Transboundary Water Resource Management and Conflict Resolution: A Coasian Strategic Negotiations Approach

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Introduction

In September 2005 the United States and Mexico resolved a decade-old water allocation dispute. Under the Treaty of 1944, Mexico is required to annually release 350,000 acre-feet of water, the majority of which originates in Mexico's Rio Conchos Basin (RCB), to the U.S. Lower Rio Grande Valley (LRGV) by way of Rio Grande tributaries. Between 1992 and 2003, Mexico failed to fully comply with the annual treaty releases, amassing a cumulative water deficit of 1.5 million acre-feet (MAF) by 2003. After much negotiation, Mexico began repaying the cumulative deficit in late 2004 with complete repayment promised by September 2005. However, repayment schemes requiring water debts to be paid exclusively in water may not maximize the collective economic welfare of the countries involved. Alternative repayment schemes that allow the debt to be repaid over a longer repayment horizon and/or in a combination of dollars and water would have been mutually beneficial to both countries. This paper estimates the potential welfare gains to Mexico and the United States, if a Coasian-based repayment scheme that allowed Mexico to repay its cumulative deficit in dollars and/or water had been negotiated, relative to the negotiated settlement.

Conflict History and Theoretical Methods

Water originating in the RCB flows into the Rio Grande and is stored in one of two internationally managed reservoirs, the Falcon and the Amistad. Water in storage under U.S. control is then allocated to farmers in the LRGV for irrigation purposes. Texas State Agricultural Commissioner Susan Combs (Combs 2003) stated that farmers in the LRGV suffered economic damages in excess of $1 billion as a result of Mexico's deficit. Mexico's water deficit imposed significant economic damages on LRGV farmers because the deficit water would have generated value in agricultural production.

In his seminal article, "The Problem of Social Cost," Coase argues that in the case of externalities, bilateral negotiations can culminate in an economically efficient resource allocation, regardless of the initial property right assignment (Coase 1960). The Treaty of 1944 provides the necessary property right assignment for Coasian negotiations to commence. The treaty specifies the annual allocation of the internationally shared river between the two countries (Treaty 1944). The application of the Coase Theorem in this paper requires information regarding the net marginal benefit and marginal cost of deficit water supplies for the U.S. and Mexico. Mathematical programming models were developed to estimate the net marginal benefit (NMB_w), or shadow price of agricultural water use in the LRGV, and in the Delicias Irrigation District (DID) in the RCB, Mexico. The DID is the primary user of irrigated water supplies in the RCB accounting for 80% of all water use. The models used to estimate U.S. and Mexico agricultural benefits and costs were adapted from Robinson, Michelsen and Gollehon (2005) for the LRGV, and Puente-Gonzalez (2002) for the DID. To control for the impact that irrigation efficiency and transit losses have on the NMB_w of water released by

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Mexico for use in the LRGV, the NMB_w of released water was discounted by 48.8%. Only 51.2% of the water released by Mexico generates agricultural value in the LRGV due to transit and application losses (Brandes 1999).

To simulate Coasian bargaining, the mathematical programming models for each country were used to estimate the NMB_w at alternate supply levels by parametrically varying the water supply level downward in 10,000 acre-foot increments and recording the shadow price (NMB_w) at each level, beginning at the supply level where water supply was not a constraining resource. A complete discussion of the analytic approach is contained in Baker (2005). The appropriate paired NMB_w and water supply values were subsequently used in two regression equations to estimate the NMB_w function for each country as a function of water supply. As would be expected, the NMB_w is negatively related to water supply. The estimated NMB_w functions for the U.S. and Mexico, respectively, are:

$$\begin{aligned} NMB_{US} &= \underset{(305.96)}{1{,}387.69} - \underset{(-37.23)}{0.00091}(w_{US}) + \underset{(35.01)}{0.00113}(d * w_{US}) \\ &\quad - \underset{(-43.79)}{83.834}(\ln(d * w_{US})) - \underset{(-9.04)}{0.4365}(\sqrt{d * w_{US}}) \end{aligned} \tag{1}$$

$$NMB_M = \underset{(26.89)}{320.5757} - \underset{(-25.18)}{22.6263}(\ln(w_M)) \tag{2}$$

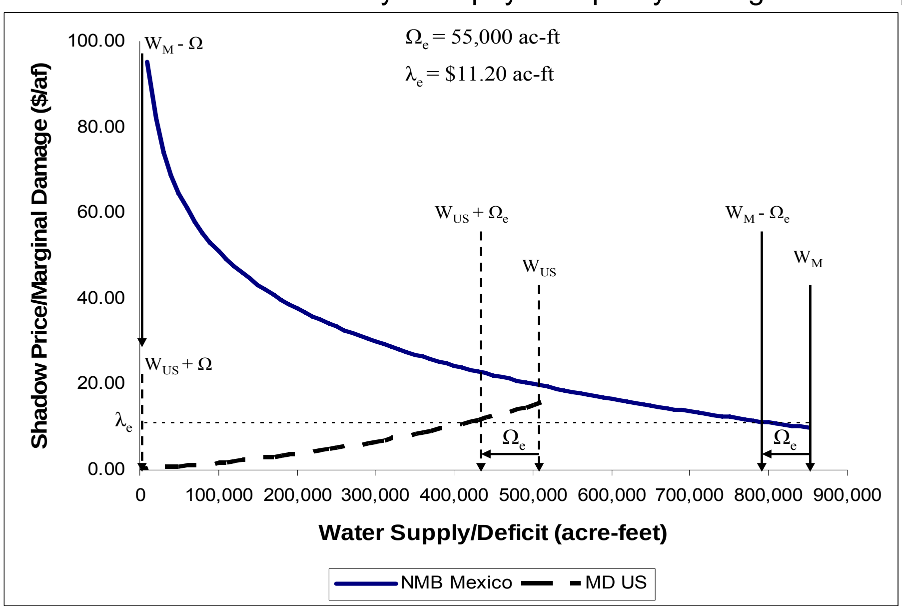
As reported by the t-value in parenthesis below each coefficient value, all estimated coefficients are significant at the .01 level, or higher, in both equations. The R-square statistic for the U.S. net marginal benefit equation is 0.999 and the R-square value for the Mexico net marginal benefit function is 0.858. A slope shifting indicator variable (d) was used in the estimation of the NMB_{US} function to control for the impact that high value citrus and melon crops grown in the LRGV have on the net marginal value of water. High profit citrus and melon crops are the last crops to go out of production as water supply becomes increasingly scarce. The NMB_{US} is approximately \$200 at 330,000 acre-feet of water, but jumps to \$1,165 per acre-foot when water supply is reduced to 320,000 acre-feet. The indicator variable was assigned a value of 1 when U.S. water supply (W_{US}) was greater than 320,000 ac-ft and a value of 0 otherwise. Because the NMB_w is a function of water supply, the value of compensation and the optimal quantity of the deficit repaid in water will vary depending on each country's initial water endowment and size of the water deficit. In a given year, the last unit of water repaid has the lowest net marginal value to the U.S., and the first unit repaid has the highest net marginal value. Conversely, the first unit of deficit repaid by Mexico imposes the lowest marginal cost on Mexico, and the last unit repaid comes at the highest marginal cost.

Graphical Analysis and Empirical Results

The estimated NMB_w functions, for each country, are used to derive the Coasian gains for three alternative water supply scenarios, and three repayment policy lengths. The water supply scenarios considered correspond to a below average, average, and an above average water supply condition in each country, where the supply levels were derived from historic water use records (Rakestraw 2005). Under the first repayment policy the entire 1.5 million ac-ft deficit is repaid in one year as per the current negotiated agreement, whereas the second repayment policy requires the deficit to be repaid over five years in equal installments of 300,000 ac-ft annually, and the third repayment policy has a ten year length, where 150,000 ac-ft is repaid each year.

The Coasian negotiations format is most easily represented and interpreted in graphical form. The NMB_w for Mexico and the MD_{US} curves are plotted in Figure 1 for a one-year contract under average water supply conditions. Here, the marginal damage (MD_{US}) function is simply the mirror image of the NMB_{US}, and estimates the net marginal damage inflicted on the U.S. for each additional unit of deficit water withheld by Mexico. Under average water supply conditions, 900,000 ac-ft of water is available for irrigation use in the LRGV in the absence of any deficit repayment by Mexico, and Mexico's DID has an initial irrigation water supply of 850,000 ac-ft which is designated as W_M in Figure 1. The MD_{US} curve only extends out to 510,000 ac-ft, W_{US} in Figure 1, because given average water supply conditions, the LRGV water supply is 900,000 ac-ft and a maximum of 1.41 MAF can profitably be used by irrigated agriculture in the LRGV in a given year with average weather conditions. Moreover, the MD_{US} curve is drawn under the assumption that the 900,000 ac-ft of water is efficiently used to irrigate the most profitable crops in the LRGV, and that any deficit repayment would be applied to crops generating lower profits per unit of applied water. Thus under average supply conditions, all Mexican deficit repayments in excess of 541,000 ac-ft will have an economic value of zero to LRGV irrigators if reservoir storage is not available. For purposes of simplicity, this illustration assumes no additional reservoir storage is available to store repayments greater then 541,000 ac-ft of water.

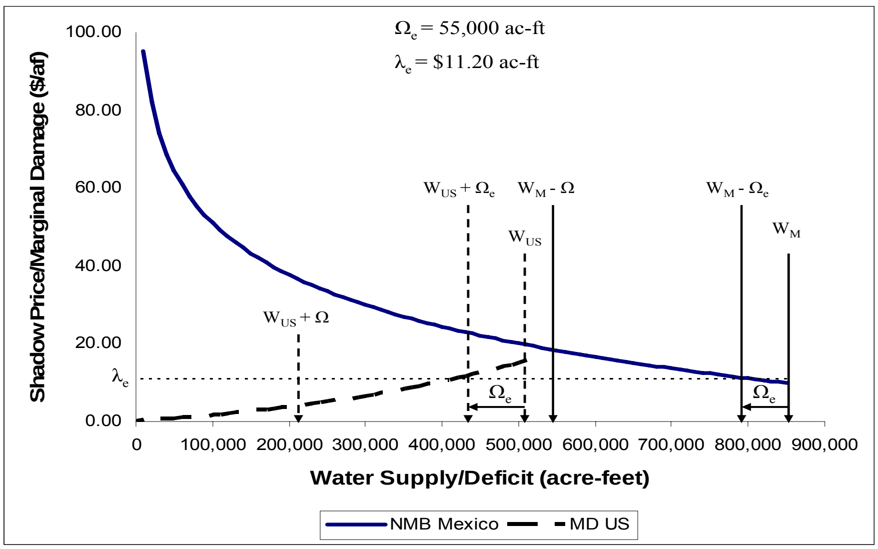
Figure 1. Coasian solution: One-year repayment policy average water supply.



In the absence of Coasian negotiations, the one-year repayment policy would require Mexico to divert the entire 850,000 ac-ft of the DID's water supply to satisfy the repayment obligation. This repayment scheme imposes a heavy compensation cost on Mexico's DID, and much of the water released by Mexico would exceed the LRGV maximum water use level and provide no economic value to agriculture. Under the Coasian solution, Mexico would repay only 55,000 ac-ft of the deficit in water. At this water repayment level, the NMB_w for agricultural production is equal in both countries at a value of $11.20 per acre-foot. If Mexico repaid 55,000 ac-ft of the deficit in water, Ω_e in Figure 1, Mexico's remaining water supply is 795,000 ac-ft and the effective deficit level in the LRGV is decreased from 510,000 to 455,000 ac-ft Repaying more than Ω_e of the deficit in water imposes a greater marginal cost on Mexico than the net marginal economic benefit received by the U.S. If each acre-foot of the residual deficit, Ω-Ω_e, (1,500,000 – 55,000) was repaid at the equilibrium shadow price value, λ_e, in a lump sum payment equal to λ_e *[Ω-Ω_e], Mexico's cost of compensation is less than it would be if Mexico had exclusively repaid the deficit in water, and the net economic benefit of compensation to the U.S. is greater than if compensation had been exclusively repaid in water.

Figure 2 illustrates the Coasian solution for the five-year deficit repayment policy assuming average water supply conditions in each country. Again, the relevant portion of the MD_{US} curve extends to 510,000 acre-feet, and Mexico's NMB_M curve once more has a length of 850,000 ac-ft What differentiates the five-year deficit repayment policy from the one-year policy is that the five-year policy requires Mexico to annually repay 300,000 ac-ft of the accumulated 1.5 million ac-ft deficit over five years ($\Omega = 300{,}000$), instead of repaying the full deficit in one year. As before, the relevant portion of the MD_{US} and NMB_M curves are $w_{US} + \Omega$ and $w_M - \Omega$.

Figure 2. Coasian solution: Five-year repayment policy, average water supply.



Assuming average water supply conditions in each contract year, only 55,000 ac-ft of the contracted deficit repayment is annually repaid in water in each contract year, and the remaining annual deficit (245,000 ac-ft) is repaid at a rate equal to the equilibrium shadow price (λ_e = \$11.20). Over the five-year contract, 275,000 ac-ft of the deficit is repaid in water. The numerical (dollar) welfare gains to the U.S. and Mexico, respectively, derived from the Coasian negotiations format are represented by Equations 3 and 4:

$$\text{U.S. Net Gains} = \lambda_e * \{\Omega - \Omega_e) - \int_{w_{US}+\Omega_e}^{w_{US}+\Omega} [1{,}387.69 \; - .00091(w_{US}) + .00113(d * w_{US}) - 83.8338(\ln(d * w_{US})) - .4365(\sqrt{d * w_{US}})]dw_{US} \quad (3)$$

$$\text{Mexico Net Gains} = -\int_{w_M-\Omega_e}^{w_M-\Omega}\left[320.5757 - 22.6263*(\ln(w_M))\right]dw_M - \lambda_e*(\Omega-\Omega_e) \quad (4)$$

Where:

$\lambda_e =$ shadow price of water at the intersection of the MD_{US} and NMB_M curves;

$\Omega_e =$ optimal quantity of the deficit repaid in water, found as the intersection point of the MD_{US} and NMB_M curves; and

$\Omega =$ total water deficit or annual contracted water repayment value.

Results and Policy Implications

Table 1 displays the increased benefits to the U.S., and the decreased costs of compensation to Mexico under the Coasian format for all repayment horizons and initial water supply levels. Also contained in the table are the dollar and water compensation values for each negotiated outcome. The empirical results reveal that the optimal deficit quantity repaid in water and the net marginal value of the last unit repaid vary with the initial water supply level in each country. The equilibrium shadow price of water, λ_e, is $32.25 per ac-ft for the low water supply scenario, $11.20 per ac-ft for the average water supply scenario, and $3.27 per ac-ft for the high water supply scenario. The greater the initial water supply in each country, the lower the marginal cost of water repayment.

By considering the net marginal value of water in each geographic region, and incorporating the expected delivery loss of water into the analysis, the U.S. and Mexico could have reached a more efficient agreement by agreeing to repay the debt over multiple years and using the Coasian strategic negotiation format. When the repayment time horizon was extended beyond one year, and payment was made exclusively in water, the U.S. value of compensation increased and Mexico's cost of compensation decreased relative to the case where the entire deficit was repaid in water in one year as per the current negotiated settlement. Moreover, for a given repayment contract length, additional net benefits accrue to both the U.S. and Mexico when the two countries use Coasian negotiations that allowed repayment to be made in dollars and water instead of exclusively in water. For example, by allowing repayment in dollars, Mexico is able to reduce compensation costs by up to 45% depending on the initial water supply scenario, and the value of compensation to the U.S. is increased by as much as 223% relative to the situation where compensation was paid exclusively in water over the five year repayment schedule.

As the allocation and efficient use of internationally shared fresh water supplies continues to become a conflictual issue, the Coasian negotiations format can alleviate tension in resolving allocation disputes by increasing the economic welfare associated with compensatory agreements. This research indicates that the agreed-upon repayment scheme between the U.S. and Mexican federal governments may not have served the best economic interests of either country. With the current property rights system established by the Treaty of 1944, the U.S. and Mexico have an opportunity to allocate water in an efficient manner which considers the highest and best use of the Rio Grande. In the future, should a similar allocation dispute arise, the bargaining framework can be applied to address potential conflict resolution. This framework is not singular to the U.S./Mexico conflict, however. There are more than 200 international river basins in the world, many of which have comprehensive agreements establishing property rights that define the allocation of shared water supplies within the basins (Wolf 1997). Once well-defined property rights exist for an internationally shared and managed body of water, the Coasian negotiations framework can be applied to resolve allocation disputes which may arise. The Coasian negotiations framework can serve as a useful tool not only in conflict resolution, but in the overall efficient management of water resources. In arid regions where fresh-water supplies are dwindling, Coasian bargaining can facilitate allocating water to its greatest net marginal economic benefit.

Table 1. Coasian gains to the U.S. and Mexico under alternative repayment time horizons and water supply conditions relative to identical contracts that specify payment exclusively in water.

Contract Repayment Length and Water Supply Level	Total Non-Coasian Water Repayment (acre-feet)	Total Coasian Water Repayment (acre-feet)	Coasian Dollar Repayment Mexico to U.S. $(\lambda_e * (\Omega - \Omega_e))$ ($'s)[1]	Coasian Net Gain to Mexico ($'s)[1]	Coasian Net Gain to U.S. ($'s)[1]
One-Year Low Supply	1,500,000	34,000	48,429,276 (48,429,276)	$25,422,911 ($25,422,911)	$38,733,727 ($38,733,727)
Five-Year Low Supply	1,500,000 (300,000 per year)	170,000 (34,000 per year)	8,578,500 (38,325,253)	$5,116,595 ($22,858,865)	$2,700,908 ($12,066,560)
Ten-Year Low Supply	1,500,000 (150,000 per year)	340,000 (34,000 per year)	3,741,000 (25,040,580)	$578,676 ($3,873,896)	$577,818 ($3,834,188)
One-Year Average Supply	1,500,000	55,000	16,184,000 (16,184,000)	$26,949,071 ($26,949,071)	$14,202,904 ($14,202,904)
Five-Year Average Supply	1,500,000 (300,000 per year)	275,000 (55,000 per year)	2,744,000 (12,259,077)	$813,950 ($3,636,396)	$1,068,590 ($4,774,023)
Ten-Year Average Supply	1,500,000 (150,000 per year)	550,000 (55,000 per year)	1,064,000 (7,121,940)	$113,458 ($759,434)	$178,742 ($798,550)
One-Year High Supply	1,500,000	0	4,905,000 (4,905,000)	$28,860,304 ($28,860,304)	$4,601,316 ($4,601,316)
Five-Year High Supply	1,500,000 (300,000 per year)	0	981,000 (4,382,709)	$799,533 ($3,540,715)	$677,316 ($3,025,973)
Ten-Year High Supply	1,500,000 (150,000 per year)	0	490,500 (3,283,188)	$189,499 ($1,268,422)	$208,440 ($2,023,058)

Note: The equilibrium shadow price of water, λ_e, is $32.25 ac-ft for the low water supply scenario, $11.20 ac-ft for the average water supply scenario, and $3.27 for the high water supply scenario.
[1] The first value reported represents the value of compensation cost/benefit in the first year of repayment and the parenthetical values represent the NPV of compensation over the entire contract length using a 3% discount rate.

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