Teaching and Educational Methods

Coordinating Environmental and Trade Policy to Protect the Environment: A Pedagogical Approach

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Abstract
Establishing appropriate environmental and trade policies is an important issue in today's globalized economy, and yet there is no comprehensive analysis in most environmental economics and international trade undergraduate textbooks of how such policies are interrelated. The purpose of this article is to provide a straightforward framework for teaching students how environmental and trade policies are indeed interconnected, utilizing the standard tools of intermediate microeconomics. Focusing on a single competitive market and (nonstrategic) welfare maximizing government, optimal environmental and trade policies are derived and explored. The framework is used to address several circumstances, including negative production and consumption externalities, small and large countries, and transboundary pollution.

1 Introduction

Significant damage to the environment, both locally and globally, pose a serious threat to the well-being of people around the world, and therefore most of the world's governments are today implementing policies that target local and global pollution. For example, countries confront the issue of rising greenhouse gas (GHG) emissions by implementing national policies, such as the Clean Air Act (CAA) in the United States, as well as pledging commitment to international agreements such as the Kyoto Protocol in 1997 and the Paris Agreement in 2015. When it comes to meeting emission reduction targets, cap-and-trade systems, which set a cap on overall emissions, and pollution taxes, which set a price per ton of (carbon) emissions, are preferred over command-and-control approaches due to their economic efficiency advantages. As of 2019, cap-and-trade systems have been preferred over pollution (carbon) taxes as exemplified by well-known cap-and-trade systems, including the European Union's (EU) Emission Trading System (ETS) and the Acid Rain Program of the U.S. Environmental Protection Agency (Lewis 2011). There are, however, three factors that recommend pollution taxes over cap-and-trade systems: (1) the price volatility of pollution permits, (2) the complexity and increased possibility of fraud with permit allowance trading, and (3) the possibility of under investment in pollution reduction technologies (Michalek 2016; Metcalf 2019).

Efforts in reducing GHG emissions might be suboptimal if policies are implemented without regard to the fact that international trade may adversely impact the environment (OECD 2019; World Trade Organization 2021). This concern is expressed by environmentalists who worry that trade might cause governments to set weaker environmental standards than warranted by the true cost of environmental damage (Esty 1994). Such "environmental dumping" may manifest either through "regulatory chill" or even a race to the bottom in environmental standards as countries compete for global market share and international investments (Esty 2001). In fact, disparate emission regulation, a situation with stringent emission regulation of industrialized nations and weaker emission regulations in the developing world, has been viewed as an impediment to meeting emission standards. Different regulations have indeed led to carbon leakage (Mehling et al. 2019; Böhringer, Schneider, and Asane-Otoo

2021), the relocation of production, and hence emissions from regulating countries to countries with weaker or no environmental regulation. That is, a strengthening of domestic environmental policy may cause a shift of production to countries with weaker standards, which in turn can raise global emissions. According to Böhringer et al. (2021), trade in carbon embodied in goods increased markedly until the 2007–2008 financial crisis due to increased offshoring of emission-intensive production from developed countries to developing countries.

Such concerns have promoted the idea of border adjustment (pollution tariff) policies, along with nations' existing pollution control policies. Recently, the EU proposed implementing a carbon border adjustment mechanism; that is, a carbon tariff on imports (Plumer 2021) by 2026, with a transitional phase from 2023 to 2025 (European Commission 2021). Aligning with the EU's decision, the United States is also evaluating the possibility of border taxes (Friedman 2021) as a form of transboundary pollution taxes. However, border taxes/border adjustments might provoke trade partners whose exporting firms may experience reduced sales and could create challenges to trade and violations of the General Agreements on Tariff and Trade (GATT). According to the World Trade Organization (WTO 1994), border adjustment levies may be permitted by provisions of Articles XX(b) and XX(g) that allow trade restrictions to "protect human, animal or plant life or health" and to ensure "the conservation of exhaustible natural resources." The most common border adjustments are taxes on imports and rebates on exports, both of which attempt to account for variation in pollution (carbon) "pricing" across nations. Although these policies may improve the environment, they are also favored by industries that are seeking a "level playing field" in environmental regulations that may reduce competitiveness. Although border adjustments could facilitate a level playing field, the GATT-approved exceptions only apply to environmental goals, they cannot be used to offset competitive disadvantages for domestic industries (Wiers 2008; Monjon and Quirion 2011). Hence, implementation of border adjustments should emphasize world (carbon) emissions, rather than carbon leakage. Other issues regarding border adjustments include how they relate to the domestic price on pollution, how they are best implemented, and whether border adjustments lead to production decline in GHG intensive sectors in pollution unregulated countries (Monjon and Quirion 2011; Balistreri, Kaffine, and Yonezawa 2019). According to Balistreri et al. (2019), correct environmental adjustments are complex. This is undoubtedly true, and the complexity of these issues cause different groups, including environmentalists, industrialists, and developing nations, to worry about environmental and trade policies adopted by nations. These are important concerns that are often shared by students in our courses. Given these misgivings, economics has an opportunity to explore how trade and environmental policies are interrelated, and whether these concerns are warranted.

Economics argues that any market distortion is most efficiently addressed at its source; that is, environmental market failures should be countered by environmental policy, not trade policy, and external distortions, market failures outside of the nation's borders, should be addressed by trade policy, not local environmental policies. In addition, to address more than one market distortion efficiently a policy maker needs at least as many policy instruments as the number of distortions and, again, the most efficient response is to address each particular distortion at its source (Bhagwati 1971). Thus, a nation facing both a negative production (consumption) externality and an external distortion, should adopt an appropriate environmental policy to deal with environmental problems and optimal trade policy to address external distortions. In this case, there is no real trade environment linkage *unless* there are either a greater number of market distortions than available policy instruments or constraints imposed on a nation; for example, a nation might deviate from an optimal environmental policy if it is constrained by either a multilateral (WTO) or regional international trade agreement (Krutilla 1991). In particular, faced with a domestic externality and trade distortions, as well as transboundary environmental externalities (a third market distortion), an absence of an international environmental institution suggests a need to coordinate trade and environmental policies.

As most current economic research is not easily accessible to undergraduate students, we present a framework that helps students understand how environmental and trade policies are interrelated in achieving environmental protection goals. We use a conventional partial equilibrium economic model, a model that assumes that governments have perfect information and seek to maximize national welfare, while considering one particular market in isolation. Partial equilibrium models are both useful and tractable in a trade and environment context as they clearly address the consequences of terms-of-trade effects, as well as allow us to easily discuss normative properties of policy actions (Krutilla 1991; Anderson 1992; Krutilla 2002). In international trade theory, the terms-of-trade is a relative price and defined as the price of exports divided by the price of imports. Thus, a positive (negative) terms-of-trade effect is when the price of exports increases (decreases) relative to price of imports; that is, a nation is able to import more (fewer) goods for the same volume of exports. The goal is to use this conventional and tractable model to explore what economic analysis recommends for optimal trade and environmental policies in disparate circumstances. Our focus is on what is optimal from the perspective of an individual country acting in its own self-interest, and the base case is a large open economy that faces a local negative production externality. That is, the country faces two market failures, the negative externality and monopoly power in trade (ability to manipulate the world price). This base case is then modified by assuming a small open economy, the existence of policy constraints, and transboundary pollution.

The next section introduces the basic assumptions underlying our approach. The model and its solution, as well as a few extensions are presented before the issue of transboundary pollution is introduced in section 4. The final section offers conclusions, as well as limitations.

2 Basic Assumptions

The economic model most familiar to students of economics is the standard supply and demand framework presented with linear supply and demand curves. The primary use of this competitive market model is to find market equilibrium and explore comparative statics, such as how government policy affects equilibrium price and quantity. Another frequent application is welfare analysis, the study of how government policies impact consumer surplus, producer surplus, as well as government revenue. Welfare analysis is also used in the presence of market failures, such as externalities or monopoly power. Although standard supply and demand is ordinarily and effectively presented graphically, there are applications that benefit from a more mathematical treatment, and one such application is the study of optimal environmental policy in open economies; that is, the derivation of optimal environmental policy in the presence of international trade and trade policies.

The important connection between environmental policy and international trade theory usually relies on general equilibrium analysis, but partial equilibrium analysis is more accessible to students of economics and also produces outcomes that are consistent with general equilibrium analysis. That is, rather than considering the aggregate economy with its many distinct markets, we focus on a particular market and conduct welfare analysis by exploring how unilateral government policies impact consumer surplus, producer surplus, government revenue, and the environment in the presence of market distortions. We thus build a familiar and tractable model of an open economy that can be used to address common concerns raised about trade and the environment.

In particular, we consider a competitive market for a tradable good (see Britten-Jones, Nettle, and Anderson 1987; Krutilla 1991, 2002; Anderson 1992). Specifically, we assume a large number of utility-maximizing households, each of which with preferences given by $U_i\left(q_i^C, Q_i\right)$, where q_i^c is quantity consumed of a particular good and Q_i is quantity consumed of all other goods by consumer i, $i = 1, \ldots, N_c$. The representative consumer has a budget (Y_i) constraint given by $pq_i^C + PQ_i = Y_i$, which implies that the constrained utility maximization yields a demand function $q^c(p, P, Y)$. Letting P be the numeraire (or benchmark unit) and defining p^c as a relative price accordingly, as well as assuming constant income levels, the demand function becomes $q^c(p^c)$. Similarly, competitive firms, $j = 1, \dots, N_p$ choose output levels (q_j) which maximizes profit (π_j), where $\max_{q_j} \pi_j = R_j(q_j) - C_j(q_j)$; that is, profit equals total revenue given the market price $(R_j(q_j) = p_p \cdot q_j)$ minus total cost $(C_j(q_j))$. The profit maximizing output level determines the market supply curve, $q^p(p^p)$.

Given these demand and supply functions, we derive optimal environmental policy in the presence of international trade and trade policies, government revenue, as well as environmental externalities. We thus consider an economy in which one group's production (or consumption) of a good imposes an externality on others through its effect on the environment; that is, marginal private and social cost of production (or benefit from consumption) differ. The reason for this divergence in cost may stem from either social preference for a clean environment having strengthened or a threshold level of pollution having been reached which triggers greater concern for the environment. For simplicity we assume there are no administrative or distortionary costs of collecting taxes or disbursing subsidies and all income distributional effects can be neglected. We also assume that all agents have full information and appropriately value the environment. In addition, we assume that the externality results from the production (or consumption) activity itself, not from use of a particular process, so that a tax or subsidy on production (consumption) is equivalent to a tax/subsidy on the source of the externality and is therefore the optimal environmental policy for addressing the distortion. This modeling approach allows for a better focus on the connection between environmental regulation and trade policies, without qualitatively affecting model conclusions. As is true for comparative static analysis, changes in preferences, technology, and factor location are not considered. Below we initially assume that environmental costs are "local," without transboundary pollution effects, and in the subsequent section we introduce transboundary pollution into the model.

3 The Model: Policy Coordination with Local Pollution

We assume that national welfare reflects the net benefits from the production, consumption, and trade of a homogeneous good, q. Benefits are represented by consumer surplus $C(\cdot)$, producer surplus $P(\cdot)$, and tax and tariff revenues. Consumer surplus is a function of quantity consumed, which in turn depends on the price paid by consumer, $C(q^c(p^c))$, assuming $\frac{\partial C}{\partial q^c} > 0$ producer surplus is a function of quantity produced, which is determined by the price received by producers, $P(q^p(p^p))$ and assuming $\frac{\partial P}{\partial q^p} > 0$; environmental tax revenue (R_e) and tariff revenue (R_t, where t designates the tariff level) are given by $R_e = e \cdot q^p(p^p)$ and $R_t = t \cdot (q^c(p^c) - q^p(p^p))$, which implies that both pollution taxes and tariffs are formulated as per unit (specific) taxes applied to domestic production and trade flows, respectively. Costs include the environmental damage associated with production (consumption) activities.

The main presentation of the model centers on a large importing nation that faces a local negative production externality. Later we extend and briefly discuss how the results change in the cases of small nations, exporting nations, consumption externalities, as well as the implications of transboundary, or global, pollution. Expression (1) thus depicts national welfare for a negative production externality, W^p:

$$W^p = C(q^c(p^c)) + P(q^p(p^p)) + e \cdot q^p(p^p) + t \cdot (q^c(p^c) - q^p(p^p)) - E(q^p(p^p)), \tag{1}$$

where p^p and p^c denote price received by domestic producers and price paid by domestic consumers, respectively. Similarly, $q^p(p^p)$ represents domestic production, $q^{p'} > 0$; $q^c(p^c)$ represents domestic consumption, $q^{c'} < 0$; $E(q^p)$ is total environmental damage associated with production, $E' > 0$, $E'' \geq 0$. In addition, e is a specific environmental tax, while t represents a specific tariff on imports, $q^c(p^c) - q^p(p^p)$. The signs of the derivatives are sufficient to assure a maximum when expression (1) is optimized.

3.1 Open Nation with Negative Production Externality

The formulation in (1) contains several open economy equilibrium conditions, for the case of a production externality they include:

$$p^p = p^w + t - e \qquad \text{(supply-side price equilibrium), and} \tag{2}$$

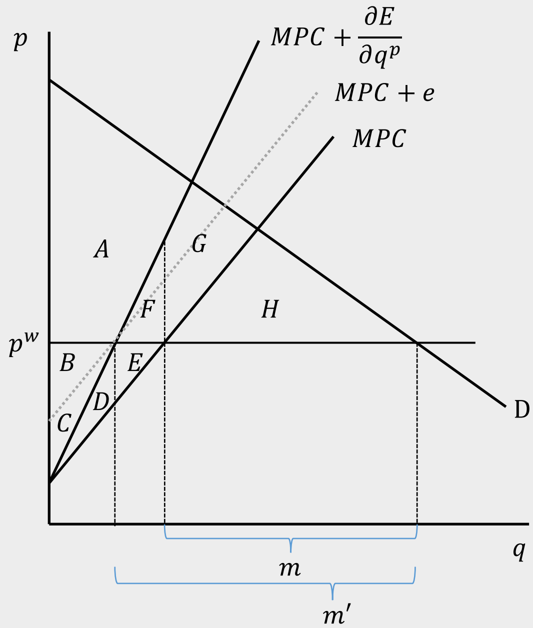
$$p^C = p^w + t \qquad \text{(demand-side price equilibrium),} \tag{3}$$

where p^w denotes the world terms-of-trade. These expressions show that in an open economy, a trade policy (t) creates a wedge between the internal relative price and the terms-of-trade $(p^p = p^c \neq p^w)$, while a domestic production tax (e) creates a wedge between the price consumers pay and the price producers receive $(p^c = p^w \neq p^p)$. The latter wedge is possible because trade flows from abroad eliminate any potential shortage or surplus.

To close the model, we specify a trade equilibrium, a relationship that determines the global terms-of-trade, p^w, and represents equilibrium between export supply and import demand in the global market. For an importing nation, import demand $M(p^p, p^c)$ is, $M(p^p, p^c) = q^c(p^c) - q^p(p^p)$, while export supply (provided by the rest of the world) can be denoted as, $X(p^w) = q^{p*}(p^w) - q^{c*}(p^w)$, where $X' > 0$, and where q^{p*} and q^{c*} represent production and consumption in the rest of the world. Trade equilibrium is obtained where:

$$M(p^p, p^c) = q^c(p^c) - q^p(p^p) = X(p^w). \tag{4}$$

This model can be described by diagrams that are familiar from both environmental economics and international trade theory. Although our ultimate interest lies in the complex issues that pertain to large nations, we proceed in steps by first considering a small economy facing a negative production externality (Figures 1 and 2). Figure 1 thus shows a small open economy that faces a negative production externality in the form of pollution, which it addresses by adopting a specific pollution tax (e). As can be seen in the diagram, as well as in the corresponding table, welfare analysis indicates that a Pigouvian tax will unambiguously raise national welfare (areas F and C); the loss in consumer and producer surplus is outweighed by government revenue and an improved environment.



	No Tax	Pigouvian Tax
Consumer Surplus	AFGH	AFGH
Producer Surplus	BCDE	BC
External Cost	DEF	D
Government Revenue	---	CD
National Welfare	AGHBC	AFGHBC+C
Change		+FC

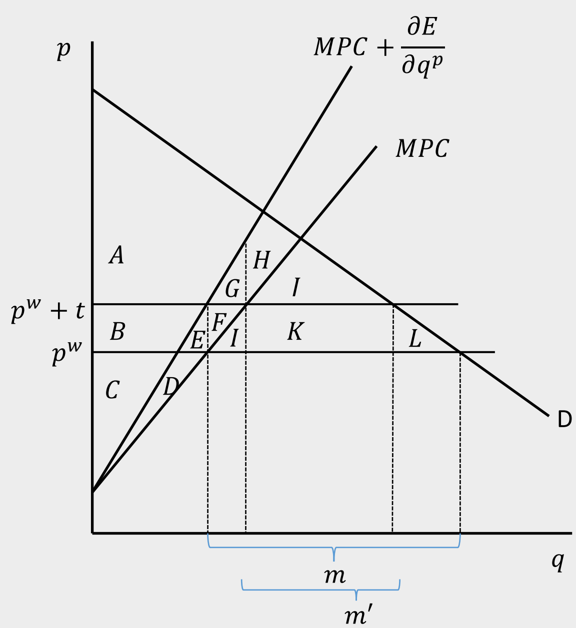
The Pigouvian tax improves national welfare by reducing environmental degradation.

p^w is the world price before import tariff, and the variables m and m' represent imports before and after a Pigouvian tax, respectively.

MPC is marginal private cost; $\frac{\partial E}{\partial q^p}$ is marginal external damage.

Figure 1. Diagram of a Small Open Importing Nation Facing a Negative Production Externality: Welfare Analysis Before and After a Pigouvian Tax (e)

Figure 2 again considers the case of a small nation with a negative production externality, but in this diagram the small nation adopts an import tariff. The accompanying analysis shows that adopting an import tariff will make this small nation unambiguously worse off by both creating a deadweight loss (IL) and raising environmental damage (FG). Combining the lessons from Figures 1 and 2, thus suggests that for a small nation facing a single market failure in the form of a negative production externality, free trade combined with a Pigouvian pollution tax is optimal; a conclusion verified in Case 1.

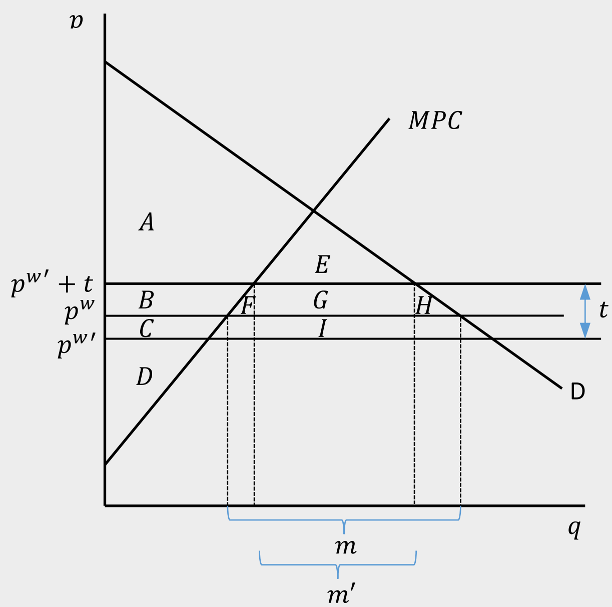


	No Import Tariff	Import Tariff
Consumer Surplus	ABEFGHIJKL	AGHJ
Producer Surplus	CD	BCDEF
External Cost	DE	DEFG
Government Revenue	---	K
National Welfare	ABCFGHIJKL	ABCGHJK
Change		-FG-IL

The import tariff reduces national welfare by both increasing environmental degradation and reducing consumer and producer surplus.

Figure 2. Diagram of a Small Open Importing Nation Facing a Negative Production Externality: Welfare Analysis Before and After an Import Tariff (t)

The analysis presented thus far ignores the possibility of a terms-of-trade effect, a second market failure due to a large nation being able to influence the terms-of-trade (the world price). In Figure 3, the standard diagram for a large open economy is offered. This diagram shows that an import tariff can in fact raise national welfare if the terms-of-trade effect (area I) outweighs the distortionary cost associated with the tariff (areas F and H). It can be shown (as discussed in footnote 3) that an optimal import tariff will in fact raise national welfare ($I > FH$).



	No Import Tariff	Import Tariff
Consumer Surplus	ABEFGH	AE
Producer Surplus	CD	BCD
Government Revenue	---	GI
National Welfare	ABCDEFGH	ABCDEGI
Change		-FH+I

The import tariff may increase welfare if the terms-of-trade effect (I) outweighs the deadweight loss (FH).

p^w = world price before import tariff
$p^{w\prime}$ = world price after import tariff (falls due to reduced global demand)
$p^{w\prime} + t$ = domestic price after import tariff

Figure 3. Diagram of a Large Open Importing Nation with Corresponding Welfare Analysis Before and After an Import Tariff (t)

Finally, Figure 4 shows that it is possible to draw a diagram that combines the two market failures depicted in Figures 1, 2, and 3; however, this diagram is not easily discussed through graphical welfare analysis. In addition, in the mathematical analysis below we add a third market distortion in the form of transboundary pollution. It is quite difficult to draw a diagram that encapsulates all these complex issues, and trying to conduct welfare analysis in order to determine what the optimal policies (e^*, t^*) are and how they are interconnected is very challenging. It is this particular challenge that we try to address by the mathematical analysis below.

Given the national welfare function and accompanying equilibrium conditions, a national government acting unilaterally with its available policy instruments, can choose either an environmental tax or a trade tax/tariff or both simultaneously, in order to maximize welfare. The goal for the government is thus to determine optimal environmental and trade policies in the presence of two market distortions, a negative production externality and monopoly power in trade (the ability of a large nation to influence the terms-of-trade).

To determine the optimal combination of environmental policy, e, and trade policy, t, we need to maximize W^p in (1) with respect to both e and t. That is, we need to find the best combination of (e, t) in order to maximize national welfare. This can be done in general (see Krutilla 1991), but in order to target our discussion to advanced undergraduate students of environmental economics and international trade,

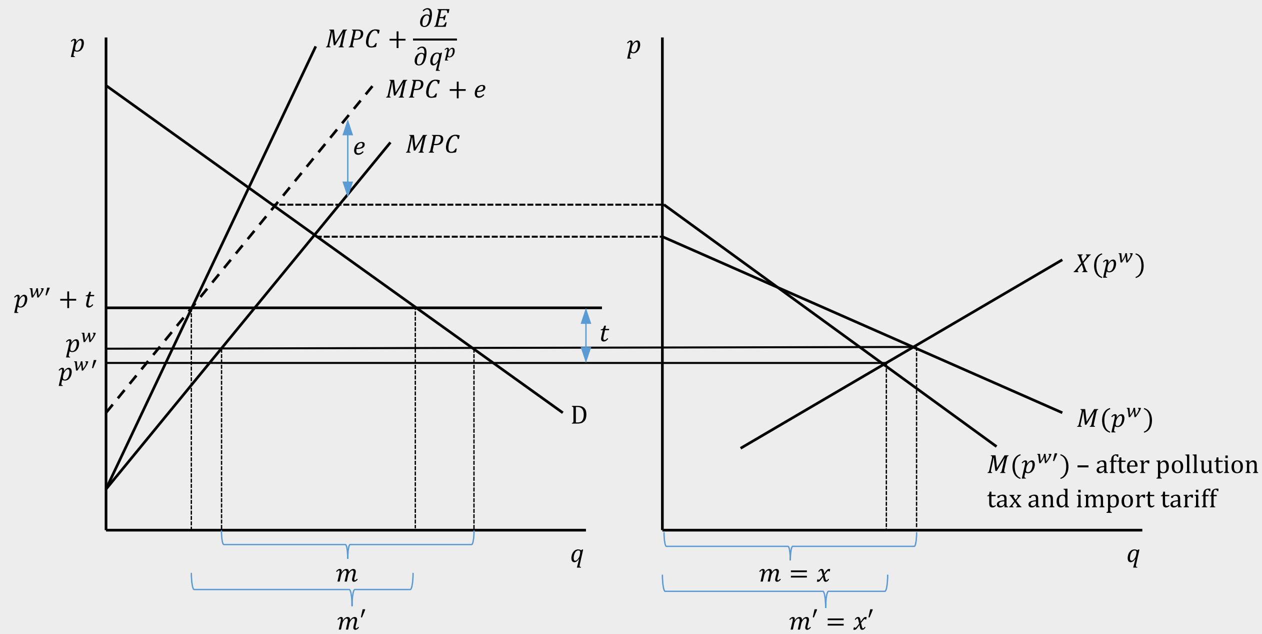


Figure 4. Diagram of a Large Open Importing Nation Facing Two Market Distortions, a Negative Production Externality and Monopoly Power in Trade

Note: MPC = marginal private cost = μq^p. Marginal environmental damage = $\partial E/\partial q^p$, which is assumed to be $2\gamma q^p$ so that optimal $e = 2\gamma q^p$. The variables m and x represent imports and exports (before tariff), respectively. The diagram on the left shows the domestic market, and the diagram on the right shows the world market.

we assume linear supply and demand functions. That is, we assume an inverse supply function $p^p = \kappa + \mu q^p$ and an inverse demand function $p^c = \alpha - \beta q^c$. Given linear supply and demand, producer surplus (P) and consumer surplus (C) can be expressed as:

$$P = \frac{\mu}{2}(q^p)^2 \text{ , and} \tag{5}$$

$$C = \frac{\beta}{2}(q^c)^2. \tag{6}$$

Using equation (1), which again depicts national welfare (W^p) in the presence of a negative production externality, the first-order conditions with respect to e and t are:

$$\frac{dW^p}{de} = \frac{\partial C}{\partial q^c}\frac{\partial q^c}{\partial p^c}\frac{dp^c}{de} + \frac{\partial P}{\partial q^p}\frac{\partial q^p}{\partial p^p}\frac{dp^p}{de} + \frac{\partial R_e}{\partial q^p}\frac{\partial q^p}{\partial p^p}\frac{dp^p}{de} + \frac{dR_e}{de} + \frac{\partial R_t}{\partial q^c}\frac{\partial q^c}{\partial p^c}\frac{dp^c}{de} + \frac{\partial R_t}{\partial q^p}\frac{\partial q^p}{\partial p^p}\frac{dp^p}{de} - \frac{\partial E}{\partial q^p}\frac{\partial q^p}{\partial p^p}\frac{dp^p}{de} = 0 \tag{7}$$

$$\frac{dW^p}{dt} = \frac{\partial C}{\partial q^c}\frac{\partial q^c}{\partial p^c}\frac{dp^c}{dt} + \frac{\partial P}{\partial q^p}\frac{\partial q^p}{\partial p^p}\frac{dp^p}{dt} + \frac{\partial R_e}{\partial q^p}\frac{\partial q^p}{\partial p^p}\frac{dp^p}{dt} + \frac{\partial R_t}{\partial q^c}\frac{\partial q^c}{\partial p^c}\frac{dp^c}{dt} + \frac{\partial R_t}{\partial q^p}\frac{\partial q^p}{\partial p^p}\frac{dp^p}{dt} + \frac{dR_t}{dt} - \frac{\partial E}{\partial q^p}\frac{\partial q^p}{\partial p^p}\frac{dp^p}{dt} = 0. \tag{8}$$

The equilibrium conditions (2) and (3) imply, $\frac{dp^p}{de} = \frac{dp^w}{de} - 1$, $\frac{dp^p}{dt} = \frac{dp^w}{dt} + 1$, $\frac{dp^c}{de} = \frac{dp^w}{de}$, $\frac{dp^c}{dt} = \frac{dp^w}{dt} + 1$. Furthermore, based on linear supply and demand we know that $\frac{\partial q^p}{\partial p^p} = \left(\frac{1}{\mu}\right)$, and $\frac{\partial q^c}{\partial p^c} = -\left(\frac{1}{\beta}\right)$. Finally, given the expressions for producer and consumer surplus as shown in equations (5) and (6), $\frac{\partial P}{\partial q^p} = \mu q^p$ and $\frac{\partial C}{\partial q^c} = \beta q^c$.

Incorporating these partial derivatives, as well as revenue and environmental damage functions, into equations (7) and (8), the first-order conditions become:[1]

$$\frac{dW^p}{de} = \beta q^c\left(-\frac{1}{\beta}\right)\left(\frac{dp^w}{de}\right) + \mu q^p\left(\frac{1}{\mu}\right)\left(\frac{dp^w}{de}-1\right) + e\left(\frac{1}{\mu}\right)\left(\frac{dp^w}{de}-1\right) + q^p + t\left(-\frac{1}{\beta}\right)\left(\frac{dp^w}{de}\right)$$
$$-t\left(\frac{1}{\mu}\right)\left(\frac{dp^w}{de}-1\right) - \frac{\partial E}{\partial q^p}\left(\frac{1}{\mu}\right)\left(\frac{dp^w}{de}-1\right) = 0 \tag{9}$$

$$\frac{dW^p}{dt} = -\beta q^c\left(\frac{1}{\beta}\right)\left(\frac{dp^w}{dt}+1\right) + \mu q^p\left(\frac{1}{\mu}\right)\left(\frac{dp^w}{dt}+1\right) + e\left(\frac{1}{\mu}\right)\left(\frac{dp^w}{dt}+1\right) - t\left(\frac{1}{\beta}\right)\left(\frac{dp^w}{dt}+1\right)$$
$$-t\left(\frac{1}{\mu}\right)\left(\frac{dp^w}{dt}+1\right) + (q^c - q^p) - \frac{\partial E}{\partial q^p}\left(\frac{1}{\mu}\right)\left(\frac{dp^w}{dt}+1\right) = 0\,. \tag{10}$$

Simplifying and solving 9 and 10 for optimal environmental and trade policies, e^* and t^* can be presented as:

$$e^* = \underbrace{\mu q^c\left(\frac{\frac{dp^w}{de}}{\frac{dp^w}{de}-1}\right)}_{\text{Consumer Effect}} - \underbrace{\mu q^p\left(\frac{\frac{dp^w}{de}}{\frac{dp^w}{de}-1}\right)}_{\text{Producer Effect}} + \underbrace{t\left(\frac{\mu}{\beta}\right)\left(\frac{\frac{dp^w}{de}}{\frac{dp^w}{de}-1}\right)}_{\text{Tariff Revenue}} + t + \underbrace{\frac{\partial E}{\partial q^p}}_{\text{Environmental Effect}} \tag{11}$$

$$t^* = \underbrace{-q^c\left(\frac{\beta\mu}{\beta+\mu}\right)}_{\text{Consumer Effect}} + \underbrace{q^p\left(\frac{\beta\mu}{\beta+\mu}\right)}_{\text{Producer Effect}} + \underbrace{e\left(\frac{\beta}{\beta+\mu}\right) + (q^c - q^p)\left(\frac{\beta\mu}{\beta+\mu}\right)\left(\frac{1}{\frac{dp^w}{dt}+1}\right)}_{\text{Government Revenue Effect}} - \underbrace{\frac{\partial E}{\partial q^p}\left(\frac{\beta}{\beta+\mu}\right)}_{\text{Environmental Effect}} \tag{12}$$

Expression (11) shows that the optimal environmental policy includes, and balances, the impact on consumers (first term), producers (second term), tariff revenue (third and fourth terms), and marginal environmental damage (fifth term). That is, a pollution tax changes all prices (p^c, p^p, p^w), which impacts both consumers, producers, the government, as well as the environment. In particular, consumers are worse off as price increases while quantity consumed decreases. This impact on consumers will argue for a lower pollution tax. Domestic producers are also made worse off due to a lower after-tax price and quantity, another effect that argues for a lower pollution tax. However, the positive impact on tariff revenue and the environment implies a more stringent pollution tax. Similarly, expression (12) shows that the optimal import tariff incorporates the impact on consumers, producers, production tax revenue (third and fourth terms), and marginal environmental damage. In this case,

[1] In the derivations we did not specify a functional form for the environmental damage function, $E^p(q^p)$, since many reasonable possibilities exist. Two common choices are: $E^p(q^p) = \gamma q^p$, so that $\partial E/\partial q^p = \gamma$ and constant (Krutilla 2002); $E^p(q^p) = \gamma \cdot (q^p)^2$, with $\partial E/\partial q^p = 2\gamma q^p$ and thus marginal environmental damage increases with production (Hultberg and Barbier 2004).

negative impacts on consumers and the environment (first and fifth terms) argue for a lower tariff, while greater government revenue (third and fourth terms) and producer surplus (second term) suggest higher tariff rates.

In order to evaluate these relationships, we must determine how the terms-of-trade is influenced by a pollution tax and an import tariff, respectively. Again, by our large country assumption, any domestic or trade policy will affect the terms-of-trade, and the national government should take these effects into account. A pollution tax reduces domestic production and thus *raises* import demand relative to foreign export supply, the resulting global shortage leads to an increase in terms-of-trade, but this increase is less than proportional to the change in the production tax. That is, a pollution tax will increase the terms-of-trade, but the increase will be smaller than the tax itself. The import tariff, on the other hand, *reduces* import demand relative to foreign export supply and the global surplus leads to a less than proportional decrease in the terms-of-trade. Again, an import tariff will reduce the terms-of-trade, but the change is smaller than the import tariff itself. In terms of the expressions in equations (11) and (12), we have:

$$0 < \frac{dp^w}{de} < 1 \text{ and therefore, } \left(\frac{\frac{dp^w}{de}}{\frac{dp^w}{de}-1}\right) < 0\ ;$$

$$-1 < \frac{dp^w}{dt} < 0 \text{ and therefore, } \left(\frac{\frac{dp^w}{dt}}{\frac{dp^w}{dt}+1}\right) < 0.$$

Given these terms-of-trade changes, we conclude from (11) and (12) that in the presence of an import tariff, optimal environmental regulation is lowered by its negative effect of higher prices on consumers, but the same effect benefits domestic producers. We also see that the presence of import tariffs suggests a need for a higher environmental tax, but this effect is somewhat alleviated by terms-of-trade effect. Of course, the main reason for the environmental tax is to address the level of marginal environmental damage, while the main reason for the import tariff is to manipulate the terms-of-trade. To determine the net effect of these various forces, we rearrange the optimal policy expressions, and simplify, to conclude that,

$$e^* = \mu\left((q^c - q^p) + \left(\frac{t^*}{\beta}\right)\right)\cdot\left(\frac{\frac{dp^w}{de}}{\frac{dp^w}{de}-1}\right) + t^* + \frac{\partial E}{\partial q^p} \tag{13}$$

$$t^* = -\left(\frac{\beta\mu}{\beta+\mu}\right)(q^c - q^p)\left(\frac{\frac{dp^w}{dt}}{\frac{dp^w}{dt}+1}\right) + \left(\frac{\beta}{\beta+\mu}\right)\left(e^* - \frac{\partial E}{\partial q^p}\right). \tag{14}$$

In order to deepen our understanding, while at the same time recognizing that trade and environmental policies are often determined separately (in fact, the WTO limits, with exceptions, member nations' ability to choose trade policies), we next consider several special cases.

Case 1: Small Country with Free Trade

Suppose first that foreign export supply is perfectly elastic, which means there is no terms-of-trade effect, and the country is classified as small. Consequently, $dp^w/de = 0$ and $dp^w/dt = 0$ and the terms-of-trade effects drop out and (13) and (14) reduce to:

$$e^* = t + \frac{\partial E}{\partial q^p}\text{, and}$$

$$t^* = \left(\frac{\beta}{\beta+\mu}\right)\left(e - \frac{\partial E}{\partial q^p}\right).$$

Solving these two equations simultaneously show that a small country will optimally use the Pigouvian tax together with free trade. That is, optimal environmental regulation is equal to the marginal environmental damage, the standard Pigouvian tax, and optimal trade policy is no import tariffs, $t = 0$.[2]

Case 2: Large Country with Free Trade Constraint
If we assume zero tariffs, perhaps assuming that the nation is part of a free trade agreement, but reintroduce the terms-of-trade effects (assume a large nation), then (13) and (14) become,

$$e^* = \mu\big((q^c - q^p)\big) \cdot \left(\frac{\frac{dp^w}{de}}{\frac{dp^w}{de} - 1}\right) + \frac{\partial E}{\partial q^p}, \text{ and}$$

$$t = 0.$$

Thus, in the absence of an import tariff, the optimal pollution tax for a large country will be *lower* than the standard Pigouvian tax (the first term is negative). The reason is that when constrained from using trade policy, the country must use its environmental policy as a second-best instrument to take advantage of the terms-of-trade effect. By, in effect, subsidizing domestic production, the nation reduces import demand relative to foreign export supply, which lowers the terms-of-trade. The lower world price is beneficial to the importing nation's consumers, and this positive effect justifies a lower pollution tax; that is, the nation accepts some additional environmental damage in return for lower prices.

Case 3: Large Country with Pigouvian Environmental Policy
If the nation does not account for the terms-of-trade effects when setting its environmental regulation and therefore adopts the Pigouvian tax, $e = \partial E / \partial q^p$, then equations (13) and (14) become,

$$e = \frac{\partial E}{\partial q^p}, \text{ and}$$

$$t^* = -\left(\frac{\beta\mu}{\beta+\mu}\right)(q^c - q^p)\left(\frac{\frac{dp^w}{dt}}{\frac{dp^w}{dt}+1}\right).$$

The nation thus combines the Pigouvian tax with a positive optimal import tariff, which can be shown to equal the optimal tariff rate from international trade theory.[3] In fact, this combination of

[2] Naturally, if we assumed a small country constrained by free trade ($t = 0$) from the very beginning, then equation (1) is $W^p = C\big(q^c(p^c)\big) + P\big(q^p(p^p)\big) + e \cdot q^p(p^p) - E^p\big(q^p(p^w)\big)$, and the first-order condition with respect to environmental regulation simplify to: $\frac{dW^p}{de} = 0 - \left(\frac{1}{\mu}\right)\mu q^p - e\left(\frac{1}{\mu}\right) + q^p + \left(\frac{1}{\mu}\right)\frac{\partial E}{\partial q^p} = 0$, with optimal pollution tax equal to marginal environmental damage, $e^* = \frac{\partial E}{\partial q^p}$, the standard Pigouvian tax.

[3] Totally differentiate equation (1) with respect to the environmental production tax and set equal to zero. Apply the equilibrium conditions from (2) and (3), and note that trade equilibrium (4), $q^c(p^c) - q^p(p^p) = X(p^w)$, implies that $\frac{\partial(q^p - q^c)}{\partial e} = \frac{\partial X}{\partial p^w}\frac{\partial p^w}{\partial e}$. Equation (11) then becomes: $\frac{dW^p}{de} = (q^p - q^c)\frac{\partial p^w}{\partial e} + \left(e - \frac{\partial E}{\partial q^p}\right)\frac{\partial q^p}{\partial p^p}\frac{\partial p^p}{\partial e} + t\frac{\partial X}{\partial p^w}\frac{\partial p^w}{\partial e} = 0$.
Assuming that $e = \frac{\partial E}{\partial q^p}$, gives us: $\left[(q^p - q^c) + t\frac{\partial X}{\partial p^w}\right]\frac{\partial p^w}{\partial e} = 0$, which implies, after some manipulation, that $t^* = -\frac{p^w}{\left(\frac{\partial X}{\partial p^w}\right)/\frac{p^w}{X}}$, where the term in the denominator denotes the elasticity of world excess supply and thus corresponds to the formula for optimal tariff rate for large importing nation.

environmental and trade policy is first-best; the domestic distortion is addressed by a domestic policy that targets the distortion at its source, and the external distortion (monopoly power in trade) is targeted by trade policy. There is an infinite number of (e, t) policy combinations that will satisfy equations (13) and (14), but they are associated with lower levels of national welfare compared to this (e^*, t^*) combination.

Case 4: Large Exporting Country
The same basic analysis can be conducted for a large exporting nation, with the only difference being the sign in front of the tariff revenue term in expression (1); that is, the tariff revenue term $t \cdot \left(q^c(p^c) - q^p(p^p)\right)$ becomes $t \cdot \left(q^p(p^p) - q^c(p^c)\right)$ instead. In fact, the optimal policies expressions shown in equations (13) and (14) remain, except that $(q^c - q^p) < 0$ in the case of an exporting nation. This affects some of the above conclusions. For example, if we assume free trade, then the optimal environmental tax is higher than the Pigouvian tax. That is, free trade encourages large exporting nations to over-protect the environment.[4] In this case the environmental tax must solve two distortions and the higher production tax acts as a second-best tool to achieve a positive terms-of-trade effect (mimicking an export tax). The high environmental tax reduces domestic production, reduces exports, and creates a global shortage that leads to an increase in the terms-of-trade, which is beneficial to the exporting nation (it gets more imports for the same amount of exports). Similarly, a small exporting nation should combine the Pigouvian tax with free trade. Finally, the first-best policy combination is for a large exporting nation to address the negative production externality with a Pigouvian tax and adopt an optimal export tax to maximize the terms-of-trade effect.

Cases 1–4 presented above show the complexity and interrelatedness of first-best environmental and trade policies for national governments. This complexity indicates the possibility that mistakes can be made in the choice of environmental policy; environmentalists may thus be warranted in their fear that international trade leads to inferior environmental policies and, on the other hand, industrialists may be justified in their concern that environmental policy will affect competitiveness. Of course, developing nations are justified in their worry about import tariffs since in the current model import tariffs are indeed a beggar-thy-neighbor policy; that is, the import tariff acts to reduce national welfare in the exporting nation.

In situations where a negative consumption externality could lead to environmental degradation, trade and environmental policies should be coordinated as well. Therefore, in the next section, we extend the model by introducing a negative consumption externality.

3.2 Open Nation with Negative Consumption Externality

If the nation instead faces a negative consumption externality, then the main change is that the external damage term in (1) is a function of domestic consumption, rather than domestic production. Another change is that environmental policy will now target consumers, so the government imposes a consumption tax. This change in equilibrium conditions (2) and (3) result in a corresponding change in partial derivatives; in particular, $dp^p/de = dp^w/de$, and $dp^c/de = (dp^w/de) + 1$. The resulting change in optimal policies stems from the different terms-of-trade implications; for a large importing nation, a consumption tax will reduce import demand relative to foreign export supply, and the ensuing global surplus will reduce the terms-of-trade, which is positive for the importing nation. Hence, we would expect that if the nation is constrained in its choice of trade policy (free trade), it will adopt a consumption tax that is *higher* than the Pigouvian tax as a second-best tool to benefit from the positive terms-of-trade effect (see Appendix for a derivation of this result). A consumption tax implemented by a large exporting nation increases exports, and the global surplus worsens its terms-of-trade, which means

[4] This is always true unless we value the environment infinitely, in which case we would not be producing anything in the first place.

that an exporting nation has an incentive to adopt a consumption tax that is *lower* than the Pigouvian tax. Finally, a small nation with a negative consumption externality should combine free trade policy with a Pigouvian tax, while a large exporting country's first-best policies is a Pigouvian tax combined with an optimal export subsidy (an unlikely import subsidy is optimal for the large importing nation).

4 The Model: Policy Coordination with Transboundary Pollution

As the introduction indicates, much of the environmental debate concerns the transboundary, or even global, nature of pollution. That is, much of pollution generated (such as carbon) crosses national borders, and therefore optimal policies must consider more than the domestically generated environmental damage. Of course, if part of the domestic pollution falls on other countries (e.g., acid rain), then the purely local approach would suggest *less* stringent environmental regulation (Esty 1994). This argument follows directly from our analysis above if we specify total environmental damage as $E(\varepsilon \cdot q^p)$, where $\varepsilon < 1$.

The more challenging case is global pollution, where production (consumption) abroad leads to environmental damage at home. In this case, unilateral domestic environmental regulation will never be first-best optimal, instead for true optimality an incentives-based cooperative agreement is needed. Although such global agreements are being implemented (Kyoto Protocol and Paris Agreement), they are currently not sufficient. Unilateral action is thus still needed, but unilateral domestic policy cannot regulate foreign production (except through possible small terms-of-trade effects). In fact, in the absence of first-best supra-national environmental policies, trade policy is an attractive second-best tool to address external market failures. The suggested combined use of domestic environmental policy and trade policy is, of course, exactly what our previous analyses have explored.

We thus revisit our analysis for a large importing nation facing a negative production externality that occurs both at home and abroad. Once again, we assume that national welfare reflects net benefits from consumption, production, and trade of a homogeneous good, q. Benefits are again represented by consumer surplus, producer surplus, and tax and tariff revenues, but costs now include the environmental costs associated with production activities both at home and abroad. In particular, assume that environmental damage can be described by $E\left(q^p(p^p), q^{p*}(p^w)\right)$, where $q^{p*}(p^w)$ represents all foreign production at the terms-of-trade p^w. The national welfare function thus becomes:

$$W^p = C\left(q^c(p^c)\right) + P\left(q^p(p^p)\right) + e \cdot q^p(p^p) + t \cdot \left(q^c(p^c) - q^p(p^p)\right) - E\left(q^p(p^p), q^{p*}(p^w)\right), \quad (15)$$

where p^p, p^c, and p^wstill denote the price received by domestic producers, price paid by domestic consumers, and the world terms-of-trade, respectively, and all quantities are as described previously. However, $E(q^p, q^{p*})$ is now total environmental damage associated with production both at home and abroad, $E' > 0, E'' \geq 0$ for both variables. As before, e is a specific environmental tax, while t represents a specific tariff on imports. All equilibrium conditions remain the same as described by (2), (3), and (4), and we continue to assume linear supply and demand functions. Given the equilibrium conditions, a national government acting unilaterally choose environmental policy, trade policy, or both, in order to maximize (15). The first-order conditions are analogous to expressions (7) and (8), except for the added terms $\frac{\partial E}{\partial q^{p*}}\frac{\partial q^{p*}}{\partial p^w}\frac{dp^w}{de}$ and $\frac{\partial E}{\partial q^{p*}}\frac{\partial q^{p*}}{\partial p^w}\frac{dp^w}{dt}$, respectively. Solving these first-order conditions for optimal environmental and trade policies yields the rules for setting optimal policies for a large importing nation faced with transboundary pollution,

$$e^* = \mu\left((q^c - q^p) + \left(\frac{t}{\beta}\right) + \frac{\partial E}{\partial q^{p*}}\frac{\partial q^{p*}}{\partial p^w}\right) \cdot \left(\frac{\frac{dp^w}{de}}{\frac{dp^w}{de} - 1}\right) + t + \frac{\partial E}{\partial q^p} \quad (16)$$

$$t^* = -\left(\frac{\beta\mu}{\beta+\mu}\right)\left((q^c - q^p) + \frac{\partial E}{\partial q^{p*}}\frac{\partial q^{p*}}{\partial p^w}\right)\left(\frac{\frac{dp^W}{dt}}{\frac{dp^W}{dt}+1}\right) + \left(\frac{\beta}{\beta+\mu}\right)\left(e - \frac{\partial E}{\partial q^p}\right) \tag{17}$$

Although similar to equations (13) and (14), these expressions contain an additional term ($\frac{\partial E}{\partial q^{p*}}\frac{\partial q^{p*}}{\partial p^w}$) that denotes how environmental damage at home is affected by foreign production changes; that is, foreign producers adjust their output levels as the terms-of-trade changes, which in turn affect the level of transboundary pollution. In order to evaluate these expressions, we recall that $\frac{\partial E}{\partial q^{p*}}\frac{\partial q^{p*}}{\partial p^w} > 0$ and note that, $\left(\frac{\frac{dp^W}{de}}{\frac{dp^W}{de}-1}\right) < 0$ and $\left(\frac{\frac{dp^W}{dt}}{\frac{dp^W}{dt}+1}\right) < 0$. To better understand the implications of transboundary pollution, we start by assuming that the nation is constrained by a free trade agreement so that $t = 0$, which implies,

$$e^* = \mu\left((q^c - q^p) + \frac{\partial E}{\partial q^{p*}}\frac{\partial q^{p*}}{\partial p^w}\right)\cdot\left(\frac{\frac{dp^W}{de}}{\frac{dp^W}{de}-1}\right) + \frac{\partial E}{\partial q^p}, \text{ and}$$

$$t^* = 0.$$

As before, the optimal pollution tax for a large importing nation is lower than the Pigouvian tax, but now for two distinct reasons. First, and as before, the environmental tax should be lower since a high production tax increases import demand relative to export supply (a global shortage) and therefore increases the terms-of-trade, a negative terms-of-trade effect for an importing nation. That is, e should be *lower* to limit this increase in the price of imports. Second, the environmental tax should be lower because a production tax shifts production from domestic producers to foreign producers, and the resulting increase in foreign production generates foreign pollution. Given transboundary pollution, the domestic government must take this indirect effect on global pollution into account. Thus, e should be *lower* to alleviate the secondary damage caused by increased pollution from abroad. Of course, in this case environmental policy acts as a second-best tool in the absence of trade policy. It is interesting to note that transboundary pollution, in the absence of an optimal import tax, gives the home country an added incentive to lower its environmental regulation. That is, free trade agreements may lead to a "regulatory chill" effect as feared by environmentalists. This is a result that is often missing from standard trade theory.

On the other hand, if a nation adopts the Pigouvian tax as usually suggested by environmental economics ($e = \partial E/\partial q^p$), then a nation should adjust its trade policy according to,

$$t^* = -\left(\frac{\beta\mu}{\beta+\mu}\right)\left((q^c - q^p) + \frac{\partial E}{\partial q^{p*}}\frac{\partial q^{p*}}{\partial p^w}\right)\left(\frac{\frac{dp^W}{dt}}{\frac{dp^W}{dt}+1}\right).$$

We see that the resulting optimal import tariff is positive for two reasons. In addition to the positive terms-of-trade effect, there is now a second benefit from an import tariff, namely that the import tariff will reduce foreign production and hence global pollution. That is, the import tariff lowers import demand relative to export supply, which means a falling terms-of-trade and falling foreign production. Of course, as foreign production declines so does foreign pollution, and this drop in transboundary pollution is beneficial to the importing nation. We see that there is an incentive and an actual benefit in terms of environmental damage, for a large importing nation to adopt an import ("carbon") tariff in order to influence foreign production. The ability to use import tariffs in this way, thus allows a country to adopt the Pigouvian tax targeting the negative production externality, while using trade policy to address all external distortions—both monopoly power in trade and a global negative production externality.

Table 1 summarizes first-best and second-best policies, in production and consumption externalities, for a large importing nation.

Table 1. Summary of Selected Optimal Environmental Taxes and Trade Tariffs for an Importing Nation

Negative Production Externality (Local)	
Large Nation:	Comments:
$e^* = \frac{\partial E}{\partial q^p}$ $t^* = -\left(\frac{\beta\mu}{\beta+\mu}\right)(q^c - q^p)\left(\frac{\frac{dp^W}{dt}}{\frac{dp^W}{dt}+1}\right)$	**First-best:** Combine a Pigouvian tax with optimal trade policy. This is optimal for both large and small nations.
$e^* = \mu\big((q^c - q^p)\big)\cdot\left(\frac{\frac{dp^W}{de}}{\frac{dp^W}{de}-1}\right) + \frac{\partial E}{\partial q^p}$ $t = 0$	**Second-best:** If constrained from using trade policy, use environmental policy to also target the external distortion. Adopt *lower* environmental regulation.
Negative Consumption Externality (Local)	
Large Nation:	Comments:
$e^* = \frac{\partial E^c}{\partial q^c}$ $t^* = -\left(\frac{\beta\mu}{\beta+\mu}\right)(q^c - q^p)\left(\frac{\frac{dp^W}{dt}}{\frac{dp^W}{dt}+1}\right)$	**First-best:** Combine a Pigouvian tax with optimal trade policy.
$e^* = -\beta\big((q^c - q^p)\big)\cdot\left(\frac{\frac{dp^W}{de}}{\frac{dp^W}{de}+1}\right) + \frac{\partial E}{\partial q^c}$ $t = 0$	**Second-best:** If constrained from using trade policy, use environmental policy to also target the external distortion. Adopt *higher* environmental regulation.

Table 1 continued.

Negative Production Externality (Transboundary)	
Large Nation:	Comments:
$e^* = \frac{\partial E}{\partial q^p}$ $t^* = -\left(\frac{\beta\mu}{\beta+\mu}\right)\left((q^c - q^p) + \frac{\partial E}{\partial q^{p*}}\frac{\partial q^{p*}}{\partial p^w}\right)\cdot\left(\frac{\frac{dp^w}{dt}}{\frac{dp^w}{dt}+1}\right)$	**First-best:** Combine a Pigouvian tax with the optimal trade policy, but trade policy must now address two external market failures: terms-of-trade effect and transboundary pollution. Since a small nation does not have the ability to address external distortions, it should combine the Pigouvian tax with free trade.
$e^* = \mu\left((q^c - q^p) + \frac{\partial E}{\partial q^{p*}}\frac{\partial q^{p*}}{\partial p^w}\right)\cdot\left(\frac{\frac{dp^w}{de}}{\frac{dp^w}{de}-1}\right) + \frac{\partial E}{\partial q^p}$ $t = 0$	**Second-best:** If constrained from using trade policy, use environmental policy to target both of the external distortions. Adopt *lower* environmental regulation to address both external distortions.

5 Conclusions

In order to combat an increasing threat to the environment, from production and consumption taking place both at home and abroad, countries must adopt policies that limit environmental damage. However, environmental regulation in the context of an open economy is a complex process due to the existence of multiple market failures and the limited reach of domestic policies. Policy decisions are thus more complicated than what standard analysis suggests in both environmental economics and international trade theory. In addition, whether a commodity is imported or exported, the size of the economy, existence of constraints, and whether pollution is local or transboundary/global critically impact the choice and level of appropriate policies.

The common advice of using environmental policy to address environmental externalities and trade policy to maximize the efficient allocation of resources, which usually implies free trade, still apply in certain circumstances. In particular, for a small nation unable to affect the terms-of-trade and facing purely local environmental damage, choosing the Pigouvian tax combined with free trade is optimal. Under these assumptions, the worries expressed by environmentalists, industrialists, and developing nations seem less relevant, and there is no need for supra-national institutions such as the WTO or its environmental equivalent. Of course, the world is more complex than the assumptions underlying the standard economic model, which is why the different groups fear the intentions and consequences of environmental and trade policies, especially when such policies are made in separation. Our model confirms arguments made by environmentalists (Esty 1994, 2001), that trade might cause governments to set weaker environmental standards, if pollution reduction policies were designed without taking into consideration the adverse effects of international trade on the environment. The fact that trade policy traditionally has been determined independently of both local and global effects of the resulting changes in production and consumption patterns further justifies these fears.

Lately the EU and the United States have proposed implementing carbon border adjustment mechanisms; that is, a tariff on imports tied to pollution created in the foreign production process. Such border adjustments, a form of trade policy, explicitly recognize that production taking place outside of a nation's environmental regulation jurisdiction might require nations to engage in unilateral trade policy as a second-best tool; that is, it is a recognition of the fact that global agreements, such as the Kyoto Protocol and the Paris Agreement, are currently not enough to slow environmental damage sufficiently. Given the concerns and proposed policy responses, it is crucial to develop a tractable model that can provide a framework to discuss and think through these issues. Theoretical research published by professional economists is rarely accessible to undergraduate students or even Master's students; there is thus a need for a familiar model that allows the economics instructor to highlight the connection between environmental and trade policies. We propose the standard linear supply and demand framework. Using this model, we are able to rigorously discuss optimal policies for a self-interested nation that cares about national welfare, while recognizing the importance of the environment, in addition to consumption, production, and tax revenue. We show that environmental policies and trade policies are intertwined in complex ways, especially if the nation is constrained in its choices of such policies. We are further able to show that transboundary pollution does suggest a possible need for carbon border adjustments; an external negative externality can only be reached by a trade policy (barring the existence of first-best international agreements) that targets both terms-of-trade effect and transboundary pollution. At the same time, large nations' ability to manipulate the terms-of-trade in their favor suggest that a healthy degree of skepticism is warranted. Developing countries are correct in their suspicions that carbon taxes could be a form of beggar-thy-neighbor protectionism. It is thus true, as argued by Monjon and Quirion (2011) and Wiers (2008), implementation of border adjustments should emphasize world (carbon) emissions, rather than carbon leakage.

Of course, the current article suffers from many and important limitations. Using a partial equilibrium model and basic welfare analysis ignore important implications across the economy, in terms of demand for scarce resources, accompanying price effects, and secondary costs associated with raising taxes. The model is also static and does not allow for changes in preferences, technology, production processes, and factor movements. Another limitation is the absence of strategic interactions between both nations and producers. We recognize these limitations, but argue that presenting a tractable model that our students can understand with a relatively small investment in mathematical notations is a justified trade-off.

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Appendix: Large Importing Nation with Negative Consumption Externality

Suppose pollution originates from consumption, rather than from the production process. National welfare is then given by:

$$W^c = C\big(q^c(p^c)\big) + P\big(q^p(p^p)\big) + e\cdot\big(q^c(p^c)\big) + t\cdot\big(q^c(p^c) - q^p(p^p)\big) - E\big(q^c(p^c)\big),$$

where p^p and p^c denote price received by domestic producers and price paid by domestic consumers, respectively. $E(q^c)$ is total environmental damage associated with consumption, $E' > 0$, $E'' \geq 0$, e is a specific environmental tax, and t represents a specific tariff on imports, $q^c(p^c) - q^p(p^p)$. Denoting the global terms-of-trade as p^w, the open economy equilibrium conditions are:

$$p^p = p^w + t \qquad \text{(supply-side price equilibrium)}$$

$$p^C = p^w + t + e \qquad \text{(demand-side price equilibrium), and}$$

$$M(p^p, p^c) = q^c(p^c) - q^p(p^p) = X(p^w). \qquad \text{(trade equilibrium)}$$

We maximize W^c with respect to both e and t, while assuming linear supply and demand functions. The first-order conditions are:

$$\frac{dW^c}{de} = \frac{\partial C}{\partial q^c}\frac{\partial q^c}{\partial p^c}\frac{dp^c}{de} + \frac{\partial P}{\partial q^p}\frac{\partial q^p}{\partial p^p}\frac{dp^p}{de} + \frac{\partial R_e}{\partial q^c}\frac{\partial q^c}{\partial p^c}\frac{dp^c}{de} + \frac{dR_e}{de} + \frac{\partial R_t}{\partial q^c}\frac{\partial q^c}{\partial p^c}\frac{dp^c}{de} + \frac{\partial R_t}{\partial q^p}\frac{\partial q^p}{\partial p^p}\frac{dp^p}{de} - \frac{\partial E}{\partial q^c}\frac{\partial q^c}{\partial p^c}\frac{dp^c}{de} = 0,$$

$$\frac{dW^c}{dt} = \frac{\partial C}{\partial q^c}\frac{\partial q^c}{\partial p^c}\frac{dp^c}{dt} + \frac{\partial P}{\partial q^p}\frac{\partial q^p}{\partial p^p}\frac{dp^p}{dt} + \frac{\partial R_e}{\partial q^c}\frac{\partial q^c}{\partial p^c}\frac{dp^c}{dt} + \frac{\partial R_t}{\partial q^c}\frac{\partial q^c}{\partial p^c}\frac{dp^c}{dt} + \frac{\partial R_t}{\partial q^p}\frac{\partial q^p}{\partial p^p}\frac{dp^p}{dt} + \frac{dR_t}{dt} - \frac{\partial E}{\partial q^c}\frac{\partial q^c}{\partial p^c}\frac{dp^c}{dt} = 0.$$

Incorporating all partial derivatives and noting that $\frac{dp^p}{de} = \frac{dp^w}{de}$ and $\frac{dp^c}{de} = \frac{dp^w}{de} + 1$, the first-order conditions become:

$$\frac{dW^c}{de} = \beta q^c\left(-\frac{1}{\beta}\right)\left(\frac{dp^w}{de}+1\right) + \mu q^p\left(\frac{1}{\mu}\right)\left(\frac{dp^w}{de}\right) + e\left(-\frac{1}{\beta}\right)\left(\frac{dp^w}{de}+1\right) + q^c + t\left(-\frac{1}{\beta}\right)\left(\frac{dp^w}{de}+1\right)$$
$$-t\left(\frac{1}{\mu}\right)\left(\frac{dp^w}{de}\right) - \frac{\partial E}{\partial q^c}\left(-\frac{1}{\beta}\right)\left(\frac{dp^w}{de}+1\right) = 0$$

$$\frac{dW^c}{dt} = \beta q^c\left(-\frac{1}{\beta}\right)\left(\frac{dp^w}{dt}+1\right) + \mu q^p\left(\frac{1}{\mu}\right)\left(\frac{dp^w}{dt}+1\right) + e\left(-\frac{1}{\beta}\right)\left(\frac{dp^w}{dt}+1\right) + t\left(-\frac{1}{\beta}\right)\left(\frac{dp^w}{dt}+1\right)$$
$$-t\left(\frac{1}{\mu}\right)\left(\frac{dp^w}{dt}+1\right) + (q^c - q^p) - \frac{\partial E}{\partial q^c}\left(-\frac{1}{\beta}\right)\left(\frac{dp^w}{dt}+1\right) = 0.$$

Simplifying and solving for optimal environmental and trade policies, (e^*, t^*) give the following expressions:

$$e^{*} = -\beta q^{c}\left(\frac{\frac{dp^{W}}{de}}{\frac{dp^{W}}{de}+1}\right) + \beta q^{p}\left(\frac{\frac{dp^{W}}{de}}{\frac{dp^{W}}{de}+1}\right) - t\left(\frac{\beta}{\mu}\right)\left(\frac{\frac{dp^{W}}{de}}{\frac{dp^{W}}{de}+1}\right) - t + \frac{\partial E}{\partial q^{c}} \tag{A1}$$

$$t^{*} = -q^{c}\left(\frac{\beta\mu}{\beta+\mu}\right) + q^{p}\left(\frac{\beta\mu}{\beta+\mu}\right) - e\left(\frac{\mu}{\beta+\mu}\right) + (q^{c}-q^{p})\left(\frac{\beta\mu}{\beta+\mu}\right)\left(\frac{1}{\frac{dp^{W}}{dt}+1}\right) + \frac{\partial E}{\partial q^{c}}\left(\frac{\mu}{\beta+\mu}\right) \tag{A2}$$

In order to evaluate these relationships, we determine how the terms-of-trade is influenced by a pollution tax on consumers and an import tariff. A pollution tax targeted at consumers reduces domestic consumption and thus *lowers* import demand relative to foreign export supply; the resulting global surplus leads to a decrease in terms-of-trade, but this decrease is less than proportional to the change in the consumption tax. The import tariff, on the other hand, *reduces* import demand relative to foreign export supply, and the global surplus leads to a less than proportional decrease in the terms-of-trade. That is,

$$-1 < \frac{dp^{W}}{de} < 0 \text{ and } \left(\frac{\frac{dp^{W}}{de}}{\frac{dp^{W}}{de}+1}\right) < 0 \text{ and } -1 < \frac{dp^{W}}{dt} < 0 \text{ and } \left(\frac{\frac{dp^{W}}{dt}}{\frac{dp^{W}}{dt}+1}\right) < 0.$$

Given these terms-of-trade changes for a large importing nation, facing a local negative consumption externality, we simplify and rearrange (A1) and (A2) to derive optimal environmental (e^{*}) and trade (t^{*}) policies:

$$e^{*} = -\beta\left((q^{c}-q^{p}) + \left(\frac{t^{*}}{\beta}\right)\right)\cdot\left(\frac{\frac{dp^{W}}{de}}{\frac{dp^{W}}{de}+1}\right) - t^{*} + \frac{\partial E}{\partial q^{c}}, \text{ and}$$

$$t^{*} = -\left(\frac{\beta\mu}{\beta+\mu}\right)(q^{c}-q^{p})\left(\frac{\frac{dp^{W}}{dt}}{\frac{dp^{W}}{dt}+1}\right) - \left(\frac{\mu}{\beta+\mu}\right)\left(e^{*} - \frac{\partial E}{\partial q^{c}}\right).$$

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