Can Trade be good for the environment?

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Working Paper No. 14032
September 2014

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October 1, 2014

Abstract

We analyze the impact of trade in a differentiated good on environmental policy when there is local and transboundary pollution. In autarky, the (equivalent) pollution tax is set equal to the marginal damage from own emissions. If the strategic policy instrument is a tax, leakage occurs under trade and tends to *lower* the tax. The net terms of trade effect, due to the exportable and importable varieties of the differentiated good, tends to *increase* the tax. We derive conditions under which pollution taxes under trade are higher than the marginal damage from own emissions, i.e., *higher* than the Pigouvian tax and than that under autarky. Then, pollution *falls* under trade relative to autarky. When countries use quotas/permits to regulate pollution, there is *no* leakage, while the net terms of trade effect tends to make pollution policy *stricter*. The equivalent tax is always higher than the marginal damage from own emissions, i.e., *always higher* than the Pigouvian tax and than that under autarky; hence, pollution *always* falls under trade. Our analysis provides some insight into the findings in the empirical literature that trade might be good for the environment.

***JEL* Classification Numbers:** Q56, F18, H23.

Key Words: Strategic environmental policy, leakage effect, intra-industry trade, transboundary pollution.

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[*] We are thankful to an Associate Editor and an anonymous referee for their comments and suggestions that significantly improved the paper. The usual disclaimer applies.

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1 Introduction

The relation between trade and environmental policy has received extensive coverage due to the concern about the detrimental effect of trade on the environment.[1] Large countries can use weaker environmental regulation as a second-best method of pursuing terms of trade goals. Also, *leakage effects* (which occur when strict domestic pollution policy leads to increased foreign pollution through changes in the world price of pollution-intensive goods) tend to make environmental policy weaker under trade.[2]

Empirical studies, in contrast to the aforementioned concerns, indicate that the impact of trade on the environment is *not* necessarily negative. Grossman and Krueger (1993), for instance, find that NAFTA would have had a positive impact on the global environment. Strutt and Anderson (2000) analyzed the case of Indonesia, which was undertaking trade liberalization, and showed that trade reforms would improve the environment.[3] Using Global Environmental Monitoring System (GEMS) data on SO_2 concentrations from 43 countries between 1971 and 1996, Antweiler, Copeland and Taylor (2001) conclude that free trade appears to be good for the environment. Our theoretical analysis seeks to identify conditions under which trade can be good for the environment in line with these empirical findings.

The effect of trade on environmental policy has been extensively analyzed theoretically in both strategic and non-strategic settings.[4] Most of the theoretical literature focuses on inter-industry trade; however, it is well known that a significant proportion of trade is intra-industry trade in *similar* goods between *similar* countries.[5] This paper analyzes the effect of intra-industry trade on environmental policies in the presence of local and transboundary pollution when countries set their policies strategically. We show that trade can lead to stricter environmental policies and consequently lower pollution than under autarky. While these results are in keeping with the empirical findings that trade can be beneficial for the environment,[6] they arise not because of the assumption that higher incomes lead to greater demand for cleaner environment, and hence decreased pollution, but rather because of the strategic effects associated with policy setting.

Leakage effects in the context of intra-industry trade have been analyzed in Rauscher (1997), chapter 6, and Gürtzgen and Rauscher (2000) using the Dixit-Stiglitz framework of monopolistic competition. Also, Fung and Maechler (2007) use a two country "price-setting duopoly model" along the lines of Brander and Krugman (1983) to examine the effect of trade liberalization on

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[1] See, for instance, *Environment and Trade, A Handbook*, 2005, published by the United Nations Environment Programme and the International Institute for Sustainable Development (available at http://www.iisd.org/sites/default/files/pdf/2005/envirotrade_handbook_2005.pdf).

[2] See, for instance, Rauscher (1997), Yanase (2007), and Lapan and Sikdar (2011). Gürtzgen and Rauscher (2000) discuss other mechanisms through which leakage occurs.

[3] See also Lee and Roland-Holst (1997) for a two-country CGE model calibrated to Indonesia and Japan which finds that trade liberalization can lower emissions and raise welfare simultaneously.

[4] See, for instance, Copeland and Taylor (2004) for a comprehensive and critical review of the issues.

[5] See Gruber and Lloyd (1975) for one of the earliest analysis. Other empirical studies on intra-industry trade include Tharakan (1984), which points out the increase in intra-industry trade between OECD and developing countries, and Bernhofen (1999), which examines intra-industry trade in petrochemicals between Germany and the United States.

[6] When property rights for renewable resources are imperfect, Karp, Sacheti and Zhao (2001) show that trade can make the property rights regime stricter.

the environment. However, these papers analyze the effect of a change in the policy of one of the two countries, while the other country holds its policy fixed. Although the strategic (Nash) equilibrium where both countries choose policies non-cooperatively would be of interest, given their framework, as Gürtzgen and Rauscher (2000) point out, "this is an intractable problem". In contrast to these papers, which consider *unilateral* policy, we analyze the strategic game between two policy-active countries when environmental policy is the strategic variable in each country and also compare outcomes under different policy instruments. To maintain tractability, we use a perfectly competitive framework of intra-industry trade rather than the monopolistic competition framework.

Haupt (2006) examines strategic interactions between countries with respect to environmental standards in a model of monopolistic competition when pollution is *purely* local; hence, there is *no* possibility of leakage.[7] On the other hand, in our model with local and transboundary pollution, we compare environmental taxes and quotas in a strategic setting when leakage is possible.

Benarroch and Weder (2006) analyze the interaction between intra-industry trade in *intermediate* goods and pollution. Pollution is generated only when "dirty intermediaries" are used in the production of the *nontradable* final good. However, pollution is *purely* local, i.e., there is *no* transboundary pollution; hence, there is *no* possibility of leakage. They consider a pollution tax as the policy instrument and do *not* examine strategic policy setting between countries. In contrast, we analyze strategic environmental policy in the presence of transboundary pollution and intra-industry trade in *final* goods. Further, we compare outcomes under different policy instruments, pollution taxes and quotas.

Our analysis, thus, adds to the existing literature on intra-industry trade and environmental policy by incorporating strategic policy setting in a setup in which there is transboundary pollution (hence, leakage can occur). Our results also provide some reconciliation with the empirical literature that trade can be good for the environment even though we do not assume that higher income resulting from opening up to trade leads to increased demand for a cleaner environment (hence, pollution abatement).

In our two country model, each country produces a different variety of a differentiated final consumption good, along with a homogeneous good, under perfectly competitive conditions. Intra-industry trade in the differentiated good arises due to consumers' preference for both varieties of the differentiated good, which are imperfect substitutes (see Armington, 1969). One example of such differentiated products is food and agricultural products; heterogeneity in these products (for instance, meat, wine, rice, cheese) and also seasonal variations can lead to intra-industry trade in these goods. It should also be noted that, while agricultural products have had special treatment under the GATT/WTO, there has been a significant push by countries to further liberalize agricultural trade and this underscores the relevance of our analysis of the

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[7] To see why transboundary pollution is a prerequisite for leakage effects, assume the home country exports the pollution-intensive good. Strict home pollution policy reduces world supply of the good, increases its world price and, thus, foreign production of the pollution-intensive good (and foreign emissions). The accompanying increase in the incidence of transboundary pollution from the foreign to the home country reduces the latter's marginal benefit from regulating own emissions. This *leakage effect* tends to *lower* the home pollution tax. Of course, without transboundary pollution, the increase in foreign emissions does *not* have any impact on home welfare and hence, *no* effect on the home pollution tax.

environmental impact of such changes in regulation. Pollution reduces consumers' welfare in both countries, i.e., there are *both* local and transboundary negative welfare effects of pollution. In this setup, we analyze the impact of trade on environmental policies when countries simultaneously and strategically set domestic environmental policies.

Under *autarky*, each country sets the (equivalent) domestic pollution tax equal to the marginal damage from own pollution and both policy instruments, taxes and quotas,[8] result in the same outcome. With trade in the differentiated good, which is assumed to be relatively more pollution-intensive,[9] the equivalency of environmental taxes and quotas breaks down. When *taxes* are the strategic variables, the net terms of trade effect tends to *increase* the environmental tax.[10] The leakage effect reduces each country's marginal benefit from environmental regulation; this tends to *lower* the pollution tax. Trade leads to *stricter environmental policies*, i.e., higher taxes, in *both* countries if the net terms of trade effect dominates the leakage effect. This occurs if, for instance, the volume of trade is high or the transboundary spillover of pollution is low. Hence, despite leakage effects, the pollution taxes are higher than the respective marginal damages from own emissions, i.e., *higher* than the Pigouvian taxes and than the autarky taxes. This leads to a fall in pollution in *both* countries.

When countries use pollution *quotas*, rather than taxes, the net terms of trade effect tends to *lower* the number of quotas. There is *no* leakage effect when the strategic variable is pollution quotas. The equivalent taxes in *both* countries are higher than the respective marginal damages from own emissions, i.e., *higher* than the Pigouvian taxes and than the autarky (equivalent) taxes. Hence, intra-industry trade *lowers* pollution when the policy instrument is quotas.

Our results suggest a possibly positive effect of trade on the environment, even in strategic settings when there is both local and transboundary pollution. This is in keeping with the empirical evidence discussed at the beginning of this section that free trade may, in fact, be good for the environment.

The model is presented in the next section, while section 3 analyzes strategic environmental policies and compares outcomes under different policy instruments, taxes and quotas. Section 4 concludes.

2 The Model

Opening a country to trade can lead to changes in environmental outcomes for a variety of reasons. First, trade will, in general, change the mix of goods produced in each country. The

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[8] Note that these quotas/permits may be auctioned by the authorities and may be traded domestically.

[9] Bernhofen (1999), and Fung and Maechler (2007) provide evidence that industries in which intra-industry trade occur are often pollution-intensive. Also, if one thinks of the differentiated good in terms of agricultural products, Stern (2006) estimates that 35% of world greenhouse gas emissions come from agriculture (including livestock production). Furthermore, as McMichael et al. (2007) point out "greenhouse-gas emissions from the agriculture sector account for about 22% of global total emissions; this contribution is similar to that of industry and greater than that of transport." Hence, our assumption of the differentiated good being relatively more pollution-intensive seeks to capture these empirical findings about the pollution intensity of goods in which intra-industry trade occurs.

[10] Countries could use environmental policies to circumvent free trade agreements which forbid the use of trade policies. For empirical evidence on environmental policies being used as secondary means of achieving terms of trade motives, see Ederington and Minier (2003).

impact of this effect on pollution depends, of course, on the relative pollution intensities of the exportable and importable goods. Second, ignoring pollution and any other market failure, trade will raise real income levels and hence increase the demand for normal goods; thus, if a clean environment is a normal good, trade will affect environmental policy through this income effect. Third, if there are asymmetries between countries such that one country cares less about pollution than others, this will lead to a shift of pollution-intensive production to countries which care less about pollution, and hence may lead to increased pollution levels. Finally, opening economies to trade leads to a strategic dimension in setting environmental policy. In constructing our model, we focus on this fourth aspect, and hence structure the model so that our results are driven purely by this strategic policy setting effect.

We consider a model of intra-industry trade between two large countries, a home country and a foreign country (foreign variables are denoted by *). Two varieties, X and X^*, of a differentiated good are produced only in the home country and the foreign country, respectively, along with a homogeneous good, Y, which is produced in both countries. The production possibility frontiers of the home and foreign countries are, respectively:[11]

$$g(x, y, z; \overrightarrow{V}) \geq 0 \quad \text{and} \quad g^*(x^*, y^*, z^*; \overrightarrow{V}^*) \geq 0, \tag{1}$$

where $g_x, g^*_{x^*}, g_y, g^*_{y^*} < 0 < g_z, g^*_{z^*}, g_{v_i}, g^*_{v^*_i}$; z (z^*) is home (foreign) emissions and $\overrightarrow{V}$ $(\overrightarrow{V}^*)$ is the vector of home (foreign) inputs. Note that X and X^* are *different* varieties of the differentiated good. This specification of the production possibility function nests the case in which pollution is generated in either or both sectors. It also allows for the possibility of abatement, substitutability between inputs, and having polluting and non-polluting inputs.

Let c_x, c_{x^*} and c_y (c^*_x, $c^*_{x^*}$ and c^*_y) denote consumption of X, X^* and Y in the home (foreign) country. Preferences of the representative agents in the home and foreign countries are given by, respectively:

$$U(c_x, c_{x^*}, c_y, z, z^*) = \phi(c_x, c_{x^*}, c_y) - \psi(z, z^*) \text{ and } U^*(c^*_x, c^*_{x^*}, c^*_y, z^*, z) = \phi^*(c^*_x, c^*_{x^*}, c^*_y) - \psi^*(z^*, z),$$

where $\phi_{c_x}, \phi_{c_{x^*}}, \phi^*_{c^*_x}, \phi^*_{c^*_{x^*}}, \phi_{c_y}, \phi^*_{c^*_y}, \psi_z, \psi_{z^*}, \psi^*_z, \psi^*_{z^*} > 0$; $\phi(.)$ and $\phi^*(.)$ are twice differentiable and concave, while $\psi(.)$ and $\psi^*(.)$ are strictly convex. Total disutility from pollution, $\psi(.)$ and $\psi^*(.)$, consists of two components: disutility from domestic emissions, i.e., due to local pollution, and from the inflow of transboundary pollution from the other country. In the home country, for instance, the marginal disutility from own emissions (local pollution) is $\psi_z(.)$, while the marginal disutility from the inflow of transboundary pollution from the foreign country is $\psi_{z^*}(.)$. Note that additive pollution, i.e., the situation in which pollution is a global public bad, is subsumed in our setup as a special case. That is, $\psi(z, z^*)$ can be of the form $\psi(z + z^*)$, which would be relevant for the analysis of global warming issues. Some examples of non-additive pollution damage would be those of acid rain and water pollution, where there can be some local clean-up and transboundary spillover is not complete or there can be more transboundary effect than

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[11] Note that when we focus on the symmetric equilibrium, the functional forms, for example $g(.)$ and $g^*(.)$, will be the same across countries, despite the arguments being different. We use * to denote foreign functions for the sake of clarity.

local effect depending on the flow of air/water.[12]

Let Y be the numeraire good, i.e., set the price of Y, $p_y \equiv 1$. Let p and p^* be the (world) prices of X and X^*, respectively. Suppose both countries use taxes on own emissions, t and t^*, which are the only policy instruments, respectively,[13] to regulate pollution. The GNP functions for the home and foreign countries are:[14]

$$R(p,t) \quad \text{and} \quad R^*(p^*,t^*).$$

Home and foreign expenditure functions are,[15] respectively:

$$e(p,p^*,u+\psi(z,z^*)) \quad \text{and} \quad e^*(p,p^*,u^*+\psi^*(z^*,z)).$$

For more details on the dual general equilibrium approach, see Dixit and Norman (1980).

In keeping with the empirical findings of Bernhofen (1999), and Fung and Maechler (2007) that industries in which intra-industry trade take place are often pollution-intensive, we assume that the differentiated good is relatively more pollution-intensive (see footnote 9):

Assumption 1. *X and X^* are relatively more pollution-intensive than Y, i.e., $R_{pt} < 0$ and $R^*_{p^*t^*} < 0$.*

By definition, intra-industry trade is trade in similar goods, which implies that different varieties of the differentiated good would be substitutes in consumption:

Assumption 2. *X and X^* are substitutes, i.e., $e_{pp^*} > 0$ and $e^*_{pp^*} > 0$.*

Hence, if the price of either variety of the differentiated good increases, demand for the other variety of the differentiated good increases in both countries. Also, following Armington (1969), we assume that the home and foreign varieties of the differentiated good are imperfect substitutes. Moreover, it is reasonable to assume:

Assumption 3. *The own price effects are greater than the cross price effects, i.e., $|e_{pp}| \geq |e_{pp^*}|$, $|e^*_{pp}| \geq |e^*_{pp^*}|$, $|e_{p^*p^*}| \geq |e_{p^*p}|$, and $|e^*_{p^*p^*}| \geq |e^*_{p^*p}|$.*

An increase in the price of the home variety of the differentiated good reduces demand for that good, X. Also, an increase in the price of X^* increases demand for the substitute good, X. Assumption 3 implies that a change in the price of X leads to a higher change in the demand for X as compared to a change in the price of X^*.

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[12] Emissions from northern US power plants have in the past had more effect on southern Canada than on the rest of the US. Also, depending on winds, Chinese emissions have been a leading contributor to the pollution levels in California.

[13] This can be due to trade agreements that restrict the use of trade policies. Moreover, given WTO obligations which generally forbid the use of tariffs or quotas, this seems to be the natural path to take.

[14] The GNP function is given by $R(p,t) = \max_{x,y,z}\{px + y - tz\}$ such that $g(x,y,z;\overrightarrow{V}) \geq 0$. Standard envelope properties of this function imply $R_t = -z$ and $R_{tt} = -z_t$. If all firms face the same prices for goods, for the factors, v, and the externality, then individual profit maximization, together with factor market equilibrium, will lead to GNP maximization, or the revenue function as defined above.

[15] Due to the presence of the externality, the expenditure function is given by: $\min_{c_x,c_{x^*},c_y}(pc_x + p^*c_{x^*} + c_y)$ s.t. $\phi(c_x,c_{x^*},c_y) - \psi(z,z^*) \geq u \Rightarrow \min_{c_x,c_{x^*},c_y}(pc_x + p^*c_{x^*} + c_y)$ s.t. $\phi(c_x,c_{x^*},c_y) \geq u + \psi(z,z^*)$.

Assumption 4. *Preferences are such that:*

A. *the optimal level of pollution is independent of income levels, i.e.,* $e_{uu} = e^*_{u^*u^*} = 0$*, and*

B. *the income elasticity of demand for the different varieties of the differentiated good,* X *and* X^**, is zero, i.e.,* $e_{pu} = e_{p^*u} = e^*_{pu^*} = e^*_{p^*u^*} = 0$*.*

Assumption 4A follows our earlier discussion that we focus on channels through which trade affects environmental outcomes that are not tied to changes in income. Since $\frac{\partial(\partial e/\partial z)}{\partial u} = \frac{\partial(e_u \psi_z)}{\partial u} = e_{uu}\psi_z$, $e_{uu} = 0 \Rightarrow$ the demand for cleaner environment (pollution/abatement) does not change with income. Assumption 4B simplifies our analysis, and under the assumption that differentiated goods are the drivers of pollution, removes an indirect channel through which income effects would affect pollution. Hence, our results are *not* driven by income effects which lead to higher demand for environmental quality, resulting in stricter environmental policies. The changes in policies in our setup are driven purely by strategic considerations.

We are going to focus on the *symmetric equilibrium*; this seems natural given the empirical observation that a significant proportion of intra-industry trade is between similar countries.[16]

Our assumptions imply that preferences are of the following form:

$$U(c_x, c_{x^*}, c_y, z, z^*) = c_y + \Theta(c_x, c_{x^*}) - \psi(z, z^*) \text{ and } U^*(c^*_x, c^*_{x^*}, c^*_y, z^*, z) = c^*_y + \Theta^*(c^*_x, c^*_{x^*}) - \psi^*(z^*, z), \tag{2}$$

where $\Theta(.)$ and $\Theta^*(.)$ are strictly concave functions, while $\psi(.)$ and $\psi^*(.)$ are strictly convex functions of their respective arguments. Furthermore, following the standard practice for differentiated goods models, we will assume that $\Theta(.)$ and $\Theta^*(.)$ are CES functions of their respective arguments. However, to allow the elasticity of demand for the CES aggregate to take on different values, we assume:

$$\begin{aligned}
\Theta(c_x, c_{x^*}) &= \frac{A}{\alpha}[\theta(c_x, c_{x^*})]^\alpha, \text{ where } \theta(c_x, c_{x^*}) = [(c_x)^\rho + (c_{x^*})^\rho)]^{\frac{1}{\rho}}, A > 0, \ \alpha < 1, \text{ and } \rho \in (0,1), \\
\Theta^*(c^*_x, c^*_{x^*}) &= \frac{A}{\alpha}[\theta^*(c^*_x, c^*_{x^*})]^\alpha, \text{ where } \theta^*(c^*_x, c^*_{x^*}) = [(c^*_x)^\rho + (c^*_{x^*})^\rho)]^{\frac{1}{\rho}}, A > 0, \ \alpha < 1, \text{ and } \rho \in (0,1).
\end{aligned}$$

Given the basic specification of preferences in eq. (2), the elasticity of substitution between the different varieties of the differentiated good is $\sigma \equiv \frac{1}{1-\rho}$, whereas α determines the elasticity of demand for the CES aggregate. Thus, as the price of the CES aggregate decreases, total spending on the differentiated goods will increase (decrease) as α is greater than (less than) zero.[17] To economize on space, we present the analysis leading to Lemma 1 and Assumption 5 (and in most of the paper) for the home country only; the foreign country's analysis is similar.

Given expenditure ($\tilde{e}$) on the differentiated variety of goods, optimization yields the following

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[16] Countries are said to be symmetric if they have the same preferences and technology. Furthermore, symmetry implies that $\psi(z, z^*) = \psi^*(\tilde{z}^*, \tilde{z})$, $\forall z, z^*$ s.t. $\tilde{z}^* = z$ and $\tilde{z} = z^*$. However, despite being symmetric, recall that the home and foreign countries produce different varieties, X and X^*, respectively, of the differentiated good along with the homogeneous numeraire good, Y.

[17] In the limiting case, as $\alpha \to 0$, the function becomes $\Theta(c_x, c_{x^*}) = A\ln(\theta(c_x, c_{x^*}))$, with a unitary price elasticity of demand with respect to the CES aggregate price index. For this case, aggregate spending on the differentiated goods – and hence total demand for the differentiated goods – will be unaffected by changes in the price aggregator due to opening the economy up to trade.

demand and indirect utility functions for this class of goods:

$$c_x^\star = \frac{\tilde{e}}{(p)^\sigma (\mathrm{P})^{1-\sigma}},\ c_{x*}^\star = \frac{\tilde{e}}{(p^*)^\sigma (\mathrm{P})^{1-\sigma}},\ \theta(c_x^\star, c_{x^*}^\star) = \frac{\tilde{e}}{\mathrm{P}},$$

where $c_x^\star$ and $c_{x*}^\star$denote the optimal consumption levels of X and X^*, respectively, while $\mathrm{P} = [(p)^{1-\sigma} + (p^*)^{1-\sigma}]^{\frac{1}{1-\sigma}}$ is the price index for the differentiated (tradable) good. Under symmetry, the above can be written as:

$$c_x^\star = \frac{\tilde{e}}{np},\ c_{x*}^\star = \frac{\tilde{e}}{np^*},\ \theta(c_x^\star, c_{x^*}^\star) = \frac{\tilde{e}}{\mathrm{P}},\ \text{where } \mathrm{P} \equiv n^{\frac{1}{1-\sigma}} p,$$

and $n = 2$ is the number of varieties of the differentiated good. Hence, given $\tilde{e}$, total demand (across all countries) for any variety of the differentiated good is unchanged due to the movement from autarky to free trade; however, consumer utility increases. In essence, *ceteris paribus*, **trade lowers the effective price of the differentiated (tradable) good**. The consumers' optimization problem can then be written as:

$$\max_{\tilde{e}}\ U\left(\frac{\tilde{e}}{\mathrm{P}}, c_y, z, z^*\right) \text{ such that } \tilde{e} + c_y = I,$$

where I is the income level. It is straightforward to see that:

Lemma 1. *Given policies and the world prices of goods, opening up to trade increases (decreases) the spending on, and the demand for, the differentiated/tradable good, and hence pollution, if the price elasticity of demand for the tradable aggregate is greater (less) than one.*

This follows since the price index of the differentiated (tradable) good falls as countries move from autarky to trade.

If the production of the differentiated good (which is relatively more pollution-intensive) increases, so does pollution. Lemma 1 implies that, *given* environmental policies, trade increases (decreases) pollution if the price elasticity of demand between the tradable aggregate and the homogeneous numeraire good is greater (lower) than one.[18] For the rest of the paper, to focus on the role of policy instruments in strategic settings, we assume:

Assumption 5. *The aggregate price elasticity of demand for the differentiated (tradable) good is one.*

This implies that, *given* environmental policies, opening up to trade has *no* effect on aggregate pollution.[19] Hence, our results are purely driven by strategic policy setting considerations.

Timing and Equilibrium. Let ν and ν^* denote the policy variables of the home and foreign governments, respectively, which will be either pollution taxes or quotas. Under profit maximization, home production of the differentiated and numeraire goods depend on the domestic relative price of the differentiated good and the domestic policy variable, (p, ν), while foreign

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[18] Of course, if the differentiated good is relatively less pollution-intensive than the numeraire good, then – *given* environmental policies – opening up to trade will increase (decrease) pollution when the relevant price elasticity is less (greater) than one.

[19] Note that an elasticity of less (greater) than one would strengthen (weaken) our results, although the qualitative results are likely to be the same as presented here.

production decisions depend on (p^*, ν^*). Home consumption of the tradable goods depends on (p, p^*), and foreign consumption of tradables also depends on (p, p^*).[20]

Actions are taken in the following sequence:

1. Governments simultaneously choose their policy variables, given their beliefs about the other government's policy and the behavior of private agents, and the resulting relationship between these policies and market clearing prices, $p^e(\nu, \nu^*)$ and $p^{*e}(\nu, \nu^*)$.
2. Given the observed policy variables, producers and consumers simultaneously make their production and consumption decisions based on their beliefs about prices.
3. Trade occurs and markets clear.

Given this timing, a Nash equilibrium under trade is a set of policy rules, (Γ^e, Γ^{*e}), and market clearing prices, (p^e, p^{*e}), such that each government chooses its policy variable to maximize the utility of its representative agent, firms choose their production decisions to maximize profits, consumers choose their consumption decisions to maximize utility, all markets clear, and all agents beliefs are correct.[21]

3 Strategic Environmental Policy

We now consider each country's non-cooperative environmental policy choice when policies are set simultaneously.

3.1 Pollution Taxes

When countries use pollution taxes to regulate pollution, the equilibrium is described by the resource constraints for the two countries and market clearing conditions for the non-numeraire goods:

$$e(p, p^*, u + \psi(z, z^*)) = R(p, t) + tz, \tag{3}$$

$$e^*(p, p^*, u^* + \psi^*(z^*, z)) = R^*(p^*, t^*) + t^* z^*, \tag{4}$$

$$e_p(.) + e^*_p(.) = R_p(.), \quad e_{p^*}(.) + e^*_{p^*}(.) = R^*_{p^*}(.), \quad z = -R_t(.), \quad z^* = -R^*_{t^*}(.). \tag{5}$$

We have assumed that all tax revenues are redistributed lump-sum to consumers. Eqs. (3) and (4) stipulate that total expenditure has to equal the sum of total revenue from the sale of goods and tax revenues in the home and foreign countries, respectively. Eq. (5) implies that total demand for each variety of the differentiated good equals supply of the good, while standard envelope properties of the GNP function imply $z = -R_t$ and $z^* = -R^*_{t^*}$.

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[20] Demand for the numeraire good, of course, is obtained from the budget constraint. By Walras Law, equilibrium in the markets for different varieties of the differentiated good implies equilibrium in the market for the numeraire good.

[21] The notion of an equilibrium without trade is similar, but less complicated because there is no strategic game involved.

Differentiating eq. (3) with respect to t, gives us the effect of a change in the home country's tax rate on its welfare via different channels:[22]

$$e_u \frac{du}{dt} = (R_p - e_p)\frac{dp}{dt} - e_{p^*}\frac{dp^*}{dt} + (t - e_u \psi_z)\frac{dz}{dt} - e_u \psi_{z^*}\frac{dz^*}{dt}. \tag{6}$$

Given that the home country exports X, i.e., $(R_p - e_p) > 0$, the first term, the terms of trade effect for X, depends on the relative pollution intensity of X, which determines the change in the price of X following a change in the pollution tax. The second term is the terms of trade effect for X^*; since X and X^* are substitutes and the home country is an importer of X^*, $e_{p^*} > 0$, this effect depends on the change in the price of the foreign variety of the differentiated good, p^*, due to a change in t. The third term is the effect of a change in t on welfare via a change in domestic emissions. The last term is the leakage effect, which works through a change in the price of X^* (hence, its production and foreign emissions) in response to a change in t.

The home country's best response function as a function of the foreign country's tax can be derived by setting $\frac{du}{dt} = 0$ in eq. (6):

$$J(t, t^*) \equiv \frac{du}{dt} = 0. \tag{7}$$

Similarly, the best response function of the foreign country is given by setting $\frac{du^*}{dt^*} = 0$ in:

$$\begin{aligned} e^*_{u^*}\frac{du^*}{dt^*} &= (R^*_{p^*} - e^*_{p^*})\frac{dp^*}{dt^*} - e^*_p\frac{dp}{dt^*} + (t^* - e^*_{u^*}\psi^*_{z^*})\frac{dz^*}{dt^*} - e^*_{u^*}\psi^*_z\frac{dz}{dt^*}, && (8) \\ \text{i.e.,} \quad J^*(t, t^*) &\equiv \frac{du^*}{dt^*} = 0. && (9) \end{aligned}$$

We assume that the second-order conditions for welfare maximization are satisfied: $\frac{\partial J}{\partial t} < 0$ and $\frac{\partial J^*}{\partial t^*} < 0$. In the symmetric equilibrium, uniqueness is guaranteed if $J(t, t^*)$, evaluated at $t = t^*$, is monotonically decreasing in t. Hence, $\left(\frac{\partial J(t,t^*)}{\partial t} + \frac{\partial J(t,t^*)}{\partial t^*}\right)\Big|_{t=t^*} < 0$ ensures a unique symmetric equilibrium and we assume this to hold.

Pareto Efficient Taxes. The Pareto efficient pollution taxes are obtained by solving a social planner's problem that maximizes one country's welfare subject to meeting a given utility target for the other country:

$$t^e = e_u \psi_z + e^*_{u^*}\psi^*_z \quad \text{and} \quad t^{e*} = e^*_{u^*}\psi^*_{z^*} + e_u \psi_{z^*}, \tag{10}$$

The efficient pollution tax in each country equals the sum of marginal damages in the two countries. Hence, efficiency requires that countries internalize both the domestic and transboundary effects of their emissions. Note that, since the income elasticity of demand for pollution

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[22] Note that the following analysis rests on the assumption that the income effect on the demand for the differentiated good is zero (Assumption 4B). Apart from ensuring that the results are not driven by income effects, this simplifies the algebra by making the system of equations to be solved block-recursive. Further, if Assumptions 4B and 5 do not hold, then the movement from autarky to trade will change production of the tradables, and hence will change emissions, given the level of the policy variables.

abatement is zero, the Pareto efficient taxes are independent of the utility distribution across countries.

Autarky. Eqs. (7) and (9) can be solved for the optimal autarky pollution taxes when countries set policies simultaneously. In autarky, domestic production equals domestic consumption, i.e., $R_p(.) = e_p(.)$ and $e_{p^*}(.) = 0$, and foreign pollution is independent of domestic policy,[23] i.e., $\frac{dz^*}{dt} = 0$; hence, eq. (6) implies $e_u \frac{du}{dt} = (t - e_u \psi_z)\frac{dz}{dt}$. Since $\frac{dz}{dt} < 0$ and $e_u > 0$, it follows that the optimal autarky pollution tax for the home country is:

$$t^a = e_u \psi_z. \tag{11}$$

Similarly, the optimal autarky tax in the foreign country is:

$$t^{a*} = e^*_{u^*} \psi^*_{z^*}.$$

Countries set emission taxes equal to the domestic marginal damage from own emissions, i.e., the autarky taxes equal the Pigouvian taxes. Comparing the efficient and autarky taxes, eqs. (10) and (11), it is clear that the autarky solution, although optimal from each country's perspective, is inefficient from the global perspective as governments do not internalize the transboundary effects of their emissions. Note that, if there is no transboundary pollution, the autarky taxes would be Pareto efficient. Next, we turn to the situation in which there is trade and countries set environmental policies non-cooperatively.

Intra-Industry Trade and Pollution Taxes. When there is intra-industry trade, emissions in any country are affected by the environmental policy in the other country. The mechanism works through changes in the (world) prices of different varieties of the differentiated good in response to a change in the pollution policy in any country.

The following lemma (proved in the Appendix) establishes the effect of a change in the pollution tax in either country on the prices of the home and foreign varieties of the differentiated good:

Lemma 2. *An increase (a reduction) in the pollution tax in either country causes the prices of both the home and foreign varieties of the differentiated good to increase (reduce). Specifically,*

$$\frac{dp}{dt} = \frac{[A^* - R^*_{p^*p^*}]R_{pt}}{D} > 0, \quad \frac{dp^*}{dt} = -\frac{BR_{pt}}{D} > 0, \tag{12}$$

$$\text{and} \quad \frac{dp}{dt^*} = -\frac{BR^*_{p^*t^*}}{D} > 0, \quad \frac{dp^*}{dt^*} = \frac{[A - R_{pp}]R^*_{p^*t^*}}{D} > 0,$$

where $A \equiv e_{pp} + e^*_{pp} < 0$, $A^* \equiv e_{p^*p^*} + e^*_{p^*p^*} < 0$, $B \equiv e_{pp^*} + e^*_{pp^*} > 0$ *and* $D = (A - R_{pp})(A^* - R^*_{p^*p^*}) - B^2 > 0$.

As the home pollution tax increases, the cost of production and hence, the price of the home variety of the differentiated good, which is pollution-intensive, also increases; thus, $\frac{dp}{dt} > 0$.

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[23] This is because the countries set policies simultaneously. If countries set policies sequentially, even under autarky, the follower's pollution depends on the leader's policy. See, for instance, Sikdar and Lapan (2012) for details on the possibility of leakage under autarky.

Further, as the price of X increases, i.e., as $p \uparrow$ due to an increase in t, consumers substitute away from X in favor of the foreign variety of the differentiated good (X^*). This increased demand for X^* in response to an increase in t leads to a higher (world) price of the foreign variety of the differentiated good; hence, $\frac{dp^*}{dt} > 0$. Similar mechanisms lead to changes in p and p^* as t^* changes.

Envelope properties of the GNP functions imply $z = -R_t \Rightarrow \frac{dz}{dt} = -R_{tt} - R_{pt}\frac{dp}{dt}$, and $z^* = -R^*_{t^*} \Rightarrow \frac{dz^*}{dt} = \frac{dz^*}{dp^*}\frac{dp^*}{dt} = -R^*_{p^*t^*}\frac{dp^*}{dt}$. Hence, the home country's best response function, eq. (7), gives us (using Lemma 2, eq. (12), and since $e_u > 0$):

$$t = \overbrace{e_u\psi_z}^{>0} - \underbrace{\frac{\overbrace{M_x}^{<0}\,\overbrace{[A^* - R^*_{p^*p^*}]}^{<0}\,\overbrace{R_{pt}}^{<0}}{\underbrace{\Delta}_{>0}}}_{\text{terms of trade effect for } X} + \underbrace{\frac{\overbrace{M_{x^*}}^{>0}\,\overbrace{R_{pt}}^{<0}\,\overbrace{B}^{>0}}{\underbrace{\Delta}_{>0}}}_{\text{terms of trade effect for } X^*} - \underbrace{\frac{\overbrace{e_u\psi_{z^*}}^{>0}\,\overbrace{R^*_{p^*t^*}R_{pt}}^{>0}\,\overbrace{B}^{>0}}{\underbrace{\Delta}_{>0}}}_{\text{leakage effect}}, \qquad (13)$$

where $M_x = e_p - R_p < 0$ and $M_{x^*} = e_{p^*} > 0$ are the home country's import of X and X^*, respectively. We define $\Delta \equiv DR_{tt} + R^2_{pt}(e^*_{p^*p^*} - R^*_{p^*p^*} + e_{p^*p^*})$, which simplifies to $\Delta = (R_{tt}R_{pp} - R^2_{pt})R^*_{p^*p^*} + (\mu + \mu^* + \gamma + \gamma^*)R_{tt} - AR^*_{p^*p^*}R_{tt} + (-A^*)(R_{tt}R_{pp} - R^2_{pt}) > 0$, where $\mu \equiv e_{pp}e_{p^*p^*} - (e_{pp^*})^2 \geq 0$, $\mu^* \equiv e^*_{pp}e^*_{p^*p^*} - (e^*_{pp^*})^2 \geq 0$, $\gamma \equiv e_{pp}e^*_{p^*p^*} - e_{pp^*}e^*_{pp^*} \geq 0$ and $\gamma^* \equiv e_{p^*p^*}e^*_{pp} - e_{pp^*}e^*_{pp^*} \geq 0$. That Δ is positive follows from the convexity of the GNP functions and the concavity of the expenditure functions, along with our assumption on the own and cross price effects (Assumption 3). The first term in eq. (13), $e_u\psi_z$, is the *marginal damage from own emissions.* In the absence of terms of trade and leakage effects, the optimal tax equals this marginal damage (for instance, under autarky, eq. (11)). The two *terms of trade effects* imply that a large country will tax (subsidize) domestic production in the export (import-competing) sector to improve its terms of trade if commercial policies are not available; here the implicit subsidy to the import-competing sector is in the form of lower pollution taxes. An increase in t reduces the home country's production of X, resulting in an increase in p. Since X and X^* are substitutes in consumption, demand for X^* increases and, hence, $p^* \uparrow$. This, in turn, increases foreign production of X^*, and hence, foreign emissions. The increased inflow of transboundary pollution from the foreign to the home country reduces the latter's welfare; this *leakage effect* reduces the home country's marginal benefit from regulating own emissions; hence, it lowers the pollution tax.

It is worth pointing out that, without our earlier assumptions, even at the same levels of the policy instruments, the term $e_u\psi_z$ can be different under trade than in autarky. That is, in moving from autarky to trade, if the relative price of tradables changes then, even at the same value of the policy variable, output of tradables, and hence pollution, changes; thus ψ_z changes. Hence, even if we ignore the terms of trade and leakage effects, the first term, $e_u\psi_z$, evaluated at the same level of the policy variables can be either higher or lower under trade relative to autarky. Our Assumptions 4 and 5 guarantee that, when evaluated at the same value of the policy variables, this term is unchanged. This can be seen from eq. (6); suppose we evaluate, under trade, the following expression at the level of the autarky policy variables:

$$e_u \frac{\partial u}{\partial t}\bigg|_{t^a, t^{a*}} = (t^a - e_u \psi_z)\frac{dz}{dt} + (R_p - e_p)\frac{dp}{dt} - e_{p^*}\frac{dp^*}{dt} - e_u \psi_{z^*}\frac{dz^*}{dt}.$$

In our analysis, we focus on the last three terms terms, under the assumption the first term is zero, and use that to compare the autarky and trade equilibrium. However, since the movement from autarky to trade, even in the case of symmetric countries, could change the production mix and pollution levels – given the policy variables – we cannot always conclude, without our assumptions, that the first term is zero (i.e., if production changes, emissions change and thus ψ_z changes).

Now, going back to our analysis, eq. (13) simplifies to:

$$t = e_u \psi_z + \underbrace{\left\{ \frac{R_{pt}\left[M_x^*(A^* - R^*_{p^*p^*}) + M_{x^*}B\right]}{\Delta} \right\}}_{\text{net terms of trade effect, } > 0} - \underbrace{\left\{ \frac{e_u \psi_{z^*} R^*_{p^*t^*} R_{pt} B}{\Delta} \right\}}_{\text{leakage effect, } > 0}, \tag{14}$$

where $M_x^* = e_p^* > 0$ is the foreign country's import of X and we have used the equilibrium condition $M_x + M_x^* = 0$. The last term, the leakage effect, is positive, which *lowers* the pollution tax. Given that own price effects dominate cross price effects (Assumption 3), $|A^*| \geq B$; under symmetry, $M_x^* = M_{x^*} > 0$. Hence, the term $[M_x^*(A^* - R^*_{p^*p^*}) + M_{x^*}B]$ can be written as $M_x^*(A^* + B - R^*_{p^*p^*})$ and is negative. Since $R_{pt} < 0$, the net terms of trade effect (the combined effect of the terms of trade effects for X and X^*) is strictly positive and *increases* the pollution tax. Thus, we have:

Proposition 1. *Suppose pollution taxes are the strategic policy variables. Then,*

1. *the leakage effect lowers the pollution tax,*
2. *the terms of trade effect due to the exportable variety of the differentiated good increases the pollution tax,*
3. *the terms of trade effect due to the importable variety of the differentiated good lowers the pollution tax, and*
4. *the net terms of trade effect increases the pollution tax.*

An increase in the home country's pollution tax increases the price of X (its export good) and hence, home welfare. The accompanying increase in the price of the substitute good (X^*), the home country's importable good, results in a loss to the home country. Since the own price effects are stronger than the cross price effects, the terms of trade effect for the exportable good (X) dominates that for the importable good (X^*). Hence, the benefit of higher taxes dominates the loss due to increased taxes, and the net terms of trade effect increases the pollution tax. Since the overall terms of trade effect works in the opposite direction from the leakage effect, the final outcome depends on which effect dominates:

Corollary 1. *If countries use pollution taxes to regulate pollution, trade leads to higher (lower) taxes and lower (higher) pollution if the net terms of trade effect dominates (is dominated by) the leakage effect.*

From eq. (14), we see that the net terms of trade effect dominates the leakage effect if (since $\Delta > 0$ and $R_{pt} < 0$):

$$\begin{array}{lrcll} & M_x^*(A^* - R^*_{p^*p^*}) + M_{x^*}B & < & e_u\psi_{z^*}R^*_{p^*t^*}B, & \\ \text{i.e.,} & M_x^*(A^* - R^*_{p^*p^*} + B) & < & e_u\psi_{z^*}R^*_{p^*t^*}B, & \text{(since, under symmetry, } M_x^* = M_{x^*} > 0\text{)}, \\ \text{i.e.,} & \dfrac{M_x^*}{e_u\psi_{z^*}} & > & \dfrac{R^*_{p^*t^*}B}{A^* - R^*_{p^*p^*} + B}, & \text{(since } A^* - R^*_{p^*p^*} + B < 0\text{)}. \end{array}$$

Hence, on the one hand, the higher the volume of trade (larger M_x^*), the larger is the net terms of trade effect, *ceteris paribus*; then, it is more likely that trade leads to an increase in the pollution tax. On the other hand, the greater the marginal damage from transboundary pollution, $\psi_{z^*}(.)$, the stronger is the leakage effect; then, it is more likely that the pollution tax is lower under trade. Hence, intra-industry trade can have a *positive* impact by increasing environmental taxes due to the dominance of the net terms of trade effect over the leakage effect. In such situations, the pollution taxes in *both* countries will be higher than the respective marginal damages from own emissions, i.e., *higher* than the Pigouvian and autarky taxes, while pollution will be *lower* under trade.

Suppose pollution is *purely* local, i.e., there is *no* transboundary pollution. Since $\psi_{z^*}(.) = 0$ for the home country, there is no leakage effect and the last term in eq. (14) disappears. Hence,

$$t = e_u\psi_z + \underbrace{\left\{\frac{R_{pt}\left[M_x^*(A^* - R^*_{p^*p^*}) + M_{x^*}B\right]}{\Delta}\right\}}_{>0},$$

and we have:

Corollary 2. *Suppose pollution is purely local, i.e., there is no transboundary pollution. If the policy instrument is a tax on pollution, the net terms of trade effect increases the pollution tax and pollution is lower under trade relative to autarky.*

Hence, with purely local pollution, the taxes in both countries are higher than the respective marginal damages from own emissions, i.e., *higher* than the Pigouvian and autarky taxes, while pollution *falls* as countries open up to trade.

If the two varieties of the differentiated good, X and X^*, are *perfect substitutes* in consumption, then we are in a situation of inter-industry trade and the net terms of trade effect depends only on net exports. Given symmetry and simultaneous moves, net exports are zero around the autarky equilibrium and around the autarky solution, the net terms of trade effect is zero. Hence, the leakage effect lowers the pollution tax under trade. Then, trade liberalization leads to *lower* pollution taxes purely due to the leakage effect. Lapan and Sikdar (2011) find a similar result in their analysis of inter-industry trade. In contrast, we show that, with intra-industry trade, pollution policies can be *stricter* compared to autarky.

3.2 Pollution Quotas

Now, suppose governments use (domestically tradable) pollution quotas to regulate pollution, i.e., governments in both countries set upper bounds on own emissions. Hence, $z \leq L$ and $z^* \leq L^*$, where L and L^* are the emission limits in the home and foreign countries, respectively. Governments simultaneously and non-cooperatively choose their quota levels to maximize own welfare. Denote the value of a quota in the home (foreign) country as τ (τ^*). When the quotas are auctioned off or traded domestically,[24] then τ and τ^* are the market prices of quotas. Equilibrium is now described by:

$$e(p, p^*, u + \psi(z, z^*)) = R(p, \tau) + \tau L, \tag{15}$$

$$e^*(p, p^*, u^* + \psi^*(z^*, z)) = R^*(p^*, \tau^*) + \tau^* L^*, \tag{16}$$

$$e_p(.) + e^*_p(.) = R_p(.), \quad e_{p^*}(.) + e^*_{p^*}(.) = R^*_{p^*}(.), \quad z = -R_\tau(.) \leq L, \quad z^* = -R^*_{\tau^*}(.) \leq L^*, \tag{17}$$

where eqs. (15), (16) and (17) are the income constraints for the home and foreign countries, and the market clearing conditions, respectively. The quota revenues (rents) are rebated lump-sum to consumers. If the quotas bind, $\tau > 0$, $\tau^* > 0$, and eq. (17) holds with equality.

Differentiating eq. (15) with respect to L gives us the impact of issuing an additional quota on domestic welfare:

$$e_u \frac{du}{dL} = (R_p - e_p)\frac{dp}{dL} - e_{p^*}\frac{dp^*}{dL} + (\tau - e_u\psi_z)\frac{dz}{dL} - e_u\psi_{z^*}\frac{dz^*}{dL}. \tag{18}$$

The first and second terms are the terms of trade effects due to X and X^*, respectively; these depend on the pattern of trade and the relative pollution intensity of the differentiated good. The third term is the domestic pollution effect, while the last term is the leakage effect. If foreign emissions change following a change in the home quota level, i.e., if leakage occurs, it affects the home country's welfare due to a change in the incidence of transboundary pollution.

The home country's best response function in terms of the foreign country's quota is derived by setting $\frac{du}{dt} = 0$ in eq. (18):

$$J(L, L^*) \equiv \frac{du}{dL} = 0. \tag{19}$$

The foreign country's best response function is given by setting $\frac{du^*}{dL^*} = 0$ in:

$$\begin{aligned} e^*_{u^*}\frac{du^*}{dL^*} &= (R^*_{p^*} - e^*_{p^*})\frac{dp^*}{dL^*} - e^*_p\frac{dp}{dL^*} + (\tau^* - e^*_{u^*}\psi^*_{z^*})\frac{dz^*}{dL^*} - e^*_{u^*}\psi^*_z\frac{dz}{dL^*}, \\ \text{i.e.,} \quad J^*(L, L^*) &\equiv \frac{du^*}{dL^*} = 0. \end{aligned}$$

As before, we assume that the second-order conditions for welfare maximization are satisfied: $\frac{\partial J}{\partial L} < 0$ and $\frac{\partial J^*}{\partial L^*} < 0$. Also, uniqueness of the symmetric equilibrium requires $J(L, L^*)$, evaluated at $L = L^*$, is monotonically decreasing in L. Hence, $\left(\frac{\partial J(L,L^*)}{\partial L} + \frac{\partial J(L,L^*)}{\partial L^*}\right)\Big|_{L=L^*} < 0$ ensures a

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[24] For analysis of international trade in pollution quotas along with trade in goods, see Copeland and Taylor (1995), Lapan and Sikdar (2011), and Antoniou, Hatzipanayotou and Koundouri (2012).

unique symmetric equilibrium.

Autarky. In autarky, domestic consumption equals domestic production, i.e., $e_p(.) = R_p(.)$ and $e_{p^*}(.) = 0$, the quota binds, i.e., $z = L$, and foreign pollution is independent of domestic policy, i.e., $\frac{dz^*}{dL} = 0$; hence, from eq. (18), we have $e_u \frac{du}{dL} = \tau - e_u \psi_z$. Setting $\frac{du}{dL} = 0$, the pollution tax equivalent of the optimal autarky pollution quota in the home country is (since $e_u > 0$):

$$\tau^a = e_u \psi_z. \tag{20}$$

Similarly, the foreign pollution tax equivalent of the optimal autarky pollution quota is:

$$\tau^{a*} = e^*_{u^*} \psi^*_{z^*}.$$

The prices of quotas in both countries equal the respective Pigouvian taxes (the respective marginal damages from own emissions). Thus, comparing eqs. (11) and (20), we have:

Proposition 2. *Under autarky, when countries set environmental policies non-cooperatively, pollution taxes and quotas are equivalent. The optimal pollution tax (equivalent) equals the domestic marginal damage from own pollution.*

Hence, in autarky, the choice of policy instrument does *not* have any differential impact on environmental outcomes. The price of pollution quotas is the same as the optimal tax on emissions in autarky.

Intra-Industry Trade and Pollution Quotas. Now, we consider the situation in which there is trade and countries set pollution quota levels strategically. The following lemma (proved in the Appendix) gives us the effect of changes in quota levels on the prices of the different varieties of the differentiated good:

Lemma 3. *An increase (a reduction) in the quota level in either country leads to a decline (an increase) in the prices of both the home and foreign varieties of the differentiated good. Specifically,*

$$\frac{dp}{dL} = -\frac{(A^* - G^*)R_{p\tau}}{\hat{D}R_{\tau\tau}} < 0, \quad \frac{dp^*}{dL} = \frac{BR_{p\tau}}{\hat{D}R_{\tau\tau}} < 0, \tag{21}$$

$$\text{and} \quad \frac{dp}{dL^*} = \frac{BR^*_{p^*\tau^*}}{\hat{D}R^*_{\tau^*\tau^*}} < 0, \quad \frac{dp^*}{dL^*} = -\frac{(A - G)R^*_{p^*\tau^*}}{\hat{D}R^*_{\tau^*\tau^*}} < 0,$$

where $G \equiv \frac{R_{pp}R_{\tau\tau} - R^2_{p\tau}}{R_{\tau\tau}} > 0$*,* $G^* \equiv \frac{R^*_{p^*p^*}R^*_{\tau^*\tau^*} - R^{*2}_{p^*\tau^*}}{R^*_{\tau^*\tau^*}} > 0$ *and* $\hat{D} = (AA^* - B^2) + (-AG^*) + (-A^*G) + (GG^*) > 0$*;* $A \equiv e_{pp} + e^*_{pp} < 0$*,* $A^* \equiv e_{p^*p^*} + e^*_{p^*p^*} < 0$*, and* $B \equiv e_{pp^*} + e^*_{pp^*} > 0$ *are as defined earlier.*

To see how a change in the quota level affects prices, suppose the home country increases its quota limit. This increases production of the home pollution-intensive good, i.e., the home variety of the differentiated good, X, thereby reducing its world price; hence, $\frac{dp}{dL} < 0$. Due to the lower world price of X in response to higher home pollution quotas, consumers substitute away from the foreign variety, X^*, in favor of the home variety, X, of the differentiated good which lowers the price of X^*; hence, $\frac{dp^*}{dL} < 0$. Similar mechanisms imply $\frac{dp^*}{dL^*} < 0$ and $\frac{dp}{dL^*} < 0$.

Lemma 4. *When pollution quotas are the strategic policy variables, there is no leakage under intra-industry trade. That is,*

$$\frac{dz^*}{dL} = 0 \quad \text{and} \quad \frac{dz}{dL^*} = 0.$$

The proof appears in the Appendix. To see why there is no leakage when countries use quotas to regulate pollution, suppose the home and foreign countries set their quota levels at $L = \tilde{L}$ and $L^* = \tilde{L}^*$, respectively. If the home country lowers its quota limit, i.e., if $L < \tilde{L}$, there is an increase in the world price of the home country's pollution-intensive good, i.e., $p \uparrow$. In response to this higher world price of X, demand for the substitute good (X^*) increases, leading to an increase in the world price of the foreign variety of the differentiated good, i.e., $p^* \uparrow$. Hence, the foreign country increases its production of the pollution-intensive good, X^*, but since the foreign quota binds, foreign emissions are unchanged.[25] Thus, $\frac{dz^*}{dL} = 0$ in the domain $L < \tilde{L}$. Furthermore, if the home country increases its quota level from $\tilde{L}$, there is a decline in the world price of the home pollution-intensive good (the home variety of the differentiated good), X, i.e., $p \downarrow$. As consumers substitute away from X^* in favor of X, there is a decline in the world price of the foreign variety of the differentiated good (X^*), i.e., $p^* \downarrow$. The market price of foreign pollution quotas declines, but is still positive, $\tau^* > 0$, and the foreign quota still binds (implying that foreign emission is unchanged). Thus, in response to changes in the home quota level, foreign production can change, but since the foreign quota binds, foreign emissions cannot change, i.e., $\frac{dz^*}{dL} = 0$. Similarly, changes in the foreign quota level do not change home emissions, i.e., $\frac{dz}{dL^*} = 0$. Hence, there is no leakage when countries use quotas to regulate pollution.

The home country's best response function, eq. (19), gives us (using Lemma 3, eq. (21), Lemma 4, and since $e_u > 0$):

$$\tau = \overbrace{e_u \psi_z}^{>0} - \underbrace{\frac{\overbrace{M_x}^{<0} \overbrace{(A^* - G^*)}^{<0} \overbrace{R_{p\tau}}^{<0}}{\underbrace{\hat{\Delta}}_{>0}}}_{\text{terms of trade effect for } X} + \underbrace{\frac{\overbrace{M_{x^*}}^{>0} \overbrace{B}^{>0} \overbrace{R_{p\tau}}^{<0}}{\underbrace{\hat{\Delta}}_{>0}}}_{\text{terms of trade effect for } X^*} ,$$

where $\hat{\Delta} = \hat{D} R_{\tau\tau}$ and $e_u \psi_z$ is the marginal damage from own emissions. These terms of trade effects imply that a large country will overregulate (underregulate) the domestic export (import-competing) sector. This implies the following price of quotas, i.e., equivalent tax on pollution, in the home country:

$$\tau = e_u \psi_z + \underbrace{\left\{ \frac{R_{p\tau} \left[M_x^* (A^* - G^*) + M_{x^*} B \right]}{\hat{\Delta}} \right\}}_{>0}, \tag{22}$$

where we have used the equilibrium condition $M_x + M_x^* = 0$. Since $\hat{\Delta} > 0$, $G^* > 0$, $R_{p\tau} < 0$, $|A^*| \geq B$ (by Assumption 3), and under symmetry, $M_x^* = M_{x^*} > 0$, the second term $\{\ldots\}$ in

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[25] Since the foreign quota limit binds, foreign emissions are unchanged while foreign production of the pollution-intensive good, X^*, can increase. This is possible, for instance, due to increased abatement in the foreign country.

eq. (22) is strictly positive. Hence, the net terms of trade effect *increases* the market price of quotas, i.e., *lowers* the level of quotas under intra-industry trade. We summarize these results as follows:

Proposition 3. *If pollution quotas are the strategic policy instruments, then*

1. *there is no leakage,*
2. *the terms of trade effect due to the exportable variety of the differentiated good lowers the quota levels,*
3. *the terms of trade effect due to the importable variety of the differentiated good increases the quota levels,*
4. *the net terms of trade effect lowers the quota levels.*

Hence, the price of quotas, i.e., the equivalent tax on pollution, is higher than the marginal damage from own emissions and than that under autarky. Pollution in both countries are lower under trade than in autarky.

On the one hand, lower quota levels, say, in the home country improve home welfare by increasing the price of the home export good (X). On the other hand, the increased price of X causes consumers to shift from consumption of X to X^* leading to an increase in the price of the home import good (X^*), thereby lowering home welfare. Since the own price effects are stronger than the cross price effects, the former dominates the latter, and the net terms of trade effect makes pollution policy stricter under trade. This, along with the fact that there is no leakage when the strategic variable is a quantitative limit on emissions, implies that trade lowers pollution if countries use pollution quotas to regulate domestic emissions. The equivalent pollution taxes in both countries are always higher than the respective marginal damages from own emissions, i.e., *always higher* than the Pigouvian taxes and than the autarky levels due to the net terms of trade effect.

Now, suppose pollution is *purely* local, i.e., there is *no* transboundary pollution. From eq. (18), it is clear that there is no change in the best response function and an analysis similar to the one above applies. Hence, we have

Corollary 3. *Suppose pollution quotas are the policy instruments. If pollution is purely local, i.e., there is no transboundary pollution, the pollution tax equivalent is higher than the marginal damage from own emissions and than that under autarky. Pollution falls under trade relative to autarky.*

If X and X^* are *perfect substitutes*, we are in a situation of inter-industry trade and the net terms of trade effect depends only on net exports. Under symmetry and simultaneous moves, net exports of each country is zero around the autarky equilibrium and there is no change in the quota level under trade as compared to autarky. Hence, the autarky and the free trade equilibria will be the same. Lapan and Sikdar (2011) find a similar result in the context of inter-industry trade. However, with intra-industry trade, we find that the environmental outcomes are different under trade compared to autarky, and trade can be beneficial for the environment.

4 Concluding Remarks

We analyzed the effect of intra-industry trade on environmental policies in the presence of local and transboundary pollution in a strategic setting. In autarky, each country sets its (equivalent) pollution tax equal to the marginal damage from own emissions, i.e., equal to the Pigouvian tax. When the strategic policy instrument is a pollution tax, the effect of intra-industry trade on environmental policy depends on the relative strengths of the net terms of trade effect (which tends to increase the tax) and the leakage effect (which tends to reduce the tax). If the volume of trade is small or the damage from transboundary pollution spillover is large, then intra-industry trade makes environmental policy *weaker*; whereas if the volume of trade is large or the damage from transboundary pollution is low, then intra-industry trade makes environmental policy *stronger*. On the other hand, when the strategic policy variable is pollution quotas, intra-industry trade *always* leads to *stricter* environmental policies. This is because, under quotas, there is no leakage effect and the net terms of trade effect increases the equivalent tax on emissions; hence, the equivalent pollution taxes (prices of quotas) in *both* countries are *always higher* than the respective marginal damages from own emissions, i.e., higher than the Pigouvian and autarky taxes. Then, pollution in both countries fall under trade. Given the possible differential outcomes under taxes and quotas under trade, it might be beneficial for countries to negotiate on the policy instrument that will be used to regulate pollution, if not the exact level of the policy.

We have also shown that the net terms of trade effect *always* tends to make pollution policy stricter in *both* countries when countries use pollution policies strategically under intra-industry trade. This is in contrast to models of inter-industry trade, in which the terms of trade effect tends to make environmental policy stricter in the country which exports the pollution-intensive good and weaker in the country which imports the pollution-intensive good. Intra-industry trade can, thus, have a positive impact on environmental policies by making pollution policies stricter in *both* countries, which tends to increase the (equivalent) taxes above the respective marginal damages from own emissions. This is in line with the empirical findings that trade can be beneficial for the environment even though the mechanism is different from the usual one of income effects used to explain this result.

We have focused on a two-country model of intra-industry trade and transboundary pollution. However, our results would generalize to a situation in which the number of countries is $n > 2$.[26] To begin with, holding policies fixed, consider the effect of trade on production (and pollution): under trade, the consumption of own (other) variety of the differentiated good falls (rises), while exports (imports) of the own (other) variety of the differentiated good increases (decreases). However, holding policies fixed, aggregate production (hence, pollution) is unchanged due to a movement to trade provided the set of assumptions used in this paper continue to hold. The strategic motives to change policies due to terms of trade and leakage effects remain the same as in the two-country model. Thus, with $n > 2$ countries, under trade, emission taxes in *all* countries increase if the terms of trade effect dominates the leakage effect, while the equivalent taxes, when quotas are the strategic variables, *always* increase in *all*

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[26] Of course, Assumptions 1 – 5 would have to be suitably modified (although in essence remaining the same) to account for $n > 2$ symmetric countries and different varieties of the differentiated good.

countries.

Appendix

Proof of Lemma 2. Taking the total differential of eqs. (3) and (5), we have

$$e_u du + (e_u\psi_z - t)dz + e_u\psi_{z^*}dz^* = (R_p - e_p)dp - e_{p^*}dp^*, \quad dz = -R_{tt}dt - R_{pt}dp. \tag{23}$$

Similarly, totally differentiating eqs. (4) and (5), we have

$$e^*_{u^*}du^* + (e^*_{u^*}\psi^*_{z^*} - t^*)dz^* + e^*_{u^*}\psi^*_z dz = (R^*_{p^*} - e^*_{p^*})dp^* - e^*_p dp, \quad dz^* = -R^*_{t^*t^*}dt^* - R^*_{p^*t^*}dp^*. \tag{24}$$

Totally differentiating eq. (5) yields:

$$[(e_{pp} - R_{pp}) + e^*_{pp}]dp + [e_{pp^*} + e^*_{pp^*}]dp^* = R_{pt}dt, \tag{25}$$

$$\text{and} \quad [(e^*_{p^*p^*} - R^*_{p^*p^*}) + e_{p^*p^*}]dp^* + [e_{pp^*} + e^*_{pp^*}]dp = R^*_{p^*t^*}dt^*. \tag{26}$$

Eqs. (23), (24), (25) and (26) can be written in matrix form (after simplification) as:

$$\begin{bmatrix} e_u & 0 & M_x - R_{pt}(e_u\psi_z - t) & M_{x^*} - R^*_{p^*t^*}e_u\psi_{z^*} \\ 0 & e^*_{u^*} & M^*_x - R_{pt}e^*_{u^*}\psi^*_z & M^*_{x^*} - R^*_{p^*t^*}(e^*_{u^*}\psi^*_{z^*} - t^*) \\ 0 & 0 & (e_{pp} - R_{pp}) + e^*_{pp} & e_{pp^*} + e^*_{pp^*} \\ 0 & 0 & e_{pp^*} + e^*_{pp^*} & (e^*_{p^*p^*} - R^*_{p^*p^*}) + e_{p^*p^*} \end{bmatrix} \begin{bmatrix} du \\ du^* \\ dp \\ dp^* \end{bmatrix}$$

$$= \begin{bmatrix} R_{tt}(e_u\psi_z - t)dt + R^*_{t^*t^*}e_u\psi_{z^*}dt^* \\ R_{tt}e^*_{u^*}\psi^*_z dt + R^*_{t^*t^*}(e^*_{u^*}\psi^*_{z^*} - t^*)dt^* \\ R_{pt}dt \\ R^*_{p^*t^*}dt^* \end{bmatrix}, \tag{27}$$

where $M_x = e_p - R_p < 0$ ($M^*_x = e^*_p > 0$) is the home (foreign) import of X and $M_{x^*} = e_{p^*} > 0$ ($M^*_{x^*} = e^*_{p^*} - R^*_{p^*} < 0$) is the home (foreign) import of X^*. In equilibrium, $M_x + M^*_x = 0$ and $M_{x^*} + M^*_{x^*} = 0$. The last two equations in the above system, eq. (27), imply

$$\begin{bmatrix} dp \\ dp^* \end{bmatrix} = \frac{1}{D}\begin{bmatrix} A^* - R^*_{p^*p^*} & -B \\ -B & A - R_{pp} \end{bmatrix}\begin{bmatrix} R_{pt}dt \\ R^*_{p^*t^*}dt^* \end{bmatrix}, \tag{28}$$

where D is the determinant of the first matrix on the RHS of eq. (28) and we define $A \equiv e_{pp} + e^*_{pp} < 0$, $A^* \equiv e_{p^*p^*} + e^*_{p^*p^*} < 0$, $B \equiv e_{pp^*} + e^*_{pp^*} > 0$. Define $\mu \equiv e_{pp}e_{p^*p^*} - (e_{pp^*})^2 \geq 0$, $\mu^* \equiv e^*_{pp}e^*_{p^*p^*} - (e^*_{pp^*})^2 \geq 0$ and $\chi \equiv -AR^*_{p^*p^*} - A^*R_{pp} > 0$. Concavity of the expenditure functions determines the sign of μ and μ^*, while convexity of the GNP functions along with concavity of the expenditure functions guarantee that $\chi > 0$. Further, define $\gamma \equiv e_{pp}e^*_{p^*p^*} - e_{pp^*}e^*_{pp^*} \geq 0$ and $\gamma^* \equiv e_{p^*p^*}e^*_{pp} - e_{pp^*}e^*_{pp^*} \geq 0$. Own price effects being stronger than cross price effects (Assumption 3) imply that γ, $\gamma^* \geq 0$. Thus, the determinant, D, in eq. (28) can be written as:

$$D = (A - R_{pp})(A^* - R^*_{p^*p^*}) - B^2 = (\mu + \mu^* + \gamma + \gamma^*) + \chi + (R_{pp}R^*_{p^*p^*}) > 0.$$

Hence, from eq. (28), we have the effects of changes in pollution taxes on the prices of the differentiated good:

$$\frac{dp}{dt} = \frac{[A^* - R^*_{p^*p^*}]R_{pt}}{D} > 0, \quad \frac{dp^*}{dt} = -\frac{BR_{pt}}{D} > 0,$$

$$\text{and} \quad \frac{dp}{dt^*} = -\frac{BR^*_{p^*t^*}}{D} > 0, \quad \frac{dp^*}{dt^*} = \frac{[A - R_{pp}]R^*_{p^*t^*}}{D} > 0.$$

Q.E.D.

Proof of Lemma 3. Taking the total differential of eq. (15) we have

$$e_u du + e_u \psi_z dz - \tau dL + e_u \psi_{z^*} dz^* = (R_p - e_p)dp - e_{p^*}dp^*; \quad dz = dL. \tag{29}$$

Similarly, totally differentiating eq. (16) we have

$$e^*_{u^*}du^* + e^*_{u^*}\psi^*_{z^*}dz^* - \tau^* dL^* + e^*_{u^*}\psi^*_z dz = (R^*_{p^*} - e^*_{p^*})dp - e^*_p dp; \quad dz^* = dL^*. \tag{30}$$

Eq. (17) implies

$$\left[(e_{pp} - R_{pp}) + e^*_{pp} + \frac{R^2_{p\tau}}{R_{\tau\tau}}\right] dp + [e_{pp^*} + e^*_{pp^*}]dp^* = -\frac{R_{p\tau}}{R_{\tau\tau}}dL, \tag{31}$$

and

$$\left[e_{pp^*} + e^*_{pp^*}\right] dp + \left[(e^*_{p^*p^*} - R^*_{p^*p^*}) + e_{p^*p^*} + \frac{R^{*2}_{p^*\tau^*}}{R^*_{\tau^*\tau^*}}\right] dp^* = -\frac{R^*_{p^*\tau*}}{R^*_{\tau^*\tau^*}}dL^*. \tag{32}$$

Eqs. (29), (30), (31) and (32) can be written in matrix form (after simplification) as:

$$\begin{bmatrix} e_u & 0 & M_x & M_{x^*} \\ 0 & e^*_{u^*} & M^*_x & M^*_{x^*} \\ 0 & 0 & (e_{pp} - R_{pp}) + e^*_{pp} + \frac{R^2_{p\tau}}{R_{\tau\tau}} & e_{pp^*} + e^*_{pp^*} \\ 0 & 0 & e_{pp^*} + e^*_{pp^*} & (e^*_{p^*p^*} - R^*_{p^*p^*}) + e_{p^*p^*} + \frac{R^{*2}_{p^*\tau^*}}{R^*_{\tau^*\tau^*}} \end{bmatrix} \begin{bmatrix} du \\ du^* \\ dp \\ dp^* \end{bmatrix}$$

$$= \begin{bmatrix} (\tau - e_u\psi_z)dL + e_u\psi_{z^*}dL^* \\ -e^*_{u^*}\psi^*_z dL + (\tau^* - e^*_{u^*}\psi^*_{z^*})dL^* \\ -\frac{R_{p\tau}}{R_{\tau\tau}}dL \\ -\frac{R^*_{p^*\tau*}}{R^*_{\tau^*\tau^*}}dL^* \end{bmatrix}. \tag{33}$$

From the last two equations in the above system, eq. (33), we have

$$\begin{bmatrix} dp \\ dp^* \end{bmatrix} = \frac{1}{\hat{D}} \begin{bmatrix} A^* - G^* & -B \\ -B & A - G \end{bmatrix} \begin{bmatrix} -\frac{R_{p\tau}}{R_{\tau\tau}}dL \\ -\frac{R^*_{p^*\tau^*}}{R^*_{\tau^*\tau^*}}dL^* \end{bmatrix}, \tag{34}$$

where we define $G \equiv \frac{R_{pp}R_{\tau\tau} - R^2_{p\tau}}{R_{\tau\tau}} > 0$ and $G^* \equiv \frac{R^*_{p^*p^*}R^*_{\tau^*\tau^*} - R^{*2}_{p^*\tau^*}}{R^*_{\tau^*\tau^*}} > 0$; $A \equiv e_{pp} + e^*_{pp} < 0$, $A^* \equiv e_{p^*p^*} + e^*_{p^*p^*} < 0$, and $B \equiv e_{pp^*} + e^*_{pp^*} > 0$ are as defined earlier. $\hat{D} = (AA^* - B^2) +$

$(-AG^*) + (-A^*G) + (GG^*) > 0$ is the determinant of the first matrix on the RHS of eq. (34). Thus, the price effects of changes in the quota levels are:

$$\frac{dp}{dL} = -\frac{(A^* - G^*)R_{p\tau}}{\hat{D}R_{\tau\tau}} < 0, \quad \frac{dp^*}{dL} = \frac{BR_{p\tau}}{\hat{D}R_{\tau\tau}} < 0,$$

$$\text{and} \quad \frac{dp}{dL^*} = \frac{BR^*_{p^*\tau^*}}{\hat{D}R^*_{\tau^*\tau^*}} < 0, \quad \frac{dp^*}{dL^*} = -\frac{(A - G)R^*_{p^*\tau^*}}{\hat{D}R^*_{\tau^*\tau^*}} < 0.$$

Q.E.D.

Proof of Lemma 4. Since $g_x, g_y < 0 < g_z$ and $g_{x^*}, g_{y^*} < 0 < g_{z^*}$, pollution quotas in both countries always bind, i.e., $z = L$ and $z^* = L^*$ implying $\frac{dz}{dL} = 1$ and $\frac{dz^*}{dL^*} = 1$. Hence, a change in the quota level in one country has no impact on the emissions of the other country, i.e., $\frac{dz^*}{dL} = 0$ and $\frac{dz}{dL^*} = 0$. **Q.E.D.**

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