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Solving water pollution problems along the US–Mexico border

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ABSTRACT. The analysis demonstrates the importance of multilateral cooperation for water managers to tackle wastewater pollution along an international border. A differential game is applied empirically with data of abatement costs, environmental damages, trade flows and pollution dynamics. The framework offers a way to compare pollution control when the US and Mexico coordinate efforts and when they act independently. Results show that trade liberalization and cooperation are useful for dealing with transboundary pollution in a shared waterway. In order to investigate further the nature of cooperation along the entire border, an econometric estimation is performed that investigates the factors influencing Mexico and the US to initiate environmental improvement projects. Results show that cooperation depends on whether the project addresses transboundary wastewater pollution. Other types of pollution are not significant, nor are attributes such as how much a project costs. A project's ability to generate revenues to sustain itself significantly disadvantages the project for cooperative approval.

1. Introduction

The problems of unemployment and environmental degradation are frequently linked in developed and developing countries of the world. International trade affects the way in which the problems are related. Changes in trade policy may change the constraints on the environment and unemployment that may ameliorate or exacerbate both. Trade may exacerbate both by altering the volume and location of the production and consumption of goods which generate environmental damage (Anderson and Blackhurst, 1992). Trade can benefit both in at least two ways. First, with increased income from trade, demand for environmental quality increases. Second, the possibility of using pollution such as wastewater as input for procuring a traded good generates employment and creates an incentive to internalize the environmental externality of transboundary water pollution. Transboundary water pollution concerns water-borne waste that crosses international political boundaries as a result of natural water flow.

This study provides an empirical analysis of how trade liberalization may ameliorate both unemployment and transboundary water pollution

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along the 2,000 mile US–Mexico border. First, within one binational watershed a differential game analysis enables comparison between cases with and without cooperation between two countries in addressing water pollution and unemployment. Second, along the entire border, an international trade and environment institution is examined econometrically to determine which factors are significant in influencing cooperative investment in environmental improvement projects. Both scales of analysis offer insight for developed and developing countries around the world where there are commonly shared watersheds and airsheds in need of resource management simultaneous with economic growth. Additionally, both scales of analysis contribute to the trade and environment literature with empirical measures of differences between cooperation and non-cooperation.

This paper adds to the literature in two important ways. First, there is a dynamic asymmetric differential game model to account for differences between the countries sharing the border and pollution. Second, there is a strong empirical component driving the specification of functional forms and carrying out cooperative and non-cooperative strategies. The literature on trade liberalization and transboundary pollution contains game models that are mostly static and may contain numerical examples that are not empirically based (Copeland and Taylor, 1995). The separate literature on transboundary pollution contains differential games and a few of these (Mäler and de Zeeuw, 1998; Wirl, 1994; Dockner and van Long, 1993) actually make the effort to include asymmetry between various countries sharing the boundary with empirical estimates on different flow of emissions and stock effects. Missfeldt (1999) provides a review of the transboundary pollution literature, contrasting the dynamic models devoted to pollution control for one country with that for transboundary pollution where there are issues beyond domestic commitment to policies over time.

2. Model for watershed analysis

The following model includes variables relevant for transboundary water quality management in the presence of economic activity. Each country produces good Q_i (t)at time t where i = S,M for the US (S) and Mexico (M), respectively. Production of a unit of the good Q_i (t) results in an amount of pollutant emissions, $E_i(t)$, given by the trade-off function of emissions and the consumption good, $Q_i(t) = F_i(E_i(t))$ (Forster, 1973, 1975). The 'technology' $F_i(E_i(t))$ indicates the amount of wastewater emissions produced when the current output of the country is Q_i (t) and is assumed to be strictly concave and to satisfy $F_i(0) = 0$ (Dockner and van Long, 1993; Forster, 1973). Three types of emissions are summed into $E_i(t)$ according to $E_i(t) = T_i(t) + U_i(t) + R_i(t)$, i = S,M. The flow of treated wastewater is $T_i(t)$. The term $U_i(t)$ is the flow of untreated wastewater and $R_i(t)$ is the flow of reclaimed wastewater that is re-used for economic activities. Since $T_i(t)$ and $R_i(t)$ require some form of treatment, each country's resource management agency implicitly chooses wastewater treatment through the choices of the types of emissions it generates. Emissions $T_i(t)$ and $U_i(t)$ from both countries are discharged to the common border waterway and add to the current stock of pollution in the waterway. Pollutants in wastewater emissions are a stock that persist in the waterway once discharged. An index of persistent pollutants depends on previous emissions as well as current emissions.

The amount of pollution in the river changes according to the difference between the amount that flows in minus the amount that flows out. This relationship can be written with the following linear differential equation

$$\dot{P} = z - \alpha P(t) + \beta_0 G + \beta_1 T_S(t) + \beta_2 U_S(t) + \beta_3 T_M(t) + \beta_4 U_M(t) \qquad (1)$$

where $P(t)$ equals the stock of accumulated pollutants, $\alpha P(t)$ equals the rate of pollutant decomposition proportionate to the existing stock, z is an intercept accounting for background pollution in the river, G is water flow from upstream, β_0 is the pollutant concentration of the upstream flow, and $\beta_1, \beta_2, \beta_3, \beta_4$ are parameters of the pollutant concentrations in the treated (T_S, T_M) and untreated (U_S, U_M) emissions from the US and Mexico respectively entering the waterway. Reclaimed flows $Ri(t)$ do not enter the waterway. Instead they are diverted from the treatment plant to be re-used. From equation (1) it is clear that P will increase as T_S, T_M, U_S, U_M increase. Due to scarce fresh water resources in the area, wastewater that receives treatment can augment water supplies for irrigation and non-potable uses.

Both countries derive benefits $\pi_i(F_i(T_i(t), U_i(t), R_i(t)))$ from production of the good $Q_i(t)$ but incur environmental costs $D_i(P(t), U(t))$ through the total stock of pollution (stock externality) in the waterway and untreated emissions and costs of treatment for $T_i(t)$ and $R_i(t)$. Net benefits to each country in period t are given by

$$\begin{aligned} B_i(T_i(t), U_i(t), R_i(t), P(t)) = \pi_i(T_i(t), U_i(t), R_i(t)) - D_i(P(t), U(t)) \\ - \; TC(T_i(t), R_i(t)) \end{aligned} \qquad (2)$$

where $\pi_i(T_i(t), U_i(t), R_i(t))$ are the benefits from production and $TC(T_i(t), R_i(t))$ is a cost of treating and reclaiming wastewater emissions.

Mexico has an additional benefit function $A(R_M(t))$ of trade revenues from reclaiming water and producing a traded agricultural crop such as cotton. The effect of liberalizing trade through NAFTA is to add this new benefit term to the payoff per period for Mexico when Mexico exercises its comparative advantage in producing cotton to be traded. The reason is that a US quota on imported cotton has been removed through NAFTA. Mexico is not plagued with pest problems like the US and textile manufacturers in El Paso do want the supply that nearby Juarez Valley can provide since the US has not been able to supply enough (Taylor, 1991).

The players in this bilateral transboundary pollution game are the public resource management agencies of the US and Mexico at the border, when each choose water pollution control strategies through the three types of emissions that maximize the discounted stream of net benefits over an infinite planning horizon. The three types of emissions indicate implicitly the level of wastewater treatment the resource management agency chooses. The maximization of the objective is subject to the pollution dynamics in the waterway according to equation (1). From the maximization it is possible to characterize the cooperative and non-cooperative pollution control strategies. The resource management agency chooses different types of emissions to maximize its net benefits in (3) for the US and (4) for Mexico, with both (3) and (4) subject to (1).

$$\max_{T_S, U_S, R_S} \int_0^\infty e^{-rt}[\pi_S(T_S(t), U_S(t), R_S(t)) - TC(T_S(t), R_S(t)) - D_S(P, U_S(t))]dt \quad (3)$$

$$\max_{T_M, U_M, R_M} \int_0^\infty e^{-rt}[\pi_M(T_M(t), U_M(t), R_M(t)) + A(R_M(t)) - TC(T_M(t), R_M(t)) - D_M(P, U_M(t))]dt \quad (4)$$

The net benefits are discounted with discount rate, r.

The linear benefit functions of wastewater emissions are

$$\pi_S(T_S(t) + U_S(t) + R_S(t)) \qquad \text{(US)} \quad (5)$$

$$\pi_M(T_M(t) + U_M(t) + R_M(t)) \qquad \text{(Mexico)} \quad (6)$$

where π_S is a parameter for the US and π_M is a parameter for Mexico that directly relates to the emission/production tradeoff function, $F(E)$, defined previously. The functional form is empirically estimated based on the manufacturing production process generating the emissions with value added data regressed on the sum of the three types of emissions.

The convex abatement cost functions are

$$TC(T_S(t), R_S(T)) = K_S + C_S(T_S(t) + R_S(t))^2 \qquad \text{(US)} \quad (7)$$

$$TC(T_M(t), R_M(T)) = K_M + C_M(T_M(t) + R_M(t))^2 \qquad \text{(Mexico)} \quad (8)$$

Both functions contain a fixed cost component (K_S or K_M) and a variable cost component that is quadratic in treated and reclaimed emissions.

The damage functions

$$D_S(P, U_S(t)) = D_{1S}P^2 + D_{2S}U^2{}_S(t) \qquad \text{(US)} \quad (9)$$

$$D_M(P, U_M(t)) = D_{1M}P^2 + D_{2M}U^2{}_M(t) \qquad \text{(Mexico)} \quad (10)$$

are quadratic in the state variable P, and untreated emissions. The empirical section will provide data to substantiate the quadratic relationship between levels of stock and untreated emissions flow and the resulting health impacts from exposure to both.

The equilibrium strategies for each country in the cooperative and non-cooperative games can be derived by solving a pair of Hamilton–Jacobi–Bellman equations (HJBs) of continuous-time dynamic programming that specify the optimization problems of both countries. Value functions, $V(P)$ and $W(P)$, are the solutions of the following two HJB equations for the US (11) and Mexico (12), respectively, where the time argument t is suppressed (Basar and Olsder, 1982). The value functions denote the maxima of the objective in (3) and (4) subject to the state equation (1) from which to derive solutions to the non-cooperative game when the US acts according to (11) and Mexico acts according to (12) independently. The terms $V'(P)$ and $W'(P)$ are the shadow values on the pollution dynamics constraint (1).

$$rV(P) = \max_{T_S, U_S, R_S} \{\pi_S(T_S + U_S + R_S) - K_S - C_S(T_S + R_S)^2 - D_{1S}P^2 - D_{2S}U_S^2 + V'(P)(z - \alpha P + \beta_0 G + \beta_1 T_S + \beta_2 U_S + \beta_3 T_M + \beta_4 U_M)\} \quad (11)$$

$$rW(P) = \max_{T_M, U_M, R_M} \{\pi_M(T_M + U_M + R_M) + A_M(R_M) - K_M - C_M(T_M + \text{RM})^2 - D_{1M}P^2 - D_{2M}U_M^2 + W'(P)(z - \alpha P + \beta_0 G + \beta_1 T_S + \beta_2 U_S + \beta_3 T_M + \beta_4 U_M)\} \quad (12)$$

The following first-order conditions are derived from (11) and (12) using Pontryagin's Maximum Principle (Leonard and van Long, 1992) where equations (13)–(15) are for the US from (1) and equations (16)–(18) are for Mexico from (12).

$$\pi_S - 2C_S T_S - 2C_S R_S + V'\beta_1 = 0, \text{ or } T_S = \frac{\pi_S - 2C_S R_S + V'\beta_1}{2C_S} \quad (13)$$

$$\pi_S - 2D_{2S}U_S + V'\beta_2 = 0, \text{ or } U_S = \frac{\pi_S + V'\beta_2}{2D_{2S}} \quad (14)$$

$$\pi_S - 2C_S R_S - 2C_S T_S = 0, \text{ or } R_S = \frac{\pi_S - 2C_S T_S}{2C_S} \quad (15)$$

$$\pi_M - 2C_M T_M - 2C_M R_M + W'\beta_3 = 0, \text{ or } T_M = \frac{\pi_M - 2C_M R_M + W'\beta_3}{2C_M} \quad (16)$$

$$\pi_M - 2D_{2M}U_M + W'\beta_4 = 0, \text{ or } U_M = \frac{\pi_M + W'\beta_4}{2D_{2M}} \quad (17)$$

$$\pi_M - 2C_M R_M - 2C_M T_M = 0, \text{ or } R_M = \frac{\pi_M - 2C_M T_M}{2C_M} \quad (18)$$

In the non-cooperative game, Mexico and the US choose a level of each type of emissions that equates either country's own marginal benefits with the marginal costs of each type of emissions, shown in equations (13)–(18). In the case of treated and reclaimed wastewater, there is a direct cost associated with treatment as equations (13), (15), (16), and (18) show. Additionally, there is an intertemporal opportunity cost for each country denoted by $V'(P)$ and $W'(P)$ that accounts for the increase in pollution in the waterway that affects environmental damages. Untreated emissions contain this environmental cost too in equations (14) and (17). Equation (18) indicates the optimal amount of reclaimed emissions when trade is liberalized. The case without trade liberalization does not include the $A(R_M)$ term. These levels of emissions are not the efficient binational optimum which internalizes the transfrontier externality.

The Markov perfect strategies result from substituting the first-order conditions (13)–(18) and value functions into the HJBs (11) and (12). The value functions $V(P)$ and $W(P)$ are quadratic in the state variable P and are the basis for deriving strategies that are linear in P. The approach of using quadratic value functions follows other literature (Basar and Olsder, 1982;

Dockner and van Long, 1993; Lockwood, 1996) where this functional form must satisfy the dynamic programming equations (11) and (12), and in the subsequent empirical case be based on data supporting quadratic form. The following value functions $V(P)$ and $W(P)$ are the net benefits for each country.

$$V(P) = -v_1P^2 - v_2P \Rightarrow V'(P) = -2v_1P - v_2 \tag{19}$$

$$WV(P) = -w_1P^2 - w_2P \Rightarrow W'(P) = -2w_1P - w_2 \tag{20}$$

It is expected that coefficients v_1 and w_1 will be positive; that is when the pollution stock is large, each country will have some incentive to reduce its emission rate. The coefficients of the value functions are found as follows. Substitution of the value functions (19) and (20) and the first-order conditions (equations 13)–(18) into the HJBs leads to equating coefficients v_1, v_2 to find the emissions decision rules. Equating coefficients literally means combining all terms containing the same coefficients to derive a final answer for the decision rules. As Dockner and van Long (1993) note, the positive root for v_1, v_2 is chosen as required by the saddlepoint stability. If the negative root were chosen, there would be an explosive nature to the state equation.

Since the analytical expressions do not yield obvious comparative statics to interpret differences between both countries, subsequent numerical simulations will yield expressions for the feedback strategies based on different numerical parameter values for each country. The parameter values indicate clear differences between a developed (US) and developing (Mexico) country. The numerical simulation will examine how changes in trade policy and damages affect wastewater emissions, the pollution stock, and unemployment. The following analytics for the solution to the cooperative game will also be numerically simulated to compare with the solution to the non-cooperative game.

The case for the BECC where both countries cooperate to decide on pollution control entails joint optimization of both countries' objective functions (3) and (4), subject to the state equation (1), according to the following HJB equation

$$\begin{aligned} rJ(P) = {} & \pi_M(T_M + U_M + R_M) + A_M(R_M) + \pi_S(T_S + U_S + R_S) - K_S \\ & - K_M - C_M(T_M + R_M)^2 - C_S(T_S + R_S)^2 - D_{1M}P^2 - D_{2M}U^2_M \\ & - D_{1S}P^2 - D_{2S}U^2_S + J'(P)(z - \alpha P + \beta_0 G + \beta_1 T_S + \beta_2 U_S + \beta_3 T_M \\ & + \beta_4 U_M) \end{aligned} \tag{21}$$

The joint welfare maximization for both countries of cooperation is justified using Pontryagin's Maximum Principle as in the literature (Dockner and van Long, 1993; Leonard and Long, 1992; Basar and Olsder, 1982). The same procedure is used to derive first-order conditions and a quadratic value function and equate coefficients to obtain control rules that are linear in the state variable and are algebraic expressions of all model parameters. The equations in the cooperative case weigh the marginal benefits of treated, untreated, and reclaimed emissions with the marginal direct costs of treatment plus the marginal damages, J', from both countries' effect on the pollution stock. The cooperative solution takes into account both countries' benefits and costs and is therefore the binational social optimum. Comparisons between cooperation and non-cooperation with and without trade liberalization are made with simulations discussed in the following section. It is useful to note here that the conditions to explore the existence of a non-linear and non-cooperative solution that Dockner and van Long (1993) have identified as a possible way to achieve what a cooperative solution may, are not likely to occur in this particular model and empirical application. First, Dockner and Long imply r, the interest rate should approach zero for the non-linear solution to equate with the cooperative solution, which does not occur. Second, the following section will highlight the empirical background for the functional forms shown above that tend towards the linear quadratic formulation. At this point, without further investigation into a more complex relationship between cotton and the textile industry, which would use cotton as an input in production, there is no rationale for deriving a nonlinear solution.

3. Watershed data

Calibration of the model is based on existing data for costs of wastewater treatment and reclamation, water quality measures, epidemiological surveys of illnesses associated with wastewater pollution, and the economic value of production of traded goods for transboundary pollution in the Rio Grande waterway that is the US–Mexico border between El Paso, Texas, and Ciudad Juarez, Chihuahua. By using such data, it is possible to provide realistic solutions to pollution problems that the players in the differential game, public resource agencies in El Paso (US) and Ciudad Juarez (Mexico), face. Table 1 summarizes the value of parameters used in the simulations. The description of the data and procedures to obtain parameter values follow the table.

The state equation (1) defines the change in the index of pollutants in the Rio Grande over time. Total suspended solids (TSS), a measure of the organic and inorganic solids, serves as the index of pollutants. The aim is to express the relationship between the existing concentration of TSS in the waterway and the wastewater emissions added to the waterway in each period. The concentrations of TSS for treated and untreated emissions from both countries are referenced from water quality data from the 1992–1993 bilateral monitoring project along the Rio Grande (IBWC, 1994). The concentration for the reclaimed wastewater emissions is obtained from measures of reclaimed flows in El Paso and the proposed reclamation plans for Ciudad Juarez (EPWUPSB, 1992; IBWC, 1994). The intercept and decay term α are obtained with information from a dynamic and spatial analysis of the volume of the reach of the river around El Paso and Ciudad Juarez and the change in P from upstream and downstream of the river reach.

The coefficients π_S and π_M in the benefits functions are estimated for the US and Mexico respectively by regressing each country's value added for aggregate production on each country's sum of weighted wastewater emissions (INEGI, 1995; US Dept. of Commerce, 1996). The coefficients for each type of emissions are the concentrations of TSS.

Table 1. *Parameter values*

Parameter	*Description*	*Value*	*Std. Error*
α	Decay rate	0.002	
β_1	TSS concentration in treated emissions (US)	5 mg/l	
β_2	TSS concentration in untreated emissions (US)	800 mg/l	
β_3	TSS concentration in treated emissions (Mexico)	5 mg/l	
β_4	TSS concentration in untreated emissions (Mexico)	900 mg/l	
z	intercept in state equation	0.22	
π_S	Benefit function for US	1.38×10^6	1.17
π_M	Benefit function for Mexico	1.37×10^6	0.92
C_S	Cost function for US	2.03×10^{-5}	0.15×10^{-7}
C_M	Cost function for Mexico	1.73×10^{-5}	0.06×10^{-7}
D_{1S}	Damage function for US	4,318	
D_{2S}	Damage function for US	13,893	
D_{1M}	Damage function for Mexico	299.45	
D_{2M}	Damage function for Mexico	862.23	

Revenues from the export of cotton by Mexico to the US constitute the additional component of Mexico's net benefits when trade is liberalized. The parameter, A, in the benefit function of reclaimed water for cotton production, $A(R_M)$, is obtained through a cotton production function that identifies how much water is used to produce cotton (Schulthies and Williams, 1992). To arrive at a figure that indicates the value of marginal production per unit of reclaimed water used as an input, net benefits per hectare are divided by the amount of liters of reclaimed water per hectare used to produce cotton. Dividing \$1,366.66/ha by 104.88 l/ha, gives a value of net benefits: \$13/liter or 13R.

The parameters in the cost function for wastewater treatment in each country are obtained with data from existing facilities in El Paso and projections on future facilities in Ciudad Juarez. There are 18 year projections of fixed and variable costs for wastewater treatment and water reclamation from 1992 to 2010 provided by the El Paso Public Utilities Authority, Texas Water Development Board, and Junta Municipal de Aguas y Sanamiento de Ciudad Juarez (EPWUPSB, 1992; JMAS, 1994). All monetary values of costs are in constant 1992 million dollars. The data for the US consist of existing treatment expenditures as well as adding new treatment units for un-sewered neighborhoods called colonias (EPWUPSB, 1992). Estimates of costs for Mexico are from projections for plants to be constructed; currently Ciudad Juarez has no wastewater treatment (Degremont, 1995; JMAS, 1994).

Valuation of damages is accomplished using an epidemiological survey of residents in six non-sewered, non-electrified residential areas (colonias) adjacent to the Rio Grande around El Paso and Ciudad Juarez to delineate the relationship between human exposure to TSS levels through water supply for drinking and washing as well as recreational use and the incidence of gastrointestinal illnesses, angina, respiratory illnesses, and pneumonia (López and Byrne, 1996; López, 1995). Monetary values of the damages are found through a method to assign the costs of illness. The cost of illness assigns a unit cost to the physical damage to convert it into monetary terms (Freeman, 1993). The unit cost includes medical care expenditures and lost wages from people not working due to the illnesses.

There are two sources of public health damages for the analysis. The first source is the stock variable, P. The second source is the flow variable of untreated emissions, U. The damage associated with P arises from well water supplying potable water for residents of the unsewered colonias on either side of the Rio Grande (López, 1995). The correlation between TSS and illness is estimated according to the following equations which express the change in incidence (percentage) of morbidity induced by changes in TSS concentrations. The coefficient γ in $PI_P = \gamma P^2$ is estimated by regressing PI_P (percentage of illnesses correlated with the stock pollutant) on P^2(quadratic stock pollutant) using four observations of different TSS levels and percentages of illness. Thus, $\gamma = 1 \times 10^{-2}$.

The damage linked to U originates from exposure to water pollution in the river through recreational fishing and swimming. The coefficient b in $PI_U = b(\beta_\eta U^2)$ is estimated by regressing PI_U (percentage of illnesses correlated with the flow pollutant) on $\beta_\eta U^2$ (weighted quadratic untreated emissions). The β_η term where $\eta = 2{,}4$ indicates the TSS concentrations of untreated emissions from the state equation (1) for the US (β_2) and Mexico (β_4), respectively. Two observations of different TSS levels in the untreated emissions are used in the regression, which yields $b = 2.8 \times 10^{-2}$.

Parameters γ and b are used to calculate a dollar value of illnesses associated with pollutant levels, according to the cost of illness technique (Tolley, Kenkel and Fabian, 1994). The equation for the dollar value of illnesses in the US from the stock pollutant is

$$D_{1S} = (m + w)t\gamma \tag{22}$$

The D_{1S} term is the parameter in the damage function for the dollar value of public health damages. The m term refers to the dollar amount of medical expenditures per person for illnesses reported in the survey (respiratory problems and angina). The w term refers to the lost wages per person associated with missing an average of four workdays due to illness (Tolley, Kenkel, and Fabian, 1994). The t term refers to the total number of people with the illness, calculated by multiplying the percentage of illnesses times the total population of the colonia. By substituting D_{1M} for D_{1S}, the equation can also be used to calculate the damages from the stock for Mexico.

The same procedure is used to calculate a dollar value of illnesses for the US and Mexico, associated with the flow variable U. The following equation shows the terms for calculating the damages for the US.

$$D_{2S} = (m + w)tb \tag{23}$$

By replacing D_{2S} with D_{2M}, Mexico's damages can be calculated.

4. Watershed results

The numerical calculation of the cooperative and Markov perfect strategies using the functional forms and parameters described in section 3 involves solving a system of equations for coefficients in the value functions of each game. Figure 1 shows aggregate emissions of both countries for both games with and without trade liberalization. Cooperation with trade liberalization yields the lowest steady state pollution of 375 mg/l TSS. This concentration is 11 per cent less than the case of cooperation in the absence of trade liberalization, 24 per cent less than the non-cooperative case with trade liberalization, and 53 per cent less than the non-cooperative case in the absence of trade liberalization. The steady state of each of the four scenarios listed in the legend of figure 1 is the intersection of the state equation that follows a 45 degree line, $\dot{P} = 0$, and the change in aggregate emissions for both countries, according to the logic of finding a steady state flow of emissions and its relationship to pollution stock. Trade liberalization lowers the steady state for both the non-cooperative and cooperative games given the opportunity costs of lost trade revenues from reclaiming. Aggregate emissions decline faster in the non-cooperative game with trade and approach the level of emissions in the cooperative game at high concentrations of TSS (TSS = 1000 mg/l).

Table 2 indicates differences between the US and Mexico. The reduction in emissions due to trade liberalization is recorded in percentage units at two concentrations of TSS pollution for each country under the non-cooperation and cooperation scenarios.

With trade liberalization, Mexico emits 5 per cent less emissions than in the absence of trade liberalization at a pollution concentration of TSS = 200 mg/l and 60 per cent less at a higher stock of pollution, TSS = 900 mg/l. The addition of trade revenues from cotton produced with reclaimed water means Mexico reclaims more water and emits less untreated and treated emissions into the waterway. The emissions in this

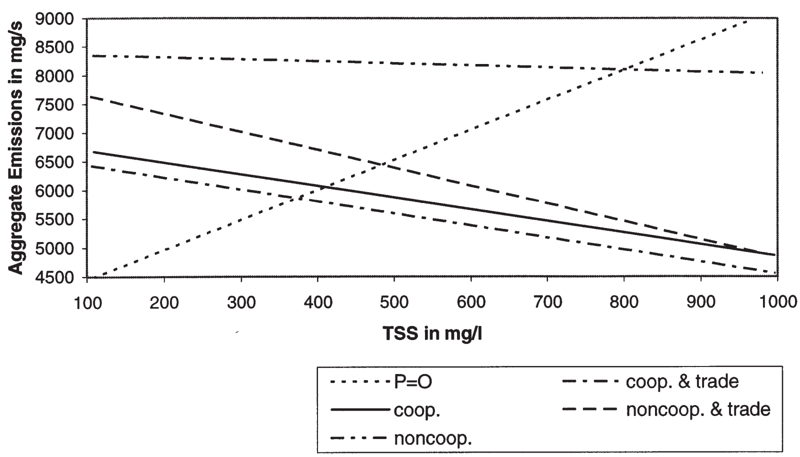

Figure 1. *Aggregate emissions and steady states of pollution*

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Table 2. *Reduction in emissions from trade liberalization*

Scenarios with trade liberalization	*Reduction in emissions at TSS = 200 mg/l*	*Reduction in emissions at TSS = 900 mg/l*
Mexico, non-cooperation	5%	60%
Mexico, cooperation	25%	31%
US, non-cooperation	−2%	8%
US, cooperation	0%	3%

scenario are 2 per cent less than that of cooperation in the absence of trade when TSS = 850 mg/l and keep declining. Cooperation and trade liberalization result in reduced emissions for Mexico of 25 per cent at TSS = 200 mg/l, 31 per cent less than in the absence of trade liberalization at TSS = 900 mg/l. The non-cooperative strategy for the US with trade liberalization yields 2 per cent more emissions than without trade liberalization at TSS = 200 mg/l. This is due to the public good nature of water quality in the waterway and the ability of the US to act strategically. Since Mexico is emitting less and it is the only one that earns trade revenues from reclaiming, the marginal cost of emissions for the US is lower and, therefore, it will emit more at this concentration of TSS. However, at the higher concentration of TSS = 900 mg/l, the US reduces emissions by 8 per cent. The cooperative strategy for the US with trade liberalization yields less emissions than without trade liberalization at TSS = 900 mg/l. Cooperation leads to lower emissions for both countries. Mexico's emissions are 60 per cent less than emissions with non-cooperation. With cooperation, the US has 25 per cent less emissions than with non-cooperation.

The model in the study provides results of the effects of trade liberalization on employment in producing the traded crop, cotton. The same information about the cotton production function used to calculate the trade revenues from reclaiming wastewater, A(R), includes the labor input quantity that is useful here. Since a Leontief fixed proportions relationship exists in the two inputs of reclaimed water and labor for cotton production, it is possible to obtain the level of employment generated through the use of reclaimed water in cotton production (Schulthies and Williams, 1992). The employment levels for both games with and without trade liberalization are calculated as follows. The fixed proportions of 104.88 liters/HA of reclaimed water and 26 laborers/HA are used. Dividing the amount of reclaimed emissions by the fixed proportion of 104.88 liters/HA, yields the amount of total HA in cotton production. The amount of land in cotton production is then multiplied by 26 people/HA to obtain the total amount of employment in cotton production with and without trade liberalization for the non-cooperative and cooperative games. Figure 2 illustrates the results for the four scenarios. Note that the linear functions parallel those of reclaimed emissions. Cooperation results in more people employed in cotton production as the stock pollution increases. There is a slight increase with trade liberalization and cooperation. Approximately six more people are employed for every 100 mg/l increase in the stock pollutant.

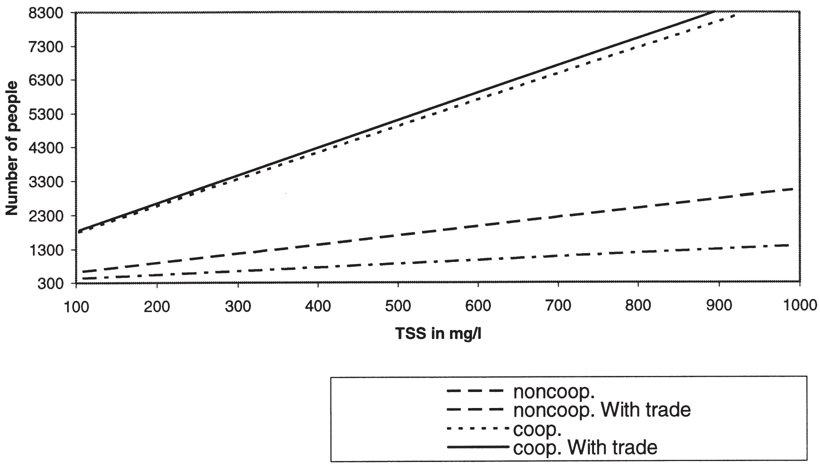

Figure 2. *Employment in Mexican cotton production*

The public resource management agency, JMAS, in Ciudad Juarez, Mexico, is currently pursuing wastewater reclamation for irrigation of tradable crops such as cotton as a means of offsetting costs of the wastewater treatment plant that is due to be online by 2001. The game theory simulations studied here highlight the relevant means of implementing the wastewater treatment in Mexico through the cooperative outcome that has resulted with NAFTA institutions in place that help to link economic growth with pollution control.

5. Analysis of cooperation along the entire border

Given the apparent advantage of cooperation to solve transboundary wastewater pollution, it is useful to quantify cooperation by a NAFTA institution, the Border Environmental Cooperation Commission (BECC). Cooperation is quantified through statistical analysis of the decisions the institution has made on environmental problems. This analysis can highlight the BECC as a formal institution that facilitates communication between the US and Mexico aimed at improving the outcome of the ongoing pollution game, not only in the watershed analyzed above, but for the entire 2000 mile boundary from the Pacific Ocean to the Gulf of Mexico. BECC is responsible for deciding whether proposed environmental improvement projects from municipalities should be certified and implemented along the border. These projects are targeted to increase environmental infrastructure to contend with the rapid industrialization and population growth that has strained the region for decades. BECC is composed of equal numbers of US and Mexican members and receives 50 per cent of funding from the US and 50 per cent from Mexico.

The characteristics of environmental projects proposed to BECC and the perceived benefits to both countries are analyzed empirically. The analysis helps identify for border resource managers which characteristics influence the likelihood of an environmental project receiving approval from BECC. Identifying the project attributes that tend to favor approval can shed light on the forces that drive bilateral cooperation for an institution focused on environmental improvement. The following two sections describe the model used for quantitative analysis of BECC's decision making on projects as well as the data used in the analysis.

6. Border model

The following model examines the behavior of BECC in its decisions on environmental projects for the US–Mexico border. The maintained hypothesis is that the probability of approval depends on the value BECC assigns to a project, which in turn is a function of the net benefits a project can bestow on the two countries. These net benefits are assumed to depend on observable project attributes. Estimating the coefficients of this model allows one to infer which project attributes, and which recipients of benefits, are favored in BECC decisions. In this manner, it is possible to test the hypothesis that BECC cares about net benefits for both countries. What BECC cares about is endogenously determined and the model enables a revelation of BECC's objective. The value (V) BECC assigns to a project is a function of its benefits to Mexico, B_{Mex}, and its benefits to the US, B_{US}. These benefits are assumed to depend on the characteristics of a project

$$V_i = V(B_{\text{Mex}}(\mathbf{X}_i + B_{\text{US}}(\mathbf{X}_i)).\ i = 1,\ldots,T, \tag{24}$$

where $\mathbf{X}_i$ is a vector of characteristics of project i.

In order to estimate an empirical model, (24) is modified to relate approval directly to project attributes as

$$V_i = \mathbf{X}_i\beta + \epsilon_i \tag{25}$$

where β are the unknown parameters of interest to be estimated, and ϵ_i is an error term for omitted variables, assumed to follow a normal distribution. The vector $\mathbf{X}_i$ includes a variable that helps determine the importance of balancing the benefits of both countries (B_{US} and B_{Mex}). The variable helps determine whether the likelihood of accepting a project from Mexico, say, depends on the amount or share of funds already spent on Mexico. By assumption, a project is approved when $V_i = >0$, that is, where BECC asserts a positive value for the project. There is information on which projects are approved, therefore a dummy variable A can be defined as

$$D_i = 1 \text{ if } V_i > 0,\ D_i = 0 \text{ otherwise} \tag{26}$$

The probability of approval, using this notation, is thus

$$\Pr[V_i > 0] = \Pr[\epsilon_i > -\mathbf{X}_i\beta] = F(\mathbf{X}_i\beta) \tag{27}$$

where $F(\mathbf{X}_i\beta)$ is the cumulative distribution function of the normally distributed ϵ_i term. The appropriate estimation method is probit.

7. Data for border analysis

There are 43 observations for the analysis, from records of 43 projects, project characteristics, and decisions by the BECC. There are 26 approved projects and 17 projects that have either been rejected permanently (5) or rejected with a chance for redefining the project to submit to the approval process again (12).

The characteristics of the 43 projects are drawn from information contained in proposals that BECC requests: (1) Human Health and the Environment; (2) Technical Feasibility; (3) Financial Feasibility and Project Management; (4) Community Participation; (5) Sustainable Development (BECC, 1997). The following variables were coded from information in each proposal. 'Type' indicates the type of environmental infrastructure project proposed. 'Type' is a dummy variable coded as 1 if a project addresses water supply, solid waste, or both, and 0 if the project is a wastewater project. This variable enables one to see if there is a bias towards one type of project (wastewater) or not.

'Transboundary' is coded 1 if a proposed project addresses transboundary pollution, and 0 otherwise. For example, a wastewater treatment plant in the US that discharges into the Rio Grande international border waterway would be a project that addresses transboundary water pollution, in that whatever flows into the Rio Grande affects both the US and Mexico.

'Public Health' is a dummy variable coded as 1 if a project addresses public health effects, and 0 otherwise. Due to variation in the level of detail provided by project proposals, it was necessary to resort to this means of addressing public health instead of attempting to quantify the magnitude of public health effects resulting from the project.

'Environment' is coded 1 if a proposed project addresses environmental health, and 0 otherwise.

'Re-use Value' offers a tangible measure of sustainable development through the ability to generate revenues through re-use of reusable waste (recycled aluminum, glass, plastic, paper, reclaimed water for irrigation, etc.) to maintain the project.

The monetary value of costs for a project are measured by the variable 'Cost'.

Another tangible measure of sustainable development is the number of jobs that are generated by a project, which is indicated in the variable 'Jobs'.

Variable 'Mexico' serves as a gauge for how benefits are split between the two countries, to indicate the nature of cooperation between the US and Mexico. Projects were not submitted and reviewed for a decision of approval or disapproval at the same time, but instead were introduced gradually over the three years BECC has been in operation. The following variable 'Mexico Share' was defined

$$\frac{S_{\mathrm{M}}}{T} = \frac{\text{sum of project spending on Mexico, to date}}{\text{Total amount requested for projects, to date}} \tag{28}$$

This ratio indicates the share of spending on Mexico in projects approved to date and the analysis will determine how the probability of project approval is affected by the size of 'Mexico Share'. The denominator is specified as 'Total amount requested for projects, to date' instead of 'Total amount spent on projects, to date' because the data include information on projects that were denied as well as projects that were approved. We estimate how project approval depends on the share of spending by

$$P_A = \theta Z + \beta_0 D_M + \beta_1 D_M(\frac{S_M}{T}) + \beta_2(1 - D_U)(\frac{S_U}{T}) \qquad (29)$$

where P_A is the probability of the project being approved, Z represents other variables in the model, D_M is a dummy variable that takes a value of 1 if the project is a Mexican project and 0 if the project is a US project. So, the effect of being a Mexican project on the probability of being approved is measured by $\beta_0 + \beta_1(\frac{S_M}{T})$ and similarly for the US there is a share ratio for US projects that is formulated as $\frac{S_U}{T}$.

In this way, the analysis includes a dynamic measure of cooperation that indicates whether or not BECC simply aims to maximize joint benefits to the US and Mexico over time, or whether it attempts to be equitable in approving Mexican and US projects. For example, finding that $\beta_1 < 0$ would indicate that BECC tends to favor Mexican projects when spending to date has been heavily allocated toward US projects. This would indicate that equity is a goal.

The final variable used in the analysis is 'Funds Available' which gauges how tight BECC's budget constraint is at the time each project is proposed. Intuitively, a tighter budget constraint should reduce the probability that any project is funded.

8. Regression results

The results of the Probit estimation are summarized in table 3.

The results indicate that there are several significant determinants of project approval by BECC. First, the negative coefficient for Type indicates that wastewater projects are the most likely to be approved versus other types of projects (solid waste, water treatment, recycling).

Table 3. *Regression results*

Variable	*Coefficient*	*Std. error*	*z*
Intercept	1.255	0.395	3.173
Type	−0.158**	0.047	−3.305
Transboundary	1.703 **	0.450	3.781
Public health	0.793**	0.119	6.615
Environmental improvement	1.54**	0.439	3.512
Re-use value	−2.19**	0.116	−1.804
Cost	0.0542	0.0338	1.605
Jobs	0.005*	0.002	1.94
Mexico	−0.669**	0.239	−2.78
Mexico's share	−0.707	0.923	−0.799
US share	0.297*	0.147	2.01
Funds available	0.01*	0.009	2.08

Notes: ** = significant at 1 per cent level. * = significant at 10 per cent level.

The coefficient for Transboundary is positive and significant indicating transboundary pollution is a strong reason for approval by BECC. The variable represents the importance of addressing environmental improvement of both countries simultaneously.

Public Health and Environmental Improvement both have positive and significant coefficients that indicate an influence on project approval.
The effect of a project having re-use value is to reduce the probability of the project being approved, as indicated by the negative coefficient for Re-use value. This appears counterintuitive in terms of the BECC's interest in promoting sustainable development goals, with projects sustaining themselves through revenues. The sign and lack of significance of the subsequent coefficient pertaining to project cost shows a consistent pattern; cost minimization is not a goal in the provision of public goods.

The ability of a project to generate jobs appears to influence on the approval of the project, with a positive coefficient for Jobs.

The negative coefficient for Mexico indicates there is less likelihood of project approval for Mexican projects. From the 43 observations, 13 out of 17 projects not approved are Mexican projects. Out of the 26 projects approved, 14 are US projects and 12 are Mexican projects. The negative coefficient for Mexico's Share, indicates that as more projects and spending to date have been allocated to Mexico, there is less likelihood of the next project for Mexico being approved.

The positive and significant coefficient for US Share indicates that the more projects and money that have been allocated to the US relative to the total amount requested to date, the more likely that the next US project will be approved. The estimated coefficient demonstrates a growing bias towards US projects.

The positive and significant coefficient for the Funds available indicates that as more funds are available, the more likely a project will be approved.

9. Conclusions

The statistical regression indicates which characteristics of projects influence project approval by a binational institution making decisions on environmental improvement. The results show that the nature of cooperation between the US and Mexico consists of emphasis on projects that benefit both countries, in that they are transboundary in nature. The analysis demonstrates a clear bias towards the US through more US projects approved. Equity between the US and Mexico does not appear to be a goal, since there is not an equal allocation of the number of projects and the amount of money spent on projects between the two countries.

The BECC does follow through with its original mandate of approving projects with public health and environmental health improvements, though it largely emphasizes wastewater projects above any other project type. Given that the single most important public health issue for the border relates to water supply and water quality, BECC is responsive to a majority of the environmental problems (Spalding and Audley, 1997).

The study reveals revenue generation is not significant for approval of a project. Some criticism of the BECC thus far has been directed at its emphasis on user fees only as a means of generating finances to sustain a project (Spalding and Audley, 1997). Perhaps the re-use value should be considered as a means of supplementing user fees in sustaining the project.

With a more focused analysis within one watershed, it is shown that the BECC's cooperation is significant, along with elimination of trade barriers to provide the right incentives for addressing transboundary pollution. Water and wastewater managers along the border, such as JMAS in Ciudad Juarez, Mexico can act on the solution indicated in the case of cooperation and trade liberalization in that trade revenues from cotton production provide incentive to reclaim wastewater for irrigation instead of polluting the Rio Grande international waterway. Tying pollution control to trade policy changes appears key for Mexico to increase environmental infrastructure beyond what BECC projects might result.

This study may be viewed as a step towards developing a methodology for studying empirically international trade and transboundary pollution problems. The potential gains from applying the methodology to other settings will be large if realistic pollution dynamics, benefits, and abatement costs are used to generate policy relevant results for natural resource managers and others.

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