CORNELL
AGRICULTURAL ECONOMICS
STAFF PAPER

TRANSFRONTIER POLLUTION:
COOPERATIVE AND NONCOOPERATIVE SOLUTIONS

By

Jon M. Conrad and Anthony Scott

June 1987 No. 87-13

Department of Agricultural Economics
Cornell University Agricultural Experiment Station
New York State College of Agriculture and Life Sciences
A Statutory College of the State University
Cornell University, Ithaca, New York, 14853

TRANSFRONTIER POLLUTION:
COOPERATIVE AND NONCOOPERATIVE SOLUTIONS

By

Jon M. Conrad and Anthony D. Scott*

*The authors are Associate Professor of Resource Economics at Cornell University and Professor of Economics at the University of British Columbia, respectively. Comments or correspondence relating to this manuscript may be addressed to: Jon M. Conrad, Department of Agricultural Economics, 310 Warren Hall, Cornell University, Ithaca, NY 14853-7801.

Transfrontier Pollution:

Cooperative and Noncooperative Solutions

ABSTRACT

A dynamic model of transfrontier pollution is constructed to analyze production and residual emission decisions for two countries under cooperative and noncooperative behavior. Each country must allocate marginal resources between more commodity production or more residual (emission) reduction. While each country produces a different commodity (say, nickel and electricity), the jointly-produced residual (say, sulfur oxide) is identical. After emission and transport, the residuals are subject to deposition and possible accumulation in both countries. Cooperative and noncooperative behavior may lead to steady state equilibria. A comparison of the equations defining such equilibria permits the identification of corrective taxes, which depend not only on marginal damage but on the rates of transport, degradation and discount as well. While the cooperative solution is Pareto superior to the noncooperative solution, the necessary corrective taxes may not be adopted without side payments between countries. Movement toward the cooperative solution might be facilitated by an international control agency with the authority to impose emission standards on sources of transfrontier pollution. It is unlikely that sovereign states would vest unlimited control over domestic emissions to an international agency, and alternative regimes based on negotiated emission standards, emission taxes and marketable pollution permits are considered. Based on a subjective assessment of resource and transactions costs, a system of marketable emission permits may be least cost.

I. Introduction and Overview

Transfrontier pollution, where residuals produced in one country cause damage in one or more other countries, is a major environmental problem in western Europe and North America. Oxides of sulfur (SO_x) and nitrogen (NO_x) are jointly produced with electricity, metals, and transportation. When emitted into the atmosphere, physical and chemical processes cause the transport and transformation into acidic compounds which may precipitate in the form of rain or snow. These oxides are frequently referred to as "acid precursors" and the process of precipitation as "acid deposition."

One of the earliest impacts, and perhaps the best understood, was the reduction in the pH of fresh-water lakes in northern Europe, Canada and the U.S.A. This caused the reduction or elimination of certain species of fish and other aquatic life in many lakes. Of concern, but less understood, is the impact of acid deposition on trees, crops and soils. While large sums of money have been spent on research leading to a better understanding of the physical/chemical processes and their biological consequences, there has not been a comparable research effort designed to determine the costs of alternative control strategies, their effectiveness, nor the international institutions which might facilitate an effective control policy.

The objectives of this paper are threefold: (1) to construct an economic model which incorporates the important dynamic aspects of commodity production, residual transport and accumulation, (2) to use the model to formulate cooperative and noncooperative control problems and identify taxes which would establish optimality in the noncooperative problem, and (3) to identify the relative cost of international policies and institutions that might allow the affected countries to realize potential improvements in excess of resource and transactions costs.

The remainder of the paper is organized as follows. In the next section, a dynamic model of transfrontier pollution is developed. Two countries produce different commodities but similar residuals. Upon emission, the residuals are subject to transport and possible accumulation in both countries. Each country must decide how to allocate resources between commodity production and residual reduction.

In the third section, cooperative and noncooperative control problems are posed and solved. Each problem admits the possibility of steady state equilibria. A comparison of conditions defining steady state equilibria permits identification of reciprocal emission taxes which depend on marginal damage in the neighboring country as well as transport, degradation and discount rates. The possible approach from the noncooperative solution to the cooperative solution via increasing, then decreasing emission taxes is considered.

The fourth section discusses two opposing principles that might underlie environmental diplomacy: territoriality and external responsibility. Under the latter principle countries might agree to create an international pollution control authority which would directly regulate emissions of the transfrontier pollutant. Such an approach is not viewed as a likely outcome, given that most industrialized countries have approached transfrontier pollution from a position more closely aligned to the principle of territoriality. Alternative regimes and their relative resource and transactions costs are considered.

The fifth and final section summarizes the major conclusions of the paper and notes some important implications for negotiations between Canada and the U.S. relevant to acid deposition in North America.

II. A Dynamic Model of Transfrontier Pollution

We will develop a two-country model where, as a mnemonic, the two countries will be the U.S. and Canada. Canada produces nickel and sulfur oxides according to the implicit function

$$F_c(N_t, S_{c,t}) \equiv 0 \tag{1}$$

where N_t is nickel production in period t, and $S_{c,t}$ is the amount of jointly-produced sulfur oxide. The U.S. is assumed to produce electricity and sulfur oxide according to

$$F_u(E_t, S_{u,t}) \equiv 0 \tag{2}$$

where E_t is the amount of electricity produced in period t and $S_{u,t}$ is the associated amount of sulfur oxide. Both production functions presume that productive inputs are fixed through time (otherwise $F_c(\cdot)$ and $F_u(\cdot)$ might have time, t, as an argument) and that productive inputs can be allocated to commodity <u>production</u> or sulfur oxide <u>reduction</u>. The production functions portray the technically efficient trade-offs between output and sulfur oxide in the following sense: for a given level of output (N_t or E_t) oxide ($S_{c,t}$ or $S_{u,t}$) are a technical minimum. Conversely, for a given level of sulfur oxide, output is a maximum. By convention it is assumed that the partials of the production functions with respect to output are positive, while the partials with respect to sulfur oxide are negative ($\partial F_c(\cdot)/\partial N_t>0$, $\partial F_u(\cdot)/\partial E_t>0$, $\partial F_c(\cdot)/\partial S_{c,t}<0$, and $\partial F_u(\cdot)/\partial S_{u,t}<0$, see Hasenkamp 1976).

After emission, the sulfur oxides undergo atmospheric transport and chemical transformation. Deposition of the transformed oxide (sulfuric acid) may occur in the country of origin or in the neighboring country. Deposition is assumed to occur during the period of generation and depending on the rates of residual emission, transformation and degradation (buffering), the mass of the deposited pollutant changes according to the difference equations

$$X_{c,t+1} - X_{c,t} = -\alpha_c X_{c,t} + \gamma_{c,c} S_{c,t} + \gamma_{u,c} S_{u,t} \tag{3}$$

$$X_{u,t+1} - X_{u,t} = -\alpha_u X_{u,t} + \gamma_{c,u} S_{c,t} + \gamma_{u,u} S_{u,t} \tag{4}$$

where $X_{c,t}$ and $X_{u,t}$ are the amounts of the accumulated pollutant in Canada and the U.S. in period t, α_c and α_u are the degradation rates in Canada and the U.S., and $\gamma_{c,c}$, $\gamma_{c,u}$, $\gamma_{u,c}$ and $\gamma_{u,u}$ are transport/transformation coefficients. The first subscript indicates the country of origin, while the second indicates the country of deposition.

Within each country, the accumulated pollutant is assumed to cause damage according to the functions

$$D_{c,t} = D_c(X_{c,t}) \tag{5}$$

$$D_{u,t} = D_u(X_{u,t}) \tag{6}$$

Only primitive estimates of the damage from acid deposition exist, and even the qualitative shape of $D_c(\cdot)$ and $D_u(\cdot)$ is subject to debate. We will assume that damage is increasing at an increasing rate ($D'_c(\cdot)$, $D'_u(\cdot)$, $D''_c(\cdot)$, $D''_u(\cdot)$ all positive).[1]

To keep things relatively simple, we will assume that transfrontier pollution is the only distortion in two otherwise competitive economies. Through trade or the perfectly elastic supply of domestic substitutes, it is assumed that the prices for nickel and electricity are exogenous and unchanging through time. We denote these prices as p_n and p_e, respectively.

Before turning to an analysis of cooperative and noncooperative solutions to the transfrontier pollution problem, it is appropriate to compare the structure of our model with other models examining similar or related problems.

In 1974 and 1976 the Organization for Economic Cooperation and Development (OECD) published two volumes of papers concerned with transfrontier pollution. The first volume, containing twelve papers, presents several models designed to determine the optimal level of pollution between two or more countries and identify principles of compensation and cost sharing which might be adopted when making payment for damages or financing joint treatment (or other abatement) facilities. With the exception of Smets (OECD 1974, pp. 75-146) the models are static, seeking to determine conditions with define a Pareto allocation of inputs, outputs and pollution between countries or to minimize the sum of treatment and damage costs. None of the models are dynamic optimization models in the sense of maximizing a measure of performance (or welfare) over time subject to equations of motion describing the accumulation or degradation of pollution stocks. The second OECD volume is more institutional in focus, seeking to refine the principles and concepts emerging from the first volume and define actual instruments and institutions which countries may need in order to implement compensatory payments, finance treatment facilities, or coordinate domestic environmental policies. Emission taxes, treatment subsidies, benefit charges, and transferable (marketable) pollution permits were evaluated.

Several authors have considered the link between international trade and pollution. If the production of exports results in the joint production of a residual causing domestic or transfrontier pollution, then expanding trade may reduce welfare. Markusen (1975a) examines the case where two countries produce and trade two goods. Domestic or foreign production of one of the goods results (additively) in a level of pollution which negatively affects domestic welfare. If the domestic economy has no direct control over the amount of pollution generated by a neighbor, and can only employ domestics taxes or subsidies on production, consumption or trade, Markusen shows that the tax structures necessary to achieve a second best (domestic) optimum will depend on whether the pollution causing good is exported or imported. In a second, related article Markusen (1975b) extends the model to consider the case where the pollutant becomes a "pure public bad" in both countries. Attainment of a Pareto optimum may require both corrective taxes and lump sum transfers if both countries are to be made better off than in a noncooperative (Cournot) solution.

Pethig (1976) examines the concept of comparative advantage as it relates to the ability of a country to assimilate the residuals jointly produced with traded goods. A less-developed country, with an initial comparative advantage in the production of an environmentally intensive (degrading) good, may experience a welfare loss from expanding trade with a developed country unless it implements domestic environmental controls. Further, the process of implementing such controls can be thought of as placing a constraint on the country's original comparative advantage. The possibility of lump sum transfers (from the developed country which gains from importing the environmentally intensive good) is not explicitly considered.

A dynamic model of trade policy is constructed by Asako (1979). The stock of a pollutant is positively augmented by the production of two goods and subject to decay (degradation) at a constant rate. A fixed supply of labor must be allocated at each point in time between the two production activities. Domestic consumption of each good is equal to domestic production less net exports. The present value of utility is maximized subject to pollution dynamics, labor availability, and consumption/production/net export balancing equations modified to require a balance of payments. The optimal time paths of production may require a curtailment in the production and export of the environmentally-intensive good as the stock of pollution grows and imposes greater utility losses.

In comparing the present model to the models constructed by Markusen, Pethig, Asako and the various contributors to the OECD volumes, we find that our model is closest to that developed by Asako. It is more detailed in that it contains two stocks of pollution (one in each country) which will depend, over time, on residual emission in both countries as well as domestic degradation (or decay in Asako's terminology). At the same time, we will be able to examine cooperative and noncooperative solutions of type considered by Markusen, the form of corrective taxes and the need for side payments.

III. Cooperative and Noncooperative Solutions

Suppose that the two countries were to confederate into a single nation. The transfrontier pollution problem becomes a domestic pollution problem but with different levels of environmental quality possibly existing between regions. Suppose further a central environmental control agency were created with the power to determine the levels for N_t, E_t, $S_{c,t}$ and

$S_{u,t}$ which

$$\text{maximize} \sum_{t=0}^{\infty} \rho^t \{p_n N_t + p_e E_t - D_c (X_{c,t}) - D_u (X_{u,t})\}$$

Subject to

$$F_c (N_t, S_{c,t}) \equiv 0$$

$$F_u (E_t, S_{u,t}) \equiv 0$$

$$X_{c,t+1} - X_{c,t} = -\alpha_c X_{c,t} + \gamma_{c,c} S_{c,t} + \gamma_{u,c} S_{u,t}$$

$$X_{u,t+1} - X_{u,t} = -\alpha_u X_{u,t} + \gamma_{c,u} S_{c,t} + \gamma_{u,u} S_{u,t}$$

where $\rho = 1/(1 + \delta)$ is a discount factor and δ is the per period discount rate (assumed constant). The current value Hamiltonian may be written as

$$\tilde{H} = p_n N_t + p_e E_t - D_c(X_{c,t}) - D_u(X_{u,t}) - \mu_{c,t} F_c(\cdot) - \mu_{u,t} F_u(\cdot)$$
$$+ \rho\lambda_{c,t+1} [-\alpha_c X_{c,t} + \gamma_{c,c} S_{c,t} + \gamma_{u,c} S_{u,t}]$$
$$+ \rho\lambda_{u,t+1} [-\alpha_u X_{u,t} + \gamma_{c,u} S_{c,t} + \gamma_{u,u} S_{u,t}] \quad (7)$$

Necessary conditions for an interior solution include:

$$\frac{\partial \tilde{H}}{\partial N_t} = p_n - \mu_{c,t}\, \partial F_c(\cdot)/\partial N_t = 0 \quad (8)$$

$$\frac{\partial \tilde{H}}{\partial E_t} = p_e - \mu_{u,t}\, \partial F_u(\cdot)/\partial E_t = 0 \quad (9)$$

$$\frac{\partial \tilde{H}}{\partial S_{c,t}} = -\mu_{c,t}\, \partial F_c(\cdot)/\partial S_{c,t} + \rho\lambda_{c,t+1} \gamma_{c,c} + \rho\lambda_{u,t+1} \gamma_{c,u} = 0 \quad (10)$$

$$\frac{\partial \tilde{H}}{\partial S_{u,t}} = -\mu_{u,t}\, \partial F_u(\cdot)/\partial S_{u,t} + \rho\lambda_{c,t+1} \gamma_{u,c} + \rho\lambda_{u,t+1} \gamma_{u,u} = 0 \quad (11)$$

$$\rho\lambda_{c,t+1} - \lambda_{c,t} = -\frac{\partial \tilde{H}}{\partial X_{c,t}} = D'_c(\cdot) + \rho\lambda_{c,t+1}\alpha_c \quad (12)$$

$$\rho\lambda_{u,t+1} - \lambda_{u,t} = -\frac{\partial \tilde{H}}{\partial X_{u,t}} = D'_u(\cdot) + \rho\lambda_{u,t+1}\alpha_u \quad (13)$$

If $F_c(\cdot)$ and $F_u(\cdot)$ are globally convex, $X_{c,o}$ and $X_{u,o}$ are given and $\rho^t\lambda_{c,t} X_{c,t} \to 0$ and $\rho^t\lambda_{u,t} X_{u,t} \to 0$ as $t \to \infty$, then equations (1)-(4) and (8)-(13) will define a unique set of optimal controls $\{N_t^*\}$, $\{E_t^*\}$, $\{S_{c,t}^*\}$ and

$\{S_{u,t}^*\}$. In steady state, these equations become a system of 10 equations in 10 unknowns: E, N, S_c, S_u, X_c, X_u, μ_c, μ_u, λ_c and λ_u. The multipliers ($\mu_c>0$, $\mu_u>0$) and the costate variables ($\lambda_c<0$, $\lambda_u<0$) can be quickly eliminated leaving a system of six equations that may be written as follows:

$$-p_n \left[\frac{\partial F_c(\cdot)/\partial S_c}{\partial F_c(\cdot)/\partial N}\right] = \frac{\gamma_{c,c} D'_c(\cdot)}{(\alpha_c + \delta)} + \frac{\gamma_{c,u} D'_u(\cdot)}{(\alpha_u + \delta)} \tag{14}$$

$$-p_e \left[\frac{\partial F_u(\cdot)/\partial S_u}{\partial F_u(\cdot)/\partial E}\right] = \frac{\gamma_{u,c} D'_c(\cdot)}{(\alpha_c + \delta)} + \frac{\gamma_{u,u} D'_u(\cdot)}{(\alpha_u + \delta)} \tag{15}$$

$$X_c = (\gamma_{c,c}\, S_c + \gamma_{u,c}\, S_u)/\alpha_c \tag{16}$$

$$X_u = (\gamma_{c,u}\, S_c + \gamma_{u,u}\, S_u)/\alpha_u \tag{17}$$

$$F_c\ (N,\ S_c) \equiv 0 \tag{18}$$

$$F_u\ (E,\ S_u) \equiv 0 \tag{19}$$

The left hand side (LHS) of equations (14) and (15) will be positive (recall our conventions on the partials of $F_c(\cdot)$ and $F_u(\cdot)$) and may be interpreted as the marginal value product of an increase in the steady state level of S_c and S_u.[2] An increase in the level of emissions will allow a reallocation of resources away from emission reduction to commodity production. These marginal value products must be equated to the present value of the increase in marginal damage. Marginal damage in this dynamic/spatial model will depend on the transport coefficients and the rates of degradation and discount as defined by the RHS of equations (14) and (15). With $F_c(\cdot)$ or $F_u(\cdot)$ nonlinear, the approach to steady state will be asymptotic.

In the noncooperative problem we assume that each country is aware of the damage imposed by pollution within its borders and also knows the physical processes (difference equations) governing transport and degradation. Even with these rather strong informational assumptions, we cannot pose a well-defined optimization for an individual country without specifying an expectation about future emissions by the neighboring country. One plausible expectation is that this year's level for foreign emission will be identical to last year's (known) level for foreign emission. For Canada, this implies $E\{S_{u,t}\} = S_{u,t-1}$, while for the U.S. it would mean $E\{S_{c,t}\} = S_{c,t-1}$.[3] The noncooperative control problems for Canada and the U.S. become

$$\underset{\{N_t\},\ \{S_{c,t}\}}{\text{Maximize}} \quad E\left\{ \sum_{t=0}^{\infty} \rho^t \left[p_n N_t - D_c\ (X_{c,t})\right] \right\}$$

$$\text{Subject to} \quad F_c(N_t,\ S_{c,t}) \equiv 0$$

$$X_{c,t+1} - X_{c,t} = -\alpha_c X_{c,t} + \gamma_{c,c} S_{c,t} + \gamma_{u,c}\, E\{S_{u,t}\}$$

$$E\{S_{u,t}\} = S_{u,t-1}$$

and

$$\underset{\{E_t\},\ \{S_{u,t}\}}{\text{Maximize}} \quad E\left\{ \sum_{t=0}^{\infty} \rho^t \left[p_e E_t - D_u\ (X_{u,t})\right] \right\}$$

$$\text{Subject to} \quad F_u(E_t,\ S_{u,t}) \equiv 0$$

$$X_{u,t+1} - X_{u,t} = -\alpha_u X_{u,t} + \gamma_{c,u}\, E\{S_{c,t}\} + \gamma_{u,u} S_{u,t}$$

$$E\{S_{c,t}\} = S_{c,t-1}$$

The current value Hamiltonians for Canada and the U.S. may be written as

$$\tilde{H}_c = p_n N_t - D_c(X_{c,t}) - \mu_{c,t} F_c(\cdot) + \rho\lambda_{c,t+1}\left[-\alpha_c X_{c,t} + \gamma_{c,c} S_{c,t} + \gamma_{u,c} E\{S_{u,t}\}\right] \qquad (20)$$

and

$$\tilde{H}_u = p_e E_t - D_u(X_{u,t}) - \mu_{u,t} F_u(\cdot) + \rho\lambda_{u,t+1}\left[-\alpha_u X_{u,t} + \gamma_{c,u} E\{S_{c,t}\} + \gamma_{u,u} S_{u,t}\right] \qquad (21)$$

with first order necessary conditions that include

$$\frac{\partial \tilde{H}_c}{\partial N_t} = p_n - \mu_{c,t}\, \partial F_c(\cdot)/\partial N_t = 0 \qquad (22)$$

$$\frac{\partial \tilde{H}_c}{\partial S_{c,t}} = -\mu_{c,t}\, \partial F_c(\cdot)/\partial S_{c,t} + \rho\, \lambda_{c,t+1}\, \gamma_{c,c} = 0 \tag{23}$$

$$\rho\, \lambda_{c,t+1} - \lambda_{c,t} = \frac{-\partial \tilde{H}_c}{\partial X_{c,t}} = D'_c(\cdot) + \rho\, \lambda_{c,t+1}\, \alpha_c \tag{24}$$

and

$$\frac{\partial \tilde{H}_u}{\partial E_t} = p_e - \mu_{u,t}\, \partial F_u(\cdot)/\partial E_t = 0 \tag{25}$$

$$\frac{\partial \tilde{H}_u}{\partial S_{u,t}} = -\mu_{u,t}\, \partial F_u(\cdot)/\partial S_{u,t} + \rho\, \lambda_{u,t+1}\, \gamma_{u,u} = 0 \tag{26}$$

$$\rho\, \lambda_{u,t+1} - \lambda_{u,t} = \frac{-\partial \tilde{H}_u}{\partial X_{u,t}} = D'_u(\cdot) + \rho\, \lambda_{u,t+1}\, \alpha_u \tag{27}$$

To achieve a steady state, the expectations on foreign emission rates must be fulfilled, i.e. $E\{S_{u,t}\} = S_{u,t-1} = S_u$ and $E\{S_{c,t}\} = S_{c,t-1} = S_c$. The first order conditions in both countries imply

$$-p_n \left[\frac{\partial F_c(\cdot)/\partial S_c}{\partial F_c(\cdot)/\partial N}\right] = \frac{\gamma_{c,c} D'_c(\cdot)}{(\alpha_c + \delta)} \tag{28}$$

$$-p_e \left[\frac{\partial F_u(\cdot)/\partial S_u}{\partial F_u(\cdot)/\partial E}\right] = \frac{\gamma_{u,u} D'_u(\cdot)}{(\alpha_u + \delta)} \tag{29}$$

and, as before, equations (16)-(19).[4] A comparison of (28)-(29) with (14)-(15) reveals that in the noncooperative solution Canada and the U.S. balance the marginal value product of emission transformation to the present value of marginal <u>domestic</u> damage. If each country had a domestic environmental policy based on emission taxes, the noncooperative rates would be

$$\hat{\tau}_c = \frac{\gamma_{c,c}\, D'_c(\cdot)}{(\alpha_c + \delta)} \tag{30}$$

and

$$\hat{\tau}_u = \frac{\gamma_{u,u}\, D'_u(\cdot)}{(\alpha_u + \delta)} \tag{31}$$

whereas the cooperative solution would result in emission taxes of

$$\tau_c = \frac{\gamma_{c,c} D'_c(\cdot)}{(\alpha_c + \delta)} + \frac{\gamma_{c,u} D'_u(\cdot)}{(\alpha_u + \delta)} = \tau_{c,c} + \tau_{c,u} \tag{32}$$

and

$$\tau_u = \frac{\gamma_{u,c} D'_c(\cdot)}{(\alpha_c + \delta)} + \frac{\gamma_{u,u} D'_u(\cdot)}{(\alpha_u + \delta)} = \tau_{u,c} + \tau_{u,u} \tag{33}$$

Let (X_c, X_u) and $(\hat{X}_c, \hat{X}_u)$ be the stocks of pollution in the cooperative and noncooperative steady states, respectively. If $X_c < \hat{X}_c$ and $X_u < \hat{X}_u$, then $\hat{\tau}_c > \tau_{c,c}$ and $\hat{\tau}_u > \tau_{u,u}$; that is, the domestic emission taxes imposed in each noncooperating country will be larger than the domestic component of the cooperative tax if pollution in each country is less with cooperation. Of interest is the relationship of $\hat{\tau}_c$ to τ_c and $\hat{\tau}_u$ to τ_u. Will domestic emission taxes go up or down when moving from noncooperation to cooperation? It can be shown that

$$\hat{\tau}_c \gtrless \tau_c \text{ if } \frac{\gamma_{c,c}}{(\alpha_c + \delta)} [D'_c(\hat{X}_c) - D'_c(X_c)] \gtrless \frac{\gamma_{c,u} D'_u(X_u)}{(\alpha_u + \delta)} \tag{34}$$

and

$$\hat{\tau}_u \gtrless \tau_u \text{ if } \frac{\gamma_{u,u}}{(\alpha_u + \delta)} [D'_u(\hat{X}_u) - D'_u(X_u)] \gtrless \frac{\gamma_{u,c} D'_c(X_c)}{(\alpha_c + \delta)} \tag{35}$$

In words, if cooperation allows a reduction in domestic damage that exceeds the increment to emission taxes attributable to foreign damage in the cooperative solution, then emission taxes will go down and <u>both</u> countries will be better off. It may be the case that the cooperative solution would require a country to increase its emission tax to account for a high transport rate or a high marginal damage in a neighboring country. While the cooperative solution is still a potential Pareto improvement, a country asked to increase its emissions tax may require a lump sum payment from countries able to lower emission taxes if a cooperative solution is to be achieved. For the countries directly benefiting from cooperation, the reduction in domestic damage exceeds the value of damage imposed on neighbors, and the lump sum payment would serve to redistribute the surplus in a way which might voluntarily induce cooperation. Comparison of $\hat{\tau}_c$ with τ_c and $\hat{\tau}_u$ with τ_u thus permits a quick determination of whether one or both countries would directly gain from movement to the cooperative solution. Note that in the case of unilateral pollution $\gamma_{c,u}$ or $\gamma_{u,c}$ would be zero and the polluting country would raise its emission tax and presumably receive a lump sum payment from its neighbor reflecting some portion of the reduction in the present value of pollution damage.

The above analysis of noncooperative and cooperative emission taxes presumed the attainment of steady state equilibria and was thus a long run comparative analysis. The approach to a cooperative solution from a noncooperative solution may require transitional tax rates that exceed steady state noncooperative rates in both countries. Figure 1 shows some plausible time paths for the emission tax, emissions and the stock of the pollutant in Canada. A noncooperative equilibrium has been established and is manifested by the constant (unchanging) values ($\hat{\tau}_c$, $\hat{N}_c$, $\hat{X}_c$) for the interval $0 \leq t < t_1$. At $t=t_1$, a cooperative agreement is implemented. The current pollution stock is above the optimal stock, X_c, and the optimal approach requires transitional taxes above $\hat{\tau}_c$. The increase in the emission tax results in a decrease in emissions (and with a similar policy in the U.S.) causes an asymptotic approach to X_c with the steady state cooperative solution approximately achieved at $t=t_2$ and maintained with $\tau_c < \hat{\tau}_c$.

While the preceding model abstracts from many technical details of transfrontier pollution and from the complexity of multicountry (> 2) transfrontier pollution, it does focus attention on several key questions which must be addressed regardless of the model's technical detail or complexity. First, are the benefits from pollution reduction so evenly distributed as to encourage multilateral initiation of cooperation, or would the obvious gainer from cooperation need to initiate negotiation and offer to share the expected net benefits of pollution reduction to induce the adoption of higher emission taxes (or higher emission standards) in countries with little or no reduction in their expected domestic damages? Second, how quickly should countries attempt to reduce stocks of pollution and what transitional tax rates or emission standards are needed? Finally, what principles of international diplomacy are likely to premise environmental negotiations, and what international institutions or agreements are compatible with those underlying principles?

IV. Environmental Pollution and Institutional Form

The recent literature on transfrontier pollution makes the point that strong countries, economically, militarily or politically, may be out of reach of any bargaining solution with their neighbors. If the strong country is a victim of TFP, it may be able to demand and obtain pollution abatement from the source in neighboring countries. If it is a source of TFP, it may be able to defy demands from its victims and pursue its emissions indefinitely. The contributors to the earlier OECD volumes, along with those in Walter (1976) make this point very clearly and suggest certain steps that may be open to vulnerable victims. Segerson (1985) considers the effect of trade relationships and the likelihood that the gains from environmental cooperation may reflect the relative importance of its markets to its neighbor.

In what follows we deal only with countries among which there is, first, some technical opportunity for a cooperative policy of reciprocal emission abatements and, second, some political opportunity for cooperation. Such countries will typically have a continuing history of international environmental relations. Each member of the group will waver between two contending principles of international law which Scott (1986) has dubbed the principles of "territoriality" and "external responsibility." Of course, economists will be impatient with characterizations of a country's behavior as matters of "principle," but in the absence of binding international law or sovereignty or property rights over the shared environment, they must accept that bargaining and threatening and the evocation of principles are the means of arriving at some kind of cooperative behavior.

International law allows the countries to adopt policies that lie between two extremes. Under the principle of territoriality, a sovereign state has the right to utilize resources and dispose of residuals within its territorial limits without interference from other states. Under the contending principle of external responsibility, a country's right to domestic resource utilization and residual emission is qualified (constrained) by the loss or damage which might be imposed on another country.

If the governments of countries facing a transfrontier pollution problem are sufficiently committed to the principle of external responsibility, then they might agree to create an international pollution control authority (IPCA) with power to directly control emissions or introduce other policies to indirectly influence emissions within member countries. In the model of the preceding section, if the IPCA set binding limits on $E_{c,t}$ and $E_{u,t}$, then equations (1)-(4) would imply values for N_t, E_t, $X_{c,t+1}$ and $X_{u,t+1}$.

Most countries are reluctant to vest such authority in an international institution without retaining a veto authority over emission standards or policies which it might regard as excessive or too costly to its domestic economy. It is more likely that countries will explore the possibility of Pareto improvements through negotiation and implementation of cooperative policies via their own domestic environmental agencies. While groups of countries faced with a transfrontier pollution problem who would negotiate over emission or ambient standards and possibly the policies to achieve those standards may establish an international agency, it is likely to be confined to research, advisory and possibly administrative roles (see D'Arge 1976, and Scott in OECD 1976). We will consider four approaches for controlling transfrontier pollution and the form and role of any international institutions likely to be required in order to implement a particular control policy. In evaluating the four schemes, we will consider the likelihood of achieving an acceptable level for environmental quality along with the associated resource and transactions costs. Transactions costs will include the costs of information gathering, monitoring and enforcement on the domestic level, and negotiation and, possibly, information gathering (research) and monitoring at the international level.

The first policy to be considered is based on a system of emission standards in each (member) country contributing to transfrontier pollution. Emission standards set upper-bound limits on the rate of emission for a particular pollutant from a particular source. For example, in a bill considered in the U.S. House of Representatives (HR 4567), the Phase I emission standards for utilities requires that by January 1, 1993, no more than 2.0 pounds of SO_2 may be emitted per million BTU (used in a steam generator system). Coal or oil burning utilities might satisfy the emission standard by using low sulfur coal or oil, pretreating high sulfur coal, "scrubbing" sulfur from stack gases before emission, or some combination of all three. Emission standards, either per unit input or per unit time have been the principle means of pollution control in most industrialized countries. When used internationally to control transfrontier pollution, a member country would negotiate to presumably stiffen the emission standards in neighboring countries, either uniformly or in regions which, based on transport models, are thought to be major sources of emissions entering their country.

Negotiation between countries to stiffen emissions standards may not require a formal treaty, and depending on the extent to which each country is known to contribute to pollution of the other, and on the degree to which "external responsibility" underpins environmental diplomacy, the additional international transactions costs may be relatively modest. One country may take the lead and campaign to persuade the others to conform. The resource cost of achieving desired levels of environmental quality within a single country, or now within a group of countries, is not likely to be least cost. As between countries, politicians in the least-cost emitter are likely to demand that apparently similar standards be suffered in the "beneficiary" countries. As between emitters in one country, it has long been known that a system of emission standards does not encourage reduction from least cost emitters first. Hence, while standards might be feasible, the resulting ambient environmental quality will not be achieved at the lowest cost.

The paragraph above assumes that least-cost emission reduction techniques are used. Otherwise, total costs of meeting the new, higher emission standards may be higher yet. For example, the U.S. Clean Air Act, as currently amended, requires scrubbers to be installed on all new coal-fired utility plants. Scrubbers are expensive to install and costly to operate. While they may permit a utility to achieve a standard, it is unlikely to be the least cost way to reduce emissions for all plants.

The above costs are the resource costs incurred by firms in meeting a given (agreed) emission standard. In addition, the domestic environmental agencies in each country would incur transactions costs, including the cost of collecting information on the type, amount and destination of emissions from various sources, the cost of research into alternatives for reducing emissions, monitoring firms for compliance and bringing suit against violators. While such functions are performed by domestic agencies already, additional direct regulation, particularly by region or industry, will only increase an already high level of domestic transactions costs.

Countries might be able to reduce their collective transactions costs by creating an international agency designed to serve as a "watchdog" for a particular transfrontier pollutant. Such an agency might be empowered to hold hearings, issue subpoenas or make their own spot checks of emitters in any member country to determine if the agreed emission standards are being met. This was as far as international agencies, traditionally, were allowed to go. However, recent treaty instruments have been given greater powers, for example in fisheries organizations, in the Nordic system of transnational law enforcement and in the EEC. If so, firms found in violation, or the government of the country in which they reside, could be subjected to international remedies, such as fines or injunctions. In the latter case, for example, a fine may provide a domestic agency with an incentive to increase the effectiveness of its own monitoring and enforcement, or it may seek to recover fines it has paid to the international agency from its domestic offenders.

Both the creation and the operation of such an international watchdog agency, requiring a treaty and ratification by member countries, would involve new international transactions costs. A qualitative assessment of these two variations of the internationally-negotiated emission standard scheme is found in the first two columns in Table 1.

The analysis of the preceding section suggested emission taxes to control transfrontier pollution. Negotiations would seek to use collective pressure to induce each country to adopt rates that reflect the sum of domestic and foreign marginal damage. The solution to the cooperative control problem showed that such taxes might increase initially. But in some countries, as the stocks of pollutants were reduced toward the lower values in the cooperative solution, they could fall below the original noncooperative tax rates.

Negotiation and implementation of a system of emission taxes and determination of rates would likely require a treaty and, depending on the role played by the domestic environmental agencies, may require also the creation of an international emission tax agency. If member countries are already imposing emission taxes or fees (such as France and the Netherlands), then the administration of a new rate structure may be assumed by existing domestic agencies, and the role and cost of an international agency may be small. If, on the other hand, domestic environmental policy is based on standards, and taxes are to be used to control only transfrontier pollutants, then the scope and cost of the international agency could be significant. In North America neither Canada nor the U.S. has employed taxes to control pollution, so that a treaty aimed at controlling acid deposition via taxes would likely run into not only the high international transactions costs of an international agency to administer the tax programs involving not only the EPA and Environment Canada, but almost certainly the states and provincial governments as well (column 3, Table 1).

The purely domestic transactions costs of a system of internationally-negotiated emission taxes would not necessarily be greater than those of an internationally-negotiated system of emission standards. If the standards were administered as they are currently, they would continue to entail the costs of mandating and inspecting approved treatment equipment. If instead they were implemented as a system of quantitatively-limited emissions, the emission taxes would require similar firm-by-firm information and so would eventually entail compliance costs similar to a system of standards. However, the setting up of the tax systems would be a new problem for all jurisdictions and could lead to unexpected calibration and teething costs.

The clearest advantage of emission taxes over standards is their capacity to achieve emission reductions at least cost. The emission reductions brought about by a uniform tax, for example, would cost less than a standard calling for equal reductions or equal percentage reductions by all firms. But a uniform tax applied over many emitting regions can permit "hot spots" where many low-cost polluters are concentrated, or where a few large high-cost polluters opt for paying the tax. Geographical variations such as these can cause unacceptably low air quality in particular districts (such as the Ohio River Valley) or in downwind areas, perhaps in the neighboring country. Such unwanted hot spots can also arise when using uniform emission standards.

A suggested improvement is to vary tax rates regionally. The objective of obtaining some desired spatial distribution of emissions could be achieved by selective emission standards, but in theory it could be done at least cost by a regionally-variable emissions tax. Such variability would require that emitters in the same industry be subjected to differing equipment requirements or tax rates. The transactions costs of getting compliance, rather than political opposition, might be very heavy.

The fourth and final scheme to be evaluated is one that has been proposed by Scott (1986). In its bare outlines it is similar to emissions rights schemes described elsewhere (Tietenberg 1985). After negotiation, each country identifies regions where emissions are contributing to transfrontier pollution. Firms would obtain quantitative permits, or quotas, which in final equilibrium would just allow a total emission rate similar to that allowed by a standards or a tax policy. Permits would be salable among other firms within a region or airshed, and possibly transferrable to other regions within the country, but at a prescribed conversion rate reflecting both domestic and transfrontier marginal damage.

Three features make this system flexible and well suited to international negotiation and coordination. First, the problem of international information and familiarization would be eased by starting firms at their current rates of emission. These rates would then be subject, however, to planned rates of reduction. Each firm will know its future schedule of emission rates. The market in permits will help to transfer the burden of reduction to those firms that reveal themselves to be most willing to carry it. Permits so exchanged would be subject to the negotiated and stated rate of emission reduction.

Second, each permit would be valid, at its stated value for that year, only in the emitting district (or zone) where it was issued. Thus the market would tend to be confined to other emitters in the same "bubble" that contributed similarly (with the same transfer coefficients) to long distance and international pollution. Their emission quota would not be cancelled but would be stepped down if they were bought and moved to zones that already discharged heavy emissions and would be stepped up if moved to zones where emissions caused little long distance and international pollution. This selective transferability would tend to encourage eventual migration of firms to regions where they would inflict less long-distance damage.

Third, outsiders including persons and governments abroad, could participate as buyers and perhaps sellers in the permits markets. This feature could be used for either of at least two purposes. If the original negotiated rates of reduction were slow, the neighboring country could accelerate them by buying permits and retiring them. The payments would have the same effects as cash lump-sum payments, mitigating the redistributive effect of the realized emission reduction by cost-sharing. Furthermore, the neighboring country could use its powers of buying and selling to "make a market" more competitive than if only local emitters participated. Finally, the neighboring country could use new meterological and environmental information to change the details of bargained emission reductions subsequent to the treaty. For example, it could sell extra permits, transferred from high-damage zones to firms in preferred zones. In the most likely case the politicians in each country would issue more permits to their own firms, and set lower agreed reduction rates, than either the international optimum or the emission schedule desired by the neighboring country. Progress to improve this timetable would depend on the foreign cash transfers used to retire permits.

An international agency would serve a useful role in research, periodic monitoring, and possibly in the administration of regional permit markets, although this latter function might also be performed by the domestic environmental agency. At the very least it would be useful for an international agency to publish data on market transactions and prices by nation and region and to perform research on market behavior and structure.[5]

Marketable pollution permits will, in theory, lead to the least cost achievement of some given level of environmental quality. The opportunity of selling a permit creates a similar incentive as the emission tax. Tietenberg (1985) and others have shown that in static equilibrium, with a given total emission, the price of a permit to emit a marginal amount would be the same as the alternative marginal tax rate.

As with taxes, even lower emission costs could be achieved with nonuniform permit prices. Variation in emission prices could be obtained by issuing regionally-specific permits.

The transactions costs of permits schemes have certain similarities to tax schemes, especially in monitoring. The start-up costs might be about the same. The tax scheme would have continuing public collection and accounting costs, whereas the buying and selling of permits might entail mostly private transactions costs. The scheduled decline in regional emissions may be the source of extra detection costs. If neighboring regions or countries decided to buy into the permit market, there is no special reason to expect transactions costs to rise or fall.

It seems very likely that an internationally-negotiated emissions system would require regional variability in domestic tax rates, standards or permit prices. Unless the principle of neighborly responsibility was carried to unprecedented lengths, the negotiations would almost certainly have to focus on treaty provisions for reducing the emissions in particular regions, for example those having high transfer coefficients.

If so, the permit scheme might well turn out to have the lowest transactions costs. On the one hand, a competitive market in permits would serve to organize regionally-linked markets, much as in an open market in local plots of land. (A permit is like a local property right to use land for an emitting purpose.) On the other hand, the demarcation of areas beyond which a permit is not valid is more easily understandable, as a right to property, than the theoretically similar regional variation of emission tax rates.

The subjective assessment and ranking in Table 1 presumes that resource costs, and thus reductions in resource costs, will quantitatively be the most significant. If this is the case, the regime of marketable pollution permits may be least cost. We offer the ranking in the last row of Table 1 as a conjecture and encourage additional empirical analysis which might support or question this conclusion.

V. Conclusions and Implications for Canadian-U.S. Negotiations on Acid Deposition

A two-country model of transfrontier pollution was constructed which permitted an examination of cooperative and noncooperative behavior. In the noncooperative model, each country allocated resources so as to produce output or reduce emissions in order to maximize the value of commodity output less domestic environmental damage. The noncooperative solution led to steady state costate variables which could be employed as domestic emission taxes. These taxes took the form $\hat{\tau}_c = \gamma_{c,c} D'_c(\cdot)/(\alpha_c + \delta)$ and $\hat{\tau}_u = \gamma_{u,u} D'_u(\cdot)/(\alpha_u + \delta)$ for Canada and the U.S., respectively. Noncooperative domestic taxes thus depended on the proportion of emissions undergoing deposition in the country of origin, marginal domestic damage from the accumulated pollution stock, and the rates of degradation and discount. If all of a country's emissions crossed its borders before deposition, its noncooperative emission tax would be zero.

Cooperation was mathematically equivalent to the maximization of the present value of output less environmental damage over both countries. The cooperative solution evaluated in steady state led to emission taxes taking the form $\tau_c = \gamma_{c,c} D'_c(\cdot)/(\alpha_c + \delta) + \gamma_{c,u} D'_u(\cdot)/(\alpha_u + \delta)$ and $\tau_u = \gamma_{u,c} D'_c(\cdot)/(\alpha_c + \delta) + \gamma_{u,u} D'_u(\cdot)/(\alpha_u + \delta)$ for Canada and the U.S., respectively. The cooperative taxes took into account the present value of marginal damage within a country's borders as well as in the neighboring country. The steady state levels for emissions and accumulated stocks of pollution will typically be less under cooperation than with noncooperation. It is entirely possible, however, that the cooperative tax rate in a country from which all or a majority of its emissions crossed its borders before deposition, would have to increase when moving to the steady state cooperative solution. Acting on the principle of territoriality, the country may be reluctant to tax its domestic emitters to account for foreign damage without some sort of compensation. The cooperative solution provides a potential Pareto improvement, and if the transfrontier pollution problem is confined to two countries bargaining over emission tax rates, a net side payment could achieve an actual Pareto improvement. Comparison of cooperative and noncooperative tax rates provides a quick way of determining whether side payments may be necessary to implement a cooperative policy.

During the process of moving from a noncooperative state toward a cooperative solution, <u>both</u> countries may have to increase emission taxes to induce a temporary decline in emissions which would in turn allow the stocks of accumulated pollutants to be depreciated (decomposed or buffered). The length of this transition period will depend on the responsiveness of emissions to increased tax rates and on the rates of decomposition.

While emission charges and fees have been levied in Europe, they have not been set at rates reflecting marginal damage. In North America neither Canada nor the U.S. has had extensive experience with emission taxes; the prevailing pollution policies have been based on direct regulation by emission standards and, in the U.S., by a specific treatment technology requirement. While taxes have theoretically attractive "least cost" attributes, they have not been mentioned officially in negotiations between the U.S. and Canada as likely candidates for a joint pollution policy. Recommendations emerging from a joint study (Lewis and Davis 1986) appear headed toward a solution stated in terms of total national emissions, or total emission reductions. These would probably be translated into regional and firm emission standards. As a sweetener, there would be a federal subsidy to private U.S. firms and public utilities to assist the adoption of emission reducing technologies. Canada would also offer a subsidy to utilities and smelters. This is likely to be a very costly approach to the problem of acid deposition.

The proposal for marketable pollution permits by Scott (1986) has several advantages. It has an economic incentive (opportunity cost of sale) which should promote a least cost solution for a given target reduction or level of ambient quality. The U.S. EPA has now had some experience with "bubble" and emission offset policies which would not make marketable emission permits a completely alien policy. They may entail lower domestic transactions costs as the number of permit holders declines over time. On the negative side, concern has been expressed that a system of uniform marketable pollution permits may result in localized "hot spots" where firms retain and acquire additional permits and, in turn, cause unacceptable pollution concentrations in regions of origin or, via transport, into regions of deposition. Pollution permits, if concentrated in the hands of a single firm, might serve as a barrier to entry and an impediment to competitive supply of certain commodities. Interregional transfer at prescribed conversion rates and opening the permit market to outsiders may help surmount these problems. Canada and the U.S. would do well to consider marketable pollution permits as a control policy in future negotiations on acid rain.

ENDNOTES

1. Threshold effects may result in discontinuities in $D_c(\cdot)$ and $D_u(\cdot)$ such that $D'_c(\cdot)$ or $D'_u(\cdot)$ become infinite or zero at some critical value for X_c or X_u.

2. Note that $-dN/dS_c = (\partial F_c(\cdot)/\partial S_c)/(\partial F_c(\cdot)/\partial N)$ and $-dE/dS_u = (\partial F_u(\cdot)/\partial S_u)/(\partial F_u(\cdot)/\partial E)$ and that in steady state $\lambda_c = -(1 + \delta)D'_c(\cdot)/(\alpha_c + \delta)$ and $\lambda_u = -(1 + \delta)D'_u(\cdot)/(\alpha_u + \delta)$.

3. This assumption about future foreign emissions means that each country will solve an initial control problem presuming <u>all</u> future foreign emissions will be at a level equal to last year's emissions. If the first period expectation is <u>not</u> fulfilled, and the domestic pollution stock is not at the level anticipated after adopting first period controls [$(N_o, S_{c,o})$ or $(E_o, S_{u,o})$], then each country will resolve a new control problem based on a new initial condition ($X_{c,1}$ or $X_{u,1}$) and a new expectation $E\{S_{u,t}\} = S_{u,o}$ and $E\{S_{c,t}\} = S_{c,o}$ for $t = 1, 2, \ldots, \infty$.

4. The production functions and steady state relationships between emissions and pollution stocks are identical for the cooperative and noncooperative solution.

5. Some critics of the marketable permit approach have expressed concern that a concentration of emission permits by a few firms might serve as a barrier to entry and thus contribute to a concentration of market power for those commodities which are jointly produced with the transfrontier pollutant.

REFERENCES

1. Asako, K. 1979. "Environmental Pollution in an Open Economy" The Economic Record 55:359-367.

2. Dales, J.H. 1968. Pollution, Property and Prices, Toronto, University of Toronto Press.

3. D'Arge, R.C. 1976. "Transfrontier Pollution: Some Issues on Regulations" in Studies in International Environmental Economics, Ingo Walter, ed., NY, John Wiley, Chapter 11 pp. 257-278.

4. Hahn, R.W. and R.S. Noll. 1982. "Designing a Market for Tradeable Emission Permits" in Reform of Environmental Regulation, W.A. Magat, ed., Cambridge, Ballinger, pp. 119-146.

5. Hasenkamp, G. 1976. Specification and Estimation of Multiple Output Production Functions. Springer-Verlag, Heidelberg.

6. Lewis, D. and W. Davis. 1986. "Joint Report of the Special Envoys on Acid Rain." A report to President Reagan and Prime Minister Mulroney. Washington, DC and Ottawa, Canada.

7. Markusen, J.R. 1975a. "International Externalities and Optimal Tax Structures" Journal of International Economics 5(1):15-29.

8. Markusen, J.R. 1975b. "Cooperative Control of International Pollution and Common Property Resources" Quarterly Journal of Economics 88:618-632.

9. Organization For Economic Co-operation and Development. 1974. Problems in Transfrontier Pollution OECD, Paris.

10. Organization for Economic Co-operation and Development. 1976. Economics of Transfrontier Pollution OECD, Paris.

12. Pethig, R. 1976. "Pollution, Welfare and Environmental Policy in the Theory of Comparative Advantage" Journal of Environmental Economics and Management 2:160-169.

13. Scott, A.D. 1976. "Transfrontier Pollution: Are New Institutions necessary?" in OECD, pp. 117-218.

14. Scott, A.D. 1986. "The Canadian-American Problem of Acid Rain" Natural Resources Journal 26(2):337-358.

15. Segerson, K. 1985. "Unilateral Transfrontier Pollution: The Role of Economic Interdependence" Land Economics 61(1):83-87.

16. Smets, H. 1974. "Alternative Economic Policies of Unidirectional Transfrontier Pollution" in Problems in Transfrontier Pollution OECD, Paris, pp. 75-146.

17. Tietenberg, T.H. 1985. Emissions Trading: An Evaluation in Reforming Pollution Policies, Resources for the Future, Washington, DC (distributed by Johns Hopkins University Press).

TABLE 1: TRANSACTIONS COSTS AND RESOURCE COSTS OF FOUR REGIMES TO CONTROL TRANSFRONTIER POLLUTION

Type of Cost	Internationally negotiated emission standards adopted via memoranda of understanding, no international agency.	Internationally negotiated emission standards, formal treaty and an international agency to monitor and advise.	Internationally negotiated emission tax system, formal treaty, international agency to monitor and advise.	Marketable emission permits, formal treaty, international agency to monitor, advise and possibly administrate or analyze regional pollution permit markets.
International Transactions Costs	MODERATE	HIGH	HIGH	HIGH
Domestic Transactions Costs	MODERATE	MODERATE	MODERATE	LOW TO MODERATE
Resource Costs (to achieve some level of environmental quality)	HIGH	HIGH	LOW	LOW
Relative Overall Cost (ranking)*	MODERATE TO HIGH (3)	HIGH (4)	MODERATE (2)	LOW TO MODERATE (1)

*1 = Least cost. Ranking assumes that resource costs dominate international and domestic transactions costs in determining relative cost and ranking.

FIGURE 1. PLAUSIBLE TIME PATHS FOR THE EMISSION TAX, EMISSION RATE AND POLLUTION STOCK