of both tariff and environmental tax made it more difficult for the foreign firm to compete in the market, which is reflected in the upper limit on λ, which is less than complete cross border pollution, given that the firms produce homogeneous products.

We get $t^*|_{\lambda=(2-\sqrt{2})} = \frac{2(a-c)\alpha(-6+3\sqrt{2}-52\alpha+36\sqrt{2}\alpha)}{(1+2\alpha)(-3+2(-8+5\sqrt{2})\alpha)}$, $w^*|_{\lambda=(2-\sqrt{2})} = \frac{(a-c)(-1+2\alpha)}{1+2\alpha}$ and $r^*|_{\lambda=(2-\sqrt{2})} = -\frac{2(a-c)\alpha(-3+3\sqrt{2}-36\alpha+26\sqrt{2}\alpha)}{(1+2\alpha)(-3+2(-8+5\sqrt{2})\alpha)}$. We also get $\frac{\partial t^*|_{\lambda=(2-\sqrt{2})}}{\partial \alpha} = \frac{2(2-\sqrt{2})(a-c)}{(1+2\alpha)^2} > 0$. Hence, a higher environmental damage increases the tariff rate if there is significant cross border pollution.

We summarize the above discussion in the following proposition.

Proposition 6. If we consider environmental taxes along with import tariff, import tariff can be positive even under no cross border pollution. If the environmental damage is significant, that is, α is high, a higher environmental damage decreases the tariff rate under no cross border pollution. If the environmental damage is either insignificant, that is, α is small, or cross border pollution is significant, a higher environmental damage increases the tariff rate.

3.3 | World welfare maximizing tariff

We have considered so far that the countries determine tariff rates to maximize their own welfare. We will now consider situations similar to Sections 2.1 and 2.2 to show the implications of world welfare maximizing tariff.

3.3.1 | One way trade

We consider in this subsection a situation of one way trade like Section 2.1. However, we consider here that the domestic country determines the tariff to maximize world welfare, that is, the total welfare of the domestic and foreign countries. Hence, the domestic country maximizes the following expression to determine the tariff:

$$\underset{t}{Max}\underbrace{\left(\frac{a-c+t}{3}\right)^2}_{\text{Profit of firm } D} + \underbrace{\frac{1}{2}\left(\frac{2a-2c-t}{3}\right)^2}_{\text{Domestic consumer surplus}} + \underbrace{t\left(\frac{a-c-2t}{3}\right)}_{\text{Domestic tariff revenue}} \underbrace{-\alpha\left(\frac{a-c+t}{3}+\frac{\lambda(a-c-2t)}{3}\right)^2}_{\text{Domestic environmental damage}}$$
$$+\underbrace{\left(\frac{a-c-2t}{3}\right)^2}_{\text{Profit of firm } F} \underbrace{-\alpha\left(\frac{(a-c-2t)}{3}+\frac{\lambda(a-c+t)}{3}\right)^2}_{\text{Foreign environmental damage}}.$$

The equilibrium tariff rate can be found as $t^* = \frac{(a-c)(-1+2\alpha(1+\lambda)^2)}{1+2\alpha(5+\lambda(-8+5\lambda))}$. The second-order condition is satisfied.

If $\lambda = 0$, we get $t^*|_{\lambda=0} = \frac{(a-c)(-1+2\alpha)}{1+10\alpha} < (>)0$ for $\alpha < (>)\frac{1}{2}$. This is different from the result shown in Section 2.1, where the domestic country provides import subsidy if there is no cross border pollution and the products are sufficiently dirty. In contrast, here the domestic country provides import subsidy if the product is sufficiently clean when there is no cross border pollution.

In Section 2.1, import subsidy of the domestic country increases the foreign firm's output, thus shifting pollution from the domestic country to the foreign country. However, if the domestic country determines tariff to maximize world welfare, the domestic country internalizes the negative effect of its import subsidy on the foreign country's welfare, which induces it to impose import tariff if the products are not sufficiently clean. If the products are sufficiently clean, the environmental concern is negligible and here the tariff is determined to reduce the oligopolistic distortion in the product-market, which creates the incentive for an import subsidy.

Now consider the case of complete cross border pollution, that is, $\lambda = 1$. We get $t^*|_{\lambda=1} = \frac{(a-c)(-1+8\alpha)}{1+4\alpha} < (>)0$ for $\alpha < (>)\frac{1}{8}$.[16] This is also different from the result shown in Section 2.1, where the domestic country always imposes import tariff if there is complete cross border pollution. In contrast, here the domestic country provides import subsidy if the product is sufficiently clean when there is complete cross border pollution. This happens since here the domestic tariff maximizes world welfare, and reducing oligopolistic distortion in the product-market is the main motive when the products are very clean.

We further get $\frac{\partial t^*}{\partial \alpha} = \frac{12(a-c)(1+(-1+\lambda)\lambda)}{(1+2\alpha(5+\lambda(-8+5\lambda)))^2} > 0$, suggesting that as the products get dirtier, the domestic tariff increases. This is also in contrast to the result in Section 2.1. The reason follows from the above argument. Since domestic import subsidy creates a negative effect on foreign welfare by shifting pollution from the domestic country to the foreign country, the domestic country internalizes this adverse effect of its tariff policy when determining tariff to maximize world welfare. Hence, as the products get dirtier, it increases the incentive for reducing pollution by imposing a higher tariff.

Like Section 2.1 we considered a quadratic damage function here. We will now show that the qualitative results of this subsection holds under a linear damage function. To avoid repetition, we will skip the mathematical details. It can be checked that the equilibrium tariff rate under a linear damage function $\alpha\left(q_d + \lambda q_f\right)$ will be $t^* = -(a-c) + 3\alpha(1+\lambda)$. If $\lambda = 0$, we get $t^* = -(a-c) + 3\alpha > (<)0$ for $\alpha > (<)\frac{(a-c)}{3}$.[17] If $\lambda = 1$, we get $t^* = -(a-c) + 6\alpha > (<)0$ for $\alpha > (<)\frac{(a-c)}{6}$.[18] Further, we get $\frac{\partial t^*}{\partial \alpha} = 3(1+\lambda) > 0$.

3.3.2 | Two way trade

Now we consider a situation of two way trade like Section 2.2. However, we consider here that the countries determine the tariff rates to maximize world welfare, thus considering tariff harmonization. Hence, the tariff rates t and s are determined to maximize the following expression:

$$\underset{t,s}{Max}\; W^{\mathrm{D}} + W^{\mathrm{F}},$$

where W^{D} (welfare of the domestic country) and W^{F} (welfare of the foreign country) are shown in (1) and (2) respectively.

The equilibrium tariff rates can be found as $t^* = s^* = \frac{(a-c)\left(-1+4\alpha(1+\lambda)^2\right)}{1+2\alpha(1+\lambda)^2}$. The second-order conditions are satisfied.

We get $t^*|_{\lambda=0} = s^*|_{\lambda=0} = \frac{(a-c)(-1+4\alpha)}{1+2\alpha} < (>)0$ for $\alpha < (>)\frac{1}{4}$,[19] $t^*|_{\lambda=1} = s^*|_{\lambda=1} = \frac{(a-c)(-1+16\alpha)}{1+8\alpha} < (>)0$ for $\alpha < (>)\frac{1}{16}$,[20] and $\frac{\partial t^*}{\partial \alpha} = \frac{\partial s^*}{\partial \alpha} = \frac{6(a-c)(1+\lambda)^2}{(1+2\alpha(1+\lambda)^2)^2} > 0$. These results are qualitatively similar to the results shown in the previous Section 3.3.1 and the reasons for these results are similar to the reasons discussed there.

The following proposition summarizes the findings of Section 3.3.

Proposition 7. If the tariffs are determined to maximize global welfare, the importing country imposes import tariff (provides import subsidy) if the goods are not sufficiently clean (sufficiently clean), and the import tariff increases (or the import subsidy decreases) as the goods get dirtier.

If we have considered a linear damage function the tariff rates will be $t^* = s^* = -(a-c) + 3\alpha(1+\lambda)$. If $\lambda = 0$, we get $t^* = s^* = -(a-c) + 3\alpha > (<)0$ for $\alpha > (<)\frac{(a-c)}{3}$.[21] If $\lambda = 1$, we get $t^* = s^* = -(a-c) + 6\alpha > (<)0$ for $\alpha > (<)\frac{(a-c)}{6}$.[22] Further, we get $\frac{\partial t^*}{\partial \alpha} = 3(1+\lambda) > 0$. If the damage function is linear, like the non-cooperative tariff setting, the results under one-way trade and two-way trade are the same under world welfare maximizing tariff, since under a linear damage function, the tariff rate imposed by the other country does not affect a country's first order condition for welfare maximization.

4 | CONCLUSION

In a recent paper Shapiro (2021) provides an in depth analysis of trade policies and CO_2 emission in a large cross section of countries and finds in a vertical structure that dirtier goods face lower import tariffs than cleaner goods. We use this result as the backdrop to theorize optimal tariff policy in the presence of pollution. We show that countries concerned about controlling pollution but maximizing own welfare might be encouraged toward relatively unfettered import of dirtier goods as long as pollution is mainly generated from domestic production and not from cross border pollution. Thus, we argue that although taxing dirtier goods may be a popular rhetoric, liberal import of dirtier goods might be the rationale choice of individual countries trying to reduce the effects of pollution in their own countries. We also derive the implications of global welfare maximizing tariff protection, pollution taxes and multiple tradable products.

Since countries are geographically far apart, cross border pollution may not affect each country in the same way. If pollution is caused mainly through domestic production, as we showed, countries maximizing own welfare will like to discard production at home and would not desire to protect domestic dirty goods industry. So, there is a case for lower tariffs on dirtier goods as the optimal policy even if there are no effects through vertical relationships.

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DATA AVAILABILITY STATEMENT

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

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ENDNOTES

[1] In general, there could be production and consumption pollution. However, like Shapiro (2021), our paper is focusing on pollution from production.

[2] As reported in Guardian (April 4, 2022: https://www.theguardian.com/environment/2022/apr/04/high-carbon-goods-imported-to-uk-should-be-subject-to-new-tariffs-say-mps), "High-carbon goods imported into the UK should be subject to new tariffs, to help ensure other countries are fulfilling their obligations to reach net zero greenhouse gas emissions as well as the UK ... " Reuters (March 16, 2022: https://www.reuters.com/world/europe/eu-countries-back-plan-world-first-carbon-border-tariff-2022-03-15/) and Euronews (March 16, 2022: https://www.euronews.com/green/2022/03/16/eu-s-proposed-co2-emissions-tariff-is-a-major-step-forward-in-the-fight-against-climate-ch) reported that European Union countries backed the bloc's plan to impose a world-first carbon dioxide emissions tariff on imports of polluting goods.

[3] Fu et al. (2022) examine the trans-city drifts of PM_{10} pollutant. They found that the transboundary pollution spillover is roughly 35.5% of the local effect at 50 km, falling to 6.2% at 550 km, and zero at 1000 km and beyond.

[4] The scale of import tariff reduction that is responsible for carbon leakage for a given nature of activities and technologies is discussed in earlier papers also (see, e.g. Grossman & Krueger, 1993).

[5] There is a literature analyzing how trade liberalization or trade agreements affect pollution (see, e.g. Cherniwchan, 2017; Tian et al., 2022). However, to the best of our knowledge, there is no paper examining how countries impose tariffs on final goods depending on their dirtiness.

[6] In a competitive model, Krutilla (1991) derives environmental taxes in an open economy and shows how a combination of environmental tax and tariff can improve the situation. In contrast, our focus is on the trade policy. Unlike us, that paper did not look at the strategic effects of the final goods producers, cross border pollution, policies when both clean and dirty products are being traded, and trade policy harmonization.

[7] Earlier papers by Markusen (1975) and Kennedy (1994) show the theoretical effects of environmental tax to control pollution.

[8] One may also look at Environment and trade—A handbook, United Nations (2005), and the edited book by Huang and Yu (2020) for more work in this area.

[9] Cole et al. (2006) measured the effects of foreign direct investment on environmental policy.

[10] There is another set of papers showing the effects of environmental regulation on outsourcing (see, e.g. Antonietti et al., 2017; Cole et al., 2014; Iida & Mukherjee, 2020; Lyu, 2016; Michel, 2013).

[11] Here the requirement for positive outputs is $\alpha < \frac{1}{2}$.

[12] Here the requirement for positive outputs is $\alpha < 2$.

[13] Here the requirement for positive outputs is $\alpha < 4(a - c)$.

[14] Here the restriction for positive outputs requires $\alpha < \frac{-9+9\gamma-2\gamma^2}{2(-9+5\gamma)}$.

[15] Export subsidy is another potential policy variable for the foreign country. Since the purposes of both export subsidy and environmental tax imposed by the foreign country are to directly influence the foreign firm's output, which, in turn, affects the output of the domestic firm through strategic interaction, it is not required to consider both the environmental tax and export subsidy separately. If one considers a per-unit environmental tax and a per-unit export subsidy, the combined values of these tax and subsidy would be equal to r^* shown below.

[16] Here the requirement for positive outputs is $\alpha < \frac{1}{4}$.

[17] Here the requirement for positive outputs is $\alpha < \frac{(a-c)}{2}$.

[18] Here the requirement for positive outputs is $\alpha < \frac{(a-c)}{4}$.

[19] Here the requirement for positive outputs is $\alpha < \frac{1}{2}$.

[20] Here the requirement for positive outputs is $\alpha < \frac{1}{8}$.

[21] Here the requirement for positive outputs is $\alpha < \frac{(a-c)}{2}$.

[22] Here the requirement for positive outputs is $\alpha < \frac{(a-c)}{4}$.

[23] Here the requirement for positive outputs is $\alpha < 4(a - c)$.

REFERENCES

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

Antweiler, W. (1996). The pollution terms of trade. *Economic Systems Research*, *8*, 361–366.

Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is free trade good for the environment? *American Economic Review*, *91*, 877–908.

Brunnermeier, S. B., & Levinson, A. (2004). Examining the evidence on environmental regulations and industry location. *The Journal of Environment & Development*, *1*, 6–41.

Cherniwchan, J. (2017). Trade liberalization and the environment: Evidence from NAFTA and U.S. manufacturing. *Journal of International Economics*, *105*, 130–149.

Cherniwchan, J., Copeland, B. R., & Taylor, M. S. (2017). Trade and the environment: New methods, measurements, and results. *Annual Review of Economics*, *9*, 59–85.

Cole, M. A., & Elliott, R. J. R. (2005). FDI and the capital intensity of 'dirty' sectors: A missing piece of the pollution haven puzzle. *Review of Development Economics*, *9*, 530–548.

Cole, M. A., Elliott, R. J. R., & Fredriksson, P. G. (2006). Endogenous pollution havens: Does FDI influence environmental regulations? *Scandinavian Journal of Economics*, *108*, 157–178.

Cole, M. A., Elliott, R. J. R., & Okubo, T. (2014). International environmental outsourcing. *Review of World Economics*, *150*, 639–664.

Copeland, B. R. (1996). Pollution content tariffs, environmental rent shifting and the control of foreign pollution. *Journal of International Economics*, *40*, 459–476.

Copeland, B. R. (2011). *Trade and the environment*. In D. Bernhofen, R. Falvey, D. Greenaway, & U. Kreickemeier (Eds.), *Palgrave handbook of international trade* (pp. 423–496). Palgrave Macmillan.

Copeland, B. R. (2020). *Trade and the environment: Recent evidence and policy implications*. In B. Huang & E. Yu (Eds.), *Ways to achieve green Asia* (pp. 187–224). Asian Development Bank Institute.

Copeland, B. R., & Taylor, M. S. (1994). North–South trade and the environment. *Quarterly Journal of Economics*, *109*, 755–787.

Copeland, B. R., & Taylor, M. S. (2003). *Trade and the environment: Theory and evidence*. Princeton University Press.

Copeland, B. R., & Taylor, M. S. (2004). Trade, growth, and the environment. *Journal of Economic Literature*, *42*, 7–71.

Dean, J. M., Lovely, M. E., & Wang, H. (2009). Are foreign investors attracted to weak environmental regulation? Evaluating the evidence from China. *Journal of Development Economics*, *90*, 1–13.

Dechezleprêtre, A., & Sato, M. (2017). The impacts of environmental regulations on competitiveness. *Review of Environmental Economics and Policy*, *11*, 183–206.

Dijkstra, B. R., Mathew, A. J., & Mukherjee, A. (2011). Environmental regulation: An incentive for foreign direct investment. *Review of International Economics*, *19*, 568–578.

Duffy-Deno, K. T. (1992). Pollution abatement expenditures and regional manufacturing activity. *Journal of Regional Science*, *32*, 419–436.

Eskeland, G., & Harrison, A. (2003). Moving to greener pastures? Multinationals and the pollution haven hypothesis. *Journal of Development Economics*, *70*, 1–23.

Falk, I., & Mendelsohn, R. (1993). The economics of controlling stock pollutants: An efficient strategy for greenhouse gases. *Journal of Environmental Economics and Management*, *25*, 76–88.

Fowlie, M., Reguant, M., & Ryan, S. P. (2016). Market-based emissions regulation and industry dynamics. *Journal of Political Economy*, *124*, 249–302.

Frankel, J. A., & Rose, A. K. (2005). Is trade good or bad for the environment? Sorting out the causality. *Review of Economics and Statistics*, *87*, 85–91.

Friedman, J., Gerlowski, D. A., & Silberman, J. (1992). What attracts foreign multinational corporations? Evidence from branch plant location in the United States. *Journal of Regional Science*, *32*, 403–418.

Fu, S., Viard, V. B., & Zhang, P. (2022). Trans-boundary air pollution spillovers: Physical transport and economic costs by distance. *Journal of Development Economics*, *155*, 102808.

Grossman, G. M., & Krueger, A. B. (1993). *Environmental impacts of a North American free trade agreement*. In P. M. Garber (Ed.), *The Mexico—U.S. free trade agreement*. Massachusetts Institute of Technology Press.

Howard, P. H., & Sterner, T. (2017). Few and not so far between: A meta-analysis of climate damage estimates. *Environmental and Resources Economics*, *68*, 197–225.

Huang, B., & Yu, E. (Eds.). (2020). *Ways to achieve green Asia*. Asian Development Bank Institute.

Iida, T., & Mukherjee, A. (2020). Make and buy in a polluting industry. *Journal of Public Economic Theory*, *22*, 1852–1874. https://doi.org/10.1111/jpet.12440

Javorcik, B. S., & Wei, S.-J. (2004). Pollution havens and foreign direct investment: Dirty secret or popular myth? *Contributions to Economic Analysis and Policy*, *3*, 8 http://www.bepress.com/bejeap/contributions/vol3/iss2/art8

Karp, L., & Zhang, J. (2006). Regulation with anticipated learning about environmental damages. *Journal of Environmental Economics and Management*, *51*, 259–279.

Kennedy, P. W. (1994). Equilibrium pollution taxes in open economies with imperfect competition. *Journal of Environmental Economics and Management*, *27*, 49–63.

Krutilla, K. (1991). Environmental regulation in an open economy. *Journal of Environmental Economics and Management*, *20*, 127–142.

Kuik, O., & Gerlagh, R. (2003). Trade liberalization and carbon leakage. *The Energy Journal*, *24*, 97–120.

Lai, Y.-B., & Hu, C.-H. (2008). Trade agreements, domestic environmental regulation, and transboundary pollution. *Resource and Energy Economics*, *30*, 209–228.

Levinson, A. (1996). *Environmental regulation and industrial location: International and domestic evidence*. In J. Bhagwati & R. Hudec (Eds.), *Harmonization and fair trade* (pp. 429–467). MIT Press.

Levinson, A. (2009). Technology, international trade, and pollution from US manufacturing. *American Economic Review*, *99*, 2177–2192.

Levinson, A. (2010). Offshoring pollution: Is the US increasingly importing polluting goods? *Review of Environmental Economics and Policy*, *4*, 63–83.

List, J. A., McHone, W. W., & Millimet, D. L. (2003). Effects of air quality regulation on the destination choice of relocating plants. *Oxford Economic Papers*, *55*, 657–678.

Lyu, Y. (2016). Evaluating carbon leakage emissions in undertaking offshored production tasks: The case of China. *Journal of Cleaner Production*, *116*, 32–39.

Managi, S., Hibiki, A., & Tsurumi, T. (2009). Does trade openness improve environmental quality? *Journal of Environmental Economics and Management*, *58*, 346–363.

Marjit, S., Kar, S., & Beladi, H. (2007). Protectionary bias in agriculture: A pure economic argument. *Ecological Economics*, *63*, 160–164.

Marjit, S., & Yu, E. (2020). *Globalization and the environment in India*. In B. Huang & E. Yu (Eds.), *Ways to achieve green Asia* (pp. 278–311). Asian Development Bank Institute.

Markusen, J. R. (1975). International externalities and optimal tax structures. *Journal of International Economics*, *5*, 15–29.

McConnell, V. D., & Schwab, R. M. (1990). The impact of environmental regulation on industry location decisions: The motor vehicle industry. *Land Economics*, *66*, 67–81.

Michel, B. (2013). Does offshoring contribute to reducing domestic air emissions? Evidence from Belgian manufacturing. *Ecological Economics*, *95*, 73–82.

Powe, N. A., & Willis, K. G. (1998). Industrial location and residential disamenity: A case study of the chemical industry in Castleford, England. *Journal of Environmental Management*, *53*, 17–29.

Schlee, E. E. (1993). A curvature condition ensuring uniqueness of Cournot equilibrium, with applications to comparative statics. *Economics Letters*, *41*, 29–33.

Shapiro, J. S. (2021). The environmental bias of trade policy. *Quarterly Journal of Economics*, *136*, 831–886.

Shapiro, J. S., & Walker, R. (2018). Why is pollution from U.S. manufacturing declining? The roles of environmental regulation, productivity, and trade. *American Economic Review*, *108*, 3814–3854.

Tarui, N., & Polasky, S. (2005). Environmental regulation with technology adoption, learning and strategic behavior. *Journal of Environmental Economics and Management*, *50*, 447–467.

Tian, K., Zhang, Y., Li, Y., Ming, X., Jiang, S., Duan, H., Yang, C., & Wang, S. (2022). Regional trade agreement burdens global carbon emissions mitigation. *Nature Communications*, *13*, 408.

United Nations. (2005). *Environment and trade—A handbook*. United Nations.

Van der Ploeg, F., & De Zeeuw, A. J. (1992). International aspects of pollution control. *Environmental and Resource Economics*, *2*, 117–139.

Weitzman, M. L. (2010). What is the "damages function" for global warming—And what difference might it make? *Climate Change Economics*, *1*, 57–69.

Xu, L., Cho, S., & Lee, S.-H. (2016). Emission tax and optimal privatization in Cournot-Bertrand competition comparison. *Economic Modelling*, *55*, 73–82.

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APPENDIX A

ONE WAY TRADE CONSIDERED IN SECTION 2.1: GENERAL DEMAND

We show here that the results derived in Section 2.1 holds under a general demand function. We consider the quadratic damage function.

We assume that the demand function is $P = P(q)$, where P is price and q is the total output. We consider $P' < 0$, $P'' \leq 0$ and $P' + qP'' < 0$.

Firms D and F maximize the following expressions to determine their outputs:

$$\underset{q_d}{Max}\ (P(q) - c)q_d, \tag{A1}$$

$$\underset{q_f}{Max}\ (P(q) - c - t)q_f, \tag{A2}$$

where the tariff rate imposed by the domestic country is denoted by t.

The equilibrium outputs are given by the following two first order conditions:

$$P + q_d P' - c = 0, \tag{A3}$$

$$P + q_f P' - c - t = 0. \tag{A4}$$

The second-order conditions are satisfied, and it follows from Schlee (1993) that the condition $P' + qP'' < 0$ ensures that there is a unique solution for equilibrium outputs.

Differentiating (A3) and (A4) with respect to t and solving them, we get $q'_d = -\frac{P' + q_d P''}{P'(3P' + qP'')} > 0$, $q'_f = \frac{2P' + q_d P''}{P'(3P' + qP'')} < 0$, $q' = \frac{1}{3P' + qP''} < 0$, where $q'_d = \frac{\partial q_d}{\partial t}$, $q'_f = \frac{\partial q_f}{\partial t}$ and $q' = \frac{\partial q}{\partial t}$.

The domestic country determines the tariff rate to maximize domestic welfare. Hence, the domestic country maximizes the following expression to determine the tariff rate:

$$\underset{t}{Max}\left(\int_0^{q(t)} P(q)dq - P(q(t))q(t)\right) + (P(q(t)) - c)q_d(t) + tq_f(t) - \alpha\left(q_d(t) + \lambda q_f(t)\right)^2. \tag{A5}$$

The equilibrium tariff is given by

$$-qP'q' + q_d P'q' + (P - c)q'_d + tq'_f + q_f - 2\alpha\left(q_d + \lambda q_f\right)\left(q'_d + \lambda q'_f\right) = 0 \tag{A6}$$

or

$$-q_f P'q' + (P - c)q'_d + tq'_f + q_f - 2\alpha\left(q_d + \lambda q_f\right)\left(q'_d + \lambda q'_f\right) = 0$$

or

$$t = \frac{-q_f\left(1 - P'q'\right) - (P - c)q'_d + 2\alpha\left(q_d + \lambda q_f\right)\left(q'_d + \lambda q'_f\right)}{q'_f}, \tag{A7}$$

where $1 - P'q' = \frac{2P' + qP''}{3P' + qP''} > 0$. The second-order condition is assumed to hold.

We get from (A7) that if $\lambda = 0$, $t|_{\lambda=0} = \frac{-q_f\left(1-P'q'\right)-(P-c)q'_d+2\alpha q_d q'_d}{q'_f} < 0$ for $\alpha > \frac{q_f\left(1-P'q'\right)+(P-c)q'_d}{2q_d q'_d}$, and if $\lambda = 1$, $t|_{\lambda=1} = \frac{-q_f\left(1-P'q'\right)-(P-c)q'_d+2\alpha q q'}{q'_f} > 0$ and $t|_{\lambda=1}$ increases with α.

Hence, like Proposition 1, we get that if there is no cross border pollution, that is, $\lambda = 0$, and the product is sufficiently dirty, that is, $\alpha > \frac{q_f\left(1-P'q'\right)+(P-c)q'_d}{2q_d q'_d}$, the equilibrium policy is import subsidy. If there is complete cross border pollution, that is, $\lambda = 1$, the equilibrium policy is import tariff whether or not the product is dirty.

Differentiating (A6) with respect to α, we get

$$\frac{\partial t}{\partial \alpha} = \frac{2\left(q_d + \lambda q_f\right)\left(q'_d + \lambda q'_f\right)}{Z}, \tag{A8}$$

where

$$Z = -2\alpha\left(q'_d\right)^2 + 2q'_f - 2\alpha\lambda^2\left(q'_f\right)^2 - q'_d\left(4\alpha\lambda q'_f - 2P'q'\right) - \left(q'\right)^2\left(P' + q_f P''\right)$$
$$+ (P - c)q''_d + tq''_f - 2\alpha\left(q_d + \lambda q_f\right)\left(q''_d + \lambda q''_f\right) - q_f P' q'' < 0$$

due to the second-order condition for maximizing (A5).

If $\lambda = 0$, that is, there is no cross border pollution, we get from (A8) that

$$\left.\frac{\partial t}{\partial \alpha}\right|_{\lambda=0} = \frac{2q_d q'_d}{Z|_{\lambda=0}} < 0, \tag{A9}$$

implying that if there is no cross border pollution, a higher environmental damage induces the domestic country to reduce the tariff rate. Since a lower tariff reduces the competitiveness of the domestic firm, it reduces the domestic firm's output and the environmental damage in the tariff imposing country.

Now consider the other extreme case of $\lambda = 1$, that is, when there is complete cross border pollution. We get from (A8) that

$$\left.\frac{\partial t}{\partial \alpha}\right|_{\lambda=1} = \frac{2\left(q_d + q_f\right)\left(q'_d + q'_f\right)}{Z|_{\lambda=1}} = \frac{2qq'}{Z|_{\lambda=1}} > 0, \tag{A10}$$

since $q' = q'_d + q'_f$. Hence, if there is complete cross border pollution, a higher environmental damage induces the domestic country to increase the tariff rate. Since a higher tariff reduces the total output and therefore, environmental pollution, it encourages the domestic country to increase the tariff rate following a higher environmental damage.

It follows from (A8) that $\frac{\partial t}{\partial \alpha} \gtreqless 0$ *if* $\frac{q_d'}{-q_f'} \lesseqgtr \lambda$, that is, if the cross border pollution is significant (not significant), that is, λ is high (low), a higher environmental damage increases (decreases) the tariff rate.

Hence, like Proposition 2, a higher environmental damage increases (decreases) the tariff rate if the cross border pollution is significant (not significant), that is, $\lambda > (<) \frac{q_d'}{-q_f'}$.

APPENDIX B

A LINEAR DAMAGE FUNCTION

Given the tariff rate, the equilibrium outputs of firms D and F are respectively $q_d^* = \frac{a-c+t}{3}$ and $q_f^* = \frac{a-c-2t}{3}$. The domestic government now maximizes the following expression to determine the tariff rate:

$$\underset{t}{Max} \underbrace{\left(\frac{a-c+t}{3}\right)^2}_{\text{Profit of firm D}} + \underbrace{\frac{1}{2}\left(\frac{2a-2c-t}{3}\right)^2}_{\text{Domestic consumer surplus}} + \underbrace{t\left(\frac{a-c-2t}{3}\right)}_{\text{Domestic tariff revenue}} - \underbrace{\alpha\left(\frac{a-c+t}{3} + \frac{\lambda(a-c-2t)}{3}\right)}_{\text{Domestic environmental damage}}.$$

The equilibrium tariff rate is $t^* = \frac{1}{3}(a-c+\alpha(-1+2\lambda))$. The second-order condition is satisfied.

We get $t^*|_{\lambda=0} = \frac{1}{3}(a-c-\alpha) < (>) 0$ for $\alpha > (<)(a-c)$.[23] Hence, if there is no cross border pollution and the products are sufficiently dirty, that is, $\alpha > (a-c)$, the equilibrium policy is import subsidy. If $\lambda = 1$, we get $t^*|_{\lambda=1} = \frac{1}{3}(a-c+\alpha) > 0$, implying that if there is complete cross border pollution, the equilibrium policy is import tariff.

We further get $\frac{\partial t^*}{\partial \alpha} = \frac{1}{3}(-1+2\lambda) < (>) 0$ for $\lambda < (>) \frac{1}{2}$, implying that the tariff rate decreases (increases) as the product gets dirtier if there is low (high) cross border pollution.

APPENDIX C

TWO WAY TRADE CONSIDERED IN SECTION 2.2: GENERAL DEMAND

We show here that the results derived in Section 2.2 holds under a general demand function. We consider a quadratic damage function.

Assume that the markets are segmented and the demand in each country is symmetric and is given by $P = P(q)$, with $P' < 0$, $P'' \leq 0$ and $P' + qP'' < 0$. The environmental concern in both countries is given by α and the extent of cross border pollution is also symmetric and is given by λ.

Firms D and F maximize the following expressions to determine their outputs:

$$\underset{q_{dd},q_{df}}{Max} \; (P_{do}(q) - c)\, q_{dd} + \left(P_{fo}(q) - c - s\right) q_{df}, \tag{C1}$$

$$\underset{q_{ff},q_{fd}}{Max} \; \left(P_{fo}(q) - c\right) q_{ff} + (P_{do}(q) - c - t)\, q_{fd}, \tag{C2}$$

where P_{do} and P_{fo} stand for the prices in the domestic and foreign countries respectively, and for outputs, the first subscript stands for the firm and the second subscript stands for the country. For example, q_{dd} shows firm D's sell in the domestic country and q_{df} shows firm D's sell in the foreign country. The tariff rate imposed by the foreign country is denoted by s.

The equilibrium outputs are given by the following first order conditions:

$$P_{do} + q_{dd}P'_{do} - c = 0 \quad \text{and} \quad P_{fo} + q_{df}P'_{fo} - c - s = 0 \tag{C3}$$

$$P_{fo} + q_{ff}P'_{fo} - c = 0 \quad \text{and} \quad P_{do} + q_{fd}P'_{do} - c - t = 0 \tag{C4}$$

The second-order conditions are satisfied, and it follows from Schlee (1993) that the condition $P'_{do} + q_{do}P''_{do} = P'_{fo} + q_{fo}P''_{fo} < 0$ ensures that there is a unique solution for equilibrium outputs.

Differentiating (C3) and (C4) with respect to t and solving them, we get $q'_{dd} = q'_{ff} = -\frac{P'_{do}+q_{dd}P''_{do}}{P'_{do}\left(3P'_{do}+q_{do}P''_{do}\right)} > 0$, $q'_{fd} = q'_{df} = \frac{2P'_{do}+q_{dd}P''_{do}}{P'_{do}\left(3P'_{do}+q_{dd}P''_{do}\right)} < 0$, $q'_{do} = q'_{fo} = \frac{1}{3P'_{do}+q_{dd}P''_{do}} < 0$, where q_{do} (q_{fo}) shows the total output sold in the domestic (foreign) country, $q'_{dd} = \frac{\partial q_{dd}}{\partial t}$, $q'_{fd} = \frac{\partial q_{fd}}{\partial t}$, $q'_{do} = \frac{\partial q_{do}}{\partial t}$, $q'_{ff} = \frac{\partial q_{ff}}{\partial s}$, $q'_{df} = \frac{\partial q_{df}}{\partial s}$ and $q'_{fo} = \frac{\partial q_{fo}}{\partial s}$.

The domestic and the foreign countries determine the respective tariff rates to maximize welfare of the domestic country and the foreign country respectively. Hence, the domestic and foreign countries maximize the following expressions to determine the respective tariff rates:

$$\begin{aligned}\underset{t}{Max}\left(\int_0^{q_{do}(t)} P(q_{do})\,dq - P(q_{do}(t))\,q_{do}(t)\right) + (P(q_{do}(t)) - c)\,q_{dd}(t) + \left(P\left(q_{fo}(s)\right) - c - s\right) q_{df}(s)\\ +\ tq_{fd}(t) - \alpha\left(q_{dd}(t) + q_{df}(s) + \lambda\left(q_{fd}(t) + q_{ff}(\mathrm{s})\right)\right)^2\end{aligned} \tag{C5}$$

$$\begin{aligned}\underset{s}{Max}\left(\int_0^{q_{fo}(\mathrm{s})} P\left(q_{fo}\right)dq - P\left(q_{fo}(s)\right) q_{fo}(s)\right) + \left(P\left(q_{fo}(s)\right) - c\right) q_{ff}(s) + (P(q_{do}(t)) - c - t)\,q_{fd}(t)\\ +\ sq_{df}(s) - \alpha\left(q_{fd}(t) + q_{ff}(s) + \lambda\left(q_{dd}(t) + q_{df}(s)\right)\right)^2.\end{aligned} \tag{C6}$$

The symmetric equilibrium tariffs are given by

$$\begin{aligned}-q_{do}P'_{do}q'_{do} + q_{dd}P'_{do}q'_{do} + (P_{do} - c)\,q'_{dd} + tq'_{fd} + q_{fd} - 2\alpha(q_{dd} + q_{df}\\ + \lambda\left(q_{fd} + q_{ff}\right))\left(q'_{dd} + \lambda q'_{fd}\right) = 0\end{aligned} \tag{C7}$$

$$\begin{aligned}-q_{fo}P'_{fo}q'_{fo} + q_{ff}P'_{fo}q'_{fo} + \left(P_{fo} - c\right) q'_{ff} + sq'_{df} + q_{df} - 2\alpha(q_{ff} + q_{fd}\\ + \lambda\left(q_{df} + q_{dd}\right))\left(q'_{ff} + \lambda q'_{df}\right) = 0\end{aligned}. \tag{C8}$$

Due to the symmetry of $q_{dd} = q_{ff}$ and $q_{df} = q_{fd}$, we can write the first order condition determining the symmetric tariff rates as

$$\begin{aligned}&-q_{do}P'_{do}q'_{do} + q_{dd}P'_{do}q'_{do} + (P_{do} - c)\,q'_{dd} + tq'_{fd} + q_{fd} - 2\alpha(q_{dd} + q_{fd}\\ &+\ \lambda\left(q_{fd} + q_{dd}\right))\left(q'_{dd} + \lambda q'_{fd}\right) = 0\end{aligned}$$

or

$$-q_{fd}P'_{do}q'_{do} + (P_{do} - c)\,q'_{dd} + tq'_{fd} + q_{fd} - 2\alpha(q_{dd} + q_{fd} + \lambda\left(q_{fd} + q_{dd}\right))\left(q'_{dd} + \lambda q'_{fd}\right) = 0$$

or

$$t = \frac{-q_{fd}\left(1 - P'_{do}q'_{do}\right) - (P_{do} - c)\,q'_{dd} + 2\alpha(1+\lambda)\left(q_{dd} + q_{fd}\right)\left(q'_{dd} + \lambda q'_{fd}\right)}{q'_{fd}}, \tag{C9}$$

where $1 - P'_{do}q'_{do} = \frac{2P'_{do} + q_{do}P''_{do}}{3P'_{do} + q_{do}P''_{do}} > 0$. The second-order conditions are assumed to hold.

We get from (C9) that if $\lambda = 0$, $t|_{\lambda=0} = \frac{-q_{fd}(1-P'_{do}q'_{do}) - (P_{do}-c)q'_{dd} + 2\alpha q_{do}q'_{dd}}{q'_{fd}} < 0$ for $\alpha > \frac{q_{fd}(1-P'_{do}q'_{do}) + (P_{do}-c)q'_{dd}}{2q_{do}q'_{dd}}$ and if $\lambda = 1$, $t|_{\lambda=1} = \frac{-q_{fd}(1-P'_{do}q'_{do}) - (P_{do}-c)q'_{dd} + 4\alpha q_{do}q'_{do}}{q'_{fd}} > 0$ and $t|_{\lambda=1}$ increases with α.

Hence, like Proposition 3, we get that if there is no cross border pollution, that is, $\lambda = 0$, and the product is sufficiently dirty, that is, $\alpha > \frac{q_{fd}(1-P'_{do}q'_{do}) + (P_{do}-c)q'_{dd}}{2q_{do}q'_{dd}}$, the equilibrium policy is import subsidy. If there is complete cross border pollution, that is, $\lambda = 1$, the equilibrium policy is import tariff whether or not the product is dirty.

Differentiating (C9) with respect to α, we get

$$\frac{\partial t}{\partial \alpha} = \frac{2(1+\lambda)\left(q_{dd} + q_{fd}\right)q'_{dd} + 2\lambda(1+\lambda)\left(q_{dd} + q_{fd}\right)q'_{fd}}{G} = \frac{2(1+\lambda)q_{do}\left(q'_{dd} + \lambda q'_{fd}\right)}{G}, \tag{C10}$$

where

$$\begin{aligned} G = {} & 2q'_{fd} - q_{fd}{q'_{do}}^{2}P''_{do} - P'_{do}\left({q'_{do}}^{2} - 2q'_{do}q'_{dd} + q_{fd}q''_{do}\right) + (P_{do} - c)\,q''_{dd} \\ & + tq''_{fd} - 2\alpha(1+\lambda)\left({q'_{dd}}^{2} + (1+\lambda)q'_{dd}q'_{fd} + \lambda {q'_{fd}}^{2} + q_{do}\left(q''_{dd} + \lambda q''_{fd}\right)\right) < 0 \end{aligned}$$

due to the second-order condition for welfare maximization.

First, consider the case of $\lambda = 0$, that is, when there is no cross border pollution. We get from (C10) that

$$\left.\frac{\partial t}{\partial \alpha}\right|_{\lambda=0} = \frac{2\left(q_{dd} + q_{fd}\right)q'_{dd}}{G|_{\lambda=0}} = \frac{2q_{do}q'_{dd}}{G|_{\lambda=0}} < 0, \tag{C11}$$

implying that if there is no cross border pollution, a higher environmental damage reduces the tariff rate. Since a lower tariff reduces the competitiveness of the domestic firm, it reduces the domestic firm's output and the environmental damage in the tariff imposing country.

Now consider the case of $\lambda = 1$, that is, when there is complete cross border pollution. We get from (C10) that

$$\left.\frac{\partial t}{\partial \alpha}\right|_{\lambda=1} = \frac{4q_{do}\left(q'_{dd} + q'_{fd}\right)}{G|_{\lambda=1}} = \frac{4q_{do}q'_{do}}{G|_{\lambda=1}} > 0, \tag{C12}$$

since $q'_{do} = q'_{dd} + q'_{fd}$. Hence, if there is complete cross border pollution, a higher environmental damage increases the tariff rate. Since a higher tariff reduces the total output and therefore, environmental pollution, it encourages the domestic country to increase the tariff rate following a higher environmental damage.

It follows from (C10) that $\frac{\partial t}{\partial \alpha} \gtreqless 0 \; if \; \frac{q'_{dd}}{-q'_{fd}} \lesseqgtr \lambda$, that is, if the cross border pollution is significant (not significant), that is, λ is high (low), a higher environmental damage increases (decreases) the tariff rate.

Hence, like Proposition 4, we get that a higher environmental damage increases (decreases) the tariff rate if the cross border pollution is significant (not significant), that is, $\lambda > (<) \frac{q'_{dd}}{-q'_{fd}}$.