Staff Papers Series

Staff Paper P90-53 August 1990

A MODEL OF POTENTIALLY IMMISERIZING UNILATERAL ENVIRONMENTAL CONTROLS

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1. Introduction

Despite public concern expressed in political debate that stringent environmental regulation will undermine a nation's competitiveness in trade, relatively little economic research has been devoted to this topic. In this paper, we address two aspects of this issue that have not been studied to date. First, we examine the conditions under which a pollution tax, imposed unilaterally by a large country in a trading world will make that country worse off. Clearly, this can happen when pollution control policies adversely affect a country's terms of trade and the welfare losses from uncontrolled pollution are small. Second, we seek to determine the qualitative nature of an optimal tax on pollution,i.e., one that reflects both the pollution effect as well as the trade effect.

In § 2, we construct a simple one factor, two good, two country static general equilibrium model of the effects of unilateral environmental controls as embodied in a pollution tax on the polluting good. We find that theoretically plausible circumstances exist in which a large country such as the USA can

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[1] This is a considerably revised version of Chapters 3 and 4 of my M. S.(Plan B) thesis - Batabyal[2] - submitted to the Department of Agricultural and Applied Economics at the University of Minnesota. Financial support from the Graduate School of the University of Minnesota by way of Grant #0350-2211-07 is greatly appreciated. I thank Andy McLennan, Jim Houck and particularly Ted Graham-Tomasi for their input. I alone am responsible for the output.

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circumstances exist in which a large country such as the USA can make itself worse off with the unilateral imposition of environmental controls. Motivated by these findings, in § 3, we pose the following question: Suppose that the USA government is not permitted to capture any trade gains by virtue of its market power in the world by setting a tariff or any other tariff equivalent policy. What steps can the USA government take to manipulate the terms of trade in its favor by using the *domestic* tax structure? Specifically, we derive a closed form expression for an optimal pollution tax and show that such a tax is always positive if the polluting good is the export good, but not necessarily positive if the polluting good is the import good. Finally, in § 4 we review our salient findings.

Previous researchers have studied questions related to ours. In an early empirical paper, D'Arge and Kneese[4] left the question of the effects of unilateral environmental controls open by demonstrating positive income effects for *all* countries being studied irrespective of whether environmental controls were instituted unilaterally or multilaterally. Pethig[15] and Asako[1] showed that under certain conditions, when a nation's pollution intensive good is exported, increased trade can diminish that country's welfare. In a somewhat different vein, McGuire[10] has shown that in an open economy with factor mobility across countries, unilateral environmental regulation can drive the regulating country out of producing the regulated good. In a rather comprehensive empirical study of the effects of unilateral environmental controls in primarily the USA manufacturing sector, Leonard[8] found little support for the "industrial flight" hypothesis.[3]

Concerning the second question that we have posed, the problem of optimal open economy, second-best taxation of an externality has been almost entirely neglected in the environmental economics literature. However, there does exist a small literature in international economics which has addressed itself to this issue. Friedlaender and Vandendorpe[6] and Dornbusch[5] have considered the second best taxation problem and have derived expressions for the optimal consumption and production tax for an economy with some monopoly power in trade but with no externality. Vandendorpe[18] has extended the two good results of Friedlaender and Vandendorpe[6] to the "n" good case, again without externalities. Markusen[9] has considered the problem of optimal taxation with international externalities. However, Markusen's characterization of the optimal tax expressions is in terms of variables which are difficult to interpret empirically. Further, a number of his results are ambiguously signed. As we shall show later in this paper, when the polluting good is the export good, our pollution tax is unambiguously positive. Since we believe that the question of the effects of unilateral environmental controls is essentially an empirical one, we characterize our tax in terms of elasticities and marginal propensities to consume, to the extent possible. The results of § 3 are a natural extension of this research on optimal second-best taxation to the case where the two country

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[3] Related issues such as transboundary pollution and the institution of multilateral policy have been studied by Segerson[17], Merrifield[12] and McGuire[10].

international economy is now characterized by a domestic externality.

2. The Open Economy Model

2.1 Assumptions

First, the two countries produce two different final goods, E and I, both of which are traded. Second, the only factor of production called labor is supplied inelastically by consumers and not traded. Third, E is the export good of the USA and I is the export good of the second country which we shall call ROW. The production of E in the USA gives rise to a pure production externality, namely pollution, which is domestic in nature. Fourth, the production externality does not affect production decisions in the USA. However, this externality does enter the utility functions of consumers in the USA in an additively separable manner. Fifth, within the USA and ROW, all consumers are identical and all consumers treat E and I as normal goods. The USA is a large economy, possessing some monopoly power in trade. Sixth, the USA government distributes the tax proceeds to consumers proportionally in a manner which does not alter the extant income distribution. Finally, ROW is assumed not to retaliate in any way against domestic USA policies which have trade implications. These assumptions are maintained throughout the remainder of this paper.

2.2 Notation

Superscripts on letters will always refer to the two countries,i.e., USA and ROW. Lower case letters will always refer to demand relationships for the two goods. Upper case letters will always refer to supply/production relationships. The letter "t" refers to the pollution tax, which takes the form of a production tax. The letter "P" refers to the USA terms of trade. "B" refers to the Balance of Payments of ROW. β refers to the marginal rate of transformation between E and I in the USA. Z^{USA} refers to the aggregate level of pollution in the USA economy. Functions are denoted by lower case or upper case letters depending on whether the function concerned describes a demand or a supply/production relationship. Finally, it is understood that all the functional relationships in this paper are maps from $\mathbb{R}^n_+$, $n \in \mathbb{N}$, to $\mathbb{R}$. This system of notation is maintained throughout the remainder of this paper.

2.3 Method of Analysis

Before proceeding to the model, we outline the method by which we propose to conduct the analysis. Whenever possible, we will attempt to characterize our results in terms of elasticities and marginal propensities to consume. The method of analysis itself is well known in trade theory and has been referred to as the "method of comparative statics" by Mundell[6, 7] and as the "Samuelsonian two stage derivation" by Bhagwati and Srinivasan[3]. The method actually consists of *three* distinct steps which can be briefly described as follows. Recognizing that a perturbation of one of the equilibrium values of a variable produces a Balance of Payments disequilibrium for one and hence both countries, in the first step, we compute the *excess demand for the export good*, holding the *terms of trade constant*. In the second step, we determine the *excess supply for USA's export good* caused by the actual *change in the terms of trade*. Finally, in the third step, we *equate excess demand with excess supply* to obtain the condition that characterizes the effect of the parameter change on the variable of interest, which often enough is the terms of trade.[4] In § 3, we shall use this method to derive a closed form expression for the optimal pollution tax.

2.4 Description of the Model

Our model is derived from the classical 2×2×2 model of international trade theory. In what follows, we proceed as in Bhagwati and Srinivasan[3, Appendix C]. The two country economic system is characterized by the following functional relationships:

(1) $D^{ROW} = Pe^{ROW} + i^{ROW} = PE^{ROW} + I^{ROW}$ and

(2) $D^{USA} = e^{USA} + (1/P)i^{USA} = E^{USA} + (1/P)I^{USA}$,

which tell us that total domestic expenditure in ROW and the USA equals national income.

(3) $e^{ROW} = a(D^{ROW}, P)$,

(4) $i^{ROW} = b(D^{ROW}, 1/P)$.

The demand for E and I in ROW depends on national income and the terms of trade.

(5) $e^{USA} = c(D^{USA}, P)$,

(6) $i^{USA} = d(D^{USA}, 1/P)$.

The demand for E and I in the USA depends on national income and the terms of trade.

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4 Briefly, the method can be illustrated as follows. Suppose that the equilibrium governing a particular system is given by the following functional relationship:
$g(a, b) = f(b)$ where "a" is a parameter. Then to determine db/da, we proceed as follows:
Step 1: Holding b constant, excess $g = (\partial g/\partial a)da$
Step 2: Excess f due to change in $b = [(\partial f/\partial b) - (\partial g/\partial b)]db$
Step 3: Equating excess g to excess f, we have $db/da = [\partial g/\partial a]/[(\partial f/\partial b) - (\partial g/\partial b)]$

(7) $I^{ROW} = F(1/P)$,

(8) $E^{ROW} = G(P)$.

The production of I and E in ROW depends on the terms of trade.

(9) $I^{USA} = H(1/P)$,

(10) $E^{USA} = J(P)$.

The production of I and E in the USA depends on the terms of trade.

(11) $B = P(e^{ROW} - E^{ROW}) = i^{USA} - I^{USA}$

The Balance of Payments condition for ROW.

(12) $U^{USA} = A(i^{USA}, e^{USA}) + C(Z^{USA})$.

The aggregate utility index of the USA is an additive function of total final good consumption, i.e., i^{USA}, e^{USA} and the aggregate level of pollution in the economy. Z^{USA} is itself a function of the total production of E, i.e., $Z^{USA} = S(E^{USA})$. We assume that $\partial A/\partial i^{USA} > 0$, $\partial A/\partial e^{USA} > 0$, $dC/dZ^{USA} < 0$ and that $\partial S/\partial E^{USA} > 0$. Observe that in writing (7) - (10) we have implicitly made use of the concept of a production possibility frontier.[5]

Since we wish to characterize our results in terms of elasticities, it will be convinient to define five separate trade demand functions.

Let $\phi^{ROW}: \mathbb{R}^2_+ \to \mathbb{R}_+$ such that $\phi^{ROW} = e^{ROW} - E^{ROW}$

$$\Rightarrow \phi^{ROW} = a(D^{ROW}, P) - G(P)$$

$$\Rightarrow \phi^{ROW} = k(D^{ROW}, P). \tag{13}$$

Import demand for E in ROW depends on total domestic expenditure and the terms of trade. Define $\phi^{USA}: \mathbb{R}^2_+ \to \mathbb{R}_+$ such that $\phi^{USA} = i^{USA}$

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[5] More conventionally, the production possibility frontier for the USA can be written as $I^{USA} = M(E^{USA})$, where it is assumed that $dM/dE^{USA} < 0$. Indeed, we shall find much use for this particular form of the production possibility frontier later in this paper.

$- I^{USA}$

$$\Rightarrow \phi^{USA} = d(D^{USA}, 1/P) - H(1/P)$$

(14) $$\Rightarrow \phi^{USA} = 1(D^{USA}, 1/P).$$

The import demand for I in the USA depends on total domestic expenditure and the terms of trade. Define $\Phi^{ROW}: \mathbb{R}^2_+ \to \mathbb{R}$ such that $\Phi^{ROW} = - \phi^{USA}$. Thus we have

(15) $$\Phi^{ROW} = - \phi^{USA} = - 1(D^{USA}, 1/P) = y(D^{USA}, 1/P).$$

The ROW "offer" function depends on total domestic expenditure in the USA and the terms of trade. Define $\psi^{USA}: \mathbb{R}^2_+ \to \mathbb{R}$ such that $\psi^{USA} = e^{USA} - E^{USA}$. Thus we have

$$\psi^{USA} = c(D^{USA}, P) - J(P)$$

(16) $$\Rightarrow \psi^{USA} = u(D^{USA}, P).$$

Total imports from USA to ROW depend on total domestic expenditure in the USA and the terms of trade. Finally, define $\psi^{ROW}: \mathbb{R}^2_+ \to \mathbb{R}_+$ such that $\psi^{ROW} = - \psi^{USA}$. Thus we have

(17) $$\psi^{ROW} = - u(D^{USA}, P) = v(D^{USA}, P).$$

Total exports from the USA to ROW depend on total domestic expenditure in the USA and the terms of trade.

This 17 equation system characterizes the two country world that we are studying. Note that (11) can be written as

(18) $$B = \phi^{USA} - P\phi^{ROW} = 1(D^{USA}, 1/P) - Pk(D^{ROW}, P).$$

2.5 Stability

Although stability is not the centerpiece of our analysis, it forms an important part of the analysis in two ways. First, it is nonsensical to apply comparative statics methods to unstable economies. Second, by Samuelson's[16, p. 258] correspondence principle,much useful information can be gained by a study of the stability condition of the aforementioned two country system.

Stability conditions can be derived in a number of different ways. In the remainder of this section, we shall follow Mundell[13, pp. 72 - 73] in obtaining the stability condition for our two country system.

We start with (18). Choose E and I units so that $P = 1$ in the initial equilibrium. It is clear that at this initial equilibrium, $B = 0$. Thus from (18) we have

$$1(D^{USA}, 1/P) = Pk(D^{ROW}, P)$$

$$\Rightarrow \phi^{USA} = P\phi^{ROW}$$

$$\Rightarrow \phi^{USA} = \phi^{ROW} = \phi.$$

To obtain the stability condition, we hold domestic expenditure in each country constant and differentiate (18) w.r.t. P. Since D^{ROW} and D^{USA} are constant, we can write (18) as

$$B = 1(1/P) - Pk(P)$$

Then $$\frac{dB}{dP} = \frac{-d\phi^{USA}}{d(1/P)}\frac{1}{P^2} - P\frac{d\phi^{ROW}}{dP} - \phi^{ROW}$$

$$= \phi^{ROW}\left\{-\frac{d\phi}{d(1/P)}\frac{1}{P^2}\frac{(1/P)}{(1/P)}\frac{1}{\phi^{ROW}} - \frac{P}{\phi^{ROW}}\frac{d\phi^{ROW}}{dP} - 1\right\}$$

$$= \phi\left\{-\frac{d\phi^{USA}}{d(1/P)}\frac{(1/P)}{\phi^{USA}} - \frac{d\phi^{ROW}}{dP}\frac{P}{\phi^{ROW}} - 1\right\}$$

$$= \phi(\epsilon^{USA} + \epsilon^{ROW} - 1) \tag{19}$$

where $\epsilon^{USA} > 0$ is the elasticity of demand for imports in the USA and $\epsilon^{ROW} > 0$ is the elasticity of demand for imports in ROW.

Equation (19) tells us that the change in the Balance of Payments of ROW due to a small change in the terms of trade can be expressed as a linear combination of the initial equilibrium level of imports(ϕ) and the elasticities of import demand for the USA and ROW. Now stability requires that a *decline* in ROW's(USA's) terms of trade *improve* ROW's(USA's) trade balance. Thus our two country system is stable iff $dB/dP = \phi(\epsilon^{USA} + \epsilon^{ROW} - 1) > 0$. From this it follows that stability requires

$$(20) \qquad \epsilon^{USA} + \epsilon^{ROW} > 1$$

This is the well known elasticity criterion for stability.

In what follows, we assume that our two country system is stable. It is important to note that (19) provides us with the *coefficient for a change in the terms of trade*. This fact will be used later in determining the effects of a USA imposed pollution tax on the two country system.

2.6 The Effects of a Pollution Tax

Recall that the USA imposes a pollution tax on the manufacturers of E, the tax taking the form of a production tax.[6] The pollution tax introduces a discrepency in the prices seen by producers in the USA and all other prices. Thus there is a direct effect and an indirect effect of the pollution tax. The direct effect consists of the *negative price effect* on producers of E in the USA. The indirect effect consists of the *positive income effect* on consumers due to the disbursement of the tax proceeds.

We now distinguish between P^{USA} and P^{ROW}. To obtain the direct effect of the pollution tax on the USA terms of trade, we first compute the excess demand for E at constant terms of trade. This is given by

$$(21) \qquad -\gamma^{USA}E^{USA}dt$$

where γ is the elasticity of supply of E in the USA and dt is the

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[6] In a one factor world, the taxation of emissions, input or output results in equivalent outcomes. In this sense there are no efficiency losses from taxing production. However, this is almost never the case in a multi factor world.

small tax that has been placed on the polluting good. The negative sign follows from the fact that the E production response to the tax is negative.

To (21) we must now add the positive income effect of the tax. The increased demand for E in the USA is given by

$$(22) \quad r^{USA}E^{USA}dt \qquad \text{where } r^{USA} \in (0, 1)$$

and r^{USA} is the marginal propensity to spend income on the home good in the USA.

Thus the total excess demand for E due to the tax is given by adding (21) and (22). This yields

$$(23) \quad (r^{USA} - \gamma^{USA})E^{USA}dt.$$

We now have to determine the excess supply of E as a result of the actual change in the terms of trade, which has been held constant so far. As has been mentioned earlier, this excess supply is given by the stability condition. It should be noted that P in (19) is now P^{USA}. Thus the excess supply for E due to the change in P^{USA} is

$$(24) \quad \phi(\epsilon^{USA} + \epsilon^{ROW} - 1)dP^{USA}.$$

We equate (23) and (24) to obtain:

$$(25) \quad \frac{dP^{USA}}{dt} = \frac{(r^{USA} - \gamma^{USA})E^{USA}}{\phi(\epsilon^{USA} + \epsilon^{ROW} - 1)}$$

Thus we observe that

$$(26) \quad \frac{dP^{USA}}{dt} > 0 \quad \text{as} \quad r^{USA} > \gamma^{USA}.$$

In other words, the terms of trade of the USA *improve* as a result of the tax provided that the positive income effect outweighs the negative price effect.

A pollution tax which takes the form of a production tax on E decreases the production of E and increases the production of I.

This can be expected to increase the relative price of the taxed good. Thus, we would expect that $dP^{USA}/dt > 0$ but as (26) shows, in a terms of trade sense, the USA can make itself *worse off* by levying a pollution tax unilaterally. Specifically, we can expect this to happen if the supply of E in the USA is highly price elastic and a relatively small proportion of total income is spent on it.

To determine the effect of the pollution tax on the domestic USA *producer* price ratio, we proceed as follows. Observe that the price seen by E producers in the USA is $\{(P^{ROW})/(1 + t)\}$. Differentiating this expression w.r.t. t we have:

$$\frac{d\{(P^{ROW})/(1 + t)\}}{dt} = P^{ROW}\{ - 1(1 + t)^{-2}(1)\} + \frac{1}{1+t}\frac{dP^{ROW}}{dt}$$

Letting $P^{ROW} = 1$ by appropriate choice of units and letting $t = 0$, assuming initial free trade, the above expression reduces to

$$\text{(27)} \quad \frac{d\{(P^{ROW})/(1 + t)\}}{dt} = -1 + \frac{dP^{ROW}}{dt}.$$

Now assuming stability and that $dP^{ROW}/dt < 0$, we observe that the domestic USA E producer price ratio declines,i.e., $[d\{(P^{ROW})/(1 + t)\}]/dt < 0$. This result makes intuitive sense since we would expect that E producers decrease production as a result of the pollution tax owing to a decline in the producer price of their final output.

Before concluding this section, we wish to compute the effect of the pollution tax on national income in the USA. To do this, we will use a method known to economists at least since Meade[11]. The method illustrates how the aggregate level of pollution in the USA economy explicitly affects some of our results. The method consists of differentiating (12) totally and then denoting the change in national income, i.e., dD^{USA}, by dU^{USA}/U_i where U_i is the marginal utility of I. More informally, in this process, we are decomposing the change in national income due to the tax into its constituent components. Differentiating (12) totally, we have

$$dU^{USA} = U_i di^{USA} + U_e de^{USA} + Z_1 dZ^{USA} \tag{28}$$

where U_i, U_e denote the marginal utility of I and E and Z_1 denotes the marginal disutility of pollution. Dividing the RHS and the LHS of (28) by U_i yields

$$dD^{USA} = dU^{USA}/U_i = di^{USA} + \alpha de^{USA} + Z_2 dZ^{USA} \tag{29}$$

where α is the marginal rate of substitution of E for I in the USA and Z_2 denotes the marginal social rate of substitution between pollution and I in the USA.

Since $i^{USA} = I^{USA} - \Phi^{ROW}$ and $e^{USA} = E^{USA} - \psi^{ROW}$ and since $\alpha = P^{USA} = P^{ROW}$ in the initial equilibrium, we can write (29) as

$$dD^{USA} = (dI^{USA}+P^{USA}dE^{USA}) - (d\Phi^{ROW}+P^{USA}d\psi^{ROW}) + Z_2 dZ^{USA}. \tag{30}$$

This tells us that a *small* change in national income from the initial equilibrium level can be expressed as the sum of a production effect, a trade effect and a pollution effect.

In order to express (30) in a more convinient form, we use the equation for the production possibility frontier described earlier in footnote 5 and differentiate the RHS of (1) totally to get

$$dD^{USA} = (P^{USA} - \beta)dE^{USA} + \psi^{ROW}dP^{USA} + Z_2 dZ^{USA}. \tag{31}$$

Now the change in the production of E due to the imposition of the pollution tax, i.e., dE^{USA} is given by $-\gamma^{USA}E^{USA}dt$. Using $Z^{USA} = S(E^{USA})$, dividing the RHS and LHS of (31) by dt and substituting for dP^{USA}/dt from (25) yields

$$(32) \quad \frac{dD^{USA}}{dt} = \frac{-[((P^{USA} - \beta)\gamma^{USA}E^{USA})\{\phi(\epsilon^{USA} + \epsilon^{ROW} - 1)\}]}{\phi(\epsilon^{USA} + \epsilon^{ROW} - 1)} + \frac{\psi^{ROW}(r^{USA} - \gamma^{USA})E^{USA}}{\phi(\epsilon^{USA} + \epsilon^{ROW} - 1)} - \frac{\left[Z_2\gamma^{USA}E^{USA}\left\{ \frac{dS}{dE^{USA}} \right\} \{\phi(\epsilon^{USA} + \epsilon^{ROW} - 1)\} \right]}{\phi(\epsilon^{USA} + \epsilon^{ROW} - 1)} .$$

This is an important relation. It tells us that the change in national income in the USA due to a small change in the tax rate is given by a combination of three distinct effects. The first component on the RHS of (32) refers to the E production effect and is negative in sign. The second component refers to the terms of trade effect, which is assumed to be positive. Finally, the third component refers to the pollution effect; this is positive.

Thus we observe that the USA will be better off from the imposition of a small pollution tax provided that the sum of the terms of trade effect and the pollution effect outweighs the negative E production effect. In theory however, once again we note that the USA can make itself *worse off* by instituting a pollution tax on its export good unilaterally. The variables which are germane to a resolution of this question of national welfare change are expressed in (32).

3. A Characterization of the Optimal Pollution Tax

3.1 Motivation

In § 2, we observed that from a theoretical standpoint, a large country such as the USA could make itself worse off by conducting environmental policy unilaterally. Specifically, when the production of the polluting good is taxed, there are trade effects which cannot reasonably be ignored by the government of the USA.

Suppose that the USA government is not permitted to capture any trade gains by virtue of its market power in the world by setting a tariff or any other tariff equivalent domestic policy.[7] What steps can the USA government take to manipulate the terms of trade in its favor by using the *domestic* tax structure? In this section, we address this particular question. We find that the government can use its monopoly power in trade to set an optimal pollution tax on the production of the export good,i.e., E. In this context, optimal means that the tax is based on explicitly maximizing the aggregate USA utility index subject to certain constraints, with the maintained assumption that there is no retaliation from ROW. Further, all possible economywide effects of pollution are taken into account in determining this tax, whereas in § 2, the tax considered was a small piecemeal change from the current status quo.

3.2 Derivation of the Optimal pollution Tax

The model that we shall use to derive the optimal pollution tax is essentially the same as the model used in § 2. The entire procedure for deriving the pollution tax is based in large part on the Meade method for calculating *small* changes in national income.[8]

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[7] By tariff equivalent, we mean a policy initiative which in effect has the same result as that of a tariff. An example would be an equal rate tax on the exportable's production and a subsidy on the consumption of the importable.

[8] As we have already mentioned earlier, this method of designating small changes in national income is well known to economists. The method has been used by numerous researchers such as Friedlaender

In our derivation, we will be using the equation of the production possibility frontier described in footnote 5 of § 2 to model the production side of the economy. To derive the optimal pollution tax, we start with equation (31). We have

$$(33) \quad dD^{USA} = (P^{USA} - \beta)dE^{USA} + \psi^{ROW}dP^{USA} + Z_2dZ^{USA}.$$

The first term on the RHS of (33) reflects the E production effect which arises from the shift in the production of E at *constant terms of trade*. The second term on the RHS of (33) refers to *the change in national income in the USA due to a change in the terms of trade*. Finally, the third component on the RHS of (33) refers to the pollution effect. Equation (33) is identical to an expression obtained by Friedlaender and Vandendorpe[6, p. 1062] except that the Friedlaender and Vandendorpe expression contains no pollution component. (33) is also very similar to Dornbusch's[5] equation (5).

We now follow Friedlaender and Vandendorpe[6] and Dornbusch[5] to accomplish our next objective. This involves decomposing the differential of the terms of trade effect on the RHS of (33) in terms of elasticities and marginal propensities to consume. In order to do this, we note that in international equilibrium, it must be true that

$$(34) \quad \phi^{USA} - P^{USA}\psi^{ROW} = 0.$$ [9]

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and Vandendorpe[6], Jones[7] and Dornbusch[5].

[9] Since $e^{ROW} - E^{ROW} = E^{USA} - e^{USA}$ in equilibrium, it is clear that in equilibrium, $\psi^{ROW} = \phi^{ROW}$. Thus we will write ϕ^{ROW} in place of ψ^{ROW} in the remainder of this decomposition procedure. Further, it should be noted that we will supress the D^{ROW} argument in the function denoting ϕ^{ROW}, since D^{ROW} is held constant in this

Writing (34) as

$$(35)\qquad \left[d\left\{\left(E^{USA} + \frac{1}{P^{USA}} M(E^{USA}) \right), \frac{1}{P^{USA}} \right\} - M(E^{USA}) \right]$$

$$- P^{USA} k(P^{USA}) = 0,$$

and recalling that $E^{USA} + (1/P^{USA})M(E^{USA}) = D^{USA}$, we totally differentiate (35) - holding D^{ROW} constant - to obtain the following relation

$$(36)\qquad \left[\frac{\partial d}{\partial D^{USA}} \frac{\partial D^{USA}}{\partial P^{USA}} + \frac{\partial d}{\partial (1/P^{USA})} \frac{d(1/P^{USA})}{dP^{USA}} - P^{USA} \frac{dk}{dP^{USA}} - k(P^{USA})\right] dP^{USA}$$

$$+ \left[\frac{\partial d}{\partial D^{USA}} \frac{\partial D^{USA}}{\partial E^{USA}} - \frac{dM}{dE^{USA}} \right] dE^{USA} = 0.$$

Equation (36) tells us that once the condition for international balance of payments equilibrium has been expressed appropriately and when all the resulting quantities are allowed to vary simultaneously, the resulting change in international equilibrium can be expressed as the sum of a terms of trade effect and a production effect due to the change in the production of E.

We will now convert (36) into another relation which makes use of elasticities and marginal propensities to consume. To this end, let:

(37) $s^{USA} = (\partial d/\partial D^{USA})(1/P^{USA})$, the marginal propensity to consume the importable.

(38) $\delta^{USA} = \{(1/P^{USA})/\phi^{USA}\}\{\partial d/\partial(1/P^{USA})\}$, the incomplete price elasticity of import demand.

(39) $\xi = (I^{USA})/\phi^{USA}$, the ratio of the aggregate production of the importable to the aggregate quantity of imports demanded by the USA.

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procedure.

(40) $\chi^{ROW} = (d\psi^{ROW}/dP^{USA})(P^{USA}/\psi^{ROW})$, the price elasticity of imports in ROW.

Using (37) - (40), we can rewrite (36) as follows:

$$(41)\qquad [s^{USA}(P^{USA} - \beta) + \beta]dE^{USA} - \psi^{ROW}[(1 + \chi^{ROW}) + (\delta^{USA} + \xi s^{USA})]dP^{USA} = 0.$$

Equation (41) accomplishes our task of decomposing the differential of the terms of trade effect on the RHS of (33). Equation (41) says that after a change in the production of E, at the new world equilibrium, the excess demand as a result of the change in E production *at constant terms of trade* must equal the *change in the terms of trade* when the terms of trade adjust by dP^{USA}. It should be clear that this is only a minor variation on "the method of comparative statics" that we used in § 2 to analyze the effects of a small pollution tax.

In our discussion of stability in § 2, we had noted that a decline in USA's terms of trade must improve USA's trade balance. Applying the same concept here, we note that stability requires a *decrease in the demand for I* (the USA importable) when the price of I, $1/P^{USA}$, *increases*. Since the USA exports E and imports I, stability requires that $[(1 + \chi^{ROW}) + (\delta^{USA} + \xi s^{USA})] < 0$.

We can now use our result in (41) to substitute for dP^{USA} in equation (33) above. Using the fact that

$$(42)\qquad dP^{USA} = \frac{[s^{USA}(P^{USA} - \beta) + \beta]}{\psi^{ROW}[(1 + \chi^{ROW}) + (\delta^{USA} + \xi s^{USA})]}\, dE^{USA},$$

and that $Z^{USA} = S(E^{USA})$, we can express (33) as

$$(43)\qquad \frac{[s^{USA}(P^{USA} - \beta) + \beta]}{[(1 + \chi^{ROW}) + (\delta^{USA} + \xi s^{USA})]} + (P^{USA} - \beta) + Z_2\left(\frac{dS}{dE^{USA}}\right) = 0.$$

Letting $[(1 + \chi^{ROW}) + (\delta^{USA} + \xi s^{USA})] = A < 0$ and $(dS/dE^{USA}) = B > 0$, we write (43) as

$$(44) \quad (P^{USA} - \beta) + \frac{[s^{USA}(P^{USA} - \beta) + \beta]}{A} + Z_2B = 0.$$

To arrive at a closed form expression for the tax, we simplify (44) and observe that the optimal pollution tax is given by:

$$(45) \quad \frac{P^{USA} - \beta}{\beta} = \frac{-\left(\dfrac{Z_2BA}{\beta}\right) - 1}{s^{USA} + A}$$

We can now state

Proposition 1: The tax implied by (45) is positive.

Proof: Since $Z_2 < 0$, $A < 0$, $B > 0$ and $\beta > 0$, the numerator of (45) is clearly negative. To see that the denominator of (45) is also negative, let $\tau = \delta^{USA} + \xi s^{USA} = \{(1/P^{USA})/\phi^{USA}\}\{\partial d/\partial(1/P^{USA})\} + \{I^{USA}/\phi^{USA}\}\{\partial d/\partial D^{USA}\}\{1/P^{USA}\}$ from the definitions of δ^{USA}, ξ and s^{USA} respectively.[10] Now observe that we can express τ alternately as

$$(46) \quad \{(1/P^{USA})/\phi^{USA}\}[\{\partial d/\partial(1/P^{USA})\} + (\partial d/\partial D^{USA})\{d(.,.)\}]$$
$$- [\{(1/P^{USA})/\phi^{USA}\}(\partial d/\partial D^{USA})\{d(.,.) - I^{USA}\}]$$

which is identical to the earlier decomposition. Let the first term of (46), i.e., the term before the negative sign $= \hat{\tau} < 0$, the pure substitution effect of τ. The second term of (46) is, of course, s^{USA}. Thus, $\tau = \hat{\tau} - s^{USA}$ and $A = (1 + \chi^{ROW}) + (\hat{\tau} - s^{USA})$. Since $P^{USA}/\beta = [-\{(Z_2AB)/\beta\} + \chi^{ROW} + \hat{\tau}]/[1 + \chi^{ROW} + \hat{\tau}] > 0$, it follows that $s^{USA} + A = < 0$. *QED.*

A comparison of (45) with some previously derived optimal tax

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[10] τ is the imperfect price elasticity of import demand. The word "imperfect" refers to the fact that in the computation of this elasticity, total production in the USA is held constant.

expressions in the literature suggests some obvious similarities. Specifically, (45) is related to equation (28) of Markusen[9], to equation (9) of Friedlaender and Vandendorpe[6] and to equation (14) of Dornbusch[5]. However, (45) is most closely related to Markusen's equation (28), which is his version of the optimal production tax with environmental pollution. Holding $S_2 = 0$ in his (28) to make our (45) and his (28) comparable, we find that both expressions contain a pollution term and a trade effect term. The similarities notwithstanding, we note that as opposed to the motivation underlying this paper, the work of the researchers cited above is motivated by, *inter alia*, an interest in determining the *second best policy initiatives* available to the government of a country with some monopoly power in trade which is precluded from using its first best policy alternative.

It is of some interest to determine the nature of an optimal tax expression for an externality when the externality is the result of domestic production of the USA import good. Using a procedure similar to the above, it can be shown that the optimal tax is now not necessarily positive. This result arises from the fact that the "B" term in (45) for the case of an import sector externality is negative. This result has interesting policy implications. If the tax is negative, then this analysis suggests that it may be necessary to *subsidize* the externality causing sector of the economy. On the other hand, if the tax is positive then the USA can be worse off in a terms of trade sense due to the implicit unfavorable price effect of the tax.

4. Conclusions

In this paper we have studied two important questions in environmental economics. In § 2 we showed that theoretically plausible circumstances exist in which a large country such as the USA could make itself worse off by pursuing environmental policy unilaterally. In this connection, this analysis has shown that the question of being better off or worse off is really an empirical one; further, the above analysis has pointed out the variables which are relevant to a resolution of the question of national welfare change.

In § 3 we showed that the USA government could use its market power in the world to set an optimal pollution tax to correct for the domestic distortion. Since this tax is positive, an optimal program always involves taxing the polluting sector.

These findings are related to some well known results in international economics involving the growth with trade literature and the transfer problem literature. In the former case, it is well known that a large country's unilateral investment policies can make it worse off. In the latter case, it is also well known that the unilateral transfer of money by a large country can make that country worse off. In this sense, the results of this paper conform to the general pattern of results regarding the pursuit of unilateral policy initiatives.

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