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Strategic Behaviour in Transboundary Water and Environmental Management

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How can an understanding of strategic behaviour and game theory improve transboundary environmental management? Game theory can improve environmental management in two ways. First, one can use game theory to explain and evaluate past conflicts, negotiations, and outcomes. Second, insights from game theory can improve the design of current transboundary environmental policies. The first point deals with ex post policy assessments, the second with ex ante policy guidance. In this second area, game theory applications have yet to reach their full potential.

This chapter draws on the history of US–Mexico border environmental management to illustrate the power of game theory as an analytic tool, but also to discuss why it has proven so difficult to apply insights from game theory to improve border environmental management. Here, I paint with a broad brush, neither delving into technical details of game theory, nor discussing border institutions in detail. This does not mean institutions are unimportant. Quite the contrary, game theory provides a richer understanding of just how important institutions are. The goal, though, is to use the history of US–Mexico border environmental management to derive general lessons for transboundary environmental management.

Developments in the strategic bargaining approach have made game theory more applicable to policy evaluation and design. The strategic bargaining approach may be contrasted with the axiomatic approach to bargaining. The axiomatic approach relies on developing a set of convincing properties that a bargaining solution would (or should) have. The next step is to show that such a solution is possible and (even better) unique. The focus is the mathematical properties of the solution and the approach abstracts from the actual bargaining process itself. The attributes of the players, the institutional rules of the game, or the precise bargaining environment are implicit. There is an emphasis on the economic efficiency of outcomes. Often (as in the classic case of bilateral monopoly) the distribution of payoffs to bargaining parties is discussed all too vaguely in terms of differences in bargaining power.[1] But, what determines differences in bargaining power?

Under the strategic bargaining approach, in contrast, the bargaining process itself, along with the attributes of bargaining parties are examined explicitly (Binmore et al, 1986). A party's bargaining power is enhanced by patience (the ability to wait for a negotiated payoff) and the speed at which it can make and respond to offers, while bargaining power is weakened by aversion to risk.

The strategic approach has features that make it naturally more appealing. While also being highly mathematical, it is couched in the language of playing games (in terms of players and moves), which is more accessible than discussion of axioms. The explicit consideration of the environment and rules of negotiations highlight how much institutions matter. Consideration of repeated games further illustrates the importance of reputation, reciprocity, institutional memory and the history of negotiations.[2] Analysis of trade assuming perfectly competitive markets focuses on the efficiency of market-based outcomes (often downplaying distributional consequences). Game theory, in contrast, is well equipped to explore issues such as the exercise of monopoly or monopsony power, distribution and often highly asymmetric benefits of exchange. By dealing with these aspects of the 'dark side' of exchange, game theory can overcome some of distrust other social scientists, environmental advocates or environmental managers have of economics and reliance on market-oriented outcomes. Staff members of international environmental institutions or academics who serve on their advisory committees are rarely economists (at least this is true in the US). So, improving communication with these groups is an important challenge.

The next section provides a brief overview of US–Mexico border environmental problems and institutions and presents examples where game theory proves useful in evaluating transboundary environmental management. The main themes include:

- the role of issue linkage and side payments;
- cost sharing rules for binational environmental projects;
- the potential for institutions to transform negotiations from one-shot prisoners' dilemma games to repeated games with greater scope for cooperative solutions.[3]

Table 15.1 summarizes some important institutional arrangements that have developed to address transboundary water issues on the US–Mexico border. Each institutional arrangement arose to deal with rather specific water management issues. Negotiated solutions required the countries to make specific decisions about how to finance and implement projects. One can view negotiation, in turn, in terms of different applications of game theory to find solutions. Finally, I highlight key aspects of negotiated solutions.

The third part of the chapter discusses the potential to apply game theory insights to ex ante policy design, rather than merely for ex post policy analysis. Game theory can provide guidance to better-designed multilateral funding programmes and facilitate issue linkage to resolve multi-faceted environmental conflicts. Yet, several constraints remain. Binational environmental programmes are often reactive and crisis-driven, which preclude negotiation that is more sophisticated. This also makes it difficult to complete sophisticated game-theoretic modelling exercises quickly enough to inform policy decisions ex ante.

Environmental management on the US–Mexico border

'¡Pobre Mexico! ¡Tan lejos de Dios y tan cerca de los Estados Unidos!'
(*Poor Mexico, so far from God and so close to the United States*)

— Porfirio Diaz, President of Mexico

Despite periodic conflicts, the US and Mexico actually have a long history of agreements and cooperation over water resources. The 1889 Convention on Boundary Waters established the International Boundary Commission (IBC) – the world's first binational agency to govern a river. The IBC was tasked with resolving disputes over the Rio Grande. A 1933 treaty authorized the first joint water infrastructure project between the countries, a canal and flood control project overseen by the IBC. It also authorized the construction of a dam for the Caballo Reservoir in New Mexico to capture irrigation water for both countries. The costs of the dam project were allocated based on the relative value of agricultural assets on lands served by the project and relative benefits of flood control on each side of the border. The US was to bear 88 per cent of project costs and Mexico 12 per cent.

This agreement set three important precedents. First, it formally recognized that investments made by one country could benefit the other and that joint project development could be more cost-effective than unilateral action. Second, it allocated project costs based on the share of expected benefits accruing to each country. Third, benefits were estimated using a simple approach requiring limited data that was available, easily understandable and verifiable for both countries.

In the 1940s, Mexico successfully linked negotiations over allocations of the Rio Grande and the Colorado River. Mexico desired an assured allocation of Colorado River water where it was the downstream riparian. But, the US held to the Harmon Doctrine asserting sovereignty over waters flowing within

Table 15.1 *Institutional arrangements for transboundary water management on the U.S.–Mexico border water management*

Year	Institutional arrangement	Water management issues	Strategic problem	Game theory applications	Negotiated solutions
1933	Convention between the US and Mexico for Rectification of the Rio Grande	Rio Grande flood control project Construction and cost apportionment of the Caballo Dam in New Mexico	Determining sites for flood control infrastructure Cost apportionment of Caballo Dam in New Mexico	Two-party cooperative game Flood control benefits measured in terms of relative productivity of agricultural assets at risk	Infrastructure chosen to minimize cost of flood control objectives regardless of location Costs apportioned based on relative benefits of flood control to each country
1944	Treaty between the US and Mexico Relating to the Waters of the Colorado and Tijuana Rivers, and of the Rio Grande (called 1944 Treaty)	US diversions of the Colorado River impose costs on Mexico Mexican diversions of the Rio Bravo/Rio Grande tributaries impose costs on the US	Because of downstream positions, Mexico had weak bargaining power in Colorado dispute and US had weak bargaining power in Rio Grande/Rio Brave dispute	Interconnected game	Allocations of waters of Colorado and Rio Grande/Rio Bravo Rivers determined simultaneously
1944	1944 Treaty	Border faced numerous transboundary water issues	Binational projects often more cost-effective than unilateral action Each new transboundary water project required a new binational treaty	Shift from a one-shot to repeated game negotiation structure	Scope of International Boundary and Water Commission (IBWC) expanded. US and Mexican Sections of IBWC given authority to negotiate terms of projects Repeated game nature of negotiations facilitates cooperation with over 300 agreements (called Minutes) approved to date

1973	Minute 242. Permanent and definitive solution to the international problem of the salinity of the Colorado River	Salinity of Colorado River water reaching Mexico from the US	Salinity harmed agricultural productivity of Mexico's Mexicali Valley	Two-party cooperative game with side payments	Minimum salinity standard established for transboundary water flows Groundwater pumping limits established around San Luis on Colorado River Side payments: US to provide assistance for Mexicali Valley rehabilitation and to assist Mexico in securing financing for rehabilitation
1974	Colorado River Basin Salinity Control Act	Compliance with Minute 242 (above), controlling Colorado River Salinity	Achieving salinity control by individual US states to comply with terms of US–Mexico binational agreement	Multi-level game with top level between US and Mexico and next level between US federal government and states	US constructs Yuma desalinization plant to bind commitment to control salinity Authorizes payments for land fallowing and improve irrigation infrastructure to control salinity
1958-	Various IBWC minutes	Border wastewater treatment	Developing sites for treatment facilities Cost apportionment of facilities Property right determination over treated effluent	Sequential bargaining game with asymmetries: US down-stream facing external costs; Mexico has fewer financial resources; Public health crises make US an 'impatient' player	Countries site facilities to minimize cost of treatment objectives Costs initially apportioned based on relative project benefits to each country US adopts then abandons equal cost sharing rule after it leads to inferior solutions

its borders. The US position changed, however, when Mexico began diverting water from tributaries of the Rio Grande, reducing water available for irrigation in southern Texas. Mexico insisted on tying negotiations over allocation of the Rio Grande to allocation of the Colorado. Ragland (1995) examined this process as an interconnected game.[4] In an isolated game allocating the Colorado, Mexico could expect little or no assurance from the US. By linking games, however, Mexico was able to achieve a greater water allocation than would otherwise be possible. The resulting 1944 Treaty between the US and Mexico Relating to the Waters of the Colorado and Tijuana Rivers, and of the Rio Grande (known as the 1944 Water Treaty) allocated Mexico 1.5 million acre-feet of Colorado River water per year, while Texas was to receive an annual average of 350,000 acre-feet from the Rio Grande.

The 1944 Water Treaty also changed the name of the IBC to the International Boundary and Water Commission (IBWC) and elevated its role, placing it in charge of 'settlement of all disputes' arising from the treaty and stating the Commission 'shall in all respects have the status of an international body'. The IBWC was thus given authority as the primary vehicle for settling water disputes and coordinating water projects on the US–Mexico border. The IBWC is made up of US and Mexican Sections, with each section required to be led by a licensed engineer. The jurisdiction of the IBWC is specific and narrow. It extends only to water issues that are fundamentally binational. The IBWC may address water sanitation problems, through projects mutually agreed upon by the two nations. These agreements are called 'Minutes'. The Commission is primarily a technical agency, focusing on scientific appraisals and engineering solutions to water management problems. Although the Commission's jurisdiction is limited in scope, on US–Mexico border water issues, its authority supercedes the claims of other domestic agencies. To alter the jurisdiction or authority of the Commission would require a new treaty approved by both governments.

This new mandate for the IBWC was a significant event in the history of transboundary water and environmental management. Prior to 1944, the 1889 Convention was extended numerous times (1895, 1896, 1897, 1898, 1899 and 1900) and separate treaties on border water issues were signed in 1906 and 1933. This meant that any border water settlement or project required a separate treaty and a two-thirds majority in the US Senate for passage. By allowing disputes to be resolved and projects to be planned via 'Minutes', it allowed negotiations between the two sections of the IBWC to take on the character of repeated games (where cooperative outcomes are more likely). Over 300 Minutes have been approved to date. The role of Congress (in both countries) was thus scaled back to approving funding for proposed projects in up-or-down votes. The IBWC has received praise for its ability to find cooperative solutions to border water problems and for its sheer longevity as a bilateral negotiation institution (Mumme, 1993; Szekely, 1993a). The IBWC has been the only permanent institution, conducting bilateral negotiations and planning of any kind, between the US and Mexico.

Since 1944, the border population has increased twelve fold, placing stress on the region's water treatment infrastructure. The IBWC's attention has been drawn increasingly toward water quality problems, particularly the salinity of Colorado River water reaching Mexico and the treatment of wastewater from rapidly growing Mexican border cities. Agreements to finance, construct and operate border water infrastructure has taken the form of binding commitments. This allows the sections of the IBWC to negotiate in a two-party cooperative game setting. Indeed both countries have insisted on agreements with more binding provisions. The US has insisted that joint wastewater treatment facilities be constructed and operated on the US side of the border in part to maintain control over pollution control operations. In 1973, the countries agreed to Minute 242, which established salinity standards for Colorado River water reaching Mexico. The Minute required the US to construct a large desalinization plant in Yuma, Arizona. The plant has proven uneconomical to operate and the US meets its treaty obligations by diverting irrigation drainage water. Yet, the plant serves as a backstop – a commitment – to meet Minute 242's obligation.

Frisvold and Caswell (2000) have examined negotiations over wastewater treatment projects between US and Mexican Sections of the IBWC as a Nash bargaining game.[5] The Nash solution has several desirable features. The outcome is Pareto efficient. For two agents bargaining over the division of treatment effort to meet a drinking water quality standard, the Nash solution guarantees that the standard is achieved at the least cost (Frisvold and Caswell, 1995). Finally, despite its simplicity, the Nash solution can closely approximate solutions to more sophisticated non-cooperative games (Binmore et al, 1986).[6]

Untreated sewage is a major transboundary externality, as polluted water flows northward from Mexican to American cities. At one time, the city of Nuevo Laredo deposited 24 million gallons per day (mgd) of raw sewage into the Rio Grande (Johnstone). In Tijuana, over 10mgd of untreated sewage, combined with industrial waste, flow into the Tijuana River and San Diego (Johnstone 1996; IBWC, Minute 283, 1990). Flows of sewage into the ocean have led to frequent beach closures in San Diego (Ganster). The New River – flowing north from the Mexicali Valley, through the Imperial Valley and into the Salton Sea – has the dubious distinction of being one of the most polluted rivers in the US (Kishel, 1993; Johnstone, 1995; Ganster, 1996). The Nogales Wash, a tributary of the Santa Cruz River, flows through the twin cities of Nogales, Sonora and Nogales, Arizona. During summer rains, there have been raw sewage flows into the Wash and through neighbourhoods on both sides of the border (Ingram and White, 1993; Varady et al, 1995). Giardia and cryptosporidium have been detected in the Wash and the aquifer serving as the primary water source for both cities (Varady and Mack, 1995).

Frisvold and Caswell (2000) consider the problem of the US attempting to meet water pollution control standards at least cost. IBWC engineers frequently make recommendations about the location and scale of waste collection and treatment systems based on the principle of minimizing cost to achieve particular objectives, such as compliance with environmental laws. Often, this can be achieved via a joint wastewater collection and treatment project that require investment and can provide benefits to both countries. Once the US and Mexican sections agree on the least-cost project, the problem simplifies to allocating project costs between the two countries.

The IBWC negotiated construction of the first joint US–Mexico sewage treatment facility in 1951 to serve the border cities of Nogales, Arizona and Nogales, Sonora. The IBWC recommended apportioning costs in proportion to benefits (Mumme, 1993). This follows the precedent of the 1933 Treaty. The downstream position of the US, combined with its greater willingness to pay for water sanitation meant that the US would derive relatively larger benefits from the project. The US therefore assumed a higher share of the project costs. This policy of apportioning costs in proportion to benefits was used repeatedly as a guideline in subsequent negotiations over wastewater treatment (Mumme, 1993). Sharing costs in proportion to benefits is certainly consistent with a Nash solution. In 1984, however, the Reagan Administration adopted the position that the Mexican government should finance half the cost of jointly developed pollution control projects (Mumme, 1993).

The Nash bargaining approach can be used to examine negotiated outcomes of pollution control projects in three border metro areas: San Diego–Tijuana, Calexico–Mexicali and Laredo–Nuevo Laredo in response to this equal cost-sharing rule. Frisvold and Caswell (2000) argue that the equal cost-sharing rule fundamentally changes the nature of the game. Instead of choosing how to share costs, given optimal project size and scope, the problem becomes one of negotiating over project scale subject to the equal cost sharing constraint. Requiring joint projects to be equally funded will generate efficient solutions only in limited and unlikely cases. The equal cost-sharing rule can discourage cooperation on projects where both total benefits and the US' share of the benefits are large (Frisvold and Caswell, 2000). A likely outcome is that Mexico will not cooperate, but rather unilaterally construct projects, ignoring transboundary impacts on the US. This is exactly what occurred.

The equal cost rule impeded a cooperative solution to border sanitation problems in San Diego–Tijuana (Mumme, 1993). In the 1980s, IBWC engineers recommended a gravity-flow collection system, with the main treatment plant located in San Diego. The objective of this system was to eliminate uncontrolled sewage flows into the Tijuana River and San Diego. Mexico balked at paying half of the estimated $730 million project cost. Instead, Mexico acted unilaterally, building a smaller, less expensive, self-financed system in Tijuana (IBWC, Minute 270, 1985). Rapid growth in Tijuana soon outstripped the capacity of the first of two facilities built and Mexico developed plans to construct a secondary treatment plant at the Rio Almar. US engineers, however, considered the proposed plant 'suboptimal and less reliable as a mechanism of managing Tijuana's growing sewage production' (Mumme, 1993, p117).

In 1990, the IBWC agreed to pursue the larger joint sewage collection and treatment project along the lines originally proposed, a gravity flow system with the treatment facility sited in San Diego (IBWC,Minute 283, 1990). Under Minute 283, the US abandoned equal cost sharing:

> *The cost corresponding to Mexico shall be in an amount … equal to that which would have been used in the construction, operation and maintenance of the treatment plant planned for the Rio Almar* (IBWC, Minute 283, 1990).

Minute 283 improves on the earlier non-cooperative outcome. The US Section believed the scale and location of facilities would allow it to comply with domestic water quality standards cost-effectively. The Mexican government would incur no greater costs than those associated with its disagreement point, yet would derive benefits from the more efficient, larger system. Fernandez (2006) notes that this allocation strategy is consistent with a Chander-Tulkens (1992) allocation rule in that Mexico's costs were no greater than its costs under non-cooperation.[7]

The equal cost constraint also affected Minute 274 (IBWC, 1987b), Joint Project for Improvement of the Quality of the Waters of the New River at Calexico, CA–Mexicali, BC. The principal engineers were asked to develop plans for a jointly funded project to improve the waters of the New River 'Utilizing funds to be provided in equal parts by the Governments of the United States and Mexico' (IBWC, Minute 274, 1987b). The result was a small project that the engineers conceded was, 'but a small part of the total works required for solution of the border sanitation problem' (IBWC, 1987a). The engineers also noted some project features were abandoned because they fell outside of Mexico's budget constraint. Subsequent Minutes regarding the New River have dropped language about equal cost sharing.

In 1997, the Commission signed Minute 297, apportioning the costs of a wastewater treatment project for the Rio Grande at Laredo–Nuevo Laredo. Here, the externalities of untreated wastewater affect the two countries more symmetrically. The project expanded collection and treatment capacity in Nuevo Laredo, Mexico. The project's goal was to prevent discharges of untreated sewage into the Rio Grande and to have discharges from new treatment facilities conform to US water quality standards. US standards are higher than standards required by Mexican law. The US agreed to pay Mexico for the incremental cost of operating and maintaining the project to meet the higher US effluent standard. The US Section believed expanding facilities in Nuevo Laredo was a more cost-effective way to meet US standards than to unilaterally build infrastructure in the US. The US, in turn, compensated Mexico for its incremental costs of meeting the higher

US standard. Again, this conforms to a Chander-Tulkens (1992) cost-sharing rule.

These examples illustrate game-theoretic models can be used to assess cost-sharing rules, not just abstractly, but for actual projects. It also illustrates how politically imposed constraints on bargaining parameters can thwart cooperation and lead to less desirable outcomes. This type of analysis can be quite simple, as it is in Frisvold and Caswell (2000). Indeed, in an introductory environmental economics course, I use a simple graph from Field and Field's (2006) *Environmental Economics: An Introduction* in a homework assignment that has students evaluate cost-sharing rules for transboundary pollution control (Figure 15.1). Students are asked to show (and generally succeed!) how an equal cost-sharing rule under circumstances like those on the US–Mexico border will lead to sub-optimal treatment plant scale. They also derive cost-sharing rules that could lead to cooperative financing of the optimally scaled facility.

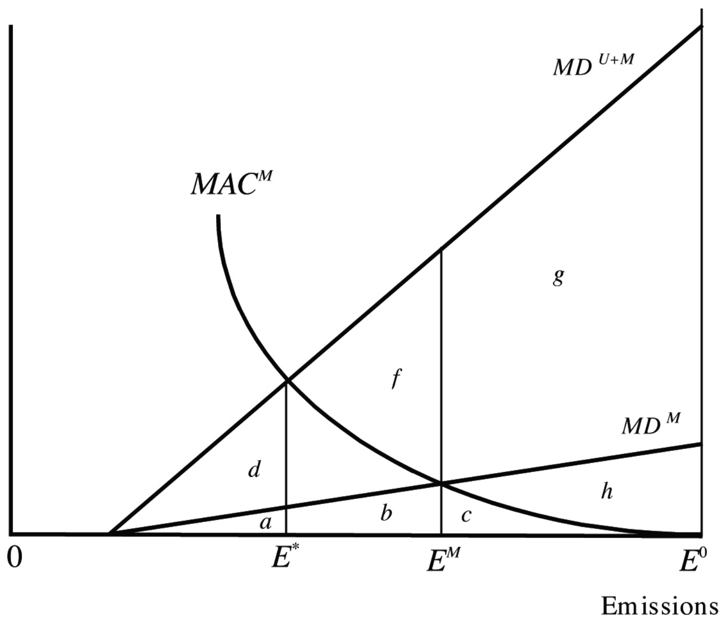
From programme assessment to policy design

Many externalities on the US–Mexico border, when viewed in isolation, are unidirectional (the lining of the All-American Canal, Colorado River salinity, sewage flows from Mexican to US cities).[9] Because of national sovereignty, dealing with such transboundary externalities must take the form of Coasian bargaining.[10] Two means of addressing unidirectional externalities are side payments and using an interconnected games approach to link issues for negotiation.[11] Table 15.2 summarizes important border institutions with the potential to encourage side payments and linked negotiations.

Institutionalizing side payments

In 1994, as side agreements to NAFTA, the US and Mexico established the Border Environmental Cooperation Commission (BECC) and the North American Development Bank (NADBank). The NADBank arranges financing of border water and other environmental issues that the BECC must certify, based on environmental, technical and financial criteria. In 2006, the organizations were merged with a common board of directors. A goal of BECC/NADBank is to address market failures that are at the centre of border environmental problems. Firms located on the border have not had to pay the full social costs of their production and release of industrial wastes into water bodies. While the IBWC has focused on responding to border sanitation problems after they arise, its mandate and organization structure is not designed to address problems of market failures and incentive problems that lead to water pollution crises in the first place.

A second problem has to do with the provision of water infrastructure needed to support the rapidly growing workforce on the border. Historically, firms have



Note: Wastewater emissions from Mexico border cities cause environmental damage to Mexico and the US. Line ***MD*** ^{M} shows marginal damages (the damage from each additional unit of pollution) to Mexico. Line ***MD*** $^{U+M}$ shows combined marginal damages to both countries. Acting unilaterally, Mexico's net benefits from damage reduction are greatest if it operates a plant to reduce emissions from E^0 to E^M. Pollution control benefits are ***h*** + ***c*** and abatement costs are ***c***, so Mexico's net benefits are ***h***. Reducing emissions to E^M reduces damage to the US by ***g***. Net benefits to both countries are highest if Mexico operated a larger plant and reduced emissions to E^*. US environmental benefits would increase by **e** + ***f*** and Mexican environmental benefits would increase by ***b***. Abatement costs, however, would increase by **e** + ***b***, more than Mexico's benefits. To induce Mexico to reduce emissions from E^M to E^*, the US could offer abatement cost sharing of **e** or greater. The US would be willing to pay up to **e** + ***f***, so the countries have room to negotiate a mutually beneficial deal with cost-share payments between **e** and **e** + ***f***. Under equal cost sharing, the US could not offer more than ½(**e** + ***b***). But this is lower than **e** (the minimum acceptable offer to Mexico) if ***b*** < **e**, as it is in the figure.[8] So, Mexico will unilaterally operate a plant too small to achieve the highest net benefits for both countries. The figure illustrates how insistence on equal cost sharing can discourage cooperative solutions and lead to pollution control projects of inadequate scope.

Figure 15.1 *An equal cost-sharing rule can discourage cooperative solutions to transboundary pollution problems*

not paid much in the way of user fees or taxes to finance safe drinking water or sewer systems for the growing workforce. Local municipalities pay only a fraction of the cost of water treatment infrastructure. The US federal government's willingness to bail out border cities is an understandable response to immediate health concerns. However, because cities are not internalizing the full costs of border growth, population and sewage growth has outstripped local infrastructure (Ingram and White, 1993; Udall Center, 1993; Johnstone, 1995).

Table 15.2 *Border institutions and their potential roles in facilitating cooperative transboundary water management solutions*

Year	Institutional	Water management issue	Strategic problem	Game theory application	Solution
1983	La Paz Agreement (Border XXI and Border 2012)	Problems of economic development and pollution control in border regions divided among multiple federal and state resource management agencies in each country	Jurisdictional fragmentation increases transactions costs of negotiations	Identify issues for interconnected game Identify institutional partners to implement joint programmes	Increases knowledge base for negotiations Establish common knowledge base for negotiations Improve coordination between sister agencies in each country
1990	Southwest Consortium for Environmental Research and Policy (SCERP)	Multiple environmental problems linked to water quantity and quality issues	Need to increase knowledge of cross-media effects	Identify issues for interconnected game	Increases knowledge base for negotiations Establish common knowledge base for negotiations
1992	The Good Neighbor Environmental Board (GNEB)	Multiple economic and institutional problems linked to water quantity and quality issues	Provides policy recommendations to US regarding transboundary management	Identify issues for interconnected game Multi-level game with top level between US and Mexico and next level between US federal government and states	Increases knowledge base for negotiations Establish common knowledge base for negotiations Facilitates cooperative state-level response to federal binational negotiations
1993	Border Environment Cooperation Commission (BECC) and the North American Development Bank (NADBank)	Many US-Mexico border water) pollution problems are unidirectional Pollution from Mexico makes it difficult for US jurisdictions to comply with US environmental laws	Financing needed for border pollution control infrastructure 'Victim pays' solutions often politically unattractive	Comparison of non-cooperative and cooperative solutions Side payments key for improving solutions	BECC-NADBank institutionalize side payments For US, financing Mexican pollution control is often more cost-effective than domestic control Work of Fernandez (2005) suggests increase in funding for side payments could improve outcomes

Yet, border cities are limited in their abilities to self-finance water infrastructure (Hinojosa-Ojeda, 1999). Because of the risks associated with these investments, it is difficult to obtain long-term financing through international markets. In addition, Mexico's legal system limits the ability of local governments to issue bonds against user fees or real estate taxes.

The NADBank's purpose is to help border communities with long-term funding of water and solid waste projects. Capitalized by both the Mexican and US governments, NADBank can secure financing at lower commercial rates than would otherwise be possible for border communities. The bank also uses its funds to leverage other private loans and grants that local entities may not otherwise be able to secure. The NADBank is not a grant-giving agency (although it does help administer an EPA grants programme). Water projects must be able to repay loans, raising funds through user fees or other mechanisms.

The BECC certification criteria include human health and environment, technical feasibility, financial feasibility and project management, community participation, and sustainable development. Along with certifying projects for funding, the BECC provides technical assistance for local entities developing projects. In addition, it analyses environmental and financial aspects of projects and helps arrange public financing for projects (EPA, 1998b).

In its first two years, the BECC failed to secure NADBank funding for any of its certified projects. NADBank (1998a) identified five constraints limiting project development: (i) insufficient community resources for high cost projects, (ii) a lack of master plans and inadequate proposal preparation, (iii) limited financial, administrative and commercial capabilities of local water agencies, (iv) inadequate revenue for the sound operation of existing services and resistance to raising user fees, and (v) lack of private sector involvement in environmental projects.

To address these constraints, the EPA and NADBank established the Border Environmental Infrastructure Fund (BEIF) (NADBank, 1998b). The fund receives and administers grants that may be combined with loans or loan guarantees. Grants may support municipal infrastructure, drinking water treatment plants, and treated water distribution systems. Funds may be used to allow user fees to be phased in over time. In its approval process, BECC gives preference to projects addressing transboundary pollution, while the BEIF (funded through appropriations to the US EPA) funding criteria state that projects must have a US interest and that priority will be given to projects which benefit both countries (NADBank, 1998b).

The NADBank also established a Project Development Program (PDP) to provide technical assistance to communities and utilities to help finance the costs involved in preparing projects for construction. The aim of the programme is to aid communities that lack the expertise or financial resources needed to plan and design infrastructure projects. By the end of 2006, NADBank had provided over $835 million in grants and loans for 97 environmental infrastructure projects in the US–Mexico border region.

The BECC/NADBank system has institutionalized a way for the US to provide Mexico with side payments for transboundary pollution control. Fernandez (2005) has examined the role of side payments in reducing sediment pollution emanating from Tijuana, Mexico and affecting San Diego, California. The analysis considered outcomes under a Nash non-cooperative equilibrium versus a cooperative game solution following alternative cost-sharing rules.[12] Because benefits accrue largely to the US, side payments are a crucial part of cooperative solutions. The level of side payments will vary, depending on whether cost allocation is determined by Shapley value, Chander-Tulkens or is based on Article V of the Helsinki Rules.[13] Currently, the US provides Mexico with side payments via the BEIF and PDP programs, but Fernandez's (2005) results suggest that payment levels would increase under a cooperative solution. The study is interesting in that it brings a wealth of empirical data to bear on the problem and ties recommendations to specific funding mechanisms and institutions.

Interconnected games and issue linkage

Bennett et al (1997) note that game theoretic solutions to unidirectional externalities tend toward victim pays outcomes and Fernandez's (2005) results support this.[14] Bennett et al (1997) find victim pays regimes unsatisfactory because they run counter to the polluter pays principle accepted in the international community and because countries may wish to avoid appearing to be weak negotiators.

An alternative to side payments or accepting externalities is to link negotiation issues. For example, Mexico obtained a greater allocation of Colorado River water, where it was the downstream country, by linking Colorado River negotiations to negotiations over allocation of Lower Rio Grande waters, where it was the upstream country.

In interconnected games, negotiations over separate issues are joined in a repeated game. Each country's action in one game is conditional on the outcome of another. This allows for equilibrium solutions not attainable in isolated games and may yield higher joint payoffs. Interlinked solutions may also avoid side payments when isolated solutions do not (Folmer et al, 1994; Bennett et al,1997).

Bennett et al (1997) and Ragland (1995) discuss how the interconnected game approach can identify issues for linkage simply by identifying issues with payoffs of the same order of magnitude and where the games have asymmetric prisoner's dilemma structure.[15] One might use their approach as a low-cost method of screening issues for potential linkage. To be policy-relevant in international water negotiations, Dinar and Dinar (2003, p1287) recommend that, 'economists should develop models that do not rely on sophisticated approaches, which necessitate accurate data that is probably as scarce as the water in the basin they are investigating'. Identifying 'same order of magnitude' payoffs would appear to follow this advice.

Linking water negotiations with other water or environmental issues may be attractive to Mexico. While the US has entered into agreements involving side payments, Mexico is less able to do so. Kishel has suggested linking negotiations over the lining of the All-American Canal to issues such as construction of a Yuma–Mexicali pipeline, groundwater banking, rights to treatment plant effluent, and transfer of water conservation technology. The canal diverts 3.5 million acre-feet (MAF) of Colorado River water to farmers in California's Imperial Valley. Because the unlined canal is built on sandy soils, 0.2 MAF of diverted water seeps into the ground annually. The US plans to line part of the canal to reduce seepage. This, however, would reduce recharge and raise the salinity of the Mesa San Luis aquifer supplying groundwater to Mexican farmers in the Mexicali Valley (LaRue). Mumme and Lybecker also suggest that issue linkage might be a useful approach for resolving the All-American Canal controversy.

The EPA's Border 2012 Program could become a vehicle for identifying issues amenable to linked negotiations. The US and Mexico signed the Border 2012: US–Mexico Environmental Program (Border 2012) in 2003. Border 2012 seeks to reduce water, solid waste, hazardous materials and air pollution, and to improve environmental health in both countries within 100km of the border. A key element of Border 2012 is coordination between the US EPA and its Mexican counterpart, SEMARNAT, as well as collection and sharing of data and information by various workgroups. Workgroups are organized into both regional and topical workgroups. The different Border 2012 Workgroups could help supply information for this screening process.

Other groups could also facilitate issue linkage. The Good Neighbor Environmental Board (GNEB) was created in 1992 as a US federal advisory committee to advise the President and the Congress about environmental and infrastructure issues in US Border States. The GNEB does not carry out specific programmes, but provides policy recommendations. Its board members include government officials from Border States, interest group representatives and academics. Another group is the Southwest Consortium for Environmental Research and Policy (SCERP), a collaboration of five US and five Mexican universities located in all ten Border States. Funded by the US Congress since 1990, SCERP addresses US–Mexico border environmental issues and is tasked to 'initiate a comprehensive analysis of possible solutions to acute air, water and hazardous waste problems that plague the United States–Mexico border region.'

Policy lessons and remaining challenges

What broader lessons can the history of US–Mexico environmental negotiations provide countries facing problems of transboundary water and environmental management? All countries have certain unique environments, institutions and histories of conflict and cooperation with their neighbours. Yet, I believe there are three areas where game theory insights can improve the design of transboundary water and environmental policies. First, negotiating and planning institutions could be structured to operate under repeated game rather than one-shot rules. Much of the success of the International Boundary and Water Commission (IBWC) owes itself to the ability of negotiators to develop a history and rules of cooperation.

Second, given many types of unidirectional externalities, side payments will often be unavoidable as a way of finding cooperative solutions. Yet, paying one's neighbours not to pollute is a 'victim pays' outcome that countries may find unattractive politically. US–Mexico border infrastructure financing projects in the post-NAFTA area have institutionalized methods of making side payments. In the US, states facing federal water and air quality mandates have found that investments in pollution control in Mexico are more cost-effective ways to meet these mandates than domestic regulation. Projects on both sides of the border supported by the IBWC, BECC, NADBank and EPA's Border Environmental Infrastructure Fund appear to have overcome resistance to side payments by reducing regulatory costs at the state level.

Finally, issue linkage in negotiation is an alternative to side payments. The theory of interconnected games suggests that issue linkage has the potential to achieve superior outcomes. Linked negotiated settlements over allocation of the Colorado and Rio Grande/Rio Bravo Rivers demonstrate that this approach is more than just a theory.

Challenges remain, however. One challenge is to develop methods that have modest data requirements and allow for timely model development. It is one thing to develop sophisticated game theoretic models to examine negotiations after the fact. It is quite another thing to develop models that are literally useful for finding cooperative solutions when negotiations are taking place. A second challenge is for economists to begin a more active dialogue with the social scientists in other disciplines and environmental scientists who participate more actively in environmental advisory committees and resource management agencies. Finally, an important precursor to greater transboundary cooperation between governments is greater international scientific collaboration in social and environmental sciences.

Notes

1 In a bilateral monopoly, a market has a single buyer and a single seller. Each must strategically consider the actions of the other in reaching an agreement on negotiation terms (usually the price and quantity of a good exchanged).

2 In game theory, there is an important distinction between static, or one-shot games, and games that actors play over and over. A repeated game allows players' strategies to depend on past moves. Actions in one period affect a player's reputation in later periods. Players may face later rewards (or retribution) for their actions.

3 An example of the classic prisoner's dilemma follows. Two suspects are arrested for a robbery. The police have insufficient evidence for a conviction without confessions, but place the suspects in separate cells so they cannot communicate. The police tell each suspect the same thing. If you both confess, you both get 2 years in prison. If you do not confess, but your partner does, he goes free and you get 5 years. If you confess, but your partner does not, you go free and your partner gets 5 years. If neither confesses, both will be charged on a lesser count and sentenced to 6 months. The outcome for each prisoner ranges from freedom to 5 years in prison, depending on what one's partner does. Not knowing what the partner will do, each prisoner has an incentive to confess to minimize his or her sentence. The result, however, is that both confess and are each sentenced to two years, while their best outcome is if neither confessed, each getting 6 months. The prisoner's dilemma illustrates a general class of problems where actors would be better off cooperating, but have individual incentives not to cooperate. As a result, actors do not cooperate and are worse off for it.

4 In an interconnected game, players can take a position in one game (or one set of negotiations) in response to another player's action in a separate game (negotiation). This allows countries to bargain over a wider set of issues and may allow a country to accept 'losses' in one set of negotiations in exchange for greater concessions or gains in other negotiations.

5 The Nash bargaining game is a two-player game where parties agree over negotiation terms where failure to agree gives each player a fixed payoff known as a threat point. For example, parties can expect a certain set of benefits if an agreement is reached and a set of lesser benefits (or even losses) if it is not. Nash's (1953) solution to the bargaining problem has the feature that no other solution can make both parties better off.

6 In a cooperative game, players can discuss strategies and make binding commitments. In contrast, in non-cooperative games, players cannot explicitly coordinate their strategies and make binding commitments. Any cooperation must be self-enforcing.

7 In a cost-sharing rule discussed by Chander and Tulkens (1992), the cost savings a country receives from cooperation is at least equal to what the country would achieve under non-cooperation.

8 One might argue equal cost sharing could be applied to Mexico's total costs, not just incremental costs of expansion so that the United States could offer more, $\frac{1}{2}(e + b + c)$. Yet, there could be cases where $(b + c) < e$ and negotiations would still break down.

9 In economics, an externality is an impact on any party not involved in a given economic transaction. Pollution is a classic example of a negative externality. For example, a power plant generating and selling electricity can generate air pollution that harms others downwind. This harm is external to the market consideration of the energy producer or consumers.

10 Because of national sovereignty, one country cannot unilaterally impose its environmental laws on another. Economist and Nobel Laureate Ronald Coase (1960) proposed that under certain conditions (clearly defined property rights, low bargaining costs, absence of wealth or income effects) then parties could (i) bargain

to achieve an efficient level of pollution reduction and (ii) that the outcome did not depend on whether the polluter had the right to pollute or those affected had the right to be free of pollution.

11 Side payments are monetary or in-kind transfers that can be used to give a party incentive to undertake costly actions as part of an agreement. In environmental agreements, in-kind transfers can take the form of technical assistance or access to technology.

12 Nash (1950, 1951) proposed a solution concept to a game where no player can increase their own benefits by unilaterally changing their strategy. A Nash equilibrium exists if each player is making the best decision he or she can, accounting for decisions of other players. A Nash equilibrium is not necessarily the best solution for all the players. They could be able to increase all their payoffs if they could agree on a coordinated strategy. In contrast, the cooperative solution maximizes the cumulative payoff to all players.

13 In a cooperative game, the Shapley Value awards gains to players in proportion to their marginal contribution to overall gains (Shapley, 1953). Fernandez notes, '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.'

14 Under the victim pays principle, an entity or entities harmed by pollution pay the polluter to reduce or stop pollution. In contrast, dating back to the Trail Smelter Case of 1941, international law has affirmed a polluter-pays principle, where polluters are responsible for compensating for environmental damage. The polluter pays principle was re-affirmed in 1972 by the declaration at the Stockholm Conference.

15 In asymmetric prisoner's dilemma games, outcomes to individual players differ. Because payoffs differ, the dilemma is more complicated than the choice between cooperation and non-cooperation. The timing and sequence of actions can affect outcomes more. Asymmetries reduce cooperation rates in repeated games. Players can have difficulty even agreeing what constitutes a desirable outcome and dilemmas require more complicated negotiations (Murnighan, 1991; Beckenkamp et al, 2007).

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