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Economic Incentives and Policies to Improve Quality in a Binational Coastal Watershed

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ABSTRACT

This research compares economic incentives for sediment and wastewater management of upstream and downstream countries in a shared waterway under cooperative and noncooperative strategies. Asymmetry between the countries in terms of costs, damages and emissions influence the incentives to abate pollution. Along the 2000 mile U.S. Mexico border, water flow runs in many directions, with asymmetric flow and stock effects. The Tijuana River watershed shared by the U.S. and Mexico is one example where the prevailing water flow is from south (in Mexico) to north (in the U.S.) where the accumulation of pollution stock occurs. Hence, Mexico is the upstream country and the U.S. is the downstream country. Quantitative analysis through applied game theory assesses strategies to abate by the U.S. and Mexico. International cooperation on environmental problems yields two types of benefits. First, the free riding incentives are mitigated. Second, costs are reduced when abatement cost differ between the contracting countries. Several game sharing rules (Shapley Value, Chander Tulkens rule, Helsinki Rule, Egalitarian Rule) are analyzed. Financial transfers from two North American Free Trade Agreement (NAFTA) institutions are examined. Two NAFTA institutions, the North American Development Bank (NADBank) and the Border Environmental Cooperation Commission (BECC) finance clean up of shared wastewater and to a lesser extent sediment pollution with 75% grants originating from the U.S. Environmental Protection Agency to pay for pollution control, often in upstream Mexico.

Results show that steady state wastewater and sediment pollution is lowest with cooperation. As expected, the highest steady state pollution occurs under independent action (non-cooperation), where damages are highest for both countries. The net costs and damages are minimized through cooperation. In all cases of cooperation, transfer payments are positive from downstream to upstream that lead to reductions in the flow and stock of pollution.

INTRODUCTION

The U.S. and Mexico need to address shared border pollution problems that plague water, air and land. Where and by how much each country is involved is in question and the topic of this research project funded through the UC Water Resources Center. The nature of asymmetry between the two countries in water pollution stock, flow, cost, damages, ability to pay do matter as this study will explore. What is key is that this international border has formal institutions designed specifically to address shared environmental problems. The binational institutions are recent and it would help to investigate what existed prior to them as well as investigate what they are doing in regards to the two countries dealing with shared pollution problems. On the westernmost end of the 2000 mile border between the two countries is the binational Tijuana Watershed. The Tijuana Estuary (the U.S. mouth of the river watershed) contains approximately half of the most valued salt marsh wetlands habitat remaining in Southern California [Zedler, 1998]. The Tijuana River flows from south to north for 1731 square miles along the Baja California-California border out of Tijuana, Mexico into San Diego, California.

In the U.S., the Tijuana Estuary is a National Estuarine Research Reserve (TJNERR) and a National Wildlife Refuge for a diverse array of terrestrial and aquatic species including six different endangered species. Unfortunately, urban sprawl within the unzoned watershed, continues to seriously affect water quality. Sediment runoff, solid waste and pollutants that cross the border degrade coastal water, ecosystems and public health [Gersberg, 2000;Herzog, 2000].

PROBLEM STATEMENT

The U.S.-Mexico border region is a laboratory for studying transboundary water processes within dissimilar countries experiencing continued expansion of shared population and commerce. So far, the expansion is far outpacing the environmental infrastructure where approximately 12% of 16.1 million lack access to safe drinking water and 57% lack access to wastewater treatment [GAO, 2000]. A consistent problem along the entire U.S.-Mexico border is related to the border residents asymmetric financial limitations for self-financing much of the water management improvements that are needed for the continually expanding residential population. Public finance differences take the form of San Diego's municipal budget as 27 times greater than Tijuana, the city right across the border. The arrival of institutions through NAFTA to address environmental infrastructure along the border warrants investigation of how well they are addressing regulated (wastewater) and nonregulated (sediment) water pollution in the Tijuana Watershed as an example of the entire 2000 mile border.

Objectives

The main research objective has been to develop and apply an economic model to evaluate the economics of water pollution control in a binational coastal watershed. Related objectives consist of:

- (1) Quantifying the economic value of public health and environmental costs from coastal water quality degradation with available information of public health risk through water recreation
- (2) Determine the economic values of public capital improvement to control border water quality that includes financial incentives for pollution prevention in both upstream and downstream areas of the watershed in both countries.
- (3)

PROCEDURE

Development of components of the economic model has involved both theory and empirical aspects of Mexico and the U.S. in the Tijuana watershed in terms of the separate but related objectives over time of minimizing expected costs of pollution control. By including a state equation as a constraint, the hydrologic details of the transboundary pollution flow and stock over time and space from upstream to downstream can be included in the optimization decision.

In order to study this decision for each country separately as well as for both countries together, the dynamic game framework has been utilized to compare

cooperation with noncooperation. The economic analyses can investigate whether there are gains to cooperation by comparing with noncooperation and the magnitude of the gains. It is also of interest to investigate how the gains can be redistributed in order to make cooperation sustainable.

There is deterministic, unidirectional flow of sediment from upstream Tijuana to downstream San Diego. A version of the universal soil loss equation that establishes a rate of change over time in sediment accumulated for transboundary pollution is the pollution constraint for one analysis. Sediment movement between upstream and downstream is governed by a classical advection-diffusion process [Schnoor, 1985].

Factors that influence the instantaneous rate of change in sediment accumulation and transport capacity are included in the analysis, such as the hydraulic radius or flood frequency that helps determine the volume of water in the watershed reach between upstream and downstream, the runoff flow, the soil erodibility factor, the slope length, are constant, whereas the vegetation cover, and abatement, are subject to change based on decisions. The natural decay of sediment within the watershed as well as the outflow to the sea is also accounted for.

The wastewater problem that is the focus of a second paper is modeled according to a state equation related to diffuse and channeled flow across the border. The flow of wastewater is deterministic, unidirectional flow from upstream Tijuana adjacent to the border with steep slopes draining immediately to the U.S. downstream. The rate of change in total suspended solids pollution in wastewater transported from upstream to downstream is measured at the downstream rivermouth where the stock accumulates,

The public watershed decisionmaker for each country aims to minimize net cost of sediment that is the sum of abatement and damages subject to the dynamics of sediment. For Mexico, upstream pollution damages and abatement are a function of flow. The U.S. minimizes the sum of damages from the pollution stock and the cost of abating sediment stock and flow. Both countries in the Tijuana watershed pursue cost minimization under the constraint of the sediment state equation in a differential game using differential calculus. Through the first order necessary conditions the optimal path of abatement is found by equating the marginal damages associated with higher control of sediment equal to the marginal cost of abatement.

If country 1 has a lower cost of abatement, through cooperation it may take over the obligation to reduce emissions from the other country that has the higher marginal abatement costs and can receive compensation for its additional costs through a financial or technological transfer. The transfer is a justified cost to one country with higher transboundary environmental benefits and lower net costs of sediment abatement under cooperation rather than not. In this manner the transfer will meet individual rationality if overall costs are minimized more with the transfer under cooperation, than costs in a noncooperative game.

Several types of sharing under cooperation and transfer payments are studied. They are the Shapley Value, Chander Tulkens cost sharing rule, and the Helsinki rule for reasonableness in sharing.

The Shapley Value awards gains to countries in a cooperative game, as a function of the average marginal contribution by each country to net gain [Shapley, 1953].

With the Chander Tulkens cost sharing rule, the proportion of savings in costs from cooperation that a country receives is equal or greater than what the country could

achieve under noncooperation [Chander and Tulkens, 1992]. The Helsinki Rule formulated by the International Law Association [Cano, 1989] suggests “reasonable and equitable sharing” of environmental protection according to several criteria. The criteria can include: land area, hydrological share, population, and practicability of compensation among other items. By assigning a percentage to each country based on the quantification of the criteria, it is possible to determine allocation of costs between the countries sharing the watershed that accommodates asymmetry rather than simply assigning an even ratio between all countries. The net savings from cooperation become the basis of equitable and reasonable sharing of costs between the countries where the interpretation of equitable in this case is other than an even split.

The empirical analysis will help determine if each country can improve its welfare by coordinating its pollution control policies jointly. The empirical application will show how changes in the magnitude of costs and damages impact sediment flows, stock, and net gain in cooperation.

DATA

The data for analysis in both papers related to sediment and wastewater pollution consist of water quality pollution measures in both countries, economic values of costs and benefits of pollution control, and amounts of financial transfers from NAFTA institutions. The following paragraphs describe data for various components of the models.

The state equation of water quality dynamics draws on numerical measures of decay, water flow, slope, flood frequency and volume from the Southwest Wetlands Interpretive Association [1999], Gersberg et al. [2000] and Fong and Zedler [2000].

Cost functions depict expenditures of conveying and treating wastewater to remove TSS pollution. Treatment includes technology and maintenance that uses labor and equipment costs of constructing infrastructure are annualized from projection over the lifetime of the plants. The data consists of current as well as projected expenses for 25 years from 1994. Abatement in Mexico consists of four infrastructure projects with expenses over 25 years of current and projected expenses including sewer connections and wastewater treatment described below that leads to estimation of an abatement cost function. The costs are a function of quantity of treated wastewater.

Tijuana’s conventional wastewater treatment plant since 1989, San Antonio de los Buenos, needs expansion and rehabilitation to help address wastewater for part of the city with more than the current primary wastewater treatment for 17 MGD capacity.

As a complement to conventional wastewater treatment, Ecoparque treats inflows from Otay Universidad housing area in Tijuana up to 273,600 gallons per day. Ecoparque provides biofiltration where wastewater may be diffuse flow over land rather than formally channeled through sewer connections [COLEF, 1997].

The Tijuana Water Master Plan is a fourth project embarked on in 2000 that contributes to infrastructure costs [BECC, 2003].

U.S. abatement expenditures of the projects discussed in the following paragraphs cover capital cost for equipment and operating costs of labor in a similar manner as described for Mexico with annualized costs for 25 years of three treatment facilities.

Before the International Wastewater Treatment Plant (IWTP) was built in 1998 on in the U.S. to treat Tijuana's wastewater flowing over the border, inflows exceeding 211 mg/l routinely bypassed the treatment plant and were combined with treated effluent prior to discharge into the Pacific Ocean without an outfall that would provide the dilution in deep water.

The South Bay Water Reclamation Plant is adjacent to the IWTP, to be part of the City of San Diego water reclamation system to provide tertiary treated effluent suitable for landscape irrigation.

Abatement costs for sediment control in Mexico consists of pollution prevention of runoff from urban sprawl and riparian habitat restoration [King, 2003]. Abatement includes labor and equipment costs of constructing sediment catchments to physically trap sediment in tons per square acre per year as well as restoring vegetative habitat to help hold soil in place [King, 2003]. The sediment abatement expenditures by Mexico for sediment catchment and retention in Tijuana. Sediment is also abated through expenditures for establishing the Matadero Canyon Conservation Easement in perpetuity as a conservation park in Mexico.

The expenditures by the U.S. include both restoration of the habitat and reduction of sediment in San Diego through riparian and tidal wetland vegetation improvements.

Damages are a function of the quadratic stock of pollution for the U.S. With the buildup of total suspended solids (TSS) there are harmful pathogens that exceed the California state regulation limit for health and environmental degradation [Cabelli et al, 1983]. The TSS correlation to illness dose is referenced from Cabelli et al. [1983]. The U.S. damage function is based on benefits transfer of value generated with the cost of illness technique that includes lost revenue and medical expenses for people impacted by gastrointestinal illnesses [Dwight et al, 2005]. The morbidity impact of gastrointestinal illness is from exposure at beaches downstream at the mouth of the Tijuana Estuary. The number of exposures multiplied by the illness rate for the number of illnesses multiplied by the average economic cost of illness per gastrointestinal illness. The population at risk was estimated using data on beach attendance provided through local lifeguard agencies [SANDAG, 2003] and reports on the proportion of beachgoers who bathe seasonally [Hanemann et al. 2003]. The average cost of illness per gastrointestinal illness referenced from Dwight et al. [2005] includes lost income (wage) and direct medical cost of a gastrointestinal illness episode of the type described in Cabelli et al. [1983]. The monetary value of damages do not include ecosystem damage values, lost recreational values, the willingness to pay to avoid getting sick from swimming, nor values to local businesses from concessions, etc.

Mexico's damage function is based on estimates from the Mexican Association of Insurance Institutions [Vargas Aguilar, 2003] for lost property value as a function of quadratic diffuse wastewater flow that destabilizes eroding land underlying colonia residences on erodable bluffs in the watershed. Colonias are residential subdivisions in unincorporated areas. They lack basic services of drainage, paved roads and public utilities of electricity, water and wastewater treatment [Pombo, 1998].

The transfer payment function is derived from the range of grants for wastewater projects that have been discussed in previous paragraphs as a function of wastewater flows that these projects address. Since 1994, the U.S. has appropriated \$575 million to the U.S. Environmental Protection Agency (EPA) to reduce public health and

environmental risks on both sides of the border. EPA supplements binational funding for the projects discussed in previous paragraphs formally channelled from the Border Environmental Cooperation Commission (BECC) and the North American Development Bank (NADBank). EPA's money helps capitalize BECC's technical assistance (PDAP) program and provides grants through the Border Environmental Infrastructure Funds (BEIF) of the NADBank [(BECC, 2003); (NADBank, 1998)].

Within the Tijuana River watershed, BEIF grant funds from the U.S. EPA channeled through NADBank cover 88% of the \$19.52 million cost of a conventional wastewater treatment plant in Tijuana, San Antonio de los Buenos, and 43% of the \$30 million cost of improving Tijuana's sewer lines. Ecoparque, has transfer payments in the form of 80% of the \$180,000 total costs covered by grants from NADBank with EPA funds.

RESULTS

The results correspond to the case where empirical marginal costs of abatement and damages increase from upstream to downstream. Maple software was used to compute the constrained optimization game solutions with steady state sediment stock, abated flow, cost savings, and the amount of transfer payment for the two countries. The steady state stock declines with cooperation compared to the noncooperative stock of 34.20 cubic feet. Abated flow under cooperation for the U.S. increases over noncooperation and for Mexico over noncooperation. Both countries experience cost savings from cooperation due to lower damages from increased abatement.

The different cost share rules can be compared by properties such as individual rationality, group rationality, and Pareto optimality that guarantees both countries are at least as satisfied as before cooperation and amount of transfers. All three properties are met with the Shapley value and the Chander Tulkens cost sharing rule. However, none of the properties are met with the equity rule [Folmer et al, 1998]. The three properties may not be met by the Helsinki rule of reasonableness. Differences among different types of sharing transfer payments are presented below.

With the total cost savings to both countries under baseline cooperation, the monetary amount of transfer payment can be quantified according to dividing up the cost savings by the amount of shares for each country under each cost sharing rule. A sensitivity analysis for the size of the transfer is conducted through different types of sharing transfer payments. Three criteria of population, land area and hydrology are part of the Helsinki rule of reasonableness. The physical scale is more like an engineering fixed proportions allocation rather than demand-driven based allocation under the Helsinki Rule. With the Shapley value sharing in proportion to each country's contribution to the cooperative cost savings, a transfer payment to Mexico corresponds with its contribution of the cost savings. With Chander/Tulkens cost sharing rule, allocation of cost savings according to the change in costs and damages from noncooperation to cooperation leads to a transfer payment to Mexico.

Sensitivity analysis of a 20% increase in abatement costs and a 30% increase in damages results in significant abatement increases under cooperation. Such abatement

results in lower steady state pollution than noncooperation. Increases in abatement are based on cost savings from avoided damages.

CONCLUSIONS

Incentives for controlling wastewater pollution consist of preventing loss of property upstream and protecting public and environmental health downstream.

Results show that coordinated binational abatement involving transfer payments from downstream to upstream is optimal for minimized costs, damages, and stock of wastewater and sediment pollution. Mexico's location and lower marginal cost advantage make it economical to pay for abatement upstream and avoid more severe damages. The negative externalities from wastewater are internalized by analyzing the watershed as a binational single unit through cooperation. Mexico gains less than the U.S. from cooperation for the baseline case. This is due to lower marginal damage costs than downstream in the U.S.. Abatement will be attractive to upstream Tijuana if there is incentive to avoid damages. Upstream abatement increases the likelihood of success for reduction in pollution in the watershed. Transfer payments to Mexico enable control at the source of pollution and hence drive down the stock.

For Mexico to cooperate, the compensation varies according to different types of sharing rules for all cases.

If transboundary cooperation for infrastructure had been envisioned when the original wastewater infrastructure was conceived, it is possible that more reliable and less costly infrastructure could have been constructed as shown by the difference between the noncooperative and cooperative cases in the baseline analysis.

While the population criterion for reasonableness to allocate shares of costs savings indicates a minor amount for transfer payment in all cases, this method is questionable as population may mean growth inducing activities would dictate more financial incentives for impacting water quality negatively. Permanent characteristics of land and hydrology imply the upstream has a higher share corresponding to the 90% amount Mexico holds in the watershed. Transfers could increase dramatically with both characteristics as criteria. Transfer payments from downstream to upstream are large in the baseline case with the Chander/Tulkens cost sharing rule and the Shapley value. The TSS stock is lowest with both sharing rules.

Asymmetry in financial resources between upstream and downstream makes transfer payments imperative. Tijuana's municipal budget is a proportion (0.05) of San Diego's budget [(INEGI, 2000); (SANDAG, 2003)]. One criterion of the Helsinki Rule is used by NAFTA institutions for allocation in the Tijuana River watershed as well as the rest of the U.S.-Mexico border. The BECC and NADBank include population as a criterion for projects they approve and fund.

The current amount of finances and technical assistance devoted to Tijuana for helping control upstream wastewater and sediment is lower than it should be in all cases as shown in the difference between transfers using the Helsinki rule with the population criterion versus any other sharing rule included in this analysis. Transfer payments to Mexico could be higher to abate wastewater. These findings are significant from the

perspective of directing available resources in a binational context to solve both countries joint watershed problems.

The model and results from the analysis are useful to other efforts worldwide given the amount of these watersheds and the increasing number of conflicts in need of a formal method to solve transboundary problems.

PUBLICATIONS FROM THIS RESEARCH:

“Coastal Watershed Management across an International Border in the Tijuana River Watershed,” *Water Resources Research*, 41(5):3209-3218.

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