Trade and Pollution Linkages: Piecemeal Reform and Optimal Intervention

John Beghin; David Roland-Holst; Dominique Van Der Mensbrugghe

The Canadian Journal of Economics, Vol. 30, No. 2. (May, 1997), pp. 442-455.

Stable URL:
http://links.jstor.org/sici?sici=0008-4085%28199705%2930%3A2%3C442%3ATAPLPR%3E2.0.CO%3B2-G

The Canadian Journal of Economics is currently published by Canadian Economics Association.

Your use of the JSTOR archive indicates your acceptance of JSTOR's Terms and Conditions of Use, available at http://www.jstor.org/about/terms.html. JSTOR's Terms and Conditions of Use provides, in part, that unless you have obtained prior permission, you may not download an entire issue of a journal or multiple copies of articles, and you may use content in the JSTOR archive only for your personal, non-commercial use.

Please contact the publisher regarding any further use of this work. Publisher contact information may be obtained at http://www.jstor.org/journals/cea.html.

Each copy of any part of a JSTOR transmission must contain the same copyright notice that appears on the screen or printed page of such transmission.

JSTOR is an independent not-for-profit organization dedicated to creating and preserving a digital archive of scholarly journals. For more information regarding JSTOR, please contact support@jstor.org.

http://www.jstor.org/
Fri Mar 31 16:07:27 2006

Trade and pollution linkages: piecemeal reform and optimal intervention

JOHN BEGHIN North Carolina State University
DAVID ROLAND-HOLST OECD Development Centre, Mills College, and CEPR
DOMINIQUE VAN DER MENSBRUGGHE OECD Development Centre

Abstract. We demonstrate how coordinated trade and environmental policy can achieve efficiency and pollution mitigation gains superior to those obtained without such coordination. We show how trade and environment linkages give rise to complex second-best policy issues and derive optimal interventions and sufficient conditions for welfare-improving piecemeal trade and environmental policy reforms in a small economy. Changing trade and environment distortions in proportion to their optimal levels increases welfare. We decompose the economic and environment effects of policies targeted at trade and pollution in both consumption and production. We also decompose production responses into output adjustments and changes in pollution intensities.

Liens entre commerce international et environnement: réforme à la pièce et l'intervention optimale. Nous démontrons comment la coordination des politiques de commerce international et de l'environnement peut accomplir des gains d'efficacité et de diminution de la pollution qui sont supérieurs aux gains obtenus sans coordination. Nous montrons comment les liens entre commerce et environnement suscitent des problèmes complexes de politique de deuxième choix et nous dérivons des interventions optimales et des conditions suffisantes pour que les réformes de politiques de commerce et de l'environnement induisent des gains de bien-être dans le cas d'un petit pays. Changer les distortions du commerce international et de l'environnement proportionellement à leur niveau optimal augmente le bien-être. Nous décomposons les effets économiques et environnementaux des politiques ciblant le commerce international et la pollution sur les producteurs et les consommateurs. Nous décomposons aussi la réponse des producteurs en terme de l'adjustement de la quantité produite et des intensités de pollution.

1. INTRODUCTION

Trade and environment linkages are coming under increasing scrutiny and a con-

The views expressed in this paper should not be attributed to the authors' affiliated institutions.

Canadian Journal of Economics Revue canadienne d'Economique, XXX, No. 2
May mai 1997. Printed in Canada Imprimé au Canada

0008-4085 / 97 / 442–55 $1.50 © Canadian Economics Association

siderable literature is emerging on the subject.[1] Some authors have looked formally at coordination of environmental and trade policy in a polluted open economy, including Markusen (1975), Baumol and Oates (1988), Krutilla (1991), and Choi and Johnson (1992), but with the exception of Copeland (1994), they emphasize optimal interventions and abstract from the more practical issues of designing second-best and piecemeal reforms. Copeland investigates piecemeal trade and environmental policy reforms in a small, open, production-polluted, and distorted economy and identifies sufficient conditions for welfare enhancement. This initiates an important new line of thinking in literature on second-best trade reform following Hatta (1977),[2] because it addresses the problem of coordination of environmental and trade policy for 'greener' trade reform. It also identifies situations in which a tariff can be used to abate pollution without decreasing welfare.

Building on these results, we account for pollution in consumption as well as production activities and let firms use two approaches to pollution abatement in production. Toxic effluents arising from final consumption are substantial, in the areas, for example, of non-electrical energy, chemicals, and post-consumption waste materials. Consumption-induced pollution critically undermines tariffs as second-best instruments for environmental policy. Further, the presence of consumption-based pollution externalities complicates the welfare effects of trade liberalization and can defeat the intentions of narrower, production-oriented policies. On the production side, firms in polluting sectors can alter output (effluent level) or technology (effluent intensity) in response to the policies considered.

Second, we consider alternative price-oriented instruments including tariffs, consumption and output taxes, and effluent taxes. Effluent taxes may be impractical for developing economies because of costly monitoring. Output and consumption taxes may provide a more realistic approach to unregulated pollution. Each instrument provides distinct incentives for firms to use one or both abatement strategies. We devote substantial attention to the decomposition of these incentives effects on substitution in consumption, shifting output composition, and 'choice of technique' (altering effluent rates).[3]

Identifying and elucidating these effects will clarify two issues in the trade and environment debate. The first is whether trade liberalization induces developing economies to specialize in pollution-intensive activities, particularly exports. Lack of policy coordination or poor instrument choice may explain output and consumption bias towards pollution-intensive goods as well as high effluent rates. The second issue relates to a sobering stylized fact: Although toxic intensity per unit of wealth eventually decreases in high income economies, toxic intensity *per*

1 In several recent survey papers using different taxonomies 'trade and environment' linkages are examined: for example, Cropper and Oates (1992), Dean (1992), and Beghin, Roland-Holst, and van der Mensbrugghe (1994).

2 See Vousden (1990), chap. 9, for a survey of many of these second-best results.

3 Grossman and Krueger (1991) suggested this categorization of pollution effects. Copeland and Taylor (1994) model trade and environment linkages following that decomposition. Their definition of composition refers to the range of goods produced within a continuum. Our definition refers to different output 'baskets' of a fixed number of commodities.

unit of industrial output increases with growth and remains high in these economies (Hettige, Lucas, and Wheeler 1992).

We first consider policy reforms (optimum and gradual) aimed at decreasing pollution in the presence of fixed distortions, showing in particular that two welfare effects arise for all reforms. First, the level of pollution is affected. Following the intuition of the targeting principle, the closest instrument, the effluent tax, does the best job in terms of pollution abatement. Production and consumption taxes are the next best, followed distantly by tariffs, as the worst environmental policy option. Second, each instrument has an indirect effect on allocative efficiency. For example, lower pollution can mean reduced economic opportunities in developing economies (Lee and Roland-Holst, in press).

Next, we combine a piecemeal trade liberalization scenario with pollution reforms, starting from a trade-distorted economy in which pollution previously has been unregulated. For these joint reforms we identify a similar dichotomy of direct effects on welfare. These two indirect effects tend to be symmetric. We identify sufficient conditions for welfare-improving reforms for these coordinated policies.

The last purpose of this paper is to motivate more extensive empirical work on trade and pollution linkages. Empirical analysis should quantify the direct and indirect welfare effects arising from different reforms. Such quantification should be explicit about the respective roles of consumption substitution, output composition, and technique effects in pollution abatement.

II. THE BASIC MODEL

Following Hatta (1977), Dixit and Norman (1980), and Copeland (1994), we use a dual treatment of a perfectly competitive and open economy. Pollution is produced by consumers and producers at different rates and all pollution produced accumulates into a public bad. This in turn enters the utility function and the expenditure function of the representative consumer, expressing its disutility and environmental damage, respectively.[4] The derivative of the expenditure function with respect to pollution is the increase in expenditure necessary to keep utility constant, given an increase in pollution.

Given the assumption of a perfectly competitive economy, production decisions are modelled by a revenue or GDP function:

$$R(P+\tau-\beta, \epsilon, \nu) = \max_{(x,\gamma)} \times \{(P+\tau-\beta)'x - \epsilon\gamma'x \mid (x, \gamma) \text{ feasible given inputs } \nu\}, \qquad (1)$$

where P is the vector of exogenous world prices; τ is the vector of trade taxes, ϵ represents the tax on effluents, γ is the vector of per unit effluent rates of output x of n commodities, and β is a vector of production taxes/subsidies. The function R

4 Alternatively, pollution can enter the expenditure function of the economy even if it is not valued directly but is constrained from above by a non-economic target.

exhibits all the desired properties, that is, it is homogeneous degree one in prices and taxes.[5] The usual envelope theorem results like $R_p = x$; $R_\epsilon = -\gamma' x$ hold, R_{pp} is the Hessian of price responses of the output vector x, and $R_{\epsilon\epsilon}$ is minus the response of production pollution to the effluent tax, $R_{\epsilon p}$ = minus the cross-price response of production pollution to output prices, $R_{\epsilon p} = R'_{p\epsilon}$, and it is the response of output to the effluent tax. For expository purposes, our attention is limited to a single pollutant type, but this framework extends without difficulty to a vector of k pollution types (γ becomes a $k \times n$ matrix and ϵ is a $k \times 1$ vector of taxes).

The matrix $R_{\epsilon\epsilon}$ is positive by convexity of R in prices and taxes. Moreover, $R_{\epsilon\epsilon}$ can be decomposed into three effects: $R_{\epsilon\epsilon} = \gamma' R_{pp}\gamma + \gamma'(\partial\gamma/\partial p)x - x'(\partial\gamma/\partial\epsilon)$.[6] The first effect is the output price response, holding effluent rates γ constant, and is positive because R is positive semi-definite. The second effect is that of prices on effluent rates, difficult to sign for individual γ_i and dependent on the effluent 'production technology,' but one can argue that this is positive as well (i.e., $\gamma(\partial\gamma/\partial p)x$ is positive). The third effect is that of the effluent tax on the effluent rate, which is negative and preceded by a negative sign.

The economy has a representative consumer with expenditure function

$$E(P+\tau+\eta, \epsilon, T, U_0) = \min_{c,\alpha} \{((P+\tau+\eta)'c + \epsilon\alpha' c) | U \geqq U_0\}, \tag{2}$$

where c represents the n-good consumption vector, η is a vector of consumption taxes on the same goods, ϵ is the per-unit effluent tax, and α denotes the vector of effluent per unit of consumption of c. As noted, pollution is a scalar and is the sum of different effluent emissions in consumption and production activities, but all refer to the same effluent type. Variable T is the public bad (or the variable constrained by a non-economic target). It is defined as $T = \alpha' c + \gamma' x$, the sum of consumption and production pollution. The scalar U represents utility with a reference level U_0. The usual optimality conditions for E include $E_p = c$ and $E_\epsilon = \alpha' c$. Here, E_{pp} is the Hessian of price responses of the consumption vector c; $E_{\epsilon p}$ denotes the cross-price response of consumption pollution to consumption prices; $E_{\epsilon p} = E'_{p\epsilon}$ is the response of consumption to the effluent tax; and $E_{\epsilon\epsilon}$ is the response of consumption pollution to the effluent tax.

Analogously, $E_{\epsilon\epsilon}$ can be decomposed into three effects[7]

$$E_{\epsilon\epsilon} = \alpha' E_{PP}\alpha + \alpha'(\partial\alpha/\partial P)c + c'(\partial\alpha/\partial\epsilon). \tag{3}$$

It is assumed for the rest of the paper that the consumer cannot alter the pollution coefficient, as is possible in production. Stylized facts suggest that most of

5 One of the goods can be chosen as a numéraire to impose homogeneity. R satisfies other properties (convex in prices and effluent taxes, increasing in prices, decreasing in effluent taxes, and the feasible technology set underlying R is convex). We refer readers to Hatta (1977) and Dixit and Norman (1980) for more details on revenue and expenditure functions.

6 This decomposition comes from $R_{\epsilon\epsilon} = \partial(-\gamma R_p)/\partial\epsilon = -x'(\partial\gamma/\partial\epsilon) - \gamma' R_{p\epsilon} = -x'(\partial\gamma/\partial\epsilon) + \gamma' R_{pp}\gamma + \gamma'(\partial\gamma/\partial p)x$.

7 This is obtained by noting that $E_{\epsilon\epsilon} = \partial(\alpha' E_p)/\partial\epsilon = \alpha'\partial c/\partial\epsilon + c'\partial\alpha/\partial = \alpha'\partial(\alpha' c)/\partial p + c'\partial\alpha/\partial\epsilon = \alpha' E_{pp}\alpha + \alpha'(\partial\alpha/\partial p)c + c'(\partial\alpha/\partial\epsilon)$.

technology-induced abatement is achieved in production, not in final consumption.[8] Hence, the identity reduces to $E_{\epsilon\epsilon} = \alpha' E_{pp}\alpha$, which is negative. Another derivative, E_T, represents the marginal damage of total pollution on utility or the necessary increase in expenditure to maintain U constant. It is positive. The final derivative of interest is the inverse of the marginal utility of income, E_U, which is positive as well. Derivatives E_U and E_T have derivatives with respect to the consumption price vector and pollution taxes ($E_{PU}, E_{\epsilon U}, E_{PT}$ and $E_{\epsilon T}$).

We obtain the interesting definitional result that the impact of effluent taxes on trade is equal to the effect of tariffs on pollution; that is,

$$\frac{\partial M}{\partial \epsilon} = \left[\frac{\partial T}{\partial \tau}\right]' \quad \text{or} \quad E_{\epsilon p} - R_{\epsilon p} = [E_{p\epsilon} - R_{p\epsilon}]'. \tag{4}$$

This equivalence arises because imports and pollution arise from the same optimizing behaviour of consumers and producers in the economy. The symmetric cross-price responses, $E_{P\epsilon}$ and $R_{P\epsilon}$, express substitution and/or complementarity between market goods and the pollution bad in consumption and production, respectively. It is convenient to define these responses in terms of substitution/complementarity between imports and pollution, that is, $\partial M/\partial\epsilon = \partial T/\partial\tau' > 0$ if they are substitutes, and $\partial M/\partial\epsilon = \partial T/\partial\tau' < 0$ if they are complements. Substitution occurs when production processes are pollution intensive relative to consumption of the same commodity; complementarity arises when production is relatively cleaner than consumption of a good. It is difficult to categorize some goods a priori, such as fuel-based energy sources, since substantial effluents are emitted in both supply and demand. These cross-price responses must be assessed empirically.

Equilibrium for this economy is described as follows

$$E = R + \tau'(E_p - R_p) + \eta' E_p + \beta' R_p + \epsilon(\alpha' E_p + \gamma' R_p) \tag{5}$$

with

$$T \equiv E_\epsilon - R_\epsilon = \alpha' E_p + \gamma' R_p \tag{6}$$

and

$$M = E_p - R_p. \tag{7}$$

Foreign and domestic specific commodities exhibit the same effluent rate. To develop some intuition about how imports, pollution, and welfare interact, we temporarily set consumption and production taxes, η and β, equal to zero and focus on

8 Modelling and implementing endogenous effluent rates may be more difficult in consumption than in production. In production we have or can develop good data on intermediate consumption (inputs) and on effluent linked to these inputs (Dessus, Roland-Holst, and van der Mensbrugghe 1994). Substitution between value added (labour and capital) and these intermediate inputs allows for lower effluent rate per unit of output. This approach has no obvious counterpart in consumption. This implementation problem motivates our simplifying assumption.

effluent taxes and tariffs. Differentiating (5) for changes in imports, welfare, and pollution yields

$$E_U dU = \tau' dM + (\epsilon - E_T)dT. \tag{8}$$

There are two sources of distortions and welfare effects. Non-zero tariffs and non-optimal effluent taxes (ϵ not equal to E_T) are distortions, which in turn have an impact on imports, M, and pollution, T. Changes in welfare, pollution, and trade are endogenously determined by policy changes. Totally differentiating (6) yields

$$dT = (E_{\epsilon\epsilon} - R_{\epsilon\epsilon})d\epsilon + (E_{\epsilon p} - R_{\epsilon p})d\tau + E_{\epsilon T}dT + E_{\epsilon U}dU. \tag{9}$$

Hence, abatement of pollution (positive or negative) has four components. First, the effluent tax induces pollution abatement in consumption and production; second, there is the cross-price responses of pollution to tariff changes ($\partial T/\partial\tau = \partial/\partial\epsilon$); third, a feedback effect of pollution on itself arises because of changes in marginal damage of pollution; and fourth, a real-income effect induced by changes in welfare occurs (Grossman and Krueger's scale effect). Copeland's model was recursive, because changes in production-pollution dT did not depend on T or U and could be solved independently for changes in policies ($d\tau$ and $d\epsilon$). Further, the abatement induced by the effluent tax can be decomposed into four sources (substitution in consumption and in production and changes in emission intensities in production; see the decomposition of $R_{\epsilon\epsilon}$ above). Equation (6) also shows that tariffs are ineffective to target pollution because they have opposite effects on consumption-induced and production-based pollution. One in subsidized, while the other is taxed. These offsetting effects can be decoupled by using production and consumption taxes instead of tariffs.

Like pollution (T), imports (M) can also be differentiated for changes in policy instruments, welfare, and pollution. Differentiating (7) in this way yields

$$dM = (E_{p\epsilon} - R_{p\epsilon})d\epsilon + (E_{pp} - R_{pp})d\tau + E_{pT}dT + E_{pU}dU. \tag{10}$$

III. OPTIMAL POLICIES AND POLLUTION REFORMS

Equations (8) to (10) can be solved for exogenous changes in policy instruments. Taking the available instruments one at a time, we first vary effluent taxes only, assessing the effects on domestic pollution and trade. Then we evaluate production and consumption taxes as next-best abatement instruments. Finally, tariffs alone are evaluated in the same context.

1. Effluent taxes

Consider changes in ϵ, holding tariffs constant and assuming $\eta = \beta = 0$; that is,

$$AdU = \{\tau'(E_{p\epsilon} - R_{p\epsilon}) + ((\epsilon - P'E_{pT})/(1 - E_{\epsilon T}))(E_{\epsilon\epsilon} - R_{\epsilon\epsilon})\}d\epsilon, \tag{11}$$

with

$$A = E_U - \tau' E_{pU} - \epsilon' E_{\epsilon U} + [(E_T - \tau' E_{pT} - \epsilon' E_{\epsilon T}) E_{\epsilon U} / (1 - E_{\epsilon T})] > 0 \qquad (12)$$

for stability.[9] The scalar A represents the general equilibrium inverse of the marginal utility of income, or a general equilibrium dE/dU, inclusive of feedback via pollution and trade distortions. The term $(P' E_{pT})$ is the general equilibrium marginal damage of pollution, since $P' E_{pT} = E_T - \tau' E_{pT} - \epsilon' E_{\epsilon T} > 0$.[10] The general equilibrium marginal damage is net of the feedback effects coming from trade taxes $(\tau' E_{pT})$, from taxes on pollution arising in consumption $(\epsilon' E_{\epsilon T})$, and the feedback of pollution on the marginal damage $(E_{\epsilon T})$.

Assuming a well-informed policymaker, the optimal effluent policy can be determined by setting (11) equal to zero. The optimum effluent tax is then

$$\epsilon = -\tau[E_{p\epsilon} - R_{p\epsilon}][E_{\epsilon\epsilon} - R_{\epsilon\epsilon}]^{-1} + \frac{P' E_{pT}}{1 - E_{\epsilon T}} = -\tau[E_{p\epsilon} - R_{p\epsilon}][E_{\epsilon\epsilon} - R_{\epsilon\epsilon}]^{-1} + D = \epsilon^*. \qquad (13)$$

This optimum policy equates the effluent tax to the general equilibrium marginal damage (D) of pollution minus the feedback effect of the tax on welfare via trade.

Any pollution policy reform introducing effluent taxes, such that $d\epsilon = k\epsilon^*$, will be welfare improving as well, because $(E_{\epsilon\epsilon} - R_{\epsilon\epsilon})$ is negative in this case and would be negative semi-definite if pollution was represented by a vector.

Next, we consider an effluent tax proportional to the deviations between the general equilibrium marginal damage and the existing tax ϵ (e.g., ϵ is equal to zero or is small, as it is in many developing economies): $d\epsilon = -k[\epsilon - D]$. Such a reform has two effects on welfare. The first effect is a positive impact on the environment by decreasing pollution. It is given by $-k[(\epsilon - D)^2 (E_{\epsilon\epsilon} - R_{\epsilon\epsilon})]$, which is positive. With respect to pollution this is the best policy type, because the effluent tax has three direct component-effects: on x and c holding per unit effluent rate constant, and on effluent rates γ via prices and effluent taxes (output and consumption being held constant).

The second effect is the indirect impact of the same pollution reform is $-k\tau'(E_{p\epsilon} - R_{p\epsilon})(\epsilon - D)$. This represents the effect of the effluent tax reform on imports. Both $E_{p\epsilon}$ and $R_{p\epsilon}$ are negative and their difference is ambiguous. Since the import effect of the pollution tax operates through cross-price/tax responses, it is presumably smaller on average than the own price effects $(E_{pp} - R_{pp})$. Adding more structure to sign these effects requires additional assumptions on the signs of τ and $\partial M/\partial\epsilon$.

9 A can be rearranged as follows: $A = E_U - \tau' E_{pU} - \epsilon' E_{\epsilon U} + [(E_T - \tau' E_{pT} - \epsilon' E_{\epsilon T}) E_{\epsilon U} / (1 - E_{\epsilon T})] = E_U - \tau' E_{pU} - (\epsilon - P' E_{pT} / (1 - E_{\epsilon T})) E_{\epsilon U}$.

10 By homogeneity we know that $(P + \alpha'\epsilon + \tau)' E_p = E$. Taking the derivative of this identity with respect to T and U yields the following identities: $(P + \epsilon\alpha + \tau)' E_{pT} = ET$ and $(P + \epsilon\alpha + \tau)' E_{pU} = E_U$, or $(P + \tau)' E_{pT} + \alpha' E_{\epsilon T} = E_T$ and $(P + \tau)' E_{pU} + \alpha' E_{\epsilon U} = E_U$, which lead to the definition of A.

Two cases are of special interest. If imports and pollution are substitutes and if tariffs are positive, then the effluent tax reform is welfare improving.[11] The intuition is that the effluent tax decreases pollution-intensive production, which is subsidized by tariffs. The tax decreases the deadweight loss of this implicit production subsidy. If imports and pollution are instead complements and if tariffs are negative (export taxes), then the effluent tax reform is welfare improving. The intuition is that the pollution tax penalizes the consumption of goods that pollute more in consumption than in production. The consumption of these goods is subsidized by the export tax, and the pollution tax decreases the deadweight loss of these subsidies. To illustrate these different cases, consider an effluent tax on pollution related to gasoline. First, consider a developing country with a protected domestic oil-refining industry but that (as a limiting case) exports all its output. All pollution arises in production, so clearly the pollution tax will decrease output (trade and pollution are substitutes) and the deadweight loss associated with too much oil refining. Conversely, consider another limit case in which the country imports all its gasoline, subsidized by a negative tariff. In this case imports and pollution are complements and an effluent tax will improve welfare by decreasing the deadweight loss of the implicit consumption subsidy. Many countries fall in between these two limits and are involved in both production and consumption of gasoline. In such cases the effect of the effluent tax on trade is an empirical question.

2. Production and consumption taxes

Now consider reform via production and consumption taxes, β and η, assuming effluent taxes are not available and no distortions exist other than tariffs. Clearly, when both consumption and production pollute and do so at different rates (α and γ not equal), the use of two separate policy instruments allows one to decouple consumption and production pollution. Tariffs are incapable of doing so, and this reveals a major advantage of production and consumption taxes.

The comparative statics corresponding to this scenario are

$$BdU = \{(\tau + \eta)' E_{pp} - DE_{\epsilon p}\} d\eta + \{(\tau - \beta)' R_{pp} - DR_{\epsilon p}\} d\beta, \tag{14}$$

with

$$B = P' E_{pU} + DE_{\epsilon U} > 0 \tag{15}$$

for stability, and where D is the general equilibrium marginal damage of pollution, net of feedbacks from trade and consumption taxes and from the pollution on the marginal damage $((E_T - (\tau + \eta)' E_{pT})/(1 - E_{\epsilon T}))$. Optimal consumption and production taxes are found by setting $dU/d\beta = dU/d\eta = 0$ in (14), which yields two sets of equations, which are solved for the optimum tax vectors. They are given

11 This is a generalization of Copeland's proposition 3.

by $\eta = -\tau' + D\alpha$ and $\beta = \tau' - DR_{\epsilon p}R_{pp}^{-1}$, respectively.[12] Note that the optimum consumption tax vector mimics the effluent tax, since it is related to the marginal damage of pollution, but it directly offsets the presence of tariffs. The combined trade and consumption taxes, $\eta + \tau'$, is equal to the marginal damage, $D\alpha$, because the consumption pollution intensities are fixed. By contrast, the production taxes are less effective for abatement, since, other things being equal, they 'overshoot' the optimum effluent tax; that is, $\beta = \tau' + D(\gamma + x'(\partial\gamma/\partial p)R_{pp}^{-1})$. Note that the correction for the existence of tariff distortions is one to one. With no pollution, these production and consumption taxes would just offset the tariffs.

Any pollution reform undertaken with consumption and production taxes proportional to these optimal levels would be welfare enhancing because E_{pp} is negative semi-definite and R_{pp} is positive semi-definite. Next, starting from zero tax levels, consider the introduction of taxes proportional to the pollution induced by the consumption and output vectors mimicking the effluent tax reform in the previous section, $d\eta = \alpha' kD$ and $d\beta = \gamma' kD$. The direct effect of this consumption and production tax reform is $-DE_{\epsilon p}\alpha kD$ for the consumption tax, with a value of $-DR_{\epsilon p}\gamma kD$ for the production tax. Both are positive (welfare improving) under the strong assumption that the elements of $-R_{\epsilon p}$ are positive (all productions are pollution intensive).

The effect of production taxes on production pollution is smaller than that for the effluent tax because the production tax captures only $-R_{\epsilon P}\gamma$, which is less than $R_{\epsilon\epsilon}$, since $R_{\epsilon\epsilon} = -\gamma' R_{p\epsilon} - x'\partial\gamma/\partial\epsilon$. Thus, the production tax captures two of the three effects of effluent taxes, omitting the important effect of effluent taxes on effluent intensity ($\partial\gamma/\partial\epsilon$). Hence, product taxes approximate effluent taxes but are less effective in terms of overall pollution abatement.

The indirect effects of these taxes on imports ($\tau' M$) are $k\tau' E_{pp}\alpha D$ for η, corresponding to $k\tau' R_{pp}\gamma D$ for β. For the consumption component, the impact on imports or tariff revenues is similar to that of the effluent tax, a result of the assumption of fixed pollution coefficients, α. For the production component, noting that ($\gamma' R_{pp} = -R_{\epsilon p} - x'\partial\gamma/\partial p$), the effect of $d\beta$ on trade via output is smaller on average than the effect of an effluent tax on trade via output, because the latter instrument has an additional effect on the effluent rates. The sum of the two indirect components on consumption and production is ambiguous unless considerable structure is added to the analysis. It is nevertheless equal to the indirect effect of the effluent tax plus ($-\tau'(\partial\gamma/\partial p)x$), which in all likelihood would decrease welfare further.[13]

3. Tariffs

The last pollution reform uses tariff changes to reduce pollution. The comparative-statics of tariff reforms, $d\tau$, are

$$AdU = \{[\tau'(E_{pp} - R_{pp})] + [(\epsilon - D)(E_{\epsilon p} - R_{\epsilon p})]\}d\tau, \tag{16}$$

12 We assume that E_{pp} and R_{pp} are full rank.

13 This conjecture assumes that the economy is distorted with positive tariffs and that effluent rates increase on average with prices.

with

$$A = E_U - \tau' E_{pU} + [(E_T - \tau' E_{pT})E_{\epsilon U}/(1 - E_{\epsilon T})] > 0 \tag{17}$$

for stability. The first policy issue is the optimal tariff. By setting (16) equal to zero, we obtain the optimum tariff vector $\tau = D(E_{\epsilon p} - R_{\epsilon p})(E_{pp} - R_{pp})^{-1}$, which may be positive or negative. The vector of optimum tariffs is different from zero, reflecting the public pollution externality, and is related to the marginal damage of pollution, representing a compromise between pollution abatement in production and consumption and efficiency losses induced by trade effects of the tariffs. In addition, if the vector of price responses of pollution, $(\partial T/\partial p)$, has both positive and negative elements, it is not clear that tariffs can successfully move total pollution to an optimum or targeted level. This ambiguity and the information required to compute the optimum tariff are prime motivations for more empirical work on trade and environmental linkages. The Lee and Roland-Holst (in press) investigation suggests in the case of Indonesia that pollution abatement with tariffs is virtually impossible and induces large trade effects.

Special cases exist for which abatement is feasible but is of limited applicability in real market conditions. For example, assume that imports and pollution are substitutes because production pollution is substantial. Consider a myopic policy reform targeting production pollution, where tariff changes take the form $d\tau = -kD\Upsilon$; that is, the tariff behaves like a production tax proportional to effluent rates. The direct effect on pollution is $kD(E_{\epsilon p} - R_{\epsilon p})\Upsilon D$, which is negative because the tax effect of the tariff on production pollution is larger than the subsidy effect of the tariff on consumption pollution. Tariffs always subsidize one of the pollution sources (production-based versus consumption-based) and do not allow for specific policy intervention in production and consumption the way effluent taxes do. The effects of tariffs as abatement policy on efficiency (imports) are the most immediate, via the price response, because they include own-price effects, but they are ambiguous a priori.

Finally, trade reform achieved by proportional tariff cuts ($d\tau = -k\tau$) have a positive effect on imports and an ambiguous effect on pollution. This latter indirect effect is symmetric to the indirect effect of the effluent tax on trade. Here we have two special cases as well, exactly symmetric to those of the effluent tax reform and based on the sign of the tariff vector and the substitutability or complementary of imports and pollution. For example, if τ is positive and imports and pollution are substitutes, then a proportional decrease in tariffs is welfare-improving.

IV. JOINT TRADE AND POLLUTION REFORMS

In this section we consider two types of reforms simultaneously: trade liberalization and pollution targeting – first with effluent taxes, then the product taxes. The optimum policy mix for the two sets of instruments is derived and piecemeal changes are considered.

1. Tariffs and effluent taxes

The comparative-statics of joint tariff reduction with introduction of effluent taxes are

$$AdU = \{\tau'(E_{p\epsilon} - R_{p\epsilon}) + (\epsilon - D)(E_{\epsilon\epsilon} - R_{\epsilon\epsilon})\}d\epsilon + \{\tau'(E_{pp} - R_{pp}) + (\epsilon - D)(E_{\epsilon p} - R_{\epsilon p})\}d\tau, \quad (18)$$

with

$$A = E_U - \tau' E_{pU} - \epsilon' E_{\epsilon U} + [(E_T - \tau' E_{pT} - \epsilon' E_{\epsilon T})E_{\epsilon U}/(1 - E_{\epsilon T})] > 0 \quad (19)$$

and assuming that $\epsilon = 0$ prior to the reform.

If the two policy instruments are freely implementable, then their optimum levels are obtained by setting $dU/d\tau = 0$ and $dU/d\epsilon = 0$. This yields $\tau = 0$, and $\epsilon = D$, assuming that the matrix $[(E_{pp} - R_{pp}) - (E_{p\epsilon} - R_{p\epsilon})(E_{\epsilon T})^{-1}(E_{\epsilon p} - R_{\epsilon p})]$ is of full rank. Hence, the optimum policy mix is the standard result – free trade and an effluent tax equal to the general equilibrium marginal damage of pollution.

Now assume that $d\tau = -k\tau$ and $d\epsilon = kD$, which correspond to proportional tariff reductions and an effluent tax proportional to and towards the general equilibrium marginal damage of pollution. The direct effect of the trade reform on utility is $-k\tau'(E_{pp} - R_{pp})\tau$, which is non-negative because the Hessian of import demand price responses is negative semi-definite. The direct effect of effluent taxes on pollution abatement is $[(-kD)^2(E_{\epsilon\epsilon} - R_{\epsilon\epsilon})]$, which is also non-negative.

The corresponding indirect effects are $k\tau'(E_{p\epsilon} - R_{p\epsilon})D$, and they are symmetric because they show the impact of tariffs on pollution or the effect of the effluent tax on imports, $(E_{\epsilon p} - R_{\epsilon p} = \partial T/\partial\tau = \partial M/\partial\epsilon)$. However, by convexity of $(R - E)$ in prices and taxes, the quadratic form corresponding to this joint reform is positive and, although we do not know the sign of the indirect symmetric effects or the magnitude of any of the effects, their sum must be positive. Empirical analysis still is essential to assess these magnitudes and the direction of the cross-effects or underlying externalities.

2. Tariffs, production, and consumption taxes

The second scenario for joint reform is tariff reduction accompanied by the introduction of taxes on consumption and production. Optimum tariff, production, and consumption tax vectors are found by setting $dU/d\tau = 0$, $dU/d\beta = 0$, and $dU/d\eta = 0$. The optimal tariff would be zero, since it is redundant with the consumption and production taxes, which are $\eta = DE_{\epsilon p}E_{pp}^{-1}$ and $\beta = -DR_{\epsilon p}R_{pp}^{-1}$. Except for the tariff correction, they are equal to the optimum taxes described in the section on pollution policy reform.

Next, consider proportional changes of all policies; that is, $d\tau = -k\tau$, $d\eta = kD\alpha$, and $d\beta = kD\gamma$. According to the individual effects of each policy (obtained in the previous section), the tariff reform includes a positive utility effect and an ambiguous indirect pollution impact. Similarly, the production and consumption taxes bring positive environmental impacts but ambiguous indirect effects on imports. Unfortunately, the two indirect effects are cumulative, but are not symmetric as in the previous case, and convexity of R and $(-E)$ can be used to sign partial effects, but not the total welfare effect. If one abstracts from the effects of the policies on effluent rates ($\partial\gamma/\partial\tau$ and $\partial\gamma/\partial\beta$), the welfare effect of joint-reform via substitution in consumption (E_{pp}) and production (R_{pp}) is positive. Further, if the reform's effect via effluent rates is positive, then the joint reform certainly enhances welfare. The latter effect is $(-d\tau + d\beta)'(\partial\gamma/\partial P)xD$, and sufficient conditions are $(d\beta - d\tau) > 0$ and production is pollution intensive (γ increases with output expansion).

The evidence gathered in Lee and Roland-Holst (in press) shows that welfare improvements are bigger when both policy instruments are used simultaneously, with tariffs set optimally to zero. Pollution taxes for a given pollution target have a larger detrimental effect on welfare than has combining trade and pollution reform to achieve the same target. The welfare gains from lower tariffs offset some of the welfare loss on imports induced by the pollution taxes.

V. CONCLUSIONS

This paper has explored second-best policy issues affecting trade and environment linkages. We derived sufficient conditions for welfare-improving piecemeal trade and environmental policy reforms in a small polluted economy. Pollution, a public bad, originates in both consumption and production, the latter being decomposed into composition and technique effects. Moving distortions proportionally to and towards their optimal level increases welfare monotonically. Proportional reductions in tariffs and gradual increases in effluent tax also increase welfare. The existence of consumption-based pollution undermines the use of tariffs as a second-best abatement instrument, because tariffs tax and subsidize pollution simultaneously.

The analysis has emphasized specific effects of tariffs, effluent taxes, and production and consumption taxes on market allocation and pollution through substitution in consumption, changes in output composition, and choice of technique. Effluent taxes have the most direct effect on toxic intensity, with limited indirect effects on imports and thereby utility in consumption. This result supports the case for economic instruments, against 'command and control' measures, to achieve reductions in pollution intensity. Indeed, over-reliance on the latter policies may explain why OECD countries have experienced stubbornly high levels of pollution intensity in production. More frequent recourse to effluent taxes or their quantitative equivalent, marketable permits, might do much to get these economies on flatter pollution growth trajectories and minimize collateral disutility effects in consumption.

Trade policy reforms increase feasible consumption but have indirect effects on pollution that are ambiguous. This calls into question any presumption of outward-orientation inducing specialization in pollution-intensive activities. We actually established two special cases in which trade liberalization decreases pollution and pollution intensities, based on substitution relationships between pollution and imports. Evidence obtained separately for the Mexico economy suggests that greater outward orientation can actually induce specialization in less pollution-intensive production activities (Beghin, Roland-Holst, and van der Mensbrugghe 1995).

Coordination of pollution and trade policies is important because the direct beneficial effects of the reform will always be larger than the indirect ones. When policies are set or changed in proportion to their optimal levels, aggregate welfare also improves positively. Reducing tariffs and setting effluent taxes proportionally to optimal levels increase welfare as well, and, requiring less information, they emerge as robust policy recommendations. In practice, estimating magnitudes of the individual effects of these coordinated trade and environmental policies is an empirical task.

This paper strengthens conceptual foundations for the empirical work that is ultimately required to support coherent policies towards trade and the environment. Although some general conclusions have been drawn, it is clear that linkages between economic efficiency and environmental values are complex, and policies to promote and reconcile the two must be designed and implemented with care. As emphasized in Lee and Roland-Holst (forthcoming), and Beghin, Roland-Holst, and van der Mensbrugghe (1995), detailed sectoral modelling and estimation are essential to such an enterprise. Future work should include sector-specific program evaluation in a general equilibrium framework, especially in sectors where the trade/environment nexus is prominent (e.g., agriculture, energy). Without detailed empirical support of this kind, it is questionable whether policy makers relying on intuition and rules-of-thumb alone will achieve sustainable welfare improvements or anything close to optimality.

REFERENCES

Baumol, W.J., and W.E. Oates (1988) *The Theory of Environment Policy* (Cambridge: Cambridge University Press)

Beghin, J., D. Roland-Holst, and D. van der Mensbrugghe (1994) 'North-South dimensions of the trade and environment nexus.' *OECD Economic Studies* 23, 167–92

— (1995) 'Trade liberalization and the environment in the Pacific basin: coordinated approaches to Mexican trade and environment policy.' *American Journal of Agricultural Economics* 77, 778–85

Choi, E.K., and S.R. Johnson (1992) 'Regulation of externalities in an open economy.' *Ecological Economics* 5, 251–65

Copeland, B.R. (1994) 'International trade and the environment: policy reform in a polluted small open economy.' *Journal of Environmental Economics and Management* 26, 44–65

Copeland, B.R., and M.S. Taylor (1994) 'North-south trade and the environment.' *Quarterly Journal of Economics* 109, 755–87

Cropper, M.L., and W.E. Oates (1992) 'Environmental economics: a survey.' *Journal of Economic Literature* 30, 675–740

Dean, J.M. (1992) 'Trade and the environment: a survey of the literature.' World Bank Working Paper WPS 966, World Bank, Washington DC, August

Dessus, S., D. Roland-Holst, and D. van der Mensbrugghe (1994) 'Input-based estimates for environmental assessment in developing countries.' OECD Development Centre Technical Papers OECD, Paris, August

Dixit, A.K., and V. Norman (1980) *Theory of International Trade* (Cambridge: Cambridge University Press)

Grossman, G.M., and A.B. Krueger (1991) 'Environmental impact of a North American free trade agreement.' NBER Working Paper No 3914, November

Hatta, T. (1977) 'A theory of piecemeal policy recommendations.' *Review of Economic Studies* 44, 1–21

Hettige, H., R.E.B. Lucas, and D. Wheeler (1992) 'The toxic intensity of industrial production: global patterns, trends, and trade policy.' *American Economic Review, Papers and Proceedings* 82, 478–81

Krutilla, K. (1991) 'Environmental regulation in an open economy.' *Journal of Environmental Economics and Management* 20, 127–42

Lee, H., and D. Roland-Holst (in press) 'The environment and welfare implications of trade and tax policy.' *Journal of Development Economics*

Markusen, J.R. (1975) 'International externalities and optimal tax structures.' *Journal of International Economics* 5, 15–29

Vousden, N. (1990) *The Economics of Trade Protection* (Cambridge: Cambridge University Press)