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INTERNATIONAL COOPERATION ON TRADE AND ENVIRONMENTAL POLICY: Cross-border Externalities with Asymmetric Information

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ABSTRACT

We consider the choice of international agreements for trade in a commodity whose production creates a negative externality for the importing country. Which policy should be used depends upon the importer's marginal welfare loss from the externality and the exporting country's cost of administering an externality tax. When the latter is private information, an efficient contract has the importer selecting the policy levels and over-compensating the exporter for its administrative costs. A negotiated settlement is inefficient. When the policies in the *status quo* are endogenous, they affect the efficiency of the contract. This has implications for piecemeal policy reform.

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1. INTRODUCTION

The interaction between international trade and the environment is fast becoming a dominant international policy issue. One of the more problematic cases of this interaction arises when the production of a good creates externalities (such as environmental pollution) considered undesirable by residents of countries importing the good. Direct intervention by an importing government to limit the pollution is generally not possible: it must either seek the cooperation of the exporting country's government or find some indirect policy such as restricting imports. When it chooses the latter policy, trade may be severely restricted and unnecessary losses may result for all countries [see Ludema and Wooton (1992)]. When it chooses the former policy, the ensuing international negotiations are complicated by incomplete information about the costs of pollution and its abatement.

The motivation for this paper stems from a number of aspects of recent trade and environmental negotiations and agreements. First, trade and environmental policies are perceived to be interrelated. For example, trade liberalization can exacerbate environmental problems by increasing production in certain pollution-intensive sectors. The recent drive for a parallel environmental pact to accompany the North American Free Trade Agreement (NAFTA) appears to be the result of such a concern. There is also ample evidence that, in the absence of explicit environmental agreements, countries use trade policies to achieve environmental ends and *vice versa* (for example, the recent US ban on Mexican tuna in order to protect dolphins).

Second, measures for dealing with environmental concerns vary widely from one situation to the next. There are, in many instances, political or administrative costs that militate against the use of the ideal policies, in favour of more expedient ones. For example, it is often argued that the high costs of administration and enforcement in Mexico makes strict environmental standards there futile. If these costs are sufficiently high, it may be better for a

less direct, but more easily administered, policy to be implemented. The World Bank in its 1992 *World Development Report* makes this point.

> "Ideally, regulators would attempt to change the behavior of resource users by means of direct policies--for instance, by taxing or regulating emissions. But these measures involve a heavy administrative burden because they target individual polluters or resource users. Blunt policies, such as taxes on polluting inputs [...], are less demanding because they can be implemented through the tax system. [...] So in many cases it will be appropriate that developing countries use blunt policies, which require less stringent monitoring." (World Bank, 1992, p. 78)

Finally both environmental damage and the costs of abatement are difficult to measure and prone to misrepresentation. This obscures the appropriate means of controlling the pollution and complicates the negotiation of transfers necessary to compensate countries bearing a disproportionate burden.[1] Again, this is addressed by the Bank.

> "The potential partners to an international environmental agreement rarely stand to gain or lose equally from it. If an agreement is to work, either it must lead to efficiency gains sufficiently large that all parties can expect to be better off (which rarely happens) or countries must be willing to negotiate transfers to assist those who will lose. [...] Arranging for such transfers will not be simple. The potential parties to an agreement may not share a common view of the urgency of the problem or of the possible solutions. It is extremely difficult to ensure that countries are paid neither more nor less than the extra costs of meeting their international obligations. Every country has incentives to distort the costs or benefits of taking action." (World Bank, 1992, pp. 155-6)

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[1] Many environmental agreements (for example, the Montreal Protocol on ozone depletion) rely on transfers, particularly from industrialized to developing countries, to gain widespread compliance. While the Montreal Protocol relies on a fund, in general these transfers may take a variety of forms including, for example, "debt-for-nature swaps", in which commercial debt of developing countries is transformed into finance for the environment (World Bank, 1992, p. 169).

In this paper, we use a simple two-country model in which the production activities of one country results in a negative externality for the consumers in the other, while none of the firms nor consumers (nor their representatives) in the producing nation cares about the externality. We look at several problems that might be encountered when the two countries attempt to cooperate on trade and environmental policy and one or both of the countries harbours some private information. First, there are administrative costs to taxing pollution that do not arise in taxing trade and whose true magnitude is known only by the exporting country. Taxing trade requires information only on the number or value of the goods crossing the international frontier and is relatively inexpensive to administer compared to implementing a pollution tax, which requires monitoring of the production process itself with the concomitant regiment of inspectors. The exporting country will have no incentive to adopt externality taxes without the promise of transfers from the importing country and this will give the exporting country an incentive to misrepresent the extent of its administrative costs. Similarly, the importing government is under both environmentalist and protectionist pressure to restrict imports, though only it may know the exact relative strengths of these interests, and only the environmental concern is a legitimate basis for restrictions in a cooperative setting. Thus, the importing government may feign environmental concern to obtain tighter restrictions in order to satisfy the protectionist lobby.

Whether the first-best policy of an externality tax or the second-best policy of a trade restriction should be used depends upon the importer's marginal welfare loss from the externality and the exporting country's cost of administering the externality tax. When the latter is private information, an *ex-post* efficient contract calls on the importer to select the policy levels and over-compensate the exporter for its administrative costs. A negotiated settlement, in which the importer makes a take-it-or-leave-it offer to the exporter, has a similar structure but is

inefficient. In particular, the contract relies on trade policy in certain instances where direct taxation of the externality would be efficient.[2]

When the policy actions that would be taken in the absence of a contract (that is, in the *status quo*) are endogenous, they affect not only the distribution of gains from the contract but its efficiency as well. The exporting country has an incentive to use an externality tax to improve its *status-quo* payoff, but in doing so relinquishes the information rent it would have captured in the contract. The exporter's decision may therefore provide a signal about its administrative costs, thereby improving the efficiency of the contract.

This suggests that proper control of trade policies in the *status quo* could yield benefits in terms of more efficient environmental contracts. In an example, we demonstrate that expected world welfare is maximized by unilateral import-tariff liberalization in the *status quo* if the onset of environmental negotiations is highly improbable; by unilateral export-tax liberalization if a contract is more likely; and by free trade if an environmental agreement is certain. Thus if negotiations for environmental agreements are conducted separately from discussions on multilateral trade liberalization, the effects of the latter on the efficiency of the former must be taken into account. For example, a successful GATT agreement need not be characterized by global free trade until such time as a parallel accord on environmental policy is also enacted.

2. Optimal Policies for Cross-border Externalities

We adopt a very simple structure for the market for the good, x. There are two countries, the home country, H, and the foreign country, F. All consumption takes place in H, while production occurs in both countries. Production located in F is supplied according to the inverse supply function $q(x)$ (where $q'(x) \geq 0$), while country H's inverse import demand function is

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[2] In Appendix A, we discuss the case where the importer's concern about the externality is also private information.

given by $p(x)$ (where $p'(x) < 0$). Along with each unit of x, foreign firms produce $m \in (0, \bar{m}]$ units of externality. Firms are assumed to possess an externality abatement technology, enabling them to select the level of m at a cost of $c(m)$ per unit of x, where $c(\bar{m}) = 0$, $c' \leq 0$, and $c'' \geq 0$. Thus, lower per-unit levels of emission of the externality are achieved at increasing cost.

There are two policy instruments available, specific trade taxes and externality taxes. The home country levies a tariff, r, on its imports of x, while the foreign country levies a production (or export) tax, s. Let $t \equiv r + s$ be the total tax levied on the trade of a unit of good x. The foreign country is also able to levy a tax e directly on the production of the externality. In response to e, firms will minimize their production costs, by choosing m so as to minimize $c(m) + em$. Let $k(e) \equiv \min\{c(m) + em\}$, the increase in the firms' marginal costs as a result of the externality tax. This gives the following market equilibrium condition,

$$p(x) = q(x) + t + k(e). \tag{1}$$

The disutility experienced by the home country per unit of externality is given by α, which we shall initially assume to be known by both countries. In Appendix A we consider the impact of α being the private information of the home country. Home country welfare is

$$U = C(e,t) + rx - \alpha mx, \tag{2}$$

where $C(e, t) \equiv \int_0^x p(y)dy - p(x)x$, that is, the sum of consumers' surplus and home producers' surplus.

The foreign country is not directly affected by the externality; however, we assume it bears an administrative cost, $\beta(e)$, when applying an externality tax. This can be thought of as the cost of monitoring firms' output of the externality. Let $\beta(0) = 0$ and $\beta(e) = \beta$, for all $e > 0$, where β is a constant from the set $B = [0, \bar{\beta}]$. The term β is the private information of the

foreign country, and is drawn from a common-knowledge probability distribution $F(\beta)$ with density $f(\beta)$.[3] The *ex-post* welfare of the foreign country is,

$$V(e,t;\beta) = P(e,t) + sx + emx - \beta(e), \tag{3}$$

where $P(e, t) \equiv q(x)x - \int_0^x q(y)dy$. Thus *ex-post* total world welfare is,

$$W(e,t;\beta) = C(e,t) + P(e,t) + \{t + (e-\alpha)m\}x - \beta(e). \tag{4}$$

In what follows it will be convenient to work with the gross values of foreign and world welfare, given by, $v(e, t) \equiv V(e, t; \beta) + \beta(e)$ and $w(e, t) \equiv W(e, t; \beta) + \beta(e)$, respectively. It is easily shown that $w(\cdot)$ is maximized at $e^* = \alpha$ and $t^* = 0$. Thus maximizing gross world welfare involves bearing the cost β. If we wished to avoid this cost by restricting e to zero, then the (second-best) *constrained* optimal trade tax t^C would be, $t^C = \alpha\bar{m}$. We will write the maximized values of w as $w^* \equiv w(e^*, t^*)$ and $w^C \equiv w(0, t^C)$.[4]

Define $\delta \equiv w^* - w^C$. This is the efficiency gain from using the optimal level of the externality tax, rather than a trade tax, ignoring the cost of imposing the externality tax. Maximizing (4), that is, maximizing *ex-post* world welfare, requires that the externality tax should be used if the cost of imposing it, β, is less than or equal to δ. Otherwise, the tariff should be used. We call this the *ex-post* efficient decision rule. Thus the *levels* of the optimal policies (e^* and t^C) depend on the home country's disutility from the externality; but *which* of the policy instruments should be used depends also on the private information of the foreign country.

This is illustrated in Figure 1. The marginal social cost is marginal private cost $q(x)$ plus the marginal damage from the externality. When the externality tax is constrained to be zero,

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[3] The basic results of this paper hold for any administrative cost function of the form $\beta(e) = \beta + h(e)$ and any foreign disutility per unit of the externality σ, where β is foreign private information and $h(e)$ and σ are common knowledge.

[4] Using $\beta(e) = \beta + h(e)$ and σ, the policies e^* and t^* are determined by the first-order conditions: $e^* = \alpha + \sigma - h'c''/x$ and $t^* = (\alpha + \sigma - e^*)m$.

marginal damage is $\alpha\bar{m}$, which is equal to the optimal corrective tariff t^C (distance AE). Equilibrium output under the tariff is x^C and the total quantity of externality produced is area AEFK. Using the optimal tax on the externality (e^*m^* equals distance BD) lowers the marginal damage from the externality to αm^* while increasing private marginal costs by $k(e^*)$. Equilibrium output under this tax regime is x^*, the total quantity of externality being produced in this case being area BDGJ. The gain in consumer and producer surplus from the higher equilibrium output under the externality tax is δ, represented by area CEFGH.

3. Designing Contracts for Trade and Environmental Objectives

3a. Incentive Compatibility

The two governments wish to bind themselves to a contract determining the control of the externality. Following the usual mechanism-design approach, we concentrate on direct revelation mechanisms, which consist of combinations of taxes and transfers contingent on the foreign country's report of its private information. The *revelation principle* enables us to focus on mechanisms which induce truthful reports, that is, *incentive-compatible* mechanisms, without loss of generality.

Let the foreign country report its cost to be b. Consider the contract $\mu(b) = [e(b), t(b), v(b)]$.[5] The *ex-post* welfare of each country can then be expressed as a function of the contract and the foreign country's private information. Thus, $U = U[\mu(b)]$ and $V = V[\mu(b), \beta]$. The contract μ is incentive compatible if and only if,

$$V[\mu(\beta),\beta] \geq V[\mu(b),\beta], \tag{5}$$

for all $b \in B$.

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[5] The contract includes $r(b)$ and $s(b)$ implicitly, as for any e and t, v is uniquely determined by $r(b)$.

Let Ω be the set of foreign reports such that, for a given α, the contract μ that satisfies (5) would prescribe a positive externality tax, that is, $\Omega = \{b \mid e(b) > 0, e(\beta) \in \mu(\beta)\}$. Suppose that the actual foreign type is $\beta' \in \Omega$. The foreign country will prefer truthtelling over misreporting its type as: *(i)* $b' \in \Omega$ if, and only if, $v(\beta') - \beta' \geq v(b') - \beta'$ for any $\beta' \in \Omega$; and *(ii)* $b'' \notin \Omega$ if, and only if, $v(\beta') - \beta' \geq v(b'')$. Similarly, if the actual foreign type is $\beta'' \notin \Omega$, then it prefers truth-telling over reporting *(iii)* $b' \in \Omega$ if, and only if, $v(\beta'') \geq v(b') - \beta''$; and *(iv)* $b'' \notin \Omega$ if, and only if, $v(\beta'') \geq v(b'')$. Condition *(i)* implies that $v(\beta)$ is a constant v' for all $\beta \in \Omega$, while *(iv)* yields a similar constraint that $v(\beta)$ is a constant v'' for $\beta \notin \Omega$. Conditions *(ii)* and *(iii)* may be rewritten as $v(\beta') - \beta' \geq v(\beta'')$ and $v(\beta'') \geq v(\beta') - \beta''$, respectively. Together, these imply that $\beta'' \geq v(\beta') - v(\beta'') \geq \beta'$. In summary, we have:

$$\Omega = [0,\tilde{\beta}],$$

$$v(b) = \begin{cases} z + \tilde{\beta} & \text{for } b \leq \tilde{\beta}, \\ z & \text{for } b > \tilde{\beta}, \end{cases} \tag{6}$$

where $\tilde{\beta} \equiv v' - v''$ and $z \equiv v''$.

This is illustrated in Figure 2. The contract defines a cut-off value $\tilde{\beta}$, which does not depend on the foreign announcement b. For any $b < \tilde{\beta}$, the externality tax is used and the foreign gross welfare is $z + \tilde{\beta}$, while net welfare is $z + (\tilde{\beta} - \beta)$. For any announcement $b > \tilde{\beta}$, no externality tax is used and foreign welfare is z. As a result, an announcement $b < \tilde{\beta}$ will give the foreign country higher net welfare than an announcement of $b > \tilde{\beta}$ if and only if β is actually less than $\tilde{\beta}$. Further, any two announcements b' and b'', both either greater than or less than $\tilde{\beta}$, give the same foreign net welfare. Thus there is no incentive for the foreign country to misrepresent its type.

3b. Individual Rationality

In addition to being incentive compatible, a feasible contract should be individually rational, meaning that it should give both countries at least their *status-quo* payoffs. Denote the status-quo taxes, e_0, r_0, and s_0. We assume that $e_0 = 0$, that is, there is no externality abatement activity in the *status quo*. Let the *status-quo* utility of the foreign country be v_0, equal to V_0 as no administrative costs are paid. The individual rationality constraints are:

$$\int_B U[\mu(\beta)]f(\beta)d\beta \geq U_0; \tag{7}$$

$$V[\mu(\beta),\beta] \geq v_0 \qquad \text{for all } \beta. \tag{8}$$

For contracts satisfying (6), a foreign country will only receive $\bar{\beta}$ if $\beta \leq \bar{\beta}$. Therefore condition (8) may be rewritten as:

$$z \geq v_0. \tag{9}$$

3c. Ex-post Efficient Contracts

Given the *ex-post* efficient decision rule found in section 2 and the incentive constraints of section 3a, we are now in a position to find *ex-post* efficient contracts. Such contracts will provide a useful benchmark for the principal-agent approach in the next section.

One aspect of the decision rule found in section 2 is that the externality tax ought to be used if $\beta < \delta$ and not otherwise. Thus a contract that satisfies both incentive compatibility and individual rationality will take the form of (6) with $\bar{\beta} = \delta$ and $z \geq v_0$. The other aspect of the efficient decision rule is that $e = \alpha$, whenever the externality tax is used, and $t = \alpha\bar{m}$, otherwise. Thus an incentive compatible, *ex-post* efficient contract that is minimally acceptable to the foreign country will be:

$$\mu(b) = \begin{cases} e(b) = \alpha, \quad t(b) = 0, \quad v = v_0 + \delta, & \text{if } b \le \delta; \\ e(b) = 0, \quad t(b) = \alpha\bar{m}, \quad v = v_0, & \text{if } b \ge \delta. \end{cases} \tag{10}$$

This contract gives an expected payoff to the home country of $w^C - v_0$. The home country's individual rationality condition (7) is met since $w^C \ge U_0 + v_0$. Thus the contract is the best, efficient, feasible contract for the home country.

This will yield the following net welfare levels for the foreign country:

$$V(\beta) = \begin{cases} v_0 + (\delta - \beta) & \text{if pollution taxes are used,} \\ v_0 & \text{if trade taxes are used.} \end{cases} \tag{11}$$

The increase in world welfare from the appropriate implementation of the pollution tax is $(\delta - \beta)$. This amount accrues entirely to the foreign country as an information rent.

3d. The Principal-Agent Approach

While *ex-post* efficient contracts are feasible, it is not certain that a pair of countries attempting to negotiate a trade and environmental policy deal would ever adopt such a contract. This is because efficient contracts enable the foreign country to extract information rent from the home country. Consequently the home country might choose to propose an alternative contract that, while inefficient, reduces the foreign country's information rent. We illustrate this point using a principal-agent framework.[6]

We consider a simple, three-stage game. The home country (the principal) makes a take-it-or-leave-it offer to the foreigner (the agent) in the first stage; the offer is either accepted or rejected by the foreign country in the second stage; then the contract is implemented

[6] The previous section can also be thought of as a principal-agent framework where the principal is a hypothetical world planner, whose objective is to maximize world welfare, and the two countries are agents. However we shall reserve the "principal-agent" terminology for this section.

(provided it is accepted) in third stage. If the offer is rejected the game ends in the *status-quo* payoffs.

The best proposal that the home country can make must satisfy,

$$\underset{\mu}{\text{Max}} \int_{B} U[\mu(\beta)] f(\beta) d\beta , \tag{12}$$

subject to the individual rationality constraint that requires each type of foreign country to do at least as well as in the *status quo*, that is, $z \geq v_0$. The contract must also be incentive compatible for the foreign country.[7] Hence, substituting (6) into (12) and imposing the foreign country's individual rationality constraint gives the objective:

$$\text{Max} \int_{0}^{\tilde{\beta}} \{w[e(\beta), t(\beta)] - \tilde{\beta}(\alpha)\} f(\beta) d\beta + \int_{\tilde{\beta}}^{\bar{\beta}} w[0, t(\beta)] f(\beta) d\beta - v_0 . \tag{12'}$$

Solving (12') for $t(\beta)$ and $e(\beta)$ gives:

$$\mu(b) = \begin{cases} e(b) = \alpha, \quad t(b) = 0, \quad v = v_0 + \tilde{\beta}, & \text{if } b \leq \tilde{\beta}; \\ e(b) = 0, \quad t(b) = \alpha\bar{m}, \quad v = v_0, & \text{if } b \geq \tilde{\beta}. \end{cases} \tag{13}$$

Rewriting (12'), using (13):

$$w^C + \underset{\beta}{\text{Max}}\{(\delta - \beta) F(\beta)\} - v_0 .$$

Thus $\tilde{\beta}$ is the solution to:

$$\underset{\beta}{\text{Max}}\{(\delta - \beta) F(\beta)\}. \tag{12''}$$

The first-order condition for an interior maximum is $\tilde{\beta} = \delta - [F(\tilde{\beta})/f(\tilde{\beta})]$. Thus the contract must specify:

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[7] The revelation principle ensures that the equilibria of the three-stage game can be characterized by those contracts satisfying (12), subject to individual rationality and incentive compatibility. See Fudenberg and Tirole (1992, ch. 7) for more details.

$$\tilde{\beta} = \min\left\{\left[\delta - \frac{F(\tilde{\beta})}{f(\tilde{\beta})}\right], \bar{\beta}\right\}. \tag{14}$$

We assume that:

$$-2[f(\tilde{\beta})]^2 + f'(\tilde{\beta})F(\tilde{\beta}) < 0, \tag{15}$$

that is, the second-order condition is satisfied.[8]

The contract comprising (13) and (14) is not *ex-post* efficient, as $\tilde{\beta}$ is always less than δ, and therefore for realizations of $\beta \in [\tilde{\beta}, \delta)$ the externality tax will not be applied even though it is efficient to do so. The burden of the inefficiency is borne by the foreign country, whose information rent is reduced to $(\tilde{\beta} - \beta)$, while the expected welfare of the home country is higher than in the *ex-post* efficient contract.

4. Environmental Policy Signalling and Trade Wars

In the absence of cooperation on trade and environmental policy, countries may use both types of policy to exploit their monopoly power in trade and reduce the cross-border externality [Ludema and Wooton (1992)]. This suggests that it is quite restrictive to assume that in the *status quo* there is no externality tax and that the trade taxes take arbitrary values. In this section and the next we endogenize the *status-quo* policy levels, which results in endogenous *status-quo* payoffs and, to some extent, makes the information pertaining to the contract endogenous as well. At the heart of this are the conflicting incentives faced by the foreign country. It should forgo using an externality tax prior to the contract in order to preserve its information rent; yet by implementing the externality tax it can raise its *status-quo* payoff. The relative importance of these depends largely on the magnitude of the administrative costs. Thus the foreign country's

[8] We further assume that (15) holds for all $\beta \in [0, \bar{\beta}]$, which implies that $\tilde{\beta}$ is increasing in δ up to $\bar{\beta}$.

tax behaviour in the *status quo* may provide a signal about β, improving the efficiency of the contract.

We now consider a principal-agent game that has been augmented with endogenous *status-quo* policy choices and uncertainty about the onset of negotiations. In the first stage, the foreign country chooses the level of its externality tax and, if it sets $e_0 > 0$, incurs the sunk cost β. In the second stage, the home country makes a contract proposal with probability $\rho \in (0, 1)$ and with probability $(1 - \rho)$ no contract is proposed. If a contract is proposed, the foreign country responds by accepting or rejecting it. If accepted, the contract is implemented, superseding e_0. Finally, if either no contract is proposed or the proposed contract is rejected, the countries choose their trade taxes, r_0 and s_0, simultaneously and non-cooperatively; that is, they engage in a trade war. The relevant solution concept for this game is perfect Bayesian Nash equilibrium.

The purpose of the uncertainty parameter, ρ, is to allow us to vary the importance of the negotiations relative to the trade war in the foreign country's decision problem. It is of little importance where in the negotiation process the uncertainty arises. For example, the uncertainty may be at the contract implementation stage. This would correspond to an institutional framework in which any deal struck between the two countries' negotiators must be ultimately ratified by an unpredictable legislature. The assumption that ρ is bounded away from unity is made for technical reasons, with the case of $\rho = 1$ being relegated to Appendix B.

The outcome of the trade war, in the final stage of the game, is just the standard Nash equilibrium in trade taxes, taking as given the externality tax chosen in the first stage.[9] No matter what level of externality tax has been chosen in the first stage of the game, the foreign country will not want to alter it in the trade war. Let the foreign gross payoff in this Nash

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[9] Conditions for existence and uniqueness of an interior Nash equilibrium are: $p' - 2q' - q''x < 0$, $2p' - q' + p''x < 0$, and $2(p' - q') + (p'' - q'')x < 0$. Autarky is always an additional Nash equilibrium outcome, but we ignore it because the two strategies supporting it are weakly dominated.

equilibrium, given the externality tax e_0, be $v_0(e_0)$. It can be shown that the externality tax that maximizes $v_0(e_0)$ is exactly α, the world's optimal level.[10] Define $\gamma \equiv v_0(\alpha) - v_0(0)$, that is, γ is the maximal gain to the foreign country from imposing a positive externality tax in the first stage of the game. If $\beta > \gamma$ then the foreign country will always choose $e_0 = 0$ in the first stage of the game as the advantage of using environmental policy in the Nash equilibrium is less than the costs of administering the externality tax. We assume that $\bar{\beta} > \gamma$ so that there is always some β that would certainly choose $e_0 = 0$ in the first stage.[11]

If the foreign country chooses $e_0 > 0$ in the first stage, the home country's optimal contract proposal in the second stage is quite simple. As β is already sunk, the home country proposes that e be set at α (which will already be the case if the foreign country has behaved optimally in the first stage) and that the trade taxes be set such that $t_0 = 0$ and $v(b) = v_0(e_0)$. This is minimally acceptable to the foreign country because it yields the same net welfare as the country would receive were it to reject the contract and play its Nash-equilibrium export tax in the last stage. Thus, if the foreign country chooses $e_0 > 0$ in the first stage, it will set $e_0 = \alpha$ and its total payoff will be $v_0(\alpha) - \beta$.

Were the foreign country to choose $e_0 = 0$ in the first stage, the home country's optimal contract proposal in the second stage is not so straightforward, because the observation of $e_0 = 0$ may influence the home country's beliefs about the foreign country's type. If some foreign types are more likely than others to have chosen $e_0 = 0$, then the home country must update its beliefs $F(\beta)$ using Bayes' rule upon observing $e_0 = 0$. Let the posterior distribution of β given $e_0 = 0$ be $\hat{F}(\beta)$. We restrict our attention to contracts satisfying incentive compatibility and individual

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[10] This result is specific to linear damage functions; however, it is also unnecessary for what follows. All that is needed is that this e is positive.

[11] This assumption implies that Bayes' rule can always be applied, thereby eliminating the need for restrictions on off-equilibrium beliefs.

rationality for all $\beta \in [0, \bar{\beta}]$, even if the posterior density function $\hat{f}(\beta)$ assigns zero probability to some β in this support.[12]

Thus, for any posterior distribution $\hat{F}(\beta)$ following the choice $e_0 = 0$, the home country's optimal contract will specify a value $\hat{\beta}$, such that:

$$\mu(b) = \begin{cases} e(b) = \alpha, \quad t(b) = 0, \quad v = v_0 + \hat{\beta}, & \text{if } b \leq \hat{\beta}; \\ e(b) = 0, \quad t(b) = \alpha\bar{m}, \quad v = v_0, & \text{if } b \geq \hat{\beta}, \end{cases} \tag{16}$$

where, analogous to the determination of $\tilde{\beta}$ in (12"), $\hat{\beta}$ maximizes $(\delta - \beta)\hat{F}(\beta)$.

When will the foreign country choose to use an externality tax in the *status quo*? It receives a payoff of $v_0(\alpha) - \beta$ from choosing $e_0 = \alpha$ in the first stage, while $v_0(0) + \rho(\hat{\beta} - \beta)$ and $v_0(0)$ are the expected payoffs to choosing $e_0 = 0$ for types $\beta \leq \hat{\beta}$ and $\beta > \hat{\beta}$, respectively. There is a critical value θ, the median of $[0, (\gamma - \rho\hat{\beta})/(1 - \rho), \gamma]$, such that all β less than θ will prefer $e_0 = \alpha$ and all β greater than θ will prefer $e_0 = 0$ in the first stage. A foreign country of the type whose administrative costs β equal θ is indifferent between $e_0 = 0$ and $e_0 = \alpha$. This implies that the home country's posterior distribution $\hat{F}(\beta)$ is just original distribution F truncated on the left by θ; that is,

$$\hat{F}(\beta) = \frac{F(\beta) - F(\theta)}{1 - F(\theta)}.$$

Using this distribution, the home country's optimal contract must specify the value $\hat{\beta}$ as the solution to the problem,

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[12] This assumption simplifies the exposition by eliminating some redundant equilibria (that is, equilibria with identical policy actions and payoffs).

$$\max_{0 \le \beta \le \bar{\beta}} [\delta - \beta] \frac{F(\beta) - F(\theta)}{1 - F(\theta)}. \tag{17}$$

Taking the partial derivative of (17) with respect to β and evaluating at $\beta = \theta$ gives the expression $(\delta - \theta)f(\theta)/[1 - F(\theta)]$. This will be positive if and only if $\delta > \theta$, which in turn implies that $\hat{\beta} > \theta$ if and only if $\delta > \theta$. Furthermore, $\hat{\beta} > (\gamma - \rho\hat{\beta})/(1 - \rho)$ implies $\delta > \hat{\beta} > \gamma > \theta$, and $\hat{\beta} \le (\gamma - \rho\hat{\beta})/(1 - \rho)$ implies $\hat{\beta} \le \gamma = \theta \le \delta$. Thus (17) will have an interior solution, that is, $\hat{\beta} > \theta$ if and only if $\delta > \gamma$.

The foregoing analysis implies that there are essentially three classes of equilibria to be explored. The simplest case is that in which $\theta = 0$. This shall be referred to as a *pooling equilibrium* because, in this case, every β chooses $e_0 = 0$ in the first stage and the home country's posterior beliefs are just its priors, $F(\beta)$. Consequently, the home country's optimal contract is the same as the one specified in the immediately preceding section, specifying the cut-off value $\bar{\beta}$. Thus, a necessary and sufficient condition for this to be an equilibrium is that $\rho\bar{\beta} \ge \gamma$. Such an equilibrium is illustrated in Figure 3.

If $\gamma > \theta > 0$, then foreign country types less than θ *separate* themselves from the other types by choosing $e_0 = \alpha$ in the first stage and thereby receive $v_0(\alpha) - \beta$. Types greater than θ choose $e_0 = 0$ in the first stage and receive expected payoffs $v_0(0) + \rho(\hat{\beta} - \beta)$ for $\beta \le \hat{\beta}$ and $v_0(0)$ for $\beta > \hat{\beta}$. The first-order condition determining $\hat{\beta}$ is:

$$[\delta - \hat{\beta}]f(\hat{\beta}) = [F(\hat{\beta}) - F(\theta)]. \tag{18}$$

Total differentiation of (18) gives:

$$\frac{d\hat{\beta}}{d\theta} = \frac{f(\hat{\beta})(\theta)}{2f(\hat{\beta})^2 - f'(\hat{\beta})[F(\hat{\beta}) - F(\theta)]} \geq 0. \tag{19}$$

The denominator of (19) is positive, by the second-order condition of (17), which is itself guaranteed by (15). Thus the necessary and sufficient condition for this to be an equilibrium is that $\rho\hat{\beta} < \gamma < \delta$.[13] An equilibrium of this sort is illustrated in Figure 4.

The third and final sort of equilibrium occurs when $\theta = \gamma \geq \delta$. In this case (17) reaches a maximum of zero and $\hat{\beta}$ can be any value between zero and γ. If the foreign country is of type $\beta \in [0, \gamma)$, then it chooses $e_0 = \alpha$ in the first stage and receives $v_0(\alpha) - \beta$; while if it is of type $\beta \in [\gamma, \bar{\beta}]$, it adopts $e_0 = 0$ and receives payoff $v_0(0)$. The foreign country receives no information rent because the only types that would choose $e_0 = 0$ in the first stage are those for whom the optimal contract would assign $e = 0$ anyway.

The inefficiency of the home country's optimal contract is lower in separating equilibria than in pooling equilibria. This is because $\hat{\beta}$ (or γ, when $\gamma \geq \delta$) is always greater than $\tilde{\beta}$ and hence closer to δ, the cut-off value under the *ex-post* efficient contract. Thus the possibility of a trade war serves the beneficial purpose of improving the efficiency of the negotiated contract. The degree to which efficiency is improved depends on the parameters γ, δ, and ρ, the distribution $F(\beta)$, and whether efficiency is measured *ex ante* or *ex post*.

5. Piecemeal Policy Reform

The previous sections reveal two facts about the relationship between trade and environmental policy. One is that trade restrictions may well be required as part of an environmental policy agreement, because administrative costs may make direct pollution restrictions prohibitively

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[13] For necessity, note that if $\rho\hat{\beta} \geq \gamma$ then (18) implies that $\rho\beta \geq \gamma$, and thus $\theta = 0$. For sufficiency, note that (15) implies that the objective function in (17) is strictly concave as long as $\gamma > \theta$ (which holds if and only if $\gamma < \delta$), so that $\hat{\beta}$ is continuous in θ. Continuity implies that if $\rho\hat{\beta} < \gamma$, then there exists a $\theta > 0$ and $\beta > \hat{\beta}$ such that $\rho\beta < \gamma$.

expensive to implement. The second is that the policies in effect in the *status quo* may have an effect on the efficiency of the agreement. This suggests that trade policy institutions, such as the GATT, should not only tolerate the use of trade policy in environmental agreements, but may also wish to promote trade policies that enhance the efficiency of prospective environmental agreements. Trade liberalization, therefore, may be thought of as a component of an exercise in piecemeal policy reform rather than as an end in itself.

To illustrate, consider the problem of a planner who has the same limited information about β as the home country and whose objective is to maximize expected world welfare by binding the tariffs of the two countries prior to the (uncertain) onset of environmental negotiations. The game of section 4 will be used, except that the trade war is replaced by the bound tariffs r_0 and s_0, and we assume that the planner can pre-commit to this policy.

We make the simplifying assumption that the distribution of β is uniform on B, that is $F(\beta) = \beta/\bar{\beta}$. Consequently the (truncated) posterior distribution is $\hat{F}(\beta) = (\beta-\theta)/(\bar{\beta}-\theta)$. The first-order condition from (18) for this function form is:

$$\hat{\beta} = \frac{\delta + \theta}{2}. \tag{20}$$

As before, the critical value θ is the median of $[0, (\gamma-\rho\hat{\beta})/(1-\rho), \gamma]$. Substituting (20) into $\theta = (\gamma-\rho\hat{\beta})/(1-\rho)$ gives $\theta = \phi[\gamma-(\rho/2)\delta]$, where $\phi \equiv 2/(2-\rho)$.

Let $w_0(e_0)$ be the level of gross world welfare for first-stage policy choice e_0 where the initial trade taxes r_0 and s_0 are chosen by the planner. Expected world welfare becomes:

$$E_\beta W = \frac{\rho}{\bar{\beta}}\left[\hat{\beta}w^* - \frac{\hat{\beta}^2}{2} + (\bar{\beta}-\hat{\beta})w^C\right] + \frac{(1-\rho)}{\bar{\beta}}\left[\theta w_0(e_0) - \frac{\theta^2}{2} + (\bar{\beta}-\theta)w_0(0)\right]. \tag{21}$$

Differentiating (21) with respect to both the foreign country's trade tax and the aggregate trade tax, using (20), gives:

$$\frac{\partial E_\beta W}{\partial i_0} = \frac{1}{\bar{\beta}}\left\{\frac{\rho}{4}(\delta-\theta)+(1-\rho)\left[w_0(e_0)-w_0(0)-\theta\right]\right\}\phi\frac{\partial\gamma}{\partial i_0} + \frac{(1-\rho)}{\bar{\beta}}\left\{\theta\frac{\partial w_0(e_0)}{\partial i_0}+(\bar{\beta}-\theta)\frac{\partial w_0(0)}{\partial i_0}\right\}, \quad (22)$$

for $i = s, t$. Expression (22) highlights the two basic components of the problem. First, a change in the *status-quo* tax levels affects γ, which in turn affects both β and θ, the probabilities that the externality tax will be used in the contract and in the absence of a contract, respectively. Raising β always improves world welfare because $\beta < \delta$ and hence the increase will make the contract more efficient. Increasing θ has ambiguous welfare implications as $w_0(e_0)$ - θ may not exceed $w_0(0)$. Second, a change in the *status-quo* trade-tax levels affects $w_0(e_0)$ and $w_0(0)$. As long as the aggregate trade tax t_0 is less than $\alpha\bar{m}$, a marginal increase in trade taxes raises $w_0(0)$. The effect of trade taxes on $w_0(e_0)$ depends on the effects that the trade taxes have on e_0.

To simplify further, let import demand and export supply by given by $p(x) = \eta - \lambda x$ and $q(x) = x$, respectively, where $\eta, \lambda > 0$. These imply the following gross welfare functions:

$$v = \frac{x^2}{2} + emx + sx, \quad (23)$$

$$w = \left\{\frac{1+\lambda}{2}\right\}x^2 + \{t+(e-\alpha)m\}x. \quad (24)$$

Further assume that the firms' cost of pollution abatement is given by, $c(m) = \kappa(\bar{m} - m)$, for $0 \le m \le \bar{m}$, where κ is a positive constant. Minimization of $c(m) + em$ gives firms' choices of m:

$$\begin{aligned} m &= 0 \qquad \text{if } e > \kappa, \\ m &= \bar{m} \qquad \text{if } e \le \kappa. \end{aligned} \quad (25)$$

Thus $k(\tau) = \min(\kappa, e)\bar{m}$, and equilibrium output is given by:

$$x = \frac{1}{1+\lambda}[\eta - k(e) - t]. \tag{26}$$

We shall assume that $\kappa\bar{m} < \alpha\bar{m} < \eta$, so that there is both pollution abatement and positive gains to trade when $e = \alpha$. As a result, after some manipulation, we have:

$$\delta = \frac{1}{2(1+\lambda)}(\alpha-\kappa)\bar{m}[2\eta - (\alpha+\kappa)\bar{m}].$$

While the planner binds the tariff levels r_0 and s_0, there may still remain an incentive for the foreign country to impose an externality tax so as to improve its terms of trade. Given the linearity of the abatement technology and the firms' resulting binary decision rule (25), the optimal externality tax is,

$$e_0 = \frac{1}{\bar{m}} \min\left\{\frac{(\eta-r)\lambda}{1+2\lambda} - s,\ \kappa\bar{m}\right\}, \tag{27}$$

for all types $\beta \le \theta$. There are therefore two possibilities. First, the externality tax is set such that $e_0 = \kappa$, that is, at its highest level without actually inducing any abatement activity. The alternative is that e_0 is set even lower than this, and hence firms will still choose not to abate any pollution. We can eliminate the latter outcome by restricting our attention to trade taxes $r_0, s_0 > 0$ and $t_0 \in [0, \bar{t}]$, where $\bar{t} < \eta\lambda/(1+2\lambda) - \kappa\bar{m}$. This is sufficient to ensure that $e_0 = \kappa$ for types $\beta \le \theta$.

Using $e_0 = 0$ and aggregate tax t_0 in (23), (24) and (26) gives:

$$\begin{aligned} w_0(0) &= \frac{(\eta-t_0)^2}{2(1+\lambda)} + (t_0-\alpha\bar{m})\frac{(\eta-t_0)}{(1+\lambda)}, \\ v_0(0) &= \frac{(\eta-t_0)^2}{2(1+\lambda)^2} + s_0\frac{(\eta-t_0)}{(1+\lambda)}. \end{aligned} \tag{28}$$

The same operation using $e_0 = \kappa$ yields:

$$
\begin{aligned}
w_0(\kappa) &= \frac{(\eta - t_0 - \kappa\bar{m})^2}{2(1+\lambda)} + (t_0 - \alpha m + \kappa\bar{m})\frac{(\eta - t_0 - \lambda\bar{m})}{(1+\lambda)}, \\
v_0(\kappa) &= \frac{(\eta - t_0 - \kappa\bar{m})^2}{2(1+\lambda)^2} + (s_0 + \kappa\bar{m})\frac{(\eta - t_0 - \kappa\bar{m})}{(1+\lambda)}.
\end{aligned} \tag{29}
$$

Thus,

$$
\gamma \equiv v_0(\kappa) - v_0(0) = \frac{\kappa\bar{m}}{(1+\lambda)}\left\{\frac{\lambda(\eta - t_0)}{(1+\lambda)} - \frac{(\kappa\bar{m})}{2(1+\lambda)} - s_0\right\}. \tag{30}
$$

Consequently, γ is strictly decreasing in the initial export and aggregate tax levels. Differentiating (28), (29), and (30) and substituting into (22) gives the marginal expected welfare effects of s_0 and t_0:

$$
\begin{aligned}
\frac{\partial E_\beta W}{\partial s_0} &= -\frac{\phi\kappa\bar{m}}{(1+\lambda)\bar{\beta}}\left\{\frac{\rho(\delta - \theta)}{4} + (1-\rho)\left[w_0(\kappa) - w_0(0) - \theta\right]\right\}, \\
\frac{\partial E_\beta W}{\partial t_0} &= -\frac{\lambda\phi\kappa\bar{m}}{(1+\lambda)^2\bar{\beta}}\left\{\frac{\rho(\delta - \theta)}{4} + (1-\rho)\left[w_0(\kappa) - w_0(0) - \theta\right]\right\} \\
&\quad - \frac{(1-\rho)}{(1+\lambda)\bar{\beta}}\left\{\theta\kappa\bar{\beta} + \bar{\beta}\left[t_0 - \alpha\bar{m}\right]\right\}.
\end{aligned} \tag{31}
$$

The solution to the planner's problem is illustrated in Figure 5.

Figure 5 shows the planner's optimal trade taxes as a function of ρ. If negotiations are quite improbable, that is, ρ is near zero, then the primary concerns of the planner are the trade-tax effects on $w_0(\kappa)$, $w_0(0)$, and θ. World welfare is maximized by choosing t_0 close to $\alpha\bar{m}$, so that $w_0(0)$ is close to w^C, and by choosing θ as close to zero as possible, so that the probability of receiving $w_0(\kappa)$ (which will be less than w^C) and incurring β is minimal. From equation (30) it is clear that γ, and hence θ, is lower the greater are s_0 and t_0. Thus expected world welfare is maximized by having the foreign country maintain its export tax at roughly the level of the optimal corrective tax, and having the home country unilaterally liberalize.

As negotiations become more probable, that is, ρ approaches unity, the relative importance of the *status-quo* welfare levels diminishes, and the primary concern of the planner shifts to improving the efficiency of the contract. This is done by raising γ and hence increasing β. For a given t_0, the efficiency of the contract is maximized by $s_0 = 0$. Thus for larger values of ρ, expected world welfare is maximized by using the home country's tariff to make a partial correction of the externality in the *status quo*, and having the foreign country unilaterally liberalize. For sufficiently high ρ, the need to correct for the externality in the *status quo* evaporates and free trade, which maximizes the efficiency of the contract, becomes the optimal policy.

6. Conclusions

We have considered the design of international agreements between countries trading in a commodity whose production creates a negative externality for the citizens of the importing country. Which policy should be used depends upon the importing country's marginal welfare loss from the externality and the exporting country's costs of administering the tax on the externality.

When these factors are private information to the national governments, both the type and level of the optimal tax are obscured, as each country may have an incentive to misrepresent the actual cost that it faces. An agreement on international trade and environmental policy between the countries must have the feature that both countries benefit from it and are willing to abide by its terms. An *ex-post* optimal agreement will involve the selection of the tax levels by the importing country and the choice of type of tax by the exporting country. Such an agreement will necessarily involve an over-compensation of the exporting country for its administrative costs when an externality tax is imposed.

We have considered whether such an efficient contract would likely be arrived at through negotiation. In the special case where the importing country makes a take-it-or-leave-it offer to the exporting nation, the negotiated contract has a similar structure to optimal contract, but is not efficient. In particular, there will be combinations of pollution and enforcement costs where trade taxes are imposed despite the fact that a pollution tax would be more efficient.

In a previous paper [Ludema and Wooton (1992)], we established that an exporting country may have an incentive to use an externality tax, despite national indifference to the externality, in order to exploit its monopoly power in trade or to appease the environmentalists abroad. We have shown in this paper that, if such an incentive is present and yet the externality tax is conspicuous by its absence, the exporting country has revealed information as to the severity of its administrative costs. That is, the presence or absence of an externality tax provides a signal, and the greater the incentive to implement the tax, the better the signal. Thus knowledge as to whether the exporting country has imposed an externality tax prior to the contract improves the efficiency of the contract itself.

If the trade taxes of the two countries are bound through some institutional arrangement, such as the GATT or NAFTA, the exporter's incentive to use an externality tax is altered. Consequently, such institutions can affect the efficiency of environmental agreements, despite their not having any explicit environmental role. We have shown that low trade taxes create the greatest incentive to use externality taxes, and thus free trade is an appropriate goal when the likelihood of reaching a parallel environmental agreement is high. If, however, the process of environmental negotiations is unreliable, with a high risk of failure, interim trade taxes may be necessary in order to offset the externality to some extent.

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APPENDIX A: PRIVATE INFORMATION OF THE HOME COUNTRY

Let α now be the private information of the home country [as in Feenstra and Lewis (1991)], where $\alpha \in A = [\underline{\alpha}, \bar{\alpha}]$ and is drawn from a common-knowledge probability distribution $G(\alpha)$ with density $g(\alpha)$. It now becomes the case that if, in equilibrium, the home country misrepresents its value of α, then the wrong externality abatement policy may be followed.

The equilibrium will now depend on the properties of $\delta(\alpha)$. By definition, $\delta(\alpha) \geq 0$. Differentiation of (1) and (4), using e^* and $t = 0$, gives $w^{*\prime}(\alpha) = -m(t^*)x(t^*)$, while using $e = 0$ and t^C, yields, $w^{C\prime}(\alpha) = -\bar{m}x(t^C)$. Thus,

$$\delta'(\alpha) = \bar{m}x(t^C) - m(\tau^*)x(\tau^*). \tag{A1}$$

From (A1) it is clear that, if the level of the externality is lower under e^* than under t^C, then $\delta(\alpha)$ is increasing in α. In general, we cannot be sure that this will hold. While the externality tax induces firms to lower their externality per unit of output, firms' marginal costs are also lower under e^* than under t^C, that is, $\alpha\bar{m} > k(\alpha^*)$, which raises equilibrium output. As long as the either the elasticities of supply and demand or the difference in marginal costs are not too large, (A1) will be positive. We denote the inverse of $\delta(\alpha)$ by $\varepsilon(\beta)$, where $\varepsilon(\beta)$ may be interpreted as the minimum gross welfare differential, between imposing the optimal externality tax and using trade taxes, that would justify spending the administrative cost β. We now consider how having α as private information may influence the *ex-post* efficient contract.

Let the report of the home country be a, that of foreign country be b, and consider the contract $\mu(a,b) = [e(a,b), t(a,b), v(a,b)]$.[14] The *ex-post* welfare of each country can then be expressed as a function of the contract and the country's own private information. Thus, $U = U[\mu(a, b), \alpha]$ and $V = V[\mu(a, b), \beta]$.

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[14] As before, the contract includes $r(a,b)$ and $s(a,b)$ implicitly, because for any e and t, v is uniquely determined by $r(a,b)$.

The contract μ is incentive compatible if and only if,

$$\int_B U[\mu(\alpha,\beta),\alpha]f(\beta)d\beta \geq \int_B U[\mu(a,\beta),\alpha]f(\beta)d\beta, \tag{A2}$$

$$\int_A V[\mu(\alpha,\beta),\beta]g(\alpha)d\alpha \geq \int_A V[\mu(\alpha,b),\beta]g(\alpha)d\alpha, \tag{A3}$$

for all α, $a \in A$ and all β, $b \in B$. The essential difference between these constraints and that in section 3, equation (5), is that now neither country may have an incentive to misrepresent its type, given that the other truthfully reveals its type. In other words, truthtelling is a Bayesian Nash equilibrium.

For simplicity, we return to the assumption that there is no externality abatement activity in the *status quo*. This again implies that the *status-quo* utility of the foreign country v_0 is independent of β. The individual rationality constraints become:

$$\int_B U[\mu(\alpha,\beta),\alpha]f(\beta)d\beta \geq U_0(\alpha) \qquad \text{for all } \alpha; \tag{A4}$$

$$\int_A \{V[\mu(\alpha,\beta),\beta] - v_0(0;\alpha)\}g(\alpha)d\alpha \geq 0 \quad \text{for all } \beta, \tag{A5}$$

where $v_0(0;\alpha)$ is used to indicate that the *status-quo* utility of the foreign country does depend on α.

In any *ex-post* efficient contract, the foreign country's expected value of report b must be,

$$E_\alpha V(\beta) = \int_A v(\alpha,b)g(\alpha)d\alpha - \beta\{1 - G[\varepsilon(b)]\}. \tag{A6}$$

That the efficient decision rule is piecewise continuously differentiable in b implies that the same is true of any $v(a,b)$ that implements it [see, Guesnerie and Laffont (1984)]. For $v(a,b)$ differentiable at β, the incentive compatibility constraint (A3) becomes,

$$\int_A v_b(\alpha,\beta)g(\alpha)d\alpha = -\beta\varepsilon'(\beta)g[\varepsilon(\beta)] \tag{A7}$$

for all β. Integration of this by parts gives,

$$\int_A v(\alpha,\beta)g(\alpha)d\alpha = \Lambda - \beta G[\varepsilon(\beta)] - \int_{\beta}^{\bar{\beta}} G[\varepsilon(y)]dy,$$

$$\text{where } \Lambda \equiv \int_A v(\alpha,\bar{\beta})g(\alpha)d\alpha + \bar{\beta}G[\varepsilon(\bar{\beta})].$$

Using this in (A6) gives,

$$E_\alpha V(\beta) = \Lambda - \int_{\beta}^{\bar{\beta}} G[\varepsilon(y)]dy - \beta. \tag{A8}$$

Further, in order to satisfy the individual rationality constraint it must be the case that $\varepsilon - \bar{\beta} \geq v_0$. That is, every type of foreign government, except possibly the one with the highest administrative cost, expects more than its *status-quo* payoff. To see why this is true, let $\varepsilon = \bar{\beta} + v_0$, then (A8) becomes,

$$E_\alpha V(\beta) = v_0 + \int_{\beta}^{\bar{\beta}} \{1 - G[\varepsilon(y)]\}dy. \tag{A8'}$$

The second half of (A8') is the minimum expected information rent accruing to the foreign country from any efficient contract.

As an example consider the contract, in which for $b \leq \delta(a)$,

$$e(a,b) = a, \quad t(a,b) = 0, \quad v(a,b) = z(a) + \min\{\delta(a),\bar{\beta}\};$$

and for $b > \delta(a)$,

$$e(a,b) = 0, \quad t(a,b) = a\bar{m}, \quad v(a,b) = z(a);$$

$$\text{where} \quad z(a) = v_0 + \int_{\underline{\alpha}}^{a} \Phi[\delta(\alpha)]g(\alpha)d\alpha - \Phi[\delta(a)] \quad \text{and} \quad \Phi(\beta) \equiv \int_{0}^{\beta} F(\beta)d\beta .$$

The structure of this contract is quite similar to that in the case where α is common knowledge. The only difference is that, while the contract (13) was based on the actual value of α, this contract is based on the home country's report of α. Recall that (13) satisfied incentive compatibility for all α, therefore this contract satisfies incentive compatibility for all home reports; that is, truthtelling is a dominant strategy for the foreign country in this contract. Also for $a = \alpha$, the expected payoff of this contract for the foreign country is just (A8'), thus it is individually rational.

Under this same contract, the expected payoff of the an α-type home government announcing a is given by,

$$E_{\beta}U(\alpha) = \{w(a,0;\alpha) - \delta(a)\}F[\delta(a)] + w(0,a\bar{m};\alpha)\{1 - F[\delta(a)]\} - z(a). \tag{A9}$$

Differentiation of (28) gives the home country's incentive-compatibility condition,

$$\{w_e(a,0;\alpha) - \delta'(a) - \bar{m}w_t(0,a\bar{m};\alpha)\}F[\delta(a)] + \bar{m}w_t(0,a\bar{m};\alpha) +$$

$$\{w(a,0;\alpha) - \delta(a) - w(0,a\bar{m};\alpha)\}f[\delta(a)]\delta'(a) + \delta'(a)F[\delta(a)] = 0,$$

which holds for $a = \alpha$. This gives a (Bayesian) equilibrium expected payoff for the home country of $w^C - z(\alpha)$. As long as this weakly exceeds $U_0(\alpha)$, the contract is feasible, and indeed it is the best efficient, feasible contract for the home country. A necessary and sufficient condition for home-country individual rationality is that $w^C(\alpha) - w_0(\alpha) \geq \Phi[\delta(\alpha^*) - \delta(\alpha)]$, for all $\alpha \in [\underline{\alpha}, \alpha^*)$ where $\alpha^* \equiv z^{-1}(v_0)$.

The principal-agent problem in which the home country has private information is considerably more complicated than that in section 5 if $v_0(0)$ is a function of α. When $v_0(0)$ is independent of α, it can be shown that the unique perfect Bayesian equilibrium payoffs of this

game are the same as when the principal has no private information at all.[15] In other words, the home country can do no better than if it were to reveal its true type in the first stage through its contract offer.

[15] See Maskin and Tirole (1989), proposition 11.

APPENDIX B: SEMI-SEPARATING EQUILIBRIA WITH $\rho = 1$

When $\rho < 1$, the critical value determining the foreign country's indifference between choosing $e_0 > 0$ and choosing $e_0 = 0$ is θ, which is the median of 0, γ, and $\frac{\gamma - \rho\hat{\beta}}{1-\rho}$. When $\rho = 1$, this last term is undefined, which poses a problem for the separating equilibria in which $\gamma > \theta > 0$. To see this problem diagrammatically, consider what would happen to Figure 4 if ρ were unity: the slope of the line $v_0(0) + \rho(\hat{\beta} - \beta)$ would equal that of $V_0(\alpha)$. Thus $V_0(\alpha)$ would either lie completely below $v_0(0) + \rho(\hat{\beta} - \beta)$, as in Figure 3, giving a pooling equilibrium and $\theta = 0$; or completely above $v_0(0) + \rho(\hat{\beta} - \beta)$, giving the third sort of equilibrium described in the text where $\theta = \gamma$; or the two lines would coincide. If they coincide, then all types in $[0, \gamma)$ are indifferent between choosing $e_0 > 0$ and choosing $e_0 = 0$ in the first stage. This implies the possibility of an enormous number of equilibria which, with some abuse of the terminology, we shall call *semi-separating*.

Let $\psi(\beta)$ be the probability that type β chooses $e_0 = 0$ in the first stage. Any equilibrium in which there exists a pair $\beta', \beta'' \in [0, \gamma)$, such that $\psi(\beta') > 0$ and $\psi(\beta'') < 1$, will be called a semi-separating equilibrium. In order for $\psi(\beta')$ to be greater than zero, it must be that $v_0(\alpha) - \beta' \leq v_0(0) + \rho(\hat{\beta} - \beta')$, and for $\psi(\beta'')$ to be less than unity, it must be that $v_0(\alpha) - \beta'' \geq v_0(0) + \rho(\hat{\beta} - \beta'')$. Together these imply $\hat{\beta} = \gamma$. The posterior density induced by $e_0 = 0$ in such an equilibrium is:

$$\hat{f}(\beta) = \pi\psi(\beta)I_{[0,\gamma)} + \pi f(\beta)I_{[\gamma,\bar{\beta}]},$$

$$\text{where } \frac{1}{\pi} = \int_0^{\gamma}\psi(y)f(y)dy + 1 - F(\gamma).$$

Differentiating $(\delta - \beta)\hat{F}(\beta)$ with respect to β and evaluating it at $\beta = \gamma$ gives the condition:

$$\gamma + \frac{\int_0^{\gamma} \psi(y) f(y)\, dy}{f(\gamma)} = \delta . \tag{B1}$$

Since some $\psi(\beta)$ are less than unity and some are greater than zero, it must be that $0 < \int_0^{\gamma} \psi(y) f(y) dy < F(\gamma)$. Thus condition (B1) can be met only if $\gamma + [F(\gamma)/f(\gamma)] > \delta > \gamma$. Moreover, if this condition is met, there are any number of functions $\psi(\beta)$ that satisfy (B1).

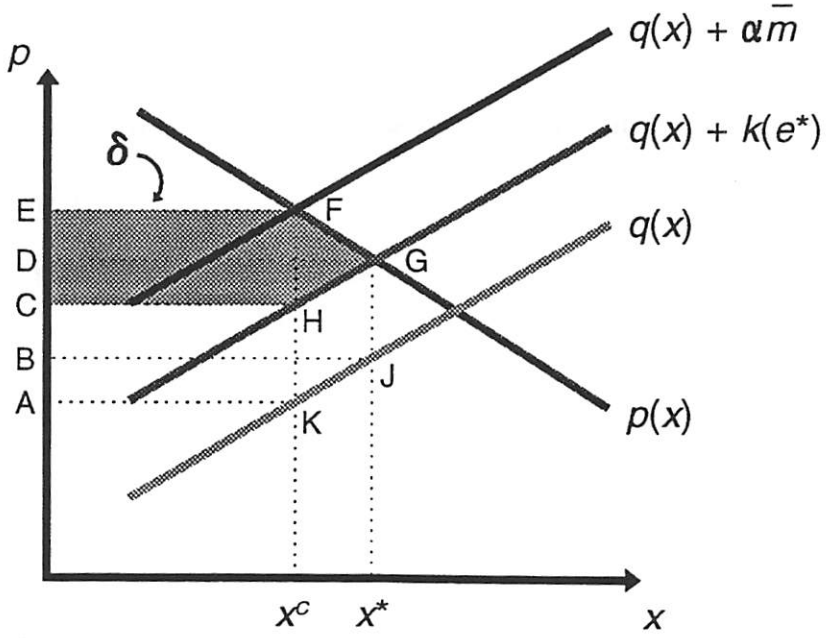

Figure 1

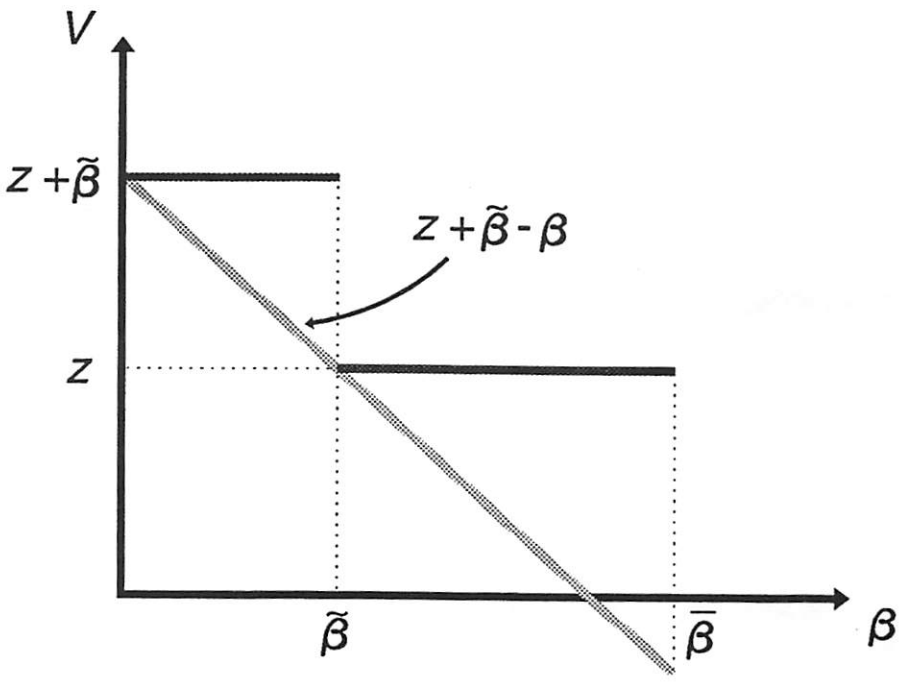

Figure 2

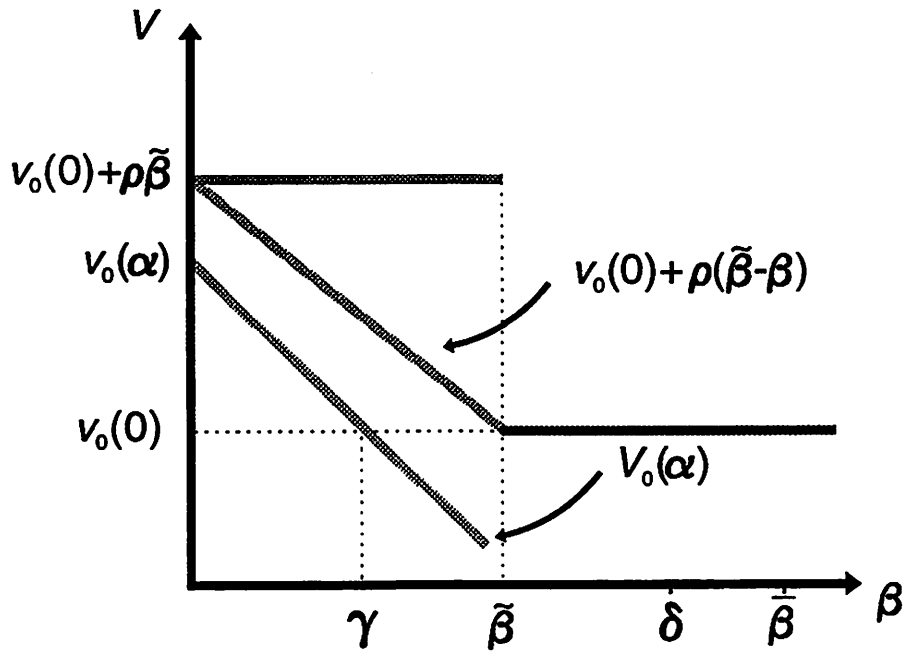

Figure 3

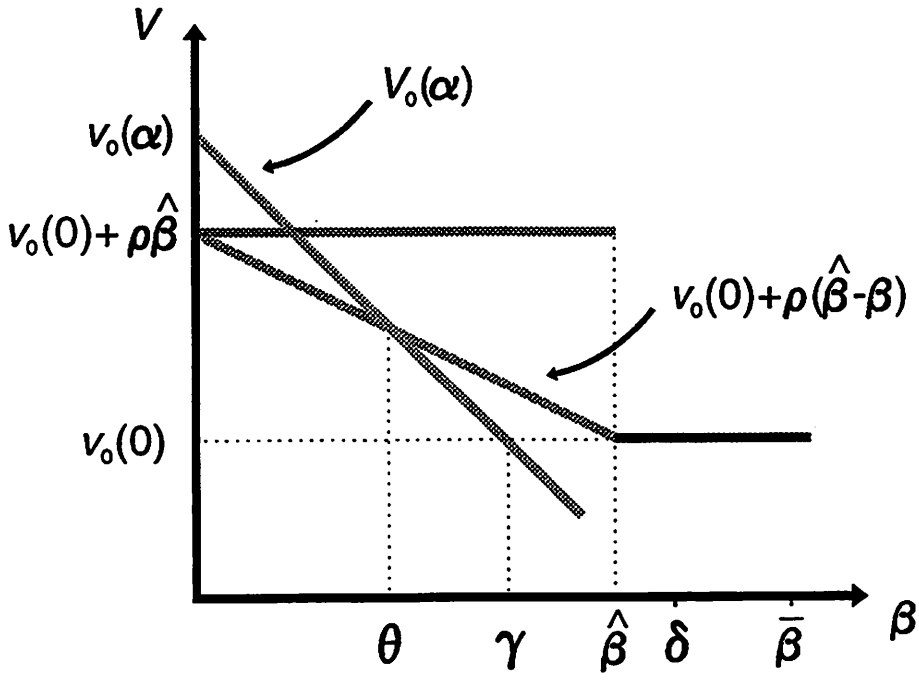

Figure 4

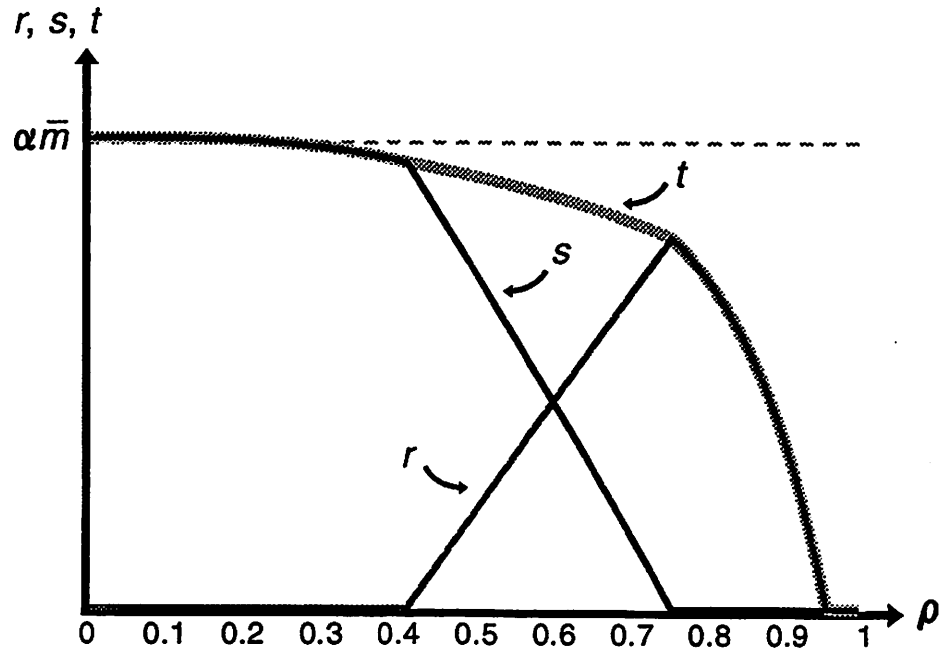

Figure 5