Trade and Commodity Taxes as Environmental Instruments in an Open Economy

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Abstract

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1 Introduction

This study employs a reciprocal dumping model of trade and scrutinizes the strategic role of commodity taxes and trade policy tools when environmental pollution is generated by final consumption of an imported product, and delineates the implications of domestic and foreign policy tools on countries' integration through international trade. The novel contribution of this paper is (i) to capture asymmetries among trading partners in terms of their marginal disutility from pollution and in terms of how much they account for environmental pollution when deciding on their (domestic/trade) policy measures, and (ii) to focus on environmental degradation that is caused by final consumption of a product imported from a trading partner. The literature has almost exclusively assumed that all countries understand and agree on their contribution to environmental pollution, and thus appropriately account for this in their policy tools. This, however, presumes that policy-makers around the globe have similar agendas and are not influenced by their own idiosyncratic environments. By contrast, as is discussed below, empirical evidence suggests that there is heterogeneity in countries' perceived marginal disutility from pollution (especially caused by idiosyncratic political or trade-related concerns).

The literature also has focused mostly on emissions from production and on the effects of environmental tax policies on competition among firms, on international trade and firms' location choices, and on social welfare. Statistical evidence, however, suggests that most industrialized countries have a larger CO_2 footprint than their CO_2 production, and that emissions from final consumption of imported products constitute a significantly large share of their total emissions.[1] Bang et al. (2008) show that, in 2001, (i) the EU's consumption of goods and services generated 4,700 million tonnes of CO_2 emissions, 500 million tonnes of which were generated mainly from imported products; (ii) while some countries (e.g., Latvia and Lithuania) have relatively low domestic emissions and large amounts embodied in their imports from the rest of the world (e.g., Russia), all OECD countries (except for Australia and Canada) have a CO_2 consumption overshoot compared with production; and (iii) all EU countries have a CO_2 consumption overshoot in their bilateral trade with China. A similar general picture exists as far as other pollutants (e.g., ground level ozone, or mercury emissions) are concerned; see Holladay (2008) for details.

The literature identifies different sources through which trade affects environmental pollution: (i) the *scale effect* that tends to increase pollution from production as a country's

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[1]Recent studies argue that indirect emissions from consumption should be considered when measuring emissions embodied in trade as indirect emissions are higher than direct ones, especially in developed countries (e.g., see, inter alia, Bang et al. 2008; Barrett et al., 2013; Marques et al., 2013; Sato, 2013).

economic activity is expected to increase with trade; (ii) the *technique* effect that tends to improve environmental quality as demand for quality is expected to increase with trade; and (iii) the *composition* effect that tends to either increase or decrease environmental pollution with a net effect depending on how trade changes the composition of production and consumption (Grossman and Krueger, 1993; Copeland and Taylor, 1994; Antweiler et al., 2001). In a perfectly competitive trade model that incorporates environmental pollution (as measured by SO_2 concentrations), Antweiler et al. (2001) find that trade liberalization reduces pollution. Frankel and Rose (2005) also find some evidence that openness to trade reduces pollution, as far as SO_2 and NO_2 emissions are concerned.

Following the seminal paper by Brander and Spencer (1984; 1985), a number of studies has applied the strategic trade policy analysis to the strategic environmental policy debate. In general, such studies employ oligopoly models of trade to examine the implications of unilateral environmental policies and show that non-cooperative Nash policies may lead to *environmental dumping* such that countries adopt laxer environmental policies. They may impose environmental taxes that are less than Pigouvian taxes (that is, the marginal tax rate is less than the marginal environmental damage), and such environmental taxes, together with import tariffs (e.g., as in Tanguay, 2001), may lead to a *race to the bottom* (in terms of environmental standards) and thus, welfare may deteriorate with trade liberalization.[2]

The strategic use of tariffs and subsidies can be deemed to be rationalizable in oligopolistic markets. Countries, however, lose their degree of freedom in using such trade policy tools with their free trade agreements. Similarly, the strategic use of environmental policy instruments (if successfully enforced) may be effective when production is the main source of pollution, but they may not be applicable when consumption is considered to be the main source of pollution.[3] As internationally traded commodities are taxed mostly

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[2]Eliminating trade policy tools and using environmental taxes (e.g., as in Walz and Wellisch, 1997; or as in Burquet and Sempere, 2003), or allowing for R&D investments by firms responding to environmental standards (e.g., as in Ulph, 1996), however, may reduce incentives to adopt laxer environmental standards, and welfare may improve with trade liberalization. Moreover, in such models, Barrett (1994) indicates that the industry structure is also important, that is, if the industry is characterized by Bertrand oligopoly (price competition), rather than Cournot oligopoly (quantity competition), then the results are reversed, such that the unilaterally optimal environmental taxes are higher than the Pigouvian taxes. Also, the demand elasticity and the shape of the damage function are crucial in terms of welfare results.

[3]While different explanations may be offered, an obvious justification is the observation that environmental taxes are not used to discriminate products according to the source country. Moreover, in Article III of the WTO, National Treatment imposes certain constraints on domestic policy so as to make sure that countries do not engage in protectionist discrimination against foreign products; for details, see for example Ferrara et al. (2015).

where they are consumed (e.g., see McCracken and Stähler, 2010; McCracken, 2015), and as countries can freely set their commodity taxes, when consumption is the main source of externality, commodity taxes can be used strategically (just like the strategic use of trade policy tools) even in the case of a free trade agreement. The strategic role of commodity taxes as environmental instruments when consumption of an imported product generates pollution and the implications of the strategic use of this policy instrument on countries' integration through international trade have not yet received much attention in the literature.[4]

There are few papers worth mentioning. Ferrara et al. (2015) consider emissions from consumption and scrutinize the welfare implications of the WTO's National Treatment clause in Article III. Given quality differences among products, they show that the WTO's restriction on non-discriminatory internal measures does not necessarily lead to higher (lower) global environmental damage (welfare). Lai and Hu (2008) consider consumption-generated externalities and delineate optimal policy measures when products are differentiated and when the trading partners cooperate in their trade policies. They show that, while cooperating in trade policies, if the trading partners do not cooperate in environmental taxes, this may lead to a counter-intuitive result that each country will subsidize the foreign firm only that imports a polluting good, especially when pollution is sufficiently high. They conclude that this would be politically infeasible, and thus in such a situation, zero tariffs would emerge as the cooperative trade policy. By taking into account consumption externalities and product-specific standards, Essaji (2010) shows that tariff reduction leads to higher standards only if the marginal impact of product standards on the externality increases substantially in consumption. In a series of research, Fujiwara (2010a, 2010b, 2012) focuses on transport costs, bilateral tariff reductions and environmental taxes under consumption externality, and shows that, as compared to autarky, trade may lead to welfare losses, and reductions in tariffs may tend to increase emission taxes. Fujiwara's papers, to some extent, follow earlier research by Kayalica and Kayalica (2005) and Kayalica and Yilmaz (2006) scrutinizing the relationship between import tariffs, export subsidies and emission taxes under consumption externalities. Another related paper is by Wu (2019) that extends Haufler et al. (2005) to production externalities, and also considers both consumption externalities and import tariffs as a robustness check for the results. The results from that robustness check suggest that destination-based consumption taxes might be better than origin-based production taxes when there is an import tariff under consumption externalities. Wu (2019), however, focuses solely on com-

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[4]Considering consumption of a product that creates pollution, Copeland and Taylor (1995) show that the optimal policy will be a consumption tax that equals the marginal environmental damage, and that trade improves welfare especially if there exists a perfectly costless institutional structure with well intentions. Though it is worth noting that their analysis focuses on a competitive framework.

paring destination-based consumption taxes versus origin-based production taxes, unlike this paper focusing on Nash trade policies and (non-discriminatory) consumption taxes, and on their role as strategic environmental instruments, as well as on the implications of these two policy tools on gains from trade under consumption-based environmental pollution.

This study would like to make further progress on consumption-based pollution. In a simple intra-industry trade model with imperfect competition, it scrutinizes the strategic role of trade and commodity taxes as environmental instruments and demonstrates that the externality generated by consumption of an imported good, as measured by countries' marginal disutility from pollution, can have detrimental effects on countries' economic integration, especially when the trading partners are asymmetric in terms of how much they account for environmental pollution when deciding on their (domestic/trade) policy measures. That is, departing from the existing literature, we would like to introduce some heterogeneity in countries' perceived marginal disutility from pollution. Our results suggest that while a substantially high marginal disutility from pollution can interrupt bilateral trade and cross-hauling can cease to exist, in the case of a sufficiently small marginal disutility from pollution, both trade and commodity taxes are deemed necessary so as to effectively address consumption-generated pollution. The tax rates, however, are less than Pigouvian taxes due to Cournot competition. For sufficiently small values of the marginal disutility from pollution, the country fully accounting for consumption-generated pollution when deciding on its optimal policy measure prefers commodity taxes over import tariffs, and compared to the case of trade policies, free trade can be maintained for higher values of the marginal disutility from pollution when commodity taxes are used strategically as environmental instruments.

Also we extend our analysis to a symmetric case where imports pollute in both countries (fully accounted for in each country when choosing the optimal policy measure) and where there is transboundary pollution between the two countries. Our results confirm that the main finding holds to some extent also for such extensions. We show that (i) sufficient asymmetries between the countries in terms of their marginal disutility from pollution may jeopardize bilateral trade relationships between the countries; (ii) free trade welfare-dominates autarky only for sufficiently small marginal disutility from pollution and for sufficiently low transboundary pollution; (iii) both Nash trade and domestic policies may prove to be helpful in addressing consumption-based pollution and we solve for threshold values of marginal disutility from pollution (decreasing with transboundary pollution) above which such policies welfare-dominate free trade; and (iv) we solve for a threshold value of marginal disutility from pollution below which domestic policies welfare-dominate trade policies when addressing pollution from consumption of imports.

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The remainder of the paper is organized as follows. Section 2 introduces the model, and scrutinizes the welfare implications of imposing import tariffs when consumption of an imported product generates pollution. Section 3 looks at consumption-generated pollution under free trade, and discusses the welfare implications. Section 4 analyzes the implications of the use of commodity taxes as environmental instruments, and compares the results with those discussed in Sections 2 and 3. Section 5 extends the analysis to a symmetric case and includes in the model also transboundary pollution and compares the results with those discussed in Sections 2, 3 and 4. Section 6 offers some concluding remarks. For convenience, most of the proofs and technical details have been relegated to the Appendix.

2   The model

Following the seminal paper by Brander and Krugman (1983), we employ a simple model of intra-industry trade, and examine the nexus between trade and the environment. We consider two countries, Home and Foreign, which are identical with respect to consumers' preferences and market size, and two firms (one in each country), which are identical with respect to production technology and costs, and which produce a good with zero marginal cost and compete by quantities against each other in both countries. While a different packaging material for the good is used for domestic consumption (that is free of environmental damage) and for imports (that causes environmental pollution where the good is consumed), consumers in both countries ignore this difference and regard the good as homogeneous. Thus, the inverse demand function in country i is given by $p_i = a - bQ_i$, $i = \{h, f\}$, where h and f stand for Home and Foreign, respectively; p_i is the price of the good in country i; a and b denote market size and the slope of the inverse demand function, respectively; and $Q_i = x_i + y_i$ is the aggregate output in country i, such that y_i is the local production in country i and x_i is country i's imports from the other country. Markets are segmented such that each firm considers each country as a separate market.

In this section, we focus on the case of no free trade agreement between the two countries, and thus trade may be subject to tariffs. To simplify the analysis, we assume away transport costs of exporting/importing throughout the analysis. We consider a simple, two-stage, non-cooperative game. In the first stage, the governments decide on their import tariffs that maximize their local welfare. Let t_h and t_f denote the tariff rates imposed by Home and Foreign, respectively. In the second stage, given the tariff rates, the firms compete against each other by quantities in both countries, such that each firm simultaneously, and non-cooperatively, decides on the outputs that maximize profits in

both markets. Firm i that locates in country i and exports to country j, $i, j = \{h, f\}, i \neq j$, will earn aggregate profits, denoted π_i, that is the sum of the profits from the domestic and the foreign market. We solve the game backwards such that we start from the second stage (the Cournot game between the two firms) and search for the subgame perfect Nash equilibrium. The maximization problem of firm i is

$$\max_{\{x_j \geq 0, \, y_i \geq 0\}} \pi_i = p_i y_i + (p_j - t_j)x_j \, ; \quad i, j = \{h, f\}, i \neq j.$$

From the first-order conditions, we find that the (optimal) outputs supplied to country i by (from country i's perspective) the foreign firm and the domestic firm are, respectively,

$$x_i = \begin{cases} (a - 2t_i)/3b & \text{if } 0 \leq t_i < a/2 \\ 0 & \text{if } t_i \geq a/2 \end{cases} \tag{1a}$$

$$y_i = \frac{a + t_i}{3b}, \qquad \text{where} \quad i = \{h, f\}. \tag{1b}$$

Using the expressions for the optimal outputs, given by equation (1), we can derive the aggregate profits for each firm such that

$$\pi_i = \underbrace{by_i^2}_{\substack{\text{Profits from} \\ \text{local sales}}} + \underbrace{bx_j^2}_{\substack{\text{Profits from} \\ \text{exports}}} \, ; \quad i, j = \{h, f\}, i \neq j, \tag{2}$$

where x and y are given by equation (1). In the first stage of the game, each government unilaterally decides on its import tariff rate that maximizes its local welfare, which we will refer to as *Nash (non-cooperative) trade policies*. Country i's welfare can be expressed as the sum of the domestic firm's profits (from both local sales and exports) π_i, consumer surplus $b(x_i + y_i)^2/2$, tariff revenues $t_i x_i$, and disutility from environmental pollution.

The existing literature predominantly studies the symmetric case that all countries appropriately account for environmental degradation in their policy tools, and thus they are symmetric in terms of their perceived marginal disutility from pollution. We defer this case until Section 5 where we consider not only a symmetric case, but also transboundary pollution as a robustness check for the results of the asymmetric case. Departing from the existing literature, we initially consider the case that Home and Foreign have different agendas. Recall that (i) domestic consumption of the good produced by Home does not cause environmental pollution; whereas (ii) the good (otherwise homogeneous) produced by Foreign for Home's consumption (imports by Home) has a packaging material that causes environmental pollution where it is consumed. Thus, Home's consumption of the good imported from Foreign is the main source of pollution in Home. When deciding on the optimal policy measure (tariffs or consumption taxes), Home fully accounts for environmental pollution generated by consumption of the good imported from Foreign, and there is constant marginal disutility from pollution, denoted by δ_h. Thus, in the

case of non-cooperative trade policies, this amounts to Home's local welfare decreasing by $\delta_h x_h$, $\delta_h > 0$. As is already discussed, we would like to introduce some heterogeneity in the countries' perceived marginal disutility from pollution. There are many different ways by which such asymmetry may be introduced. Without loss of generality, and to keep the model as simple as possible, we assume that although Foreign's consumption of imports from Home generates pollution in Foreign, there are some non-pecuniary benefits, denoted Γ (e.g., political benefits offered by some interest groups in Foreign, etc.) that the policy makers in Foreign will take into account. In what follows, we will assume that such non-pecuniary benefits are at a level that just compensates for negative consumption externalities in Foreign (i.e., $\Gamma = \delta_f x_f$).[5] Such non-pecuniary benefits affecting policy makers' decisions are not so uncommon and can be also due to trade-related concerns. Anecdotal evidence suggests that some countries may opt to overlook environmental degradation when pro-trade concerns dominate environmental concerns. For example, according to the European Commission's 2001 report on *European Packaging Waste Management Systems* (EC DGX1.E.3, 2001), Sweden removed the reuse targets for bottles in 2001 and closed down the deposit refund system already in 1998 due to sharp decreases in bulk imports.

To summarize, Home and Foreign choose their unilateral tariff rates t_h and t_f to maximize, respectively,

$$W_h^t = \pi_h + \frac{b(x_h + y_h)^2}{2} + (t_h - \delta_h)x_h, \tag{3a}$$

$$W_f^t = \pi_f + \frac{b(x_f + y_f)^2}{2} + t_f x_f, \tag{3b}$$

where the optimal outputs, x_i and y_i, and the maximized profits, π_i, $i = \{h, f\}$, are given by equations (1) and (2), respectively, and where superscript t denotes the case that the two countries adopt Nash trade policies. Given $\Gamma = \delta_f x_f$, let us drop the subscript from Home's marginal disutility from pollution such that $\delta_h = \delta$, which can be interpreted also as a measure of heterogeneity in the two countries' perceived marginal disutility from pollution. Differentiating W_h^t and W_f^t, given by equation (3), w.r.t. t_h and t_f, respectively, and setting the results equal to zero (i.e., $\partial W_i^t(\mathbf{t})/\partial t_i = 0$, $i = \{h, f\}$) and solving for t_h and t_f yield the welfare-maximizing tariff rates such that [6]

$$t_h^* = t_f^* + \frac{2}{3}\delta = \underbrace{\frac{a}{3}}_{\substack{\text{Optimal tariff} \\ \text{(no disutility)}}} + \underbrace{\frac{2}{3}\delta}_{\substack{\text{Environmental} \\ \text{protection}}}. \tag{4}$$

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[5]As this may feel rather a strong assumption, in Section 5, we relax this assumption and carry out the analysis for the case imports pollute in both countries and both countries fully account for their consumption-based pollution.

[6]Note that the objective function is strictly concave, that is, the sufficient condition for a unique maximum, $\mathbf{t}^* = \text{argmax } W^t(\mathbf{t})$, is fulfilled.

As is clear from equation (4), in the presence of consumption-generated pollution, Home's optimal tariff rate exceeds Foreign's tariff rate should the policy maker in Foreign evaluates Foreign's marginal utility from pollution at zero.

Proposition 1 *In the case that countries adopt Nash trade policies, and that the good imported from a trading partner generates pollution, the importing country that appropriately accounts for pollution (Home) attempts to internalize the consumption externality by imposing a higher tariff rate, although the increase in the per-unit tariff rate is less than the marginal disutility from pollution.*

The following remarks are in order. For any given Foreign tariff rate, increasing the tariff rate in Home (within the relevant range $t_h^* < a/2$ as is given by equation (1a)) increases the local firm's aggregate profits by increasing its domestic market share. Aggregate consumption in Home, however, decreases as the decrease in imports is more than the increase in local sales, and thus consumer surplus decreases. Although increasing the tariff rate in Home decreases imports, and thus pollution decreases (and so does disutility from environmental degradation), tariff revenues also decrease, leading Home to compromise and increase the per-unit tariff rate by less than the marginal disutility from pollution. The implicit assumption here is that cross-hauling exists, that is, the marginal disutility from pollution is sufficiently small ($\delta < a/4$) such that the tariff rate maximizing Home's welfare is still less than the prohibitive tariff rate (i.e., $(a + 2\delta)/3 < a/2$).

Lemma 1 *A sufficiently high marginal disutility from pollution may jeopardize bilateral trade such that cross-hauling may cease to exist, and there may be only one-way trade.*

It should be noted that Lemma 1 assumes both countries can freely choose their tariff rates for their imports, consumption of which pollutes environment.[7] Lemma 1 may be interpreted as follows: greater heterogeneity between the two countries in terms of their perceived marginal disutility from pollution can be trade disrupting. A sufficiently high marginal disutility from pollution (i.e., $\delta > a/4$) leads Home to impose a tariff above the prohibitive rate, in which case exporting is not profitable for the firm located in Foreign, while exporting to Foreign will still be profitable for the firm located in Home. In the next section, we scrutinize the question whether (and under which circumstances) free trade would be welfare dominating.

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[7] While environmental concerns may be, to some extent, a legitimate reason to increasing tariff rates especially when consumption of imports generate pollution (similar to the arguments over goods associated with national security for which the WTO has given its members more flexibility), in most cases, setting tariff rates are subject to some limits. Throughout this paper, we refrain from such discussions, and assume simply that both countries non-cooperatively choose their tariff rates that maximize welfare.

3 Consumption-generated pollution under free trade

In this section, we first look at the case of autarky in both countries such that firms have monopoly power in their respective domestic markets. In such a situation, each firm is active only in the domestic market, produces at the monopoly level for this market (i.e., $x_i = 0$, and $y_i = a/2b$, $i = \{h, f\}$), and earns monopoly profits (i.e., $\pi_i = b(a/2b)^2$, $i = \{h, f\}$). There is no trade, and thus no tariff revenue in either country, nor is there environmental pollution that has to be accounted for. Using equation (3), it is straightforward to show that $W_i^{*a} = 3a^2/8b$, $i = \{h, f\}$. Note that superscript a stands for autarky.

In case of free trade (compared to autarky), market competition increases, decreasing the two firms' market share in their respective domestic markets (moving from monopoly to international duopoly), while each firm shares the market across borders such that $x_i = y_i = a/3b$, $i = \{h, f\}$. This implies an increase in each firm's aggregate profits, and an increase in total consumption in each country. Welfare would improve with free trade in both countries (compared to autarky) had there been no pollution such that $W_i^{*ft}(\delta = 0) = 4a^2/9b > W_i^{*a} = 3a^2/8b$, $i = \{h, f\}$, where superscript ft stands for free trade. In case of pollution from consumption of an imported good, however, this result does not hold as Home's welfare decreases due to disutility from pollution, such that

$$W_h^{*ft} = \underbrace{\left(\frac{4a^2}{9b}\right)}_{\substack{\text{Welfare} \\ \text{(no disutility)}}} - \underbrace{\delta\left(\frac{a}{3b}\right)}_{\substack{\text{Disutility} \\ \text{(pollution)}}}. \tag{5}$$

Comparing equation (5) with autarky welfare immediately leads to

Proposition 2 *Free trade would not be welfare-dominating autarky in the country accounting for consumption-generated pollution (Home) if the marginal disutility from pollution is sufficiently high.*

Free trade decreases local sales and increases imports (which increase pollution from consumption). Although free trade increases both total consumption in a given country and the aggregate profits of a given firm, with which welfare increases, a sufficiently high marginal disutility from pollution (i.e., $\delta > 5a/24$) leads welfare to decrease by more than gains from free trade. Note that free trade does not leave any room for a trade policy that could internalize the negative externality of consuming the imported good. As for Foreign where marginal disutility from pollution is evaluated at zero, compared to autarky, free trade always improves local welfare. In the case that Home does not allow for imports from Foreign (i.e., $\delta > 5a/24$), Foreign will be better off by opening its

10

market to trade and by imposing an import tariff (as compared to autarky and to the case it allows Home to export to its market freely). The intuition is that, in the case of one-way trade (from Home to Foreign), imposing a tariff not only generates additional revenues, but also increases the domestic firm's market share (as compared to the case of one-way free trade). There exists an optimal import tariff rate ($t_f = a/3$) at which welfare is maximized such that the decrease in welfare due to a decrease in total consumption (with an import tariff) is overcompensated by the increase in welfare due to an increase in the domestic firm's profits and in tariff revenues. Also, as compared to autarky, Home will be better off in such a situation, because there will be no change in consumption, nor will there be disutility from pollution generated by consumption of the imported good, yet it will export to Foreign, which will increase the local firm's profits. It is now clear that given the asymmetry between the two countries in terms of how much they account for negative consumption externality when deciding on the optimal tariffs, the size of the marginal disutility from pollution generated by consumption of the imported good may lead to different trade regimes:

Proposition 3 *One-way trade (from Home to Foreign) that is subject to an import tariff imposed by Foreign may be welfare dominating for a sufficiently high marginal disutility from pollution (i.e., $\delta > a/4$). If, however, the marginal disutility from pollution takes some intermediate values (i.e., $a/6 < \delta < a/4$), then the two countries may find it optimal to engage in bilateral trade and adopt Nash trade policies. Free trade may be welfare dominating only if the marginal disutility from pollution is sufficiently low (i.e., $\delta < a/6$).*

Proof.   See Appendix A.1. ∎

It is now clear that Nash trade policies become important in the presence of pollution, as they may be used not only to generate tariff revenues, to increase the domestic firm's market share, and to correct domestic distortions, but also to restrict imports so as to decrease pollution generated by consumption of the imported good.

4   Commodity taxes as environmental instruments

In this section, we turn our attention to domestic policies. In the case of product differentiation and trade policy cooperation, Lai and Hu (2008) have shown that there is a negative relationship between cooperative tariff rates and environmental taxes, especially when they are used together. If, however, there is no product differentiation and no cooperation in trade policy, then allowing for both domestic and trade policy will be

inconsequential. When both policy tools are used together, it is straightforward to show in this model that in equilibrium, both countries impose positive import tariffs above the prohibitive rate so as to ensure there is no trade, and they subsidize local consumption such that the first-best is attained with no trade, and thus with no further insight.[8] We scrutinize domestic policies when there is free trade (such that there will be no room for a trade policy), and delineate commodity taxes employed as environmental instruments in the absence of environmental taxes. As is already discussed, there are certain constraints on domestic policies: domestic taxes cannot be used to discriminate against foreign goods. Thus in this model, commodity taxes are non-discriminatory, and apply to both domestic consumption and consumption of imports. Simply, following real practices, we assume away commodity taxes that may discriminate products according to the source country.

As in the preceding sections, we consider a two-stage non-cooperative game between firms, and between governments, and solve the game backwards for the subgame perfect Nash equilibrium. In the first stage, governments now decide on their commodity taxes that maximize their local welfare. We denote by τ_h and τ_f, commodity taxes imposed by Home and Foreign, respectively. Firms take commodity taxes as given, and decide on their outputs (both for the domestic and the foreign market) that maximize the profits in both markets. Once again, let π_i denote the aggregate profits (the sum of the profits from the domestic and the foreign market) of the firm that locates in country i and exports to country j, $i, j = \{h, f\}, i \neq j$. The maximization problem of the firms is now

$$\max_{\{x_j \geq 0, y_i \geq 0\}} \pi_i = (p_i - \tau_i)y_i + (p_j - \tau_j)x_j \; ; \; i, j = \{h, f\}, i \neq j.$$

From the first-order conditions, we find that the (optimal) outputs supplied to country i by (from country i's perspective) the domestic firm and the foreign firm are, respectively,

$$y_i = x_i = \begin{cases} (a - \tau_i)/3b & \text{if } 0 \leq \tau_i < a \\ 0 & \text{if } \tau_i \geq a \end{cases} \; ; \; i = \{h, f\}. \tag{6}$$

Using the expressions for the optimal outputs, given by equation (6), we can derive the aggregate profits for each firm as in equation (2), where x and y are now given by equation (6). In the first-stage of the game, each government unilaterally decides on the commodity tax rate that maximizes its local welfare, which we refer to as *Nash (non-cooperative) domestic policies*. As in the preceding sections, country i's welfare can expressed as the sum of the domestic firm's aggregate profits π_i, given by equation (2), consumer surplus $b(x_i + y_i)^2/2$, where y_i and x_i are given by equation (6), and tax revenues, $\tau_i(x_i + y_i)$. In addition, negative consumption externalities are present in both Home and Foreign,

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and non-pecuniary benefits simply compensate for negative externalities only in Foreign. Thus Home and Foreign choose the tax rates τ_h and τ_f to maximize, respectively,

$$W_h^\tau = \pi_h + \frac{b(x_h + y_h)^2}{2} + \tau_h(x_h + y_h) - \delta x_h, \tag{7a}$$

$$W_f^\tau = \pi_f + \frac{b(x_f + y_f)^2}{2} + \tau_f(x_f + y_f), \tag{7b}$$

where superscript τ denotes the case that the two countries adopt Nash domestic policies (commodity taxes). Differentiating W_h^τ and W_f^τ, given by equation (7), w.r.t. τ_h and τ_f, respectively, and setting the results equal to zero (i.e., $\partial W_i^\tau(\boldsymbol{\tau})/\partial \tau_i = 0, i = \{h, f\}$), and solving for τ_h and τ_f yield the welfare-maximizing commodity tax rates such that [9]

$$\underbrace{\tau_h^* = \frac{\delta}{2}}_{\substack{\text{Environmental} \\ \text{protection}}} > \underbrace{\tau_f^* = 0}_{\substack{\text{Optimal tax} \\ \text{(no disutility)}}}, \quad \text{for any } \delta > 0. \tag{8}$$

As is clear from equation (8), when there is no pollution from consumption of the imported good (i.e., when $\delta = 0$) - or if some non-pecuniary benefits are present and just compensate negative consumption externalities (as in Foreign) - then the optimal (non-discriminatory) commodity tax rate is equal to zero. The reason is that, for any given commodity tax rate imposed by the other country, increasing the tax rate (imposing a positive tax rate) generates positive tax revenues for the government, with which local welfare increases. That said, a positive commodity tax increases the market price and decreases local consumption, and both consumer surplus and the domestic firm's profits from local sales decrease, with which local welfare decreases. These effects of a positive commodity tax, however, cancel out each other (the profit-shifting incentive and the incentive for domestic correction eliminate each other) especially in the case of a linear inverse demand function. If, however, there is pollution from consumption of the imported good that the importing country appropriately accounts for - if $\delta > 0$ (as in Home) - then there is an additional incentive to impose a positive commodity tax rate, which is the incentive for environmental correction that attempts to internalize negative consumption externality.

Proposition 4 *In the case that countries adopt Nash domestic policies (commodity taxes) under free trade, the importing country that appropriately accounts for pollution attempts to internalize the consumption externality by imposing a positive commodity tax rate. This (positive) optimal tax rate is, however, less than the marginal disutility from pollution.*

Note that in both Nash trade and domestic policies (import tariffs and commodity taxes), the incentive for domestic correction of distortions is present. Using Nash trade policies,

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[9]Note that the objective function is strictly concave, that is, the sufficient condition for a unique maximum, $\boldsymbol{\tau}^* = \operatorname{argmax} W^\tau(\boldsymbol{\tau})$, is fulfilled.

governments shift profits not only from foreign firms to their treasury via tariff revenues, but also from foreign firms to domestic firms, which is mainly due to Cournot competition. Using Nash domestic policies, however, the domestic country shifts profits from both the domestic and foreign firms to its treasury via tax revenues (provided the policy tool is non-discriminatory), that is, consumption of both the locally-produced and the imported good decreases, only the latter of which, however, increases welfare via decreasing disutility from pollution in addition to positive tax revenues.

We can compute the maximized welfare levels, $W_h^{*\tau}$ and $W_f^{*\tau}$, by substituting the optimal commodity tax rates, given by equation (8), back into the welfare expressions, given by equation (7). Comparing W_h^{*ft}, given by equation (5), and $W_h^{*\tau}$, we can show that the optimal commodity tax rate imposed by Home decreases pollution by decreasing consumption and increases local welfare above the level that would have been maintained had there been free trade and no commodity taxes imposed ($W_h^{*\tau} \geq W_h^{*ft}$ for any δ : $\delta \geq 0 \mid W^* \in \mathbb{R}_+^2$) such that

$$W_h^{*\tau} = \underbrace{W_h^{*ft}}_{\substack{\text{Welfare under} \\ \text{free trade} \\ \text{(no tariffs/taxes)}}} + \underbrace{\left(\frac{\delta^2}{12b}\right)}_{\substack{\text{Gains from} \\ \text{commodity taxes}}} . \tag{9}$$

It is straightforward to show that commodity taxes imposed by Home decreases welfare in Foreign and that if the marginal disutility from pollution is sufficiently high (i.e., $\delta > 2a$), then Home's optimal tax rate exceeds the prohibitive tax rate (see equation (6)), in which case consumption may not be possible, while there may be one-way trade (from Home to Foreign). In such a situation, autarky may be considered. Proposition 2 has shown that free trade would not be welfare-dominating autarky in the importing country accounting for consumption-generated pollution (Home), provided the size of its marginal disutility from pollution is sufficiently high such that $\delta > 5a/24$. Following Proposition 2 and equation (9), we can show that in the presence of non-discriminatory commodity taxes, free trade can be welfare dominating not only when $\delta \leq 5a/24$ (in which case the importing country accounting for consumption-generated pollution imposes a positive commodity tax rate) but also when $\delta > 5a/24$.

We can now argue that

Proposition 5 *In the presence of non-discriminatory Nash domestic policies, compared to the case of Nash trade policies, free trade can be welfare dominating also for higher values of the marginal disutility from pollution such that $5a/24 < \delta = 2\tau_h^* < \hat{\delta}$ (for which free trade would not be welfare-dominating autarky in the absence of commodity taxes as environmental instruments).*

Proof.   See Appendix A.1 and Appendix A.2.   ∎

The intuition is as follows. In the case of Nash trade policies, the importing country accounting for consumption-generated pollution (Home) loses its strategic environmental instrument whenever it engages in free trade, whereas in the case of Nash domestic policies, non-discriminatory commodity taxes substituting environmental instruments can still be used under free trade. That is, as compared to Nash trade policies (import tariffs), Nash domestic policies (non-discriminatory commodity taxes) allow for a wider range of the marginal disutility from pollution, within which free trade welfare-dominates autarky. Moreover, if we consider the trade regime that generates the highest welfare for a given marginal disutility from pollution, Nash trade policies lead to even a smaller range ($0 < \delta < a/6$; see Proposition 3), within which free trade will be welfare dominating, whereas free trade (with a positive commodity tax imposed by Home) will be maintained under Nash domestic policies whenever $\delta < \hat{\delta}$ where $a/6 < \hat{\delta}$.[10]

Using Propositions 2, 3 and 5 , we can now show that

Proposition 6 *For sufficiently small values of the marginal disutility from pollution, the importing country accounting for pollution from consumption of the imported good (Home) prefers Nash domestic policies (non-discriminatory commodity taxes) over Nash trade policies (import tariffs), whereas for sufficiently high values of the marginal disutility from pollution, this policy preference is reversed.*

Proof.   See Appendix A.2.   ∎

Although Nash domestic policies increase the range of the marginal disutility from pollution, within which free trade can be welfare dominating, they are less effective for sufficiently high values of the marginal disutility from pollution. If the marginal disutility from pollution is sufficiently small such that free trade can be welfare dominating, imposing a positive commodity tax will not much distort local consumption (as the tax rate will be sufficiently small), while it will effectively decrease pollution via decreasing consumption of the imported good. If, however, the marginal disutility from pollution is sufficiently high such that free trade cannot be welfare dominating (and assuming they can set tariffs freely for polluting imports), then it would be optimal that countries either engage in (one-way or bilateral) trade and impose positive import tariffs under Nash trade policies, or stay in autarky under Nash domestic policies. In such a situation, it is already clear that they will prefer trade under Nash trade policies.

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[10]Note that Foreign's welfare under free trade (with a positive commodity tax imposed by Home) is larger than its welfare under autarky, for any $\delta \leq 0.77$ (see Appendix A.2).

5 Extensions and discussions

In this section, we extend the model to a symmetric case such that there are no non-pecuniary benefits from imports in Foreign, and thus imports pollute in both countries and are appropriately accounted for in welfare computations. In addition, we introduce transboundary pollution to the model. In particular, we would like to delineate whether (and to what extent) our results from the previous sections hold true.

While consumer and firm behavior is the same as before, each country now has a symmetric welfare equation such that in the case of Nash trade policy, equation (3) changes to

$$\omega_i^t = \pi_i + \frac{b(x_i + y_i)^2}{2} + (t_i - \delta_i)x_i - \theta\delta_j x_j, \quad i \neq j \in \{h, f\} \tag{10}$$

and that in the case of Nash domestic policy, equation (7) changes to

$$\omega_i^\tau = \pi_i + \frac{b(x_i + y_i)^2}{2} + \tau_i(x_i + y_i) - \delta_i x_i - \theta\delta_j x_j, \quad i \neq j \in \{h, f\} \tag{11}$$

where $\theta \in [0, 1]$ represents the strength of leakage (transboundary pollution) from country j to country i decreasing country i's welfare. Maximizing equation (10) w.r.t. t_i, and equation (11) with respect to τ_i, $i = \{h, f\}$ leads to

$$t_i^* = \frac{(a + 2\delta_i)}{3}, \quad \tau_i^* = \frac{\delta_i}{2}, \quad i = \{h, f\}. \tag{12}$$

Following remarks are in order. Unlike the previous (asymmetric) case, in the case that imports pollute in both countries, the optimal tariff and tax rates are symmetric. The higher is a country's marginal disutility from pollution, the higher is its optimal tariff or tax rates. Although both countries now attempt to internalize the consumption externality by imposing tariff or tax rates that are increasing with their marginal disutility from pollution, the increase is still less than their marginal disutility from pollution. It is worth noting that given the linear environmental damage function in the welfare function, transboundary pollution does not change the optimal rates. Moreover, it is clear from equations (1) and (12) that a sufficiently high marginal disutility from pollution in country i (i.e., $\delta_i > a/4$) makes its optimal tariff rate prohibitive (i.e., $t_i^* > a/2$) at which country i will stop importing from country j, $i \neq j \in \{h, f\}$.

We can now show that

Lemma 2 *One-way trade may be the case if and only if the two countries have sufficiently asymmetric marginal disutility from pollution such that $\delta_j < a/4 < \delta_i$ may lead to exports only from country i to country j.*

It is straightforward to show that one-way trade cannot be the case should the two countries have identical marginal disutility from pollution. Moreover, it is worth noting that both Lemma 1 and Lemma 2 assume that there is no restriction on tariff bounds, which may not be the case in reality. The main motivation behind such an assumption is, however, that we would like to discuss also the extreme impact of negative consumption externality on the optimal trade policy and the trade pattern.

Welfare under free trade in each country can be expressed as

$$
\omega_i^{*ft} = \underbrace{\left(\frac{4a^2}{9b}\right)}_{\substack{\text{Welfare} \\ \text{(no disutility)}}} - \underbrace{\delta_i\left(\frac{a}{3b}\right)}_{\substack{\text{Disutility} \\ \text{(direct pollution)}}} - \underbrace{\theta\delta_j\left(\frac{a}{3b}\right)}_{\substack{\text{Disutility} \\ \text{(transboundary pollution)}}} \quad , \quad i \neq j \in \{h, f\}, \quad (13)
$$

and comparing this to autarky welfare ($W_i^{*a} = 3a^2/8b$, $i = \{h, f\}$), we can show that

Proposition 7 *Free trade welfare-dominates autarky in country i, $i = \{h, f\}$, only if both countries' marginal disutility from pollution is sufficiently small and the leakage (transboundary pollution) is sufficiently low such that $\delta_i + \theta\delta_j < 5a/24$, $i \neq j \in \{h, f\}$.*

Given that the condition in Proposition 7 should hold for both countries so that free trade welfare-dominates autarky in both countries, it is straightforward to show that $\delta_i < 5a/24(1 + \theta)$, $i = \{h, f\}$ is a sufficient condition under which both countries' welfare under free trade is greater than that under autarky. Comparing this to Proposition 2, we can conclude that with transboundary pollution the threshold value of marginal disutility (only below which free trade welfare-dominates autarky) gets lower (i.e., $5a/24 > 5a/24(1 + \theta)$).

In the case that there is only local pollution such that $\theta = 0$, free trade welfare-dominates autarky for sufficiently low values of marginal disutility from pollution such that $\delta_i < 5a/24$. Proposition 5 has already shown that free trade can be welfare dominating not only for $\delta < 5a/24$, but also for higher values of δ so long as consumption taxes are imposed increasing this threshold. This holds true also for the case that imports pollute in both countries and the trading partner's marginal disutility is sufficiently low. We can show this following Lemma 3 given below.

Lemma 3 *There is a threshold value of marginal disutility from pollution in each country (as a function of the other country's marginal disutility and the strength of transboundary pollution), denoted $\delta_i^{A/CT}(\theta, \delta_j)$, only below which free trade implemented together with consumption taxes welfare-dominates autarky. This threshold decreases not only as the strength of transboundary pollution increases, but also with the other country's marginal disutility from pollution.*

Proof. See Appendix A.3. ■

Appendix A.3 shows that when pollution is purely local such that $\theta = 0$, for any $\delta_j < \overline{\delta_j}$, $\delta_i^{A/CT} > 5a/24$. We shall note that transboundary pollution decreases both $\overline{\delta_j}$ and $\delta_i^{A/CT}$.

Equation (9) in Section 3 has shown that commodity taxes under free trade increase welfare above free-trade welfare. This is, however, no longer the case when the other country's marginal disutility from pollution is strictly positive, such that

Proposition 8 *There is a threshold value of marginal disutility from pollution in each country (as a function of the other country's marginal disutility and the strength of trans-boundary pollution), denoted $\delta_i^{FT/CT}(\theta, \delta_j)$, only above which free trade implemented together with consumption taxes welfare-dominates free trade without taxes.*

Proof. See Appendix A.3. ■

While this threshold decreases as the strength of transboundary pollution increases, it increases with the other country's marginal disutility from pollution in the case of pure local pollution (i.e., $\theta = 0$) or for sufficiently weak transboundary pollution and for sufficiently low marginal disutility of the trading partner.

Comparing welfare under Nash trade policies to free trade, we can also show that

Proposition 9 *There is a threshold value of marginal disutility from pollution in each country (as a function of the other country's marginal disutility and the strength of trans-boundary pollution), denoted $\delta_i^{FT/NT}(\theta, \delta_j)$, only above which Nash trade policies welfare-dominate free trade.*

Proof. See Appendix A.4. ■

Appendix A.4 also shows that (i) $\partial \delta_i^{FT/NT}(\theta, \delta_j)/\partial \delta_j > 0$ when pollution is purely local such that $\theta = 0$, or when transboundary pollution is sufficiently weak (i.e., $\theta < 0.44$ and the trading partner's marginal disutility is sufficiently small such that $\delta_j < a(4-9\theta)/4(4+9\theta)$), otherwise the threshold decreases with an increase in the trading partner's marginal disutility from pollution; (ii) $\delta_i^{FT/NT}(\theta, \delta_j)$ decreases as the strength of transboundary pollution increases; and (iii) $\delta_i^{FT/NT}(\theta, \delta_j)$ tends to $a/6$ as both θ and δ_j tend to zero just as in the asymmetric case presented in Section 3. A higher value of δ_j above zero increases this threshold above $a/6$. That is, free trade welfare-dominates Nash trade policies even for larger values of marginal disutility from pollution so long as the trading partner also

has some higher marginal disutility from pollution. A special case is that both countries have identical marginal disutility from pollution such that $\delta_h = \delta_f = \delta$. In such a case, when there is no transboundary pollution such that $\theta = 0$, δ tends to $7a/34$, which is greater than $a/6$.

Finally, we can compare free-trade welfare when consumption taxes are introduced to welfare under Nash trade policies, and show that

Proposition 10 *There is a threshold value of marginal disutility from pollution in each country (as a function of the other country's marginal disutility and the strength of transboundary pollution), denoted $\delta_i^{CT/NT}(\theta, \delta_j)$, only above which Nash trade policies welfare-dominate free trade implemented together with consumption taxes. This threshold decreases not only as the strength of transboundary pollution increases, but also with the other country's marginal disutility from pollution.*

Proof.   See Appendix A.4.   ∎

Proposition 3 in Section 3 has shown that for sufficiently small values of the marginal disutility from pollution, it is possible that Nash domestic policies are preferred over Nash trade policies. Following Propositions 8, 9, and 10, it is possible to show that for some constellations of parameter values (especially those with sufficiently weak transboundary pollution and sufficiently low marginal disutility from pollution for the trading partner), this result still holds true. Appendix A.4 presents an example of such a constellation of parameter values at which $\omega_i^{*\tau} > \omega_i^{*t} > \omega_i^{*ft}$.

6   Concluding remarks

In a simple reciprocal dumping model of trade, this study has scrutinized the strategic role of trade and commodity taxes as environmental instruments when there is consumption-generated pollution. Although statistical evidence suggests that consumption-generated pollution constitutes a significantly large share of most industrialized countries' total emissions, the related literature (except for a greatly limited number of studies) has mainly taken on board production as the main source of pollution and studied the strategic use of environmental policy instruments. The main contribution of this study is thus to study environmental pollution that is generated by consumption of an imported good from a trading partner. In addition, in an attempt to discuss an empirically relevant case, this study has introduced also some asymmetry among countries (especially

19

in terms of their marginal disutility from pollution). As far as consumer-generated pollution is considered, environmental taxes may be inapplicable, especially when countries are not allowed to use domestic taxes to discriminate products according to the source country. This study has shown that in such a situation, trade and commodity taxes become important and can crucially affect trade patterns, as they can be used not only to generate tax revenues, to increase the domestic firm's market share, and to correct domestic distortions, but also to internalize the negative consumption externality.

According to our results, a sufficiently high marginal disutility from pollution (or sufficient asymmetries between the countries in terms of their marginal disutility from pollution) may jeopardize bilateral trade, especially if countries are given the option to set tariffs freely for imported goods (consumption of which generate environmental pollution). For sufficiently weak transboundary pollution and sufficiently low marginal disutility from pollution, (i) both Nash trade and domestic policies may prove to be helpful in addressing consumption-based pollution, and (ii) it is possible to show in such a case that Nash domestic policies may be preferred over Nash trade policies, especially when both transboundary pollution and the trading partner's marginal disutility from pollution are sufficiently low. We shall note that in the analysis we have assumed no transport costs. This, however, can be relaxed easily, and one can show that optimal taxes and/or tariffs decrease with an increase in transport costs. That said, the impact of transport costs on welfare will not be monotonic.

While the current paper's analysis is limited to homogeneous goods, it is equally important to capture also the role trade and domestic policies play as environmental instruments when products are both horizontally and vertically differentiated. This, however, deserves its own model. In such a model, one can include not only negative consumption externalities, but also negative production externalities, which may allow for discussing even a wider range of direct and indirect environmental instruments. We leave this, however, to future research.

Appendix A

A.1 Nash Trade Policies

As is already discussed, in the case that the two countries adopt Nash trade policies and there is bilateral trade between these two countries, the optimal outputs, x_i and y_i, and the maximized profits, π_i, $i = \{h, f\}$, are given by equations (1) and (2), respectively, and the optimal tariff rates, t_i^*, $i = \{h, f\}$, that maximize welfare, W_i, $i = \{h, f\}$, are given by equation (4). Substituting the optimal outputs, x_i and y_i, the maximized profits, π_i, $i = \{h, f\}$, and the optimal tariff rates, t_i^*, $i = \{h, f\}$, back into the welfare expressions given by equation (3) yields the maximized welfare levels, denoted W_i^{*t}, $i = \{h, f\}$, where superscript t stands for the case that the two countries impose tariffs and trade, such that

$$W_h^{*t} = \frac{65a^2 - 18a\delta + 36\delta^2}{162b}, \tag{A.1a}$$

$$W_f^{*t} = \frac{65a^2 - 16a\delta + 32\delta^2}{162b}. \tag{A.1b}$$

If, however, the two countries engage in free trade (i.e., $t_i = 0$, $i = \{h, f\}$), then the maximized welfare levels, denoted W_i^{*ft}, are given by equation (5). If there is autarky in both countries, then the maximized welfare levels are $W_i^{*a} = 3a^2/8b$, $i = \{h, f\}$.

In the case of one-way trade (from Home to Foreign), we have already shown that Foreign is always better off by imposing an import tariff, $t_f^* = a/3$, in which case the maximized welfare levels in Home and in Foreign are $W_h^{*at} = 251a^2/648b$ and $W_f^{*at} = 7a^2/18b$, respectively, where superscript at stands for the regime in Home (autarky) and in Foreign (trade with an import tariff), respectively. We will distinguish between two cases.

<u>Case 1:</u> *The two countries are initially adopting Nash trade policies.*

As is already discussed, if the marginal disutility from pollution is sufficiently high such that $\delta > a/4$, Home's tariff rate becomes higher than the prohibitive tariff rate implying that cross-hauling will cease to exist, and there may be only one-way trade (from Home to Foreign), in which case Foreign will impose an import tariff, $t_f^* = a/3$. Although Foreign would be better off had there been free trade ($W_f^{*ft} > W_f^{*at} > W_f^{*a}$), especially as compared to one-way trade (with foreign import tariffs), or to autarky, for Home, free trade would not be welfare superior in such a situation since $\delta > a/4$ at which $W_h^{*at} > W_h^{*ft}$. Therefore, $\delta > a/4$ may lead to one-way trade under Nash policy.

Suppose now the marginal disutility from pollution is such that $a/6 < \delta < a/4$, that is, Home's tariff rate is less than the prohibitive tariff rate. In such a situation, although free trade would improve welfare in Foreign (given $\delta < a/4$, $W_f^{*ft} > W_f^{*t}$), the marginal

21

disutility from pollution is still too high such that Home is better off by adopting Nash trade policies. If, however, the marginal disutility from pollution is sufficiently small ($\delta < a/6$), then free trade between the two countries may be welfare dominating, since $W_i^{*ft} > W_i^{*t}$, $i = \{h, f\}$, provided $\delta < a/6$. Note that, autarky in both countries would be welfare dominated in such cases.

<u>**Case 2:**</u> *The two countries are initially in autarky.*

As is already shown by Proposition 2, free trade cannot welfare-dominate autarky in Home when the marginal disutility from pollution is sufficiently high such that $\delta > 5a/24$. Also, as is already discussed, Foreign is always better off by opening its market to trade and by imposing an import tariff, as compared to autarky. It is also straightforward to show that welfare improves in Home ($W_h^{*t} > W_h^{*a}$) should it open its market to trade and adopt Nash trade policies. As we have already discussed above, as compared to free trade, Nash trade policies improve welfare in Home if $\delta > a/6$. Therefore, given $a/6 < \delta < a/4$, free trade cannot be welfare superior, but both countries will find it optimal to open their markets to trade and will adopt Nash trade policies. As for $\delta > a/4$, it is clear from equations (1) and (4), and from Lemma 1 that Home's tariff rate will be higher than the prohibitive tariff rate, in which case one-way trade (from Home to Foreign) may be the case. Not surprisingly, free trade may be welfare superior if the marginal disutility from pollution is sufficiently small such that $\delta < a/6$ (completing the proof of Proposition 3).

A.2 Commodity Taxes and the Equilibrium Trade Regime

In the case that the two countries adopt Nash domestic policies, the optimal outputs, x_i and y_i, and the maximized profits, π_i, $i = \{h, f\}$, are given by equations (6) and (2), respectively, and the optimal commodity tax rates, τ_i^*, $i = \{h, f\}$, that maximize welfare, W_i^τ, $i = \{h, f\}$, are given by equation (8). Substituting the optimal outputs, x_i and y_i, the maximized profits, π_i, $i = \{h, f\}$, and the optimal tax rates, τ_i^*, $i = \{h, f\}$, back into the welfare expressions given by equation (7) yields the maximized welfare levels, denoted $W_i^{*\tau}$, $i = \{h, f\}$, where superscript τ stands for the case that the two countries adopt Nash domestic policies and impose non-discriminatory commodity taxes, such that

$$W_h^{*\tau} = \frac{16a^2 - 12a\delta + 3\delta^2}{36b}, \tag{A.2a}$$

$$W_f^{*\tau} = \frac{16a^2 - 4a\delta + \delta^2}{36b}. \tag{A.2b}$$

If, however, the two countries engage in free trade, and impose no tax/tariff (i.e., $\tau_i = t_i = 0$, $i = \{h, f\}$), then the maximized welfare levels, denoted W_i^{*ft}, $i = \{h, f\}$, are

given by equation (5). We can rewrite equations (A.2a) and (A.2b) such that

$$W_h^{*\tau} = W_h^{*ft} + \frac{\delta^2}{12b},$$

$$W_f^{*\tau} = W_f^{*ft} - \frac{\delta(4a - \delta)}{36b},$$

which imply that Home is always better off as compared to free trade by imposing a positive commodity tax rate under free trade, whereas Foreign is worse off as compared to free trade when Home imposes a positive commodity tax rate. We can compare autarky welfare and welfare under free trade (subject to a positive commodity tax rate imposed only by Home), and show that

$$\lim_{\delta \to \hat{\delta}} W_h^{*\tau} = \lim_{\delta \to \delta'} W_f^{*\tau} = W_i^{*a}, \ \ i = \{h, f\},$$

where $\hat{\delta} \simeq 0.220487a$ and $\delta' \simeq 0.775255a > \hat{\delta}$, and that $W_h^{*\tau} > W_h^{*a}$ if and only if $\delta < \hat{\delta}$, and $W_f^{*\tau} > W_f^{*a}$ if and only if $\delta < \delta'$, because $\partial[W_h^{*\tau} - W_h^{*a}]/\partial\delta < 0$ and $\partial[W_f^{*\tau} - W_f^{*a}]/\partial\delta < 0$ for any $\delta < 2a$. It is now clear that for a sufficiently small marginal disutility from pollution such that $\delta < \hat{\delta}$, free trade can be maintained because the two countries can improve welfare under free trade (as compared to autarky), provided a positive commodity tax rate is imposed by Home (together with Appendix A.1 completing the proof of Proposition 5).

Proposition 3 and Appendix A.1 have already shown that whenever the marginal disutility from pollution is sufficiently small such that $\delta < a/6$, free trade is welfare superior in the case of Nash trade policies (import tariffs), in which case Home is unambiguously better off by imposing a positive (non-discriminatory) commodity tax rate $(W_h^{*\tau} > W_h^{*ft})$ so as to internalize the negative consumption externality. If, however, $a/6 < \delta < \hat{\delta}$, the two countries engage in trade and impose positive import tariffs in equilibrium (Home internalizes the negative consumption externality by imposing a higher tariff rate than Foreign) under Nash trade policies (Proposition 3 and Appendix A.1), whereas free trade (subject to a positive commodity tax rate imposed only by Home) is the equilibrium trade regime under Nash domestic policies. In such a case, we can show that

$$\lim_{\delta \to \tilde{\delta}}[W_h^{*\tau} - W_h^{*t}] = \lim_{\delta \to \tilde{\delta}}\left[\frac{14a^2 - 72a\delta - 45\delta^2}{324b}\right] = 0,$$

$$\lim_{\delta \to \delta''}[W_f^{*\tau} - W_f^{*t}] = \lim_{\delta \to \delta''}\left[\frac{14a^2 - 4a\delta - 55\delta^2}{324b}\right] = 0,$$

where $\tilde{\delta} \simeq 0.175249a < \hat{\delta}$ and $\delta'' \simeq 0.46947a < \delta'$, and that $W_h^{*\tau} > W_h^{*t}$ if and only if $\delta < \tilde{\delta}$, and $W_f^{*\tau} > W_f^{*t}$ if and only if $\delta < \delta''$, because $\partial[W_h^{*\tau} - W_h^{*t}]/\partial\delta < 0$ and $\partial[W_f^{*\tau} - W_f^{*t}]/\partial\delta < 0$, $\forall \ \delta$. Therefore, Nash domestic policies leads to higher welfare for both countries than that under Nash trade policies, if and only if $a/6 < \delta < \tilde{\delta}$ (completing the proof of the first part of Proposition 6)

If, however, $\tilde{\delta} < \delta < \hat{\delta}$, then Home is better off under Nash trade policies, whereas Foreign is better off under Nash domestic policies. In such a situation, we can show that (i) if the two countries are initially under autarky, free trade (with or without commodity taxes) cannot be welfare superior, because the marginal disutility from pollution is sufficiently high (in which case the two countries would trade and impose positive import tariffs; and (ii) if the two countries are initially trade partners, and are currently imposing import tariffs, free trade (with or without commodity taxes) cannot be welfare superior, either.

Finally, if the marginal disutility from pollution is sufficiently high such that $\delta > \hat{\delta}$, under Nash domestic policies, autarky would be the case, with which welfare would be dominated by the case under Nash trade policies (either by cross-hauling subject to positive import tariffs if $\hat{\delta} < \delta < a/4$, or by one-way trade subject to a positive import tariff imposed by Foreign if $\delta > a/4$). Therefore, free trade (subject to a positive commodity tax imposed by Home) can be welfare superior if and only if the marginal disutility from pollution is sufficiently small. If, however, the marginal disutility from pollution is sufficiently high, then free trade (with or without commodity taxes) is not welfare improving as compared to autarky, so the two countries prefer Nash trade policies over domestic ones, because they can still engage in trade and impose import tariffs, and improve their local welfare (completing the proof of the second part of Proposition 6).

A.3   Proof of Lemma 3 and Proposition 8

In the case that imports pollute in both countries with some transboundary pollution and the two countries adopt Nash domestic policies, the optimal outputs, x_i and y_i, and the maximized profits, π_i, $i = \{h, f\}$, are given by equations (6) and (2), respectively, and the optimal commodity tax rates, τ_i^*, $i = \{h, f\}$, that maximize welfare, ω_i^τ, $i = \{h, f\}$, are given by equation (12). Substituting the optimal outputs, x_i and y_i, the maximized profits, π_i, $i = \{h, f\}$, and the optimal tax rates, τ_i^*, $i = \{h, f\}$, back into the welfare expression given by equation (11) yields the maximized welfare levels, denoted $\omega_i^{*\tau}$, $i = \{h, f\}$, where, as in the previous sections, superscript τ stands for the case that the two countries adopt Nash domestic policies and impose non-discriminatory commodity taxes, such that

$$\omega_i^{*\tau} = \frac{16a^2 - 4a(1 + 3\theta)\delta_j + (1 + 6\theta)\delta_j^2 - 3\delta_i(4a - \delta_i)}{36b}, \quad i = \{h, f\}. \tag{A.5}$$

Note that $\partial \omega_i^{*\tau}/\partial \delta_i < 0$ for any $\delta_i < 2a$. Comparing equation A.5 to autarky welfare

24

$W_i^{*a} = 3a^2/8b$ shows that $\omega_i^{*\tau} \geq W_i^{*a}$ for any $\delta_i \leq \delta_i^{A/CT}(\theta, \delta_j)$, where

$$\delta_i^{A/CT}(\theta, \delta_j) = 2a - \sqrt{\frac{19a^2 + 8(a + 3a\theta)\delta_j - 2(1 + 6\theta)\delta_j^2}{6}}.$$

It is straightforward to show that (i) $\partial\delta_i^{A/CT}(\theta, \delta_j)/\partial\delta_j < 0$ for any $\delta_j < a(1 + 1/(1 + 6\theta))$, where the RHS of the inequality ranges between $2a$ and $1.4a$ for $\theta \in [0, 1]$; and (ii) $\partial\delta_i^{A/CT}(\theta, \delta_j)/\partial\theta < 0$ for any $\delta_j < 2a$. Also we can now show that when pollution is purely local such that $\theta = 0$, $\delta_i^{A/CT} > 5a/24$ for any $\delta_j < 0.0328214a$.

As for the proof of Proposition 8, we can compare free trade welfare ω_i^{*ft}, given by equation (13), to welfare under consumption taxes $\omega_i^{*\tau}$, given by equation (A.5), and show that $\omega_i^{*\tau} \geq \omega_i^{*ft}$ for any $\delta_i \geq \delta_i^{FT/CT}(\theta, \delta_j)$, where

$$\delta_i^{FT/CT}(\theta, \delta_j) = \sqrt{\frac{\delta_j(4a - (1 + 6\theta)\delta_j)}{3}}.$$

It is straightforward to show that (i) $\partial\delta_i^{FT/CT}(\theta, \delta_j)/\partial\delta_j > 0$ for any $\delta_j < 2a/(1 + 6\theta)$, where the RHS of the inequality ranges between $2a$ and $0.286a$ for $\theta \in [0, 1]$; and (ii) $\partial\delta_i^{FT/CT}(\theta, \delta_j)/\partial\theta < 0$.

A.4   Proof of Propositions 9 and 10

In the case that imports pollute in both countries with some transboundary pollution and the two countries adopt Nash trade policies, the optimal outputs, x_i and y_i, and the maximized profits, π_i, $i = \{h, f\}$, are given by equations (6) and (2), respectively, and the optimal tariff rates, t_i^*, $i = \{h, f\}$, that maximize welfare, ω_i^t, $i = \{h, f\}$, are given by equation (12). Substituting the optimal outputs, x_i and y_i, the maximized profits, π_i, $i = \{h, f\}$, and the optimal tariff rates, t_i^*, $i = \{h, f\}$, back into the welfare expression given by equation (10) yields the maximized welfare levels, denoted ω_i^{*t}, $i = \{h, f\}$, where, as in the previous sections, superscript t stands for the case that the two countries adopt Nash trade policies and impose import tariffs, such that

$$\omega_i^{*t} = \frac{65a^2 - 2a(8 + 9\theta)\delta_j + 8(4 + 9\theta)\delta_j^2 - 18\delta_i(a - 2\delta_i)}{162b}, \quad i = \{h, f\}. \tag{A.6}$$

Lemma 2 has already shown that this case (bilateral trade) requires $\delta_i < a/4$, $i = \{h, f\}$. We can now show that that $\partial\omega_i^{*t}/\partial\delta_i < 0$ for any $\delta_i < a/4$. Comparing equation A.6

to free trade welfare ω_i^{*ft}, given by equation (13), shows that $\omega_i^{*t} \geq \omega_i^{*ft}$ for any $\delta_i \geq \delta_i^{FT/NT}(\theta, \delta_j)$, where

$$\delta_i^{FT/NT}(\theta, \delta_j) = \frac{2\sqrt{(a + 2\delta_j)(4a - (4 + 9\theta)\delta_j)} - 3a}{6}.$$

It is straightforward to show that (i) $\partial\delta_i^{FT/NT}(\theta, \delta_j)/\partial\delta_j > 0$ when pollution is purely local such that $\theta = 0$, or when transboundary pollution is sufficiently weak (i.e., $\theta < 0.44$ and the trading partner's marginal disutility is sufficiently small such that $\delta_j < a(4 - 9\theta)/4(4 + 9\theta)$), otherwise the threshold decreases with an increase in the trading partner's marginal disutility from pollution; and (ii) $\partial\delta_i^{FT/NT}(\theta, \delta_j)/\partial\theta < 0$. Also we can now show that when pollution is purely local such that $\theta = 0$, $\delta_i^{FT/NT}$ tends to $a/6$ as θ tends to zero. Also as θ tends to zero, when both countries have identical marginal disutility from pollution, $\delta_i^{FT/NT}$ tends to $7a/34$.

As for the proof of Proposition 10, we can compare free trade welfare under consumption taxes $\omega_i^{*\tau}$, given by equation (A.5), to welfare under tariffs ω_i^{*t}, given by equation (A.6), and show that $\omega_i^{*\tau} \geq \omega_i^{*t}$ for any $\delta_i \leq \delta_i^{CT/NT}(\theta, \delta_j)$, where

$$\delta_i^{CT/NT}(\theta, \delta_j) = \frac{\sqrt{214a^2 - 5\delta_j(4a(1 + 18\theta) + (55 + 90\theta)\delta_j)} - 12a}{15}.$$

Also we can show that (i) $\partial\delta_i^{CT/NT}(\theta, \delta_j)/\partial\delta_j < 0$; and (ii) $\partial\delta_i^{CT/NT}(\theta, \delta_j)/\partial\theta < 0$.

Finally, we can illustrate that in the case of pure local pollution such that $\theta = 0$, for any $\delta_j < 0.022807a$, $\delta_i^{CT/NT}(\theta, \delta_j) > \delta_i^{FT/NT}(\theta, \delta_j)$. In such a case, we can show that for any $\delta_i^{FT/NT}(\theta, \delta_j) < \delta_i < \delta_i^{CT/NT}(\theta, \delta_j)$, $\omega_i^{*\tau} > \omega_i^{*t} > \omega_i^{*ft}$, that is, country i prefers domestic policies over trade policies.

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