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# **Trade, Transboundary Pollution, and Foreign Lobbying**

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# **Trade, Transboundary Pollution, and Foreign Lobbying**

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## **Abstract**

In this paper, we explore the use of trade policy in addressing transboundary stock pollution problems such as acid rain and water pollution. We show that a tariff determined by the current level of accumulated pollution can induce the time path of emissions optimal for the downstream (polluted) country. But if the upstream (polluting) country can lobby the downstream government to impose lower tariffs, distortions brought by corruption and foreign lobbying lead to a rise in the upstream country's social welfare, and to a decrease in social welfare in the downstream country. Thus, the usefulness of trade policy as a tool for encouraging cooperation and internalizing transboundary externalities depends critically on the degree of governments' susceptibility to foreign political influence.

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## 1. Introduction

Transboundary pollution poses a special challenge to regulators because of the features that distinguish it from national environmental problems. Transboundary pollution is characterized by damages occurring in one country owing to the actions of one or more other countries. As long as there exists no supranational institution with complete authority to enforce cooperation, and no government can regulate polluters located outside her political jurisdiction, Pigouvian taxes to control transboundary pollution are not feasible. Although each country may recognize that it has a certain influence on the payoffs of another, the countries' interests often conflict. Hence, there is a need to analyze the strategic interactions between the affected countries. While there have been attempts to negotiate international cooperation to regulate some forms of transboundary pollution, attaining such a cooperative solution at the international level has been difficult, especially when countries have asymmetric incentives.<sup>2</sup>

While transboundary pollution has proven difficult to regulate, it is becoming a growing regional and global environmental problem (UNEP 2002; OECD 2007). Acid rain, for example, has become one of the major environmental concerns in North America, Europe, and Asia, causing damages that amount to billions of dollars (David Newbery 1990; Yoko Nagase and Emilson Silva 2000, 2007). Due to prevailing winds, acid rain precursors often accumulate well beyond the borders of the polluting country.<sup>3</sup> There are also examples of transboundary pollution

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<sup>2</sup> For example, several upwind countries, including the United Kingdom, refused to ratify the 1985 Helsinki protocol on the Reduction of Sulfur Emissions on their Transboundary Fluxes as it was estimated that the costs of abatement for these countries would exceed the domestic environmental benefits (Hakan Nordstrom and Scott Vaughan 1999).

<sup>3</sup> It is well documented that as a result of their unfortunate downwind location, much of the US production of SO<sub>2</sub> and NO<sub>x</sub> is deposited in Canada and much of the UK production is deposited in Scandinavian countries (e.g.,

involving water pollution. The contamination of seas and rivers is frequently attributed to pollutants crossing national boundaries and accumulating in downstream regions. For instance, the eutrophication<sup>4</sup> of the North and Black Seas, which results from agricultural run-off brought from upstream countries via rivers, is responsible for radical changes in marine ecosystems and is affecting fishing and tourism in countries where coastal waters are relatively shallow such as Denmark, Romania, and Ukraine.<sup>5</sup>

If cooperation between the countries to regulate the transboundary pollution is not forthcoming, the government of the downwind or downstream country has limited options to control the externality. Indeed, it has been argued that trade policies are one of the few available instruments for creating or increasing the incentives to internalize cross-border externalities. The role of trade policy in addressing transboundary pollution problems is twofold. First, a number of studies showed that trade policy may serve a “second-best” instrument to control such cross-border externalities, playing a role that is somewhat similar to the role a Pigouvian tax performs within a single political jurisdiction (James Markusen 1975; William Baumol and Wallace Oates 1988; Brian Copeland 1996). Second, it has been suggested that trade policy may serve as a mechanism for promoting cooperation between countries linked by the externality. For instance,

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Newbery 1990). It has also been shown that Chinese emissions of SO<sub>2</sub> cause acid rain in Japan (Nagase and Silva 2007).

<sup>4</sup> Eutrophication is an over-enrichment of the water bodies with phytoplankton due to overloading with nitrogen and phosphorus nutrients.

<sup>5</sup> See Basak Bayramoglu (2006). Among other cases that have historically been important are heavy metals and chloride pollution suffered by downstream countries on the Danube and Rhine Rivers (Thomas Bernauer and Peter Moser 1996; Jacqueline McGlade 2000), and salinity problems in the lower basin of the Colorado River where it crosses the Mexican-American border (Karl-Goran Maler 1990).

Nordstrom and Vaughan (1999, p. 3), note that “while trade measures are rarely, if ever, the first-best policy for addressing environmental problems, governments have found trade measures a useful mechanism for encouraging participation in and enforcement of multilateral environmental agreements in some instances, and for attempting to modify the behavior of foreign governments in others.”

While it has been argued that such a use of trade measures may create or increase incentives to cooperate for the polluting country, little attention has been given to the fact that it may also create other incentives that could adversely affect the externality regulation and lead to the aggravation of the transboundary pollution problem. Failure to identify and consider these negative incentives may lead to misleading conclusions regarding the effectiveness of trade policy in promoting cooperation between the countries linked by the externality. Recent events have brought to public attention the significant extent of foreign lobbies’ involvement in domestic economic policymaking.<sup>6</sup> International trade is by far the most common issue targeted by foreign lobbies. Being a key player in the world markets, the United States economy, in particular, has become a focus of lobbying by foreign governments and private organizations, trying to achieve more favorable trade regime (Andreas Jobst 2002; Hiau Kee et al. 2007). Another trend observed is that increasingly foreign lobbying is affecting domestic environmental

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<sup>6</sup> These include the connection between foreign lobbying and 2008 U.S. presidential campaign fundraising (Will Evans and Avni Patel 2008; Jim McElhatton and Jerry Seper 2008), allegations of foreign contributions during fundraising for the 1996 U.S. presidential campaign (Allan Miller 1996; Bob Woodward and Brian Duffy 1997); the controversy surrounding the Chinese government recently hiring the top lobbying firms to represent Chinese interests in the U. S. (Marina Guevara 2005) or the recent investigation by Harper’s Magazine’s Ken Silverstein (2007) revealing the inside details about foreign lobby industry in Washington DC.

policies and regulations.<sup>7</sup> Such lobbying influence may be particularly effective in situations where two countries are linked by trade flows and also share a transboundary pollution problem. Since trade and environmental policies affect income distribution within and between the countries, they may create incentives for *both* domestic and foreign special interest groups to influence domestic policy decisions. While a few recent studies have considered how the presence of *domestic* environmental lobbies may affect the determination of trade and environmental regulations when trading countries share a cross-border pollution externality (Paola Conconi 2003; Nuno Limao 2005), to our knowledge none have investigate the role of *foreign* lobbying in determining environmental and trade policy outcomes.

By examining how the foreign lobbying activity may affect environmental and trade outcomes in two countries sharing the transboundary pollution externality, this paper bridges two distinct literatures on the political economy of trade issues. Most of the analytical contributions in this area build on the common agency model of Gene Grossman and Elhanan Helpman (1994) where policy is determined by interactions between the policymaker and lobby groups offering the government political contributions contingent on policy decisions made. Although the focus of the Grossman-Helpman model is on trade policy and no environmental externalities are considered, a number of extensions do introduce such externalities (Richard Damania and John List 2000; Richard Damania and Per Fredriksson 2003; Edward Barbier et al. 2005). The second set of studies extends the Grossman-Helpman model to consider the competing influence of domestic and foreign lobbies in the political process of trade policy formation (Kishore Gawande

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<sup>7</sup> For example, the LobbyWatch project of the Center for Public Integrity (<http://www.publicintegrity.org/lobby/>) reports that British Petroleum plc, one of the biggest foreign spenders on Washington DC lobbying, lobbied almost as much on environmental issues and Superfund as it did on matters related to oil and gas.

et al. 2006), which is supported by empirical evidence on the role of foreign lobbies in influencing the U.S. trade policies such as export growth promotion and tariff preferences (Jobst 2002; Kee et al. 2007).

An important shortcoming in the extant literature is that existing studies generally use a static framework. This framework is suspect on two counts: it tends to regard pollution as a flow, despite the fact that the majority of pressing transboundary pollution problems (such as acid rain and water pollution examples mentioned above) are characterized by damages caused by pollution stock. This suggests a need for a dynamic analysis of strategic decision-making. In this paper we develop such a model to consider trade policy as a regulation tool when externality arises from a transboundary *stock* pollutant.<sup>8</sup> Moreover, lobbying “influence” often has to be built and maintained over time. Thus effective lobbying requires close monitoring of legislative processes and maintaining contact with politicians in and out of administration. In other words, “many economists commonly refer to foreign lobbying as a form of ‘investing’ in trade” (Jobst 2002, p. 9) but then ignore the ‘investment’ implication of such lobbying efforts. We address this issue by treating foreign lobbying as an investment in the political capital stock that allows one country to influence the policy choice made by the other country’s government.<sup>9</sup> This approach requires us to use a differential game to characterize the dynamic interaction of the two governments and to examine the optimal strategies that emerge in this setting.

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<sup>8</sup> Such modeling approach is in line with contributions to environmental economics literature that study transboundary pollution problems using differential games (e.g., Engelbert Dockner and Ngo Van Long 1993; John List and Charles Mason 2001; Linda Fernandez 2002).

<sup>9</sup> Hossein Farzin and Jinhua Zhao (2003) use a similar approach. They develop a dynamic model to examine the optimal decisions of a typical firm that foresees a possible future increase in domestic pollution tax and can respond by investing in lobby capital and abatement capital.

We construct a partial equilibrium model to consider two countries, Upstream and Downstream, characterized by two interactions: unidirectional trade and unidirectional transboundary pollution externality. The Upstream country produces and exports to Downstream a consumption good that generates pollution during the manufacturing process. To highlight the case when two countries have conflicting interests and upstream country has no incentives to control for pollution, we assume that Upstream does not suffer any damages from pollution. Upstream emissions contribute to a stock of pollution that only causes damages in Downstream. As it has no authority to directly control Upstream emissions, the Downstream government cannot use environmental policy to regulate the externality. It can, however, choose a sequence of tariffs as a “second-best” measure to address the problem.<sup>10</sup> Using this dynamic model, we show that while a tariff is levied on the flow of imports at each instant, the tariff is determined by accumulated pollution. Thus, the time path of optimal tariffs is tied to the evolution of the pollution stock. This linkage provides a motive for the Upstream government to attempt to influence Downstream’s decision by using political economic tools such as lobbying. Our analysis suggests that the success of trade policy as a tool of promoting cooperation in solving

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<sup>10</sup> Like earlier studies of tariffs as “second-best” tools to tackle transboundary pollution, we make a limiting assumption that Downstream imports the good whose production causes damages in Downstream and thus a tariff against imports is able to reduce the output of the polluting industry. While the WTO rules generally do not allow its members to increase import tariffs, the GATT Article XX (paragraphs b and g) gives limited freedom to use trade measures to protect human health, biodiversity, or to conserve exhaustible natural resources. In cases of transboundary air and water pollution it is conceivable that trade instruments might be used to induce the government with jurisdiction over polluter to address the externality (Francisco Cabo et al, 2001; Bradley Condon 2004; UNEP 2005).



transboundary pollution problems depends crucially on the degree of Downstream government's susceptibility to foreign political influence.<sup>11</sup>

## 2. A Model of Transboundary Pollution Control

Consider two countries, "Upstream" and "Downstream." A single consumption good is produced only in Upstream with a given fixed endowment of factors of production and a given technology. At the trading price, there is an excess supply of this good in the Upstream country, which is being exported to the Downstream country. Consumers are homogeneous within each country, but may be heterogeneous across countries. At every instant, Upstream production  $Q(t)$  in results in a flow of emissions,  $E(t)$ , given by the output-emissions tradeoff function,

$$E(t) = E(Q(t)),$$

We assume that this output-emissions tradeoff function is time-invariant and increasing in the level of output produced

The amount of pollutants emitted by the Upstream country contributes to the stock of pollution,  $Z$ , which evolves according to the following equation of motion:<sup>12</sup>

$$\dot{Z} = E(Q) - kZ, \quad (1)$$

where  $k$  represents the rate of pollution decay. The initial stock of the pollutant is  $Z_0$ . Although pollution is generated by emissions in the Upstream country, we assume that the environmental damage from the stock of pollution is realized in Downstream only and that there are no damages

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<sup>11</sup> Here we restrict our attention to the comparison of two second-best scenarios and do not consider the socially optimal solution to the problem. The comparison of our results to the optimum would involve a contrast between the effects of the environmental tax (first-best) and a tariff (not two different tariffs), which would lead to obvious results.

<sup>12</sup> From now on, unless otherwise stated, we will suppress the time argument  $t$ .

from the flow of emissions. We assume Downstream damages,  $D(Z)$ , are an increasing and convex function of the pollution stock.

Such externalities emerge when the pollutant is transmitted via air, rivers, lakes, or precipitation, and include important cases such as the deterioration of soil and water quality attributed to acid deposition and the degradation of water quality due to accumulated emissions of heavy metals or agricultural runoff. The key feature of such exported externalities is that there exists no supra-national authority with the ability to intervene and enforce cooperation. Thus countries will act only if their efforts ultimately serve their own interest. Since the Upstream country does not suffer any damages from the pollution stock, we assume that it does not impose any environmental regulations on its firms. The Downstream government, in turn, does not have political authority to address the source of pollution directly by imposing a Pigouvian tax or abatement standard on foreign producers. However, it can indirectly tackle the externality by imposing a tariff,  $\tau$ , on imports from the Upstream country. The tariff lowers the price in Upstream and forces firms to cut down the level of production and with it the flow of transboundary emissions, contributing to the pollution stock.<sup>13</sup> The effects of the tariff can be summarized as follows:

$$\partial Q / \partial \tau < 0, \partial Y / \partial \tau < 0, 0 < \partial p / \partial \tau < 1,$$

where  $Y$  is the volume of trade and  $p$  is the Downstream market price; the price in Upstream is  $p - \tau$ .

For any given level of tariff, equilibrium conditions for both countries' markets imply the level of production by Upstream producers, the level of exports to Downstream, and the equilibrium after-tariff prices in both countries are all determined by Downstream's choice of the

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<sup>13</sup>We assume that Downstream has the market power to influence the terms of trade through its tariff.

tariff:  $Q(\tau)$ ,  $Y(\tau)$ ,  $p(\tau)$ . This allows us to write the net benefit functions for Upstream and Downstream, respectively, in the following form:

$$U_u(Q(\tau) - Y(\tau)) - C_u(Q(\tau)) + (p(\tau) - \tau)Y(\tau) \equiv W_u(\tau) \quad (2)$$

$$U_d(Y(\tau)) - (p(\tau) - \tau)Y(\tau) - D(Z) \equiv W_d(\tau) - D(Z), \quad (3)$$

where,  $U_i$  represents consumer benefits in country  $i = u, d$  and  $C_u$  is the cost of production in Upstream. The tariff revenue is assumed to be redistributed among Downstream consumers. Since  $Q$  is influenced by the choice of tariff, so are the associated emissions:  $E(\tau) = E(Q(\tau))$ . As  $E'(Q) > 0$ , the flow of emissions is decreasing with tariff:  $E'(\tau) < 0$ . Through this impact on emissions,  $\tau$  influences the evolution of the stock of pollution.

The objective of the Downstream government is to choose the sequence of tariffs that maximizes the discounted stream of net benefits (3) taking into account the evolution of the pollution stock:

$$\max_{\tau} \int_0^{\infty} e^{-rt} [W_d(\tau) - D(Z)] dt$$

subject to  $\dot{Z} = E(\tau) - kZ, \quad Z(0) = Z_0,$

where  $r$  is the discount rate, common to both countries. The current-value Hamiltonian for this optimization problem can be written as

$$H = W_d(\tau) - D(Z) + \theta [E(\tau) - kZ],$$

where  $\theta$  is the co-state variable representing the shadow price of pollution for the Downstream government and thus is presumably negative.

The necessary conditions for the maximum principle require that the optimal tariff sets the marginal welfare cost associated with the tariff equal to the marginal benefit represented by the shadow value of the marginal pollution reduction,

$$W_d'(\tau) = -\theta E'(\tau), \quad (4)$$

and that the shadow price of pollution evolves at the rate equal to the marginal damage from pollution less the opportunity cost of cutting down emissions by one unit,

$$\dot{\theta} = D'(Z) + (r+k)\theta. \quad (5)$$

By totally differentiating (4) and substituting from (5), we can characterize the equilibrium state and trajectories leading to that state. Accordingly, the evolution of the tariff can be written as

$$\dot{\tau} = \frac{W_d'(\tau)(r+k) - E'(\tau)D'(Z)}{W_d''(\tau) - \frac{W_d'(\tau)}{E'(\tau)}E''(\tau)}. \quad (6)$$

Combining equations (1) and (6), and using the fact that  $\dot{\tau} = \tau'(Z)\dot{Z}$ , we obtain the decision rule for the optimal tariff:

$$\tau'(Z) = \frac{W_d'(\tau)(r+k) - E'(\tau)D'(Z)}{\left(W_d''(\tau) - \frac{W_d'(\tau)}{E'(\tau)}E''(\tau)\right)(E(\tau) - kZ)}. \quad (7)$$

Expression (7) shows that the optimal tariff at every instant is determined by the current level of the pollution stock.<sup>14</sup> In earlier static “second-best” models the players’ environment is considered given rather than evolving endogenously as a result of their actions: pollution is often assumed to be directly proportional to foreign output, making an import tariff optimal. Here we demonstrate that if the externality arises from a stock pollutant, the value of the optimal tariff

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<sup>14</sup> The equilibrium tariff function is characterized by a non-linear first-order ordinary differential equation. Existence of a solution over some compact set of stocks follows from standard theorems (see William Boyce and Richard DiPrima 2005, pp. 68-70).

varies reflecting the evolution of the pollution stock, even though the tax is still applied to the flow of imports rather than to the pollution level directly.

It can be demonstrated that the solution to this optimization problem leads to a unique saddle point steady state  $(Z^e, \tau^e)$  characterized by the following conditions:

$$W_d'(\tau^e)(r+k) = E'(\tau^e)D'(Z^e), \quad (8)$$

$$Z^e = E(\tau^e)/k. \quad (9)$$

The corresponding equilibrium value of the shadow price is

$$\theta^e = -\frac{D'(Z^e)}{r+k}. \quad (10)$$

Figure 1 presents a phase diagram for the problem.

[Figure 1 here]

To characterize the time paths of the tariff and pollution stock and the long-run equilibrium, we consider a model that is based on the linear demand and supply curves, linear marginal cost functions and fixed output-emissions proportions. This gives rise to the following linear-quadratic payoff functions:

$$W_d(\tau) = W_d^0 + A\tau - \frac{B+C}{2}\tau^2,$$

$$W_u(\tau) = W_u^0 - A\tau + \frac{B}{2}\tau^2,$$

where  $A$ ,  $B$ , and  $C$  are positive parameters.  $W_d^0$  and  $W_u^0$  are the trade equilibrium levels of payoffs for the Downstream country and for the Upstream country, respectively, before the tariff

was imposed.<sup>15</sup> Downstream's payoffs are strictly concave, Upstream's payoffs are strictly convex, and both countries' payoff functions are decreasing in tariff.<sup>16</sup> Within this linear-quadratic framework, emissions are linear and decreasing in tariff:

$$E(\tau) = E^0 - \lambda \tau ,$$

where  $E^0$  is the level of emissions generated by the equilibrium level of output produced before the tariff imposition and  $\lambda > 0$  is the marginal decrease in emissions caused by the tariff. Finally, we assume that the stock of pollution generates damages according to the strictly convex quadratic function:

$$D(Z) = \frac{s}{2} Z^2 ,$$

where  $s > 0$  is the rate of increase of the marginal pollution damage.

**PROPOSITION 1:** *There exists a unique globally and asymptotically stable outcome that results in a steady-state pollution stock*

$$Z^e = \Omega(r+k) / \{k(r+k) + s\Phi\} ,$$

*and a steady state tariff*

$$\tau^e = A/(B+C) + s\lambda\Omega / \{(B+C)(k(r+k) + s\Phi)\} ,$$

*where  $\Omega = E^0 - \lambda A/(B+C)$  and  $\Phi = \lambda^2/(B+C)$ . If the initial stock of pollution is small, both the tariff and pollution stock rise monotonically from the initial level to the steady state level.*

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<sup>15</sup> Since we assumed that Downstream is a large country, there exists a small optimum tariff that maximizes Downstream's welfare.  $W_d^0$  and  $W_u^0$  represent welfare levels at the equilibrium established in the presence of the optimal tariff. Introduction of the environmental tariff, considered in this paper, implies that the tariff is increased beyond its optimal level, which is costly for Downstream.

<sup>16</sup> We restrict our attention to the class of non-negative payoff functions, which implies that  $\tau^2 \leq 2(W_d^0 + W_u^0)/C$ .

*Proof.* See Appendix.

The optimal time paths of the pollution stock and tariff solve the system of linear first-order differential equations induced by (1) and (6). We show in the Appendix that these paths are

$$Z(t) = (Z_0 - Z^e)e^{\mu t} + Z^e, \quad (11)$$

$$\tau(t) = h(Z_0 - Z^e)e^{\mu t} + \tau^e. \quad (12)$$

Equations (11) and (12) show that  $Z(t)$  is globally convergent to the steady state  $Z^e$  and  $\tau(t)$  is globally convergent to the steady state  $\tau^e$ . Both the stock of pollution and the tariff rise monotonically from the initial level to the steady state level, assuming that the initial stock of pollution is small. At the same time, emissions and the tariff move in opposite directions across time, so that the emission level decreases over time.

Using (11) and (12) we can rewrite the optimal tariff choice as a feedback rule in terms of the current pollution stock:

$$\tau(Z) = h(Z - Z^e) + \tau^e. \quad (13)$$

The coefficient of proportionality  $h$  captures the marginal response of the Downstream government to an increase in the pollution stock. Since  $h$  is positive, it follows from the feedback rule (13) that  $\tau'(Z) > 0$ , i.e., if the stock of pollution is increasing, the Downstream authority will react by raising the tariff. While the tariff still targets the flow of goods, at every point in time it is adjusted to reflect the current level of the pollution stock, the source of the externality. We show in the Appendix that  $h$  is increasing in  $s$  and  $\lambda$ , and decreasing in  $k$  and  $r$ . If the rate of change of the marginal damages from pollution,  $s$ , rises or if total emissions decrease faster with the tariff, at every instant, the Downstream government will respond to an increase in pollution by a larger increase in tariff. By contrast, increases in the rate of discount,  $r$ , or the rate of

pollution decay,  $k$ , lead to a decrease in the marginal tariff response to a higher pollution level by the Downstream policymaker, since both  $r$  and  $k$  are increasing the opportunity cost of reducing emissions via tariff imposition.

The equilibrium emission path in this simple model can also be contrasted to those found in earlier papers on transboundary pollution problems (Dockner and Long 1993; List and Mason 2001). These earlier studies generally assume the existence of some kind of over-arching regulatory authority that can control emissions. This authority chooses the rate of emissions for both of the countries, with the goal of maximizing the joint welfare of the two regions. In our model, the time path of the pollution control is determined by unilateral and non-cooperative actions of a single policymaker. Welfare maximization problem of this government, however, contains the information about the effect of the policy on the other country's welfare, implicit in the volume of trade and price changes over time, induced by the tariff.

The downstream tariff choice determines the level of welfare in the Upstream country, with increased tariffs lowering Upstream's net surplus. As a result, there is an incentive for Upstream to attempt to influence Downstream's policy decisions in its favor.

### **3. Transboundary Pollution Control in the Presence of Foreign Lobbying**

We now consider the possibility that the Upstream government attempts to exert political pressure so as to impact the Downstream's tariff policy. Imagine that the Upstream government can engage in foreign lobbying to affect the tariff decision by the Downstream government. We interpret this lobbying as an investment in political capital, where accumulated political capital is used by the Upstream government to lobby the authority in Downstream. To fix ideas, one can think of this stock of political capital as a fund of actual financial capital, which is used to make contributions to political parties, candidates or election campaigns. The accumulated influence



over the legislative members in Downstream may be translated into majority of votes necessary to make a tariff policy decision. Increases in political capital allow the Upstream government to exert a greater influence on the Downstream policymaker's tariff choice, leading to increased Upstream welfare. The political capital,  $P$ , is assumed to evolve over time according to the following rule:

$$\dot{P} = I - \delta P, \quad (14)$$

where  $I$  is the level of investment in political capital by the Upstream government, and  $\delta$  is the rate of depreciation of political capital. Depreciation captures the notion that past lobby contributions are not as effective as current ones in influencing current policy determination. Investment in political capital entails an opportunity cost  $\varphi(I)$  to Upstream; we assume  $\varphi(I)$  is increasing and strictly convex in  $I$ .

When the Upstream country engages in lobbying for a less stringent tariff policy, it is no longer acting as a static player in the game. With both countries now making dynamic decisions that affect each player's payoffs, the appropriate model for our analysis is a differential game. We assume that both governments use Markov-perfect (feedback) strategies. These strategies are decision rules that dictate optimal actions of the respective players conditional on the current values of the pollution stock  $Z(t)$  and political capital stock  $P(t)$ , which summarize the latest available information of the dynamic system. Thus Markov perfect strategies determine a subgame-perfect equilibrium: at every time  $t$  and for every possible value of  $Z(t)$  and  $P(t)$ , the strategy defines an equilibrium set of decisions independent of previous actions.

Assuming that the Downstream government plays the Markov strategy  $\tau(Z(t), P(t))$ , the Upstream government chooses the time path of investment by solving the following maximization problem:

$$\max_I \int_0^{\infty} e^{-rt} [W_u(\tau(Z, P)) - \varphi(I)] dt$$

subject to

$$\dot{Z} = E(\tau(Z, P)) - kZ, \quad Z(0) = Z_0,$$

$$\dot{P} = I - \delta P, \quad P(0) = P_0.$$

We solve this problem using Pontryagin's maximum principle. The current-value Hamiltonian is formulated as

$$H_u = W_u(\tau(Z, P)) - \varphi(I) + \xi_Z(E(\tau(Z, P)) - kZ) + \xi_P(I - \delta P),$$

where  $\xi_Z$  represents the shadow price of pollution and  $\xi_P$  represents the shadow price of political capital for the Upstream country. The maximum condition and the adjoint equations for the shadow prices of pollution and political capital, respectively, are

$$\varphi'(I) = \xi_P, \quad (15)$$

$$\dot{\xi}_Z = (r + k)\xi_Z - W'_u(\tau) \frac{\partial \tau(Z, P)}{\partial Z} - \xi_Z E'(\tau) \frac{\partial \tau(Z, P)}{\partial Z}, \quad (16)$$

$$\dot{\xi}_P = (r + \delta)\xi_P - W'_u(\tau) \frac{\partial \tau(Z, P)}{\partial P} - \xi_Z E'(\tau) \frac{\partial \tau(Z, P)}{\partial P}. \quad (17)$$

The partial derivatives  $\partial \tau(Z, P) / \partial Z$  and  $\partial \tau(Z, P) / \partial P$  capture the reactions of the Downstream government to an increase in the two stocks. The marginal response of the Downstream government to an increase in pollution stock is  $\partial \tau(Z, P) / \partial Z$ , while  $\partial \tau(Z, P) / \partial P$  is the marginal influence of the Upstream's lobbying efforts on the tariff decision by the Downstream policymaker. One expects that the Downstream government will be inclined to increase the tariff when the pollution stock increases, i.e.,  $\partial \tau(Z, P) / \partial Z > 0$ . One also expects that increases in the political capital stock will induce the Downstream government to reduce the tariff, i.e.,  $\partial \tau(Z, P) / \partial P < 0$ . The maximum condition (15) implies that, at every instant, the Upstream

government chooses the level of investment in political capital that equates the marginal cost of such investment and the shadow price of the political capital. Equation (16) shows that the rate of change in the shadow price of pollution for the Upstream government is determined by the opportunity cost of reducing emissions by one unit, marginal reduction in Upstream's net surplus induced by that unit of emissions, and marginal contribution of that emission unit to the current value of the pollution stock. The evolution rule for the shadow price of political capital, (17), implies that the shadow price of  $P(t)$  changes at the rate determined by the opportunity cost of holding on to a unit of political capital, marginal change in the current level of welfare in Upstream induced by that unit, marginal contribution of that unit to the current value of pollution stock. The system of equations (15)-(17) illustrates that strategic considerations make the Upstream policymaker account for pollution accumulation in determining her strategy, even though the Upstream country is not adversely affected by the stock of pollution.

**PROPOSITION 2** *If the Downstream government's Markov-perfect strategy  $\tau(Z, P)$  has  $\partial\tau(Z, P)/\partial Z > 0$  and  $\partial\tau(Z, P)/\partial P < 0$  in the neighborhood of the steady state, then the steady state levels of investment and political capital are both positive.*

*Proof.* See Appendix.

Politics adds yet another layer to the Downstream policymaker's decision process: the choice of the optimal tariff strategy is now influenced by lobbying efforts of the Upstream government and, in particular, by the level of political capital at every instant. In spirit of Grossman and Helpman (1994), we assume that the Downstream government's objective function in this case is represented by the additional utility that the Downstream policymaker derives from political contributions made by the Upstream government plus the discounted sum

of citizens' welfare,  $(W_d(\tau) - D(Z))$ . The first component represents the political influence of the Upstream government, achieved by the accumulation of political capital that we model as an increasing and concave function of political capital,  $F(P)$ ; we assume this function satisfies the Inada conditions.<sup>17</sup>

Assuming that the Upstream authority plays the Markov-perfect strategy  $I(Z(t), P(t))$ , the Downstream government chooses the time path of the tariff by solving the following maximization problem:

$$\max_{\tau} \int_0^{\infty} e^{-rt} [W_d(\tau) - D(Z) + F(P)] dt$$

subject to

$$\dot{Z} = E(\tau) - kZ, \quad Z(0) = Z_0,$$

$$\dot{P} = I(Z, P) - \delta P, \quad P(0) = P_0.$$

The current-value Hamiltonian for this problem can be written as:

$$H_d = W_d(\tau) - D(Z) + F(P) + \eta_z(E(\tau) - kZ) + \eta_p(I(Z, P) - \delta P),$$

where  $\eta_z$  denotes the shadow price of pollution and  $\eta_p$  denotes the shadow price of political capital for the Downstream country's government. The maximum principle conditions are

$$W_d'(\tau) = -\eta_z E'(\tau), \quad (18)$$

$$\dot{\eta}_z = (r + k)\eta_z + D'(Z) - \eta_p \frac{\partial I(Z, P)}{\partial Z}, \quad (19)$$

$$\dot{\eta}_p = (r + \delta)\eta_p - F'(P) - \eta_p \frac{\partial I(Z, P)}{\partial P}. \quad (20)$$

The partial derivative  $\frac{\partial I(Z, P)}{\partial Z}$  represents the marginal response of the Upstream authority to an increase in the stock of pollution. It is expected that  $\frac{\partial I(Z, P)}{\partial Z} > 0$ ; i.e., when

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<sup>17</sup> These are  $\lim_{P \rightarrow 0} F'(P) = \infty$  and  $\lim_{P \rightarrow \infty} F'(P) = 0$ . We also assume that  $F(0) = 0$ .

the pollution stock is large, the Upstream decision-maker will have some incentive to invest in political capital and lobby for the lower tariff rate. The partial derivative  $\partial I(Z, P) / \partial P$  captures the marginal rate of investment induced by an increase in the political capital stock.  $\partial I(Z, P) / \partial P$  is expected to be negative, since the marginal contribution of political capital to the influence upon the Downstream policymaker's decisions gained through lobbying diminishes as the stock of political capital grows over time. Equation (18) implies that the optimal tariff chosen by the Downstream government sets the marginal loss of net payoffs, resulting from the tariff imposition, equal to the shadow value of the marginal decrease in combined emissions induced by this tariff. Equation (19) shows that the shadow price of pollution evolves at a rate determined by the opportunity cost of reducing emissions by one unit, the marginal damages caused by that unit, and also by the marginal contribution of that emission unit to the enhancement of political capital value. Equation (20) tells us that the rate of change of the shadow price of political capital for the Downstream government is given by the opportunity cost of holding on to a unit of political capital, marginal benefits received by the Downstream government from that unit, and the marginal contribution of that unit to the political capital value.

The system (18)-(20) illustrates how the accumulation of political capital translates into the influence of the Upstream country's government over the Downstream authority's decisions. Because the Downstream policymaker derives additional utility from political contributions, she realizes the shadow price of the political capital stock, representing the marginal utility she would give up if one less unit of political capital was available. This information is being used by the Downstream authority in formulating the Markov perfect strategy: equation (19) implies that the dynamics of the shadow price of pollution is conditioned on the shadow price of political capital for the Downstream government. Comparison between equations (5), representing the

evolution of the shadow price of pollution in the simple version of the model, and (19), showing the time path of the pollution co-state variable in the presence of international lobbying, demonstrates that political capital investment affects the evolution of the shadow price of pollution in the Downstream country, which, in turn, alters the time path of the optimal tariff, as implied by equation (18).

The steady state equilibrium requires  $\dot{\eta}_Z = \dot{\eta}_P = 0$ . The Downstream shadow prices of political capital and pollution in the Markov perfect equilibrium,  $(\eta_P^{MP}, \eta_Z^{MP})$ , are therefore

$$\eta_P^{MP} = \frac{F'(P^{MP})}{(r + \delta) - \partial I(Z^{MP}, P^{MP}) / \partial P}, \quad (21)$$

$$\eta_Z^{MP} = \theta^{MP} + \frac{\eta_P^{MP} \partial I(Z^{MP}, P^{MP}) / \partial Z}{r + k}. \quad (22)$$

From (10), the term  $\theta^{MP} = -\frac{D'(Z^{MP})}{r + k}$  is the marginal value of pollution that would be realized

for  $Z^{MP}$  in the absence of foreign lobbying. Hence the second term in expression (22) represents the distortion that Upstream's lobbying introduces in the valuation of pollution stock by the Downstream government. The steady state tariff,  $\tau^{MP}$ , can be obtained by substituting from equation (22) into the first order condition (18), and the steady state level of pollution is given by

$$Z^{MP} = E(\tau^{MP}) / k. \quad (23)$$

LEMMA  $W_d'(\tau) / E'(\tau)$  is a positive and increasing function of  $\tau$ .

*Proof.* See Appendix.

We can now state and prove the following result.

PROPOSITION 3 *If the Upstream country's Markov-perfect strategy  $I(Z,P)$  has  $\partial I(Z,P)/\partial Z > 0$  and  $\partial I(Z,P)/\partial P < 0$  in the neighborhood of the steady state, then compared to the simple version of the model: a) the steady state tariff chosen by the Downstream country is smaller, and b) the steady state pollution level is larger.*

*Proof.* See Appendix.

Proposition 3 demonstrates how political factors such as foreign lobbying can lead to less stringent regulations of the transboundary pollution externality in the long-run. If the Upstream country brings international political capital into play, it is capable of increasing the magnitude of the steady state shadow price of pollution for the Downstream authority and thus achieving a lower tariff rate in the long-run, which favors Upstream's welfare. Lower equilibrium tariff leads to a higher level of combined emissions in the long run and, consequently, to exacerbation of the environmental problem. As follows from equation (22), the distortion in the long run tariff rate depends on the magnitude of the steady state shadow price of political capital for the Downstream government. Equation (21) shows that the steady state shadow price of  $P$ , in turn, is determined by the marginal utility,  $F'(P^{MP})$ , that the Downstream government derives from lobby contributions in the long run. Higher values of  $F'(P^{MP})$  indicate the Downstream policymaker's willingness to set the tariff rate that diverges from the social welfare-maximizing level in return for political contributions. Thus the marginal utility  $F'(P^{MP})$  can be interpreted as an indicator of the level of corruption in the Downstream government or susceptibility of the Downstream authority to the international political influence. The level of corruption is reflected by the government's willingness to allow Upstream's lobby to influence its policy, i.e., the propensity to sell policies for personal gains in the form of monetary transfers.

The latter interpretation is in line with Gunter Schulze and Heinrich Ursprung (2001), who note that in the political-economic models of trade and environment political contributions may have a purpose of influencing government policy, not the election outcome.

In order to examine long-run welfare implications of foreign lobbying, consider first the two countries in the neighborhood of the steady state of our reference scenario presented in the second section, where the Upstream country does not engage in foreign lobbying and the Downstream government determines the tariff rate by maximizing her constituents' welfare.<sup>18</sup> After the steady state is reached, the Downstream country's social welfare is given by  $W_d(\tau^e) - D(Z^e)$  and the Upstream country's social welfare is given by  $W_u(\tau^e)$ , where  $\tau^e$  is the Downstream citizens' welfare maximizing long-run level of the tariff, and  $Z^e$  is the corresponding steady state level of pollution. Let us then allow the Upstream government to engage in foreign lobbying for a lower tariff according to our second scenario described in the present section. Our findings indicate that at each point in time, the rate of political investment is determined by the current level of the shadow price of political capital, and in the steady state associated with this scenario, the Upstream country's welfare is determined by  $W_u(\tau^{MP}) - \varphi(I^{MP})$ . Proposition 2 illustrates the existence of the interior solution where the steady state investment rate,  $I^{MP}$ , is positive. Then similarly to the revealed preference argument, we can infer that political investment allows the Upstream government to increase her country's long-run welfare level, since otherwise she would choose a zero investment rate. The steady state social welfare level in the Downstream country in the presence of foreign lobbying

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<sup>18</sup> While we realize that the welfare transition path to the long-run equilibrium is interesting, solving for this path is generally analytically intractable. While one could obtain these paths by resorting to numerically specified functions, we prefer to not do so, and therefore focus on the comparison of the steady states.



is given by  $W_d(\tau^{MP}) - D(Z^{MP})$ . According to Proposition 3,  $\tau^{MP} < \tau^e$ . Since  $\tau^e$  maximizes Downstream's social welfare in the long run, it then follows that foreign lobbying leads to a reduction in the social welfare of Downstream's citizens. The same argument can be extended to the cases when foreign lobbying is introduced at any point along the Downstream's optimal path described by the model without lobbying from the previous section. At any point in time, political capital used by the Upstream country to make contributions to the Downstream government imposes a cost on the rest of the society in Downstream and causes a divergence of the tariff rate, pollution stock, and thus citizen's welfare, from the socially optimal paths. We summarize these remarks in the following proposition.

**PROPOSITION 4** *If the Upstream authority engages in foreign lobbying for a lower tariff, then social welfare of the Upstream country increases and social welfare in the Downstream country falls.*

#### **4. Evolution and Stability Properties of the Markov Perfect Equilibrium**

We lastly discuss the evolution of pollution and political capital stocks and stability properties of the steady state equilibrium generated in the foreign lobbying game. In order to do so, we need to obtain the equilibrium strategies of both players. In general, finding the Markov perfect equilibrium is very difficult, since it requires solving two simultaneous partial differential equations. This difficulty can be resolved in a linear-quadratic framework, as this allows Markov perfect strategies to be linear in both state variables. We therefore return to the linear-quadratic specifications introduced in Section 2, assuming in addition that the political investment cost,  $\varphi(I)$ , and the Downstream government's utility derived from foreign lobby contributions,  $F(P)$ , are each quadratic functions. Specifically, we assume:

$$\varphi(I) = \frac{1}{2}I^2, \text{ and}$$

$$F(P) = fP - \frac{1}{2}P^2,$$

where  $f$  is a positive parameter that reflects the weight given to lobby contributions in the Downstream authority's objective function. Similarly to Grossman and Helpman (1994), higher values of  $f$  indicate that Downstream authority is more willing to set tariff policy that diverge from the optimal tariff strategy in return for lobby contributions.

As above, both governments maximize their net benefits subject to the evolution rules for the pollution stock and political capital stock:

$$\begin{aligned} \max_I \int_0^\infty e^{-rt} \left[ W_u^0 - A\tau + \frac{B}{2}\tau^2 - \frac{1}{2}I^2 \right] dt \\ \max_\tau \int_0^\infty e^{-rt} \left[ W_d^0 + A\tau - \frac{B+C}{2}\tau^2 - \frac{s}{2}Z^2 + (fP - \frac{1}{2}P^2) \right] dt \end{aligned}$$

subject to

$$\dot{Z} = E^0 - \lambda\tau - kZ, \quad Z(0) = Z_0,$$

$$\dot{P} = I - \delta P, \quad P(0) = P_0.$$

This class of linear-quadratic differential games has equilibrium strategies that are linear in state variables:

$$\tau(Z, P) = \alpha_1 + \alpha_2 Z - \alpha_3 P, \quad (24)$$

$$I(Z, P) = \gamma_1 + \gamma_2 Z - \gamma_3 P, \quad (25)$$

where  $\alpha_i$  and  $\gamma_i$ ,  $i=1,2,3$ , are positive parameters. We restrict our consideration to interior solutions and assume that Markov-perfect strategies (24) and (25) satisfy conditions of Propositions 2 and 3, meaning that both the tariff and investment are increasing in the pollution stock and decreasing in political capital.

Upon substitution of the equilibrium strategies (24) and (25) into state equations, can the state equations for pollution and political capital can be rewritten as:

$$\dot{Z} = (E^0 - \lambda\alpha_1) - (\lambda\alpha_2 + k)Z + \lambda\alpha_3P, \quad (26)$$

$$\dot{P} = \gamma_1 + \gamma_2Z - (\gamma_3 + \delta)P. \quad (27)$$

The solution to the system (26) - (27) gives the Markov perfect equilibrium strategies. The following proposition describes the existence and stability characteristics of the Markov perfect equilibrium, along with the monotonicity properties of the time paths for pollution and political capital.

**PROPOSITION 5** *There exists a pair of linear feedback strategies that constitutes an asymptotically stable Markov perfect equilibrium (stable node) that results in a steady state pollution stock given by*

$$Z^{MP} = \frac{(E^0 - \lambda\alpha_1)(\gamma_3 + \delta) + \lambda\alpha_3\gamma_1}{(\lambda\alpha_2 + k)(\gamma_3 + \delta) - \lambda\alpha_3\gamma_2}, \quad (28)$$

*and political capital stock given by*

$$P^{MP} = \frac{\gamma_1(\lambda\alpha_2 + k) + \gamma_2(E^0 - \lambda\alpha_1)}{(\lambda\alpha_2 + k)(\gamma_3 + \delta) - \lambda\alpha_3\gamma_2}. \quad (29)$$

*If the initial levels of pollution and political capital are small, both the pollution stock and political capital stock rise from the initial level to the steady state level.*

*Proof.* See Appendix.

If the initial stock of pollution,  $Z_0$ , is sufficiently smaller than the steady state pollution stock,  $Z^{MP}$ , then pollution will rise monotonically to the steady state level. However, if we start with the accumulated pollution level that is fairly close to its steady state value then the stock of pollution will fall initially and then rise monotonically to  $Z^{MP}$ . A similar property holds for the

political capital stock. Arguments similar to those given in the proof of Proposition 5 can be used to show that both stocks will decrease monotonically to their steady state equilibrium level when the initial level are sufficiently larger than the steady state values. However, if the starting level of either stock is fairly close to the long-run equilibrium, then the stock will experience an initial increase followed by a monotonic descent to the steady state.

The optimal solution paths for the stock of pollution and political capital are depicted graphically in Figure 2. In general, our model would require construction of a four-variable phase diagram to illustrate the convergence of the system to the Markov perfect equilibrium. But in view of the fact that both the optimal tariff and investment paths are linearly dependent on  $\dot{Z}$  and  $\dot{P}$ , we are able to reduce the representation of our four-dimensional equilibrium to a two-dimensional phase diagram. Figure 2 displays a unique and stable equilibrium, and the directions of phase trajectories suggest that the time paths of political capital and pollution stocks are determined by their initial levels. If both the initial levels of stocks are sufficiently far away from the long run equilibrium, the streamlines never venture beyond a single phase space region, and both the stocks monotonically ascend to the steady state (or descend, in the case of high initial levels of  $Z$  and  $P$ ). By contrast, if the initial value of either stock is sufficiently close to the respective steady state level, the streamlines will cross over from one phase space region onto another, showing that the direction of movement of this stock will change along its evolution path.

[Figure 2 here]

## 5. Concluding Remarks

Pollution often does not respect political boundaries; in many cases, several countries are concerned with and affected by environmental degradation. Regulation of transboundary

externalities is particularly problematic when damages are asymmetric, and some countries are unaffected or less affected by the externality than other countries. In such cases, trade policies can be both a “second best” tool to control the problem and a mechanism to encourage cooperation between upstream and downstream countries. This paper improves our understanding of both aspects of trade policy role in transboundary externalities regulation by allowing for transboundary stock pollutants and international political lobbying.

While transboundary stock pollutants, which encompass important real world examples such as acid rain and water pollution, are of substantial interest for international environmental policymaking, they have been largely ignored in the extant literature. Our results show that an atemporal import tariff alone cannot be an optimal response to the transboundary externality. Instead, at every point in time, the optimal tariff is determined by the current level of accumulated pollution as it adjusts to the endogenous changes in the pollution stock: if the stock of pollution increases, so does the tariff. The feedback rule of tariff determination we derive can be seen as the “good news” for the use of trade policy as a regulation tool for transboundary pollution problems.

It has been suggested that trade measures may serve as one of the plausible ways to modify the behavior of the upstream government and to stimulate international cooperation. In the context of our model, this could imply that the Upstream country has an incentive to engage in pollution abatement to deter the Downstream country from imposing more severe tariffs in response to the rising pollution stock. But these same concerns also create an incentive for the Upstream country to engage in activities that would negatively affect the externality regulation, such as the incentive to lobby for lower tariffs. Failure to identify and consider these negative incentives can lead to misleading conclusions regarding the effectiveness of trade policy in

promoting cooperation between the countries linked by the externality. We show that if the government of the downstream country is susceptible to foreign political influence, then the upstream authority finds it optimal to maintain a positive steady state level of investment in foreign lobbying capital, used to impact the downstream authority's policy choice. As a result of foreign lobbying, downstream country's tariff policy exhibits signs of divergence from its socially optimal path, and distortions in the externality regulation depend on the degree of corruptibility of the downstream authority. Consequently, foreign lobbying leads to the degradation of environmental quality and the model leads to an intuitive outcome: distortions brought by corruption and foreign lobbying lead to a rise in the upstream country's social welfare, and to a decrease in social welfare in the downstream country.

Our findings suggest that the usefulness of trade policy as an instrument for promoting cooperation and internalizing transboundary externalities depends critically on the degree of governments' susceptibility to foreign political influence. Essentially, foreign lobbying offers the upstream government an alternative to environmental regulation and abatement if she is trying to lower the tariff her country is facing. As noted in Hiau Kee et al. (2004, pp. 3-4), foreign lobbying is a high return activity, and may therefore provide a cheaper alternative to the administrative costs of implementation and monitoring of environmental regulations. When the Downstream authority is susceptible to such political influence, the potential for trade measures to encourage international cooperation in regulating the externality can be sharply reduced. Given that corruption exists in all countries (Ramon Lopez and Siddhartha Mitra 2000, pp. 138-39), at least to some degree, this result is the "bad news" for the usefulness of trade policy in encouraging international cooperation in regulating transboundary pollution.

While our results show the importance of including political economy considerations in the trade and environmental policy discussion, we have only considered one aspect of political lobbying. It would be interesting to consider lobbying by other special-interest groups, such as domestic producers in the downstream country seeking higher level of protection or consumer interest groups. Allowing for such additional political lobbying could yield interesting results, and may therefore represent a fruitful line of further inquiry.

## Appendix

### Proof of Proposition 1

The linear-quadratic functional forms allow us to rewrite the time path for the tariff, equation (6),

$$\text{as } \dot{\tau} = -A(r+k)/(B+C) + (r+k)\tau - s\lambda Z/(B+C).$$

Similarly, the equation of motion for the pollution stock can be rewritten as

$$\dot{Z} = E^0 - \lambda\tau - kZ.$$

This pair of differential equations can be expressed in matrix notation as

$$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \dot{\tau} \\ \dot{Z} \end{bmatrix} + \begin{bmatrix} -(r+k) & s\lambda/(B+C) \\ \lambda & k \end{bmatrix} \begin{bmatrix} \tau \\ Z \end{bmatrix} = \begin{bmatrix} -A(r+k)/(B+C) \\ E^0 \end{bmatrix}$$

To solve for the steady state values of  $\tau$  and  $Z$ , we set  $\dot{\tau} = \dot{Z} = 0$ ; this yields:

$$\tau^e = A/(B+C) + s\lambda\Omega/\{(B+C)(k(r+k) + s\Phi)\},$$

$$Z^e = \Omega(r+k)/\{k(r+k) + s\Phi\},$$

where  $\Omega = E^0 - \lambda A/(B+C)$  and  $\Phi = \lambda^2/(B+C)$ . The solution to the above system of differential

equations in is a pair of exponentials. Accordingly, we adopt trial solutions of the form

$Z(t) = me^{\mu t}$  and  $\tau(t) = ne^{\mu t}$ . Substitution of these into the reduced equation yields the result

$$\begin{bmatrix} \mu - (r+k) & s\lambda/(B+C) \\ \lambda & \mu + k \end{bmatrix} \begin{bmatrix} n \\ m \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

To avoid trivial solutions, the determinant of the coefficient matrix must be equal to zero. This produces the characteristic equation for this system as

$$\mu^2 - r\mu - (k(r+k) + s\Phi) = 0.$$

There are two roots to this quadratic:  $\mu = r/2 \pm \sqrt{r^2/4 + k(r+k) + s\Phi}$ . To ensure stability of the

system, and the steady-state, we select the negative root:  $\mu = r/2 - \sqrt{r^2/4 + k(r+k) + s\Phi}$ .



An infinite number of combinations of  $m$  and  $n$  solve the system; these are tied together

by the equation  $n = hm$ , where  $h = \frac{s\lambda}{(B+C)(r+k-\mu)}$  is a coefficient of proportionality. The

general solution emerges in the form

$$Z(t) = (Z_0 - Z^e)e^{\mu t} + Z^e, \quad (\text{A1})$$

$$\tau(t) = h(Z_0 - Z^e)e^{\mu t} + \tau^e. \quad (\text{A2})$$

### Comparative Dynamic Effects

Using the expression for  $\mu$  in derived above, and the definition of  $\Phi$ , we can express  $h$  as

$$h = \frac{s\lambda}{(B+C) \left[ r/2 + k + \sqrt{(r/2 + k)^2 + s\lambda^2 / (B+C)} \right]}.$$

It is then straightforward to show that

$$\frac{\partial h}{\partial s} = \frac{\lambda}{(B+C) \left[ r/2 + k + \sqrt{(r/2 + k)^2 + s\lambda^2 / (B+C)} \right]^2} \left( r/2 + k + \frac{2(r/2 + k)^2 + s\lambda^2 / (B+C)}{2\sqrt{(r/2 + k)^2 + s\lambda^2 / (B+C)}} \right) > 0$$

$$\frac{\partial h}{\partial \lambda} = \frac{s}{(B+C) \left[ r/2 + k + \sqrt{(r/2 + k)^2 + s\lambda^2 / (B+C)} \right]^2} \left( r/2 + k + \frac{(r/2 + k)^2}{\sqrt{(r/2 + k)^2 + s\lambda^2 / (B+C)}} \right) > 0$$

$$\frac{\partial h}{\partial k} = -\frac{s\lambda}{(B+C) \left[ r/2 + k + \sqrt{(r/2 + k)^2 + s\lambda^2 / (B+C)} \right]^2} \left( 1 + \frac{r/2 + k}{\sqrt{(r/2 + k)^2 + s\lambda^2 / (B+C)}} \right) < 0$$

$$\frac{\partial h}{\partial r} = -\frac{s\lambda}{2(B+C) \left[ r/2 + k + \sqrt{(r/2 + k)^2 + s\lambda^2 / (B+C)} \right]^2} \left( 1 + \frac{r/2 + k}{\sqrt{(r/2 + k)^2 + s\lambda^2 / (B+C)}} \right) < 0$$

## Proof of Proposition 2

It follows from equations (16) and (17) that at the steady state equilibrium where  $\dot{\xi}_Z = \dot{\xi}_P = 0$  holds the Upstream decision-maker has the following long-run shadow prices of pollution and political capital, respectively (the superscript MP stands for the Markov perfect equilibrium):

$$\xi_Z^{MP} = \frac{W'_u(\tau^{MP}) \frac{\partial \tau(Z^{MP}, P^{MP})}{\partial Z}}{r + k - E'(\tau^{MP}) \frac{\partial \tau(Z^{MP}, P^{MP})}{\partial Z}} \quad (A3)$$

$$\xi_P^{MP} = \frac{(r + k)W'_u(\tau^{MP}) \frac{\partial \tau(Z^{MP}, P^{MP})}{\partial P}}{(r + \delta)(r + k - E'(\tau^{MP}) \frac{\partial \tau(Z^{MP}, P^{MP})}{\partial Z})} \quad (A4)$$

If  $\partial \tau(Z, P) / \partial Z > 0$  in the neighborhood of the steady state, equation (A3) shows that the Markov perfect equilibrium is characterized by a negative shadow price of pollution for the Upstream government. It indicates that although the Upstream country does not suffer environmental damages from the stock of pollution, being a strategic player it considers pollution to be a “bad”: the Upstream authority recognizes that accumulated pollution leads to a reduction in the Upstream country’s welfare via increasing tariff and uses this information when formulating the Markov perfect strategy. As it follows from equation (A4),  $\partial \tau(Z^{MP}, P^{MP}) / \partial Z > 0$  and  $\partial \tau(Z^{MP}, P^{MP}) / \partial P < 0$  imply that the steady state shadow price of political capital for the Upstream government is positive. It is clear from equations (14) and (15), that in this case the steady state level of political investment,  $I^{MP}$ , and the steady state level of the political capital stock,  $P^{MP} = I^{MP} / \delta$ , are both positive.

### Proof of Lemma

It is clear from the maximum conditions for the Downstream country that marginal net benefits,  $W_d'(\tau)$ , and marginal total emissions,  $E'(\tau)$ , have the same sign since the shadow price of pollution is negative. Intuitively, it means that a reduction in the net surplus induced by the tariff is equal to the opportunity cost of a decrease in emissions flow that this tariff allows to achieve. To show that  $W_d'(\tau)/E'(\tau)$  is an increasing function of the tariff, we differentiate this function with respect to  $\tau$ :

$$\left( \frac{W_d'(\tau)}{E'(\tau)} \right)' = \frac{1}{E'(\tau)} \left[ W_d''(\tau) - \frac{W_d'(\tau)}{E'(\tau)} E''(\tau) \right] \quad (\text{A5})$$

In (A5), the expression in brackets is the second order condition for the Downstream country's maximization problem, and therefore is negative. Since  $E'(\tau) < 0$ , the whole expression (A5) is positive; thus  $W_d'(\tau)/E'(\tau)$  is an increasing function of  $\tau$ .

### Proof of Proposition 3

Assume the opposite and let the steady state tariff chosen by the Downstream government be higher in the presence of foreign lobbying:

$$\tau^{MP} \geq \tau^e. \quad (\text{A6})$$

Since emissions are decreasing with tariff, we can write that

$$E(\tau^{MP}) \leq E(\tau^e).$$

It is then clear from equations (9) and (23) that  $Z^{MP} \leq Z^e$ . Given that the damage function,  $D(Z)$ , is increasing and strictly convex, it follows that

$$D'(Z^{MP}) \leq D'(Z^e),$$

and therefore

$$-\frac{D'(Z^{MP})}{r+k} \geq -\frac{D'(Z^e)}{r+k},$$

or equivalently

$$\theta^{MP} \geq \theta^e. \quad (\text{A7})$$

If  $\partial I(Z^{MP}, P^{MP}) / \partial Z > 0$  and  $\partial I(Z^{MP}, P^{MP}) / \partial P < 0$ , equation (21) implies that

$$\frac{\eta_P^{MP} \partial I(Z, P) / \partial Z}{r+k} > 0. \quad (\text{A8})$$

Combining inequalities (A7)-(A8) with equation (22), we can infer that

$$\eta_Z^{MP} > \theta^e.$$

In light of Lemma, it then follows from equations (4) and (18) that

$$\tau^{MP} < \tau^e,$$

which says the opposite to our initial assumption (A6). Hence Proposition 3 is proved by contradiction.

### Proof of Proposition 5

A first-order linear differential equation system (26)-(27) produces the following solution paths for the pollution stock and political capital stock, respectively:

$$Z(t) = m_1 e^{\rho_1 t} + m_2 e^{\rho_2 t} + Z^{MP}, \quad (\text{A9})$$

$$P(t) = a_1 m_1 e^{\rho_1 t} + a_2 m_2 e^{\rho_2 t} + P^{MP}, \quad (\text{A10})$$

where

$$\rho_1 = -\frac{1}{2}(\lambda\alpha_2 + k + \gamma_3 + \delta) - \sqrt{\frac{1}{4}(\lambda\alpha_2 + k - \gamma_3 - \delta)^2 + \lambda\alpha_3\gamma_2}$$

and

$$\rho_2 = -\frac{1}{2}(\lambda\alpha_2 + k + \gamma_3 + \delta) + \sqrt{\frac{1}{4}(\lambda\alpha_2 + k - \gamma_3 - \delta)^2 + \lambda\alpha_3\gamma_2}$$

are the characteristic roots.  $\rho_1 < 0$ , while  $\rho_2$  can be positive or negative, depending on the parameters of the model. To ensure stability of the steady state equilibrium, we assume that  $\rho_1 < \rho_2 < 0$ .  $m_1$  and  $m_2$  are the arbitrary constants, and  $a_1$  and  $a_2$  are proportionality coefficients:

$$a_1 = (\lambda\alpha_2 + k + \rho_1) / \lambda\alpha_3 = \gamma_2 / (\gamma_3 + \delta + \rho_1), \quad (\text{A11})$$

$$a_2 = (\lambda\alpha_2 + k + \rho_2) / \lambda\alpha_3 = \gamma_2 / (\gamma_3 + \delta + \rho_2), \quad (\text{A12})$$

where  $a_1 < 0$  and  $a_2 > 0$ . Finally,  $Z^{MP}$  and  $P^{MP}$  are the steady state values of pollution stock and political capital, defined in (28) and (29).

Since we consider both characteristic roots  $\rho_1$  and  $\rho_2$  to be negative, it entails that the determinant of the Jacobian matrix of the system (26)-(27),  $|J_E| = (\lambda\alpha_2 + k)(\gamma_3 + \delta) - \lambda\alpha_3\gamma_2 > 0$  and the trace of this Jacobian matrix,  $trJ_E = -(\lambda\alpha_2 + k) - (\gamma_3 + \delta) < 0$ . It is straightforward to show that  $(trJ_E)^2 > 4|J_E|$ , thus the obtained Markov perfect equilibrium is a stable node.<sup>19</sup>

Using the initial conditions  $Z(0) = Z_0$  and  $P(0) = P_0$ , we can obtain specific values for the arbitrary constants  $m_1$  and  $m_2$ :

$$m_1 = [a_2(Z_0 - Z^{MP}) - (P_0 - P^{MP})] / (a_2 - a_1) \quad (\text{A13})$$

$$m_2 = -[a_1(Z_0 - Z^{MP}) - (P_0 - P^{MP})] / (a_2 - a_1) \quad (\text{A14})$$

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<sup>19</sup>  $(trJ_E)^2 - 4|J_E| = (\lambda\alpha_2 + k)^2 + (\gamma_3 + \delta)^2 + 2(\lambda\alpha_2 + k)(\gamma_3 + \delta) - 4(\lambda\alpha_2 + k)(\gamma_3 + \delta) + 4\lambda\alpha_3\gamma_2$   
 $= [(\lambda\alpha_2 + k) - (\gamma_3 + \delta)]^2 + 4\lambda\alpha_3\gamma_2 > 0$

Upon substitution of (A13) and (A14) into equations (A9) and (A10), we find that the evolution of the stock of pollution follows the time path

$$Z(t) = \frac{Z_0 - Z^{MP}}{a_2 - a_1} (a_2 e^{\rho_1 t} - a_1 e^{\rho_2 t}) - \frac{P_0 - P^{MP}}{a_2 - a_1} (e^{\rho_1 t} - e^{\rho_2 t}) + Z^{MP} \quad (A15)$$

and the time path for the political capital stock is

$$P(t) = a_1 a_2 \frac{Z_0 - Z^{MP}}{a_2 - a_1} (e^{\rho_1 t} - e^{\rho_2 t}) - \frac{P_0 - P^{MP}}{a_2 - a_1} (a_1 e^{\rho_1 t} - a_2 e^{\rho_2 t}) + P^{MP} \quad (A16)$$

Substitution of (A15) and (A16) into equations (24) and (25) will yield the expressions for optimal time paths for the tariff and investment strategies. Since  $\rho_1 < \rho_2 < 0$  and  $a_1 < 0 < a_2$ , it is clear from the equilibrium time paths expressions (A15) and (A16) that both the stock of pollution and the stock of political capital rise from their initial levels to the steady state values, assuming that the initial levels of both stocks are small, that is  $Z_0 < Z^{MP}$  and  $P_0 < P^{MP}$ . If for some reason the initial stocks of pollution and political capital exceed their steady state levels, time paths (A15) and (A16) imply that both stocks fall to the steady state level.

In order to explore monotonicity properties of the time paths for pollution and political capital, time differentiate (A15) and (A16):

$$Z'(t) = \frac{Z_0 - Z^{MP}}{a_2 - a_1} (a_2 \rho_1 e^{\rho_1 t} - a_1 \rho_2 e^{\rho_2 t}) - \frac{P_0 - P^{MP}}{a_2 - a_1} (\rho_1 e^{\rho_1 t} - \rho_2 e^{\rho_2 t}) \quad (A17)$$

$$P'(t) = a_1 a_2 \frac{Z_0 - Z^{MP}}{a_2 - a_1} (\rho_1 e^{\rho_1 t} - \rho_2 e^{\rho_2 t}) - \frac{P_0 - P^{MP}}{a_2 - a_1} (a_1 \rho_1 e^{\rho_1 t} - a_2 \rho_2 e^{\rho_2 t}) \quad (A18)$$

It is clear from equations (A17) and (A18) that each of the functions  $Z(t)$  and  $P(t)$  may have only one extremum, i.e., there may exist only one value of  $t$ ,  $t = \tilde{t}$ , that sets  $Z'(t)$  equal to zero and only one value of  $t$ ,  $t = \tilde{t}$ , that sets  $P'(t)$  equal to zero, and where these derivatives change their signs. It then follows that if the initial stock of pollution,  $Z(0) = Z_0$ , is below the

steady state level,  $Z^{MP}$ , and  $Z'(0) \geq 0$ , we can conclude that  $Z(t)$  rises monotonically from its initial level to the steady state. Using equation (A17), we can rewrite  $Z'(0) \geq 0$  condition as

$$\frac{Z_0 - Z^{MP}}{P_0 - P^{MP}} \geq \frac{\rho_1 - \rho_2}{a_2 \rho_1 - a_1 \rho_2}, \quad (\text{A19})$$

where if the non-negativity constraint is binding, function  $Z(t)$  reaches its minimum at the time  $t = 0$ . Upon substitution of expressions (A11) and (A12) for  $a_1$  and  $a_2$  into condition (A19), we find that (A19) is equivalent to

$$\frac{Z_0 - Z^{MP}}{P_0 - P^{MP}} \geq \frac{\lambda \alpha_3}{\lambda \alpha_2 + k} \quad (\text{A20})$$

Condition (A20) says that the line connecting the initial point  $(Z_0, P_0)$  and the steady state equilibrium point  $(Z^{MP}, P^{MP})$  is at least as steep as the  $\dot{Z} = 0$  isocline. Thus it implies that if the initial stock of pollution,  $Z_0$ , is sufficiently less than the steady state pollution stock,  $Z^{MP}$ , then pollution will rise monotonically to the steady state level. However, if we start with  $Z_0$  that is fairly close to the steady state pollution level then the stock of pollution will initially fall but starting with the time  $\tilde{t}$  it will rise monotonically to  $Z^{MP}$ .

Similarly, considering the case where the initial political capital stock is below its steady state level, we can argue that if  $P'(0) \geq 0$  then  $P(t)$  grows monotonically from its initial level,  $P_0$ , to its steady state value,  $P^{MP}$ . Using equation (A18), this condition can be formalized as

$$\frac{Z_0 - Z^{MP}}{P_0 - P^{MP}} \leq \frac{a_1 \rho_1 - a_2 \rho_2}{a_1 a_2 (\rho_1 - \rho_2)}, \quad (\text{A21})$$

where binding non-negativity constraint implies that function  $P(t)$  has a minimum point at the time  $t = 0$ . Substitution of expressions (A11) and (A12) yields the following condition:

$$\frac{Z_0 - Z^{MP}}{P_0 - P^{MP}} \leq \frac{\gamma_3 + \delta}{\gamma_2} \quad (\text{A22})$$

Condition (A22) states that the  $\dot{P} = 0$  isocline is at least as steep as the line connecting the initial point with the steady state point. It suggests that if the initial stock of political capital,  $P_0$ , is sufficiently below its steady state level,  $P^{MP}$ , then the stock of political capital rises monotonically to  $P^{MP}$ . Conversely, if  $P_0$  is rather close to the steady state political capital level, then the stock of political capital will go down initially, but then starting at time  $\bar{t}$  it will increase monotonically to  $P^{MP}$ .

Since stability of the characterized Markov perfect equilibrium requires  $(\lambda\alpha_2 + k)(\gamma_3 + \delta) - \lambda\alpha_3\gamma_2 > 0$ , it follows that the slope of the  $\dot{Z} = 0$  isocline,  $\lambda\alpha_3/(\lambda\alpha_2 + k)$ , is less than the slope the  $\dot{P} = 0$  isocline,  $(\gamma_3 + \delta)/\gamma_2$ . Therefore, both  $Z$  and  $P$  will rise monotonically from the initial level to the steady state if

$$\left. \frac{dZ}{dP} \right|_{\dot{Z}=0} \leq \frac{Z_0 - Z^{MP}}{P_0 - P^{MP}} \leq \left. \frac{dZ}{dP} \right|_{\dot{P}=0}, \quad (\text{A23})$$

that is if both the initial levels of  $Z$  and  $P$  are sufficiently below their equilibrium levels.



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Figure 1 The long run equilibrium in a model of trade and transboundary pollution

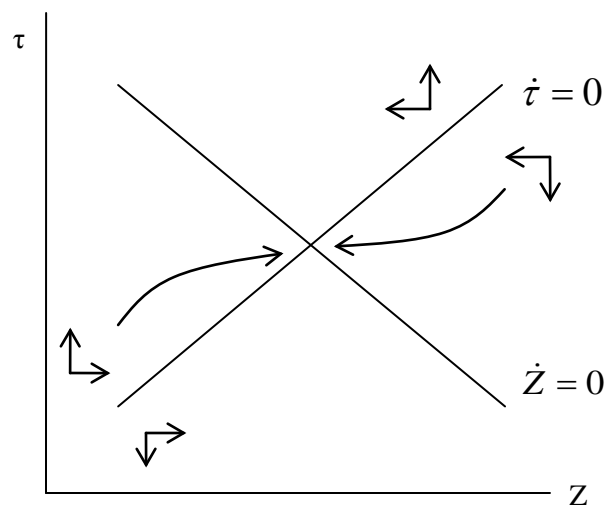


Figure 2 The long run equilibrium in the model of trade, transboundary pollution control and foreign lobbying

