Journal of Agricultural and Applied Economics, 40,2(August 2008):473–484

A Coasian Approach to Efficient Water Allocation of a Transboundary River

David B. Willis and Justin S. Baker

The United States and Mexico recently resolved a decade-old water dispute that required Mexico to repay the accumulated water debt within one year. A Coasian analysis estimates the social welfare gains attainable to each country under an alternative debt repayment scheme that allows repayment over a longer time horizon and in a combination of dollars and water, instead of solely in water. Assuming average water supply conditions, under the agreed 1-year repayment contract, U.S. compensation value is 534% greater and Mexico's compensation cost is 60% less relative to when compensation is paid exclusively in water.

Key Words: coase, water allocation, water compensation, water markets

JEL Classifications: Q1, Q2

Under the Treaty of 1944 between the United States and Mexico, Mexico is obligated to annually release 350,000 acre-feet of water, the majority of which originates in Mexico's Rio Conchos River Basin (RCB), to the U.S. Lower Rio Grande Valley (LRGV) by way of the Rio Grande tributaries (Treaty of 1944). Between 1992 and 2003, Mexico failed to comply with the annual treaty releases, and amassed a cumulative water deficit of 1.5 million acre-feet (maf). After extended negotiations, Mexico agreed to repay the cumulative water deficit in one year beginning in late 2004 with complete water repayment by September 2005. Alternative repayment schemes that did not require repayment exclusively in water, but instead allowed repayment to be paid over a longer time horizon and 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 type repayment approach had been used in the negotiation process and Mexico had been allowed to repay its cumulative deficit in dollars and/or water relative to the negotiated settlement.

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Geographic Setting

The Treaty of 1944 requires Mexico to annually release 350,000 acre-feet of water into the Rio Grande River that is subsequently redirected into one of two international reservoirs, the Amistad and Falcon, for U.S. use. The Amistad reservoir is located just west of Del Rio, TX along the Rio Grande, and the Falcon reservoir is located further southeast, near Laredo, TX. From these two reservoirs, the U.S. share of the stored water supplies is allocated to municipalities for domestic and industrial use, or to irrigation districts to be redirected to farmers for irrigation purposes. Priority is given to municipal use, followed by industrial and agricultural uses.

Mexico argued the accumulated 1.5 maf debt was caused by a series of droughts in the

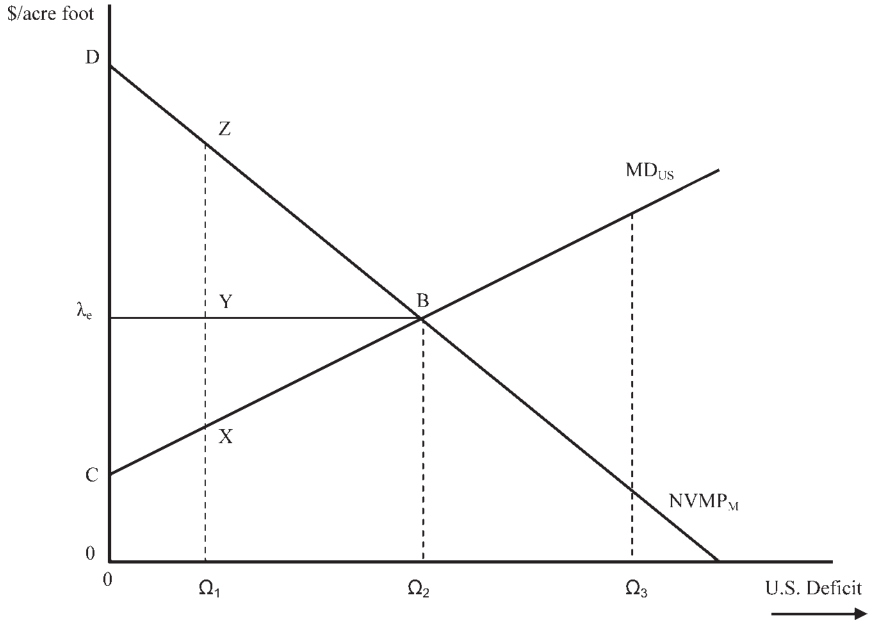

Figure 1. $NVMP_M$ in the Rio Concho Basin and MD_{US} in the LRGV for Alternative Water Deficit Levels

1990s. However, between 1980 and 1997 irrigation water use in Mexico's Rio Conchos Basin (RCB) increased from 2.0 maf to 4.5 maf. Adcock, Hobbs, and Rosson believe this rapid increase in agricultural water use was the primary cause for the LRGV water shortage. In 2003, Susan Combs, the Texas State Agricultural Commissioner, stated that farmers in the LRGV had suffered economic damages in excess of $1 billion because of Mexico's noncompliance (Combs). Combs' value was based on a study by Robinson that estimated the average gross value of irrigation water in the LRGV at $652 per acre-foot. Even though Combs' estimate was a gross value estimate of damages and not a net damage value, Mexico's accumulated water deficit did impose significant economic damages on LRGV farmers because the undelivered water would have generated economic profits in agricultural production.

Conceptual Model

In his seminal article, "The Problem of Social Cost," Coase argues that bilateral negotiations will result in an economically efficient resource allocation as long as a property right to the resource has been assigned, regardless of the initial property right assignment. The Treaty of 1944 provides the necessary property right assignment regarding the initial water allocation for Coasian negotiations to determine the social welfare maximizing water allocation level for the two countries.

Information for both the marginal net benefit of water repayment to the United States and the marginal net cost of repayment to Mexico is required before Coasian bargaining can commence. A stylized illustration of the U.S. marginal damage function (MD_{US}) and Mexico's net value marginal product function ($NVMP_M$) for potential water deficit levels is presented in Figure 1. The MD_{US} and the $NVMP_M$ curves are drawn for an arbitrary initial water supply level in each country before any deficit repayment is made. Assuming a fixed quantity of acreage can be irrigated in each region and a diminishing marginal net return to irrigation water supplies in each country, the more abundant the initial water supply in a each region the lower the net benefit of repayment to the United States and the lower Mexico's net marginal repayment cost.

The MD_{US} curve has a positive slope because as the U.S. deficit level increases, increasingly valuable irrigated crop acreage is forced out of production. Each point on the MD_{US} curve represents the marginal net value produced in the LRGV as each unit of the deficit water is repaid by Mexico. The MD_{US} curve has been implicitly shifted downward to account for transit losses such as seepage and evaporation losses. Not every acre-foot of water released by Mexico is ultimately delivered to the LRGV.

The $NVMP_M$ curve slope is negative because for a given initial water supply, each additional unit of nonreleased water retained by Mexico is used in irrigation at a decreasing marginal net value to Mexico. Three potential deficit levels are identified on the horizontal axis of Figure 1. Deficit Ω_1 is the lowest and Ω_3 is the highest.

At deficit level Ω_1 an additional acre-foot of water used in agricultural production in Mexico produces a higher net value in Mexico ($NVMP_M$) than the same acre-foot of deficit water, if released, would produce in the United States after accounting for delivery loses. This is true for all units of the deficit less than Ω_1. Thus at deficit level Ω_1, it is optimal for Mexico to repay the entire debt exclusively in cash and not water. For example, if after negotiations the United States agreed to accept a cash payment of λ_e dollars per acre-foot for nondelivered water, a total payment equal to the area $0\Omega_1 Y\lambda_e$ in Figure 1 is paid. The net compensation dollar gain to the United States is equal to area $CXY\lambda_e$, and the net reduction in compensation cost to Mexico is equal to area $DZY\lambda_e$.

At the highest deficit level illustrated, Ω_3, the MD_{US} value is greater than the $NVMP_M$ value. However, the MD_{US} value is not greater than $NVMP_M$ value over the entire deficit range and is less at deficit levels below Ω_2. In this situation, the portion of the deficit equal to Ω_3 minus Ω_2 ($\Omega_3 - \Omega_2$) should be repaid in water and the remaining deficit quantity (Ω_2) should be repaid in dollars at the shadow price value λ_e, where $MD_{US} = NVMP_M$. The dollar value of the payment made to the United States is the rectangular area ($O\Omega_2 B\lambda_e$) in Figure 1. The collective social welfare of both countries is increased by triangle CBD relative to the situation where repayment is made entirely in water. The U.S. net increase is equal to triangle $\lambda_e BC$ and the net reduction in repayment cost to Mexico is equal to area $\lambda_e BD$. As Figure 1 illustrates, there are situations where the optimal repayment scheme should allow repayment to be paid in a combination of water and dollars.

As shown in Figure 1, water is efficiently allocated between the two countries when the net marginal value of an additional acre-foot of deficit water released by Mexico to the United States is equal for each country. When a fraction of the water released by one country to another is lost in transit, the efficiency condition needs to be modified to account for any transit losses before the released water is received by the second country. The efficiency condition must also be adjusted to control for transit losses between the point of diversion and where the water is agriculturally used in the country controlling the water supply. The new efficiency condition dictates that the per acre-foot NVMP of water in Mexico discounted by the factor $(1-\Phi)$ of water released must be equal to the NVMP of water in the United States discounted by the factor $(1-\delta)$ where Φ and δ are the respective transit loss percentages for each country. Recognizing that the $NVMP_{US}$ forgone due to noncompliance by Mexico is MD_{US}, the efficiency condition for optimal repayment in water is mathematically expressed as:

$$(1) \quad NVMP_M(1 - \Phi) = MD_{US}(1 - \delta)$$

Empirical Model

Existing mathematical programming models were updated and modified to estimate the net value marginal product functions, hereafter referred to as the net marginal benefit functions, for agricultural water use in the LRGV, and for agricultural water use in the Delicias Irrigation District (DID) in Mexico's Rio Conchos Basin (RCB). The DID is the primary user of irrigated water supplies in the RCB, accounting for 80% of all water use. The adapted and updated mathematical models were originally developed by Robinson for the LRGV, and Puente–Gonzalez 2002 for the DID.

The net marginal benefit function of agricultural water use in each country was estimated using valuation data simulated by the mathematical programming models. This was accomplished by initially optimizing the agricultural water use model for each country without a binding water supply restriction to determine the maximum volume of water that could be profitably used in each country under average weather conditions, existing acreage restrictions, soil types, crop rotations, and technology. A complete discussion of the mathematical programming model is found in Baker. Given the modeling assumptions, the maximum quantity of water that can be profitably used by irrigated agriculture in the LRGV is 1,410,000 acre-feet per year, and the comparable annual maximum use in the DID is 1,200,000 acre-feet. The optimization model for each country was subsequently reoptimized for alternative water supply levels by parametrically varying the water supply level downward in 10,000 acre-foot increments beginning at the level where water supply was not a constraining resource. For each alternative supply level the shadow price of the water supply constraint was recorded.

The appropriate paired shadow price value and water supply value were subsequently used in two regression equations to estimate the net marginal benefit function for each country as a function of water supply. As expected, the net marginal benefit of water is negatively related to the water supply level. The estimated net marginal benefit functions for the United States and Mexico, respectively, are:

$$\begin{aligned} NMB_{US} = {} & \underset{(305.96)}{1{,}387.69} - \underset{(-37.23)}{0.00091}(w_{US}) \\ & + \underset{(35.01)}{0.00113}(d * w_{US}) \\ & - \underset{(-43.79)}{83.834}(\ln(d * w_{US})) \\ & - \underset{(-9.04)}{0.4365}\left(\sqrt{d * w_{US}}\right) \end{aligned} \tag{2}$$

$$NMB_M = \underset{(26.89)}{320.5757} - \underset{(-25.18)}{22.6263}(\ln(w_M)) \tag{3}$$

As reported by the *t*-value in parentheses below each coefficient value, all estimated coefficients are significant at the .01 level, or higher, in both equations. The R^2 statistic for the U.S. net marginal benefit equation is 0.999 and the R^2 value for the Mexican 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 benefit function. 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 one when U.S. water supply (W_{US}) was greater than 320,000 af and a value of zero otherwise.

To control for the impact that transit losses have on the net marginal benefit of water released by Mexico for use in the LRGV, the net marginal benefit of repaid deficit water supplies 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). Water released by Mexico from the Rio Conchos Basin for delivery to the LRGV has an average conveyance loss of 17.5% before reaching the Amistad and Falcon Reservoirs (Robinson). An additional 17.0% of released flows are lost in transit between the two international reservoirs and the irrigation district pumping stations in the LRGV (Robinson). Finally, intra-district conveyance losses in the LRGV average 25.3% (Robinson). The estimated MD_{US} function was adjusted downward by 48.8% to account for the reality that not all water released by Mexico from the Rio Conchos is ultimately used on-farm in the LRGV. Conveyance loss from the Rio Conchos to the DID was estimated at 15.0% (Puente–Gonzales 2003) and NMB_M function was accordingly adjusted for these losses.

Because the net marginal benefit functions are a function of water supply level, the value of compensation and the optimal quantity of

Table 1. Average Agricultural Water Use in the LRGV and Rio Conchos Basin under Alternative Supply Conditions

	LRGV Agricultural Use	Rio Conchos Basin Agricultural Use
Low water supply	600,000 acre-feet	300,000 acre-feet
Average water supply	900,000 acre-feet	850,000 acre-feet
High water supply	1,200,000 acre-feet	1,200,000 acre-feet

Source: Rakestraw, K. International Boundaries and Water Commission. Personal communication. July 2005.

the deficit repaid in water vary with each country's initial water endowment and the size of the water deficit. In a given year, the last unit of water repaid has the lowest net marginal value to the United States, 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

In this section, the net marginal benefit functions are used to derive the Coasian gains achievable by broadening Mexico's deficit repayment options to allow repayment in both dollars and water, instead of strictly in water. Coasian gains are estimated for nine combinations of three repayment contract lengths and three initial water supply scenarios. The water supply scenarios correspond to below average, average, and above average water supply conditions in each country. The supply levels were derived from historic water use records and are reported in Table 1. The first repayment contract requires that the entire 1.5 million acre-feet deficit is repaid in 1 year as per the current negotiated agreement, whereas the second repayment contract allows the deficit to be repaid over 5 years in 300,000 acre-feet annual payments, and the third repayment contract has a 10-year length, where 150,000 acre-feet is repaid each year.

To establish a frame of reference for the benefits of the subsequent Coasian negotiation approach, the U.S. value of compensation and cost of compensation to Mexico was calculated for all three alternative contract lengths and initial water supply combinations, under the assumption that compensation was exclusively paid in water. Table 2 presents these results. As expected, for a given contract length, the results show that as the initial water supply is increased in both countries, both the benefit and cost of water repayment decreases. Moreover, for a given water supply level, the net present value of compensation to the U.S. increases and the net present value cost of repayment to Mexico deceases as the contract length is increased. For a given initial water supply level in each country, as the length of the contract increases, the volume of water repaid in each time period is decreased and the last unit repaid in each period has a lower marginal net cost in Mexico and a higher marginal net benefit in the United States.

The net economic gains to the United States and Mexico achieved under Coasian negotiations, relative to similar contracts requiring repayment exclusively in terms of water are reported in Table 3 for the nine combinations of three repayment time horizons and three water supply scenarios. The 5-year repayment plan under low, average, and high water supply conditions are now discussed in detail.

Five-Year Repayment with Low Water Supplies

Under low water supply conditions, 600,000 acre-feet of water is initially available for U.S. irrigation use in the LRGV, and Mexico's DID initial water supply level is 300,000 acre-feet before any water repayment. The appropriate NMB_M and the MD_{US} curves are plotted in Figure 2 for the 5-year repayment contract under low water supply conditions. The marginal damage (MD_{US}) function is the mirror image of the NMB_{US} function discounted for transit losses and measures the net

Table 2. Value of U.S. Compensation and Mexico's Cost of Compensation under Alternative Contract Lengths and Water Supply Conditions When Repayment is Exclusively Paid in Water

Contract Length and Water Supply Level	Water Repayment (Acre-Feet)	U.S. Value[a]	Mexico Cost[a]
One-year low supply	1,500,000	$9,739.590 ($9,739,590)	$73,756,735 ($73,756,735)
Five-year low supply	1,500,000 (300,000 per year)	$7,069,334 ($33,346,742)	$14,751,347 ($69,583,555)
Ten-year low supply	1,500,000 (150,000 per year)	$4,345,135 ($38,176,832)	$5,376,191 ($47,235,803)
One-year average supply	1,500,000	$2,670,246 ($2,670,246)	$43,713,262 ($43,713,262)
Five-year average supply	1,500,000 (300,000 per year)	$2,371,158 (11,184,987)	$4,138,050 ($19,519,589)
Ten-year average supply	1,500,000 (150,000 per year)	$1,580,012 ($13,882,158)	$1,757,489 ($15,441,793)
One-year high supply	1,500,000	$299,088 ($299,088)	$32,414,660 ($32,414,660)
Five-year high supply	1,500,000 (300,000 per year)	$299,088 ($1,410,827)	$1,773,604 ($8,366,263)
Ten-year high supply	1,500,000 (150,000 per year)	$279,279 ($2,453,774)	$680,034 ($5,974,855)

[a] The first value reported represents the cost/benefit of water compensation in the first repayment year and the parenthetical values represent the NPV of water compensation over the entire contract length, using a 3% discount rate.

marginal economic damage inflicted on LRGV production agriculture for each additional unit of nonrepaid water withheld by Mexico. Under low water supply conditions, the MD_{US} curve extends to 810,000 acre-feet because a maximum of 1.41 maf of water can profitably be used under average weather conditions in a year in the LRGV. The length of the MD_{US} curve is the difference between the maximum volume of water that can profitably used in agricultural production in a year less the initial water supply level (1,410,000–600,000 acre-feet). It is assumed agricultural producers in the LRGV will apply their initial 600,000 acre-feet supply to their most profitable crops. Consequently, the net marginal benefit of the first acre-foot of water repaid is equal to the shadow price of water corresponding to a shortage level of 810,000 acre-feet of water ($35.49). The relevant portion of the MD_{US} function for calculating the value of deficit repayment begins 810,000 acre-feet, identified at W_{US} in Figure 2, and extends leftward to the vertical axis where the MD_{US} function has a shadow price value of $0 per acre-foot at the full water supply level of 1.41 million acre-feet.

The initial Mexican water supply in the DID (W_M), is 300,000 acre-feet, and as deficit repayment is simulated the first acre-foot of water repaid by Mexico has a marginal cost of $29.93, Mexico's shadow price for the 300,000th acre-foot of water agriculturally used in the DID. As water repayment to the United States is increased, Mexico's marginal cost of repayment increases until the 300,000th acre-foot is repaid at a marginal net economic cost of about $98. After Mexico releases the 300,000 acre-feet deficit repayment from the DID's water supply, the DID's residual district water supply is zero and is identified as $W_M - \Omega$ in Figure 2, where Ω is the 300,000 acre-feet contractual repayment required under the 5-year repayment contract. The total cost to Mexico of releasing 300,000 acre-feet is the area under Mexico's net marginal benefit of water curve (NMB_M) between zero and 300,000 acre-feet. Once Mexico pays the required 300,000 acre-feet payment, the remaining agricultural water shortage in the LRGV is 510,000 and is labeled $W_{US} - \Omega$.

Despite the differences in the acre-foot lengths for the MD_{US} and NMB_M curves, the Coasian approach can be used to determine

Table 3. Coasian Gains to the U.S. and Mexico under Alternative Repayment Time Horizons and Water Supply Conditions Relative to Identical Contracts that Specify Repayment Exclusively in Water

Contract Length and Water Supply Level	NonCoasian Water Repayment (Acre-Feet)	Coasian Water Repayment (Acre-Feet)	Coasian Dollar Repayment Mexico to U.S. $((\lambda_e{*}(\Omega-\Omega_e))$ ($)[a]	Coasian Net Gain to Mexico ($)[a]	Coasian Net Gain to U.S. ($)[a]
One-year low supply	1,500,000	34,000	47,278,500 (47,278,500)	$21,195,776 ($21,195,776)	$38,696,841 ($38,696,841)
Five-year low supply	1,500,000 (300,000 per year)	170,000 (34,000 per year)	8,578,500 (40,465,626)	$5,116,355 ($24,134,351)	$2,667,087 ($12,580,911)
Ten-year low supply	1,500,000 (150,000 per year)	340,000 (34,000 per year)	3,741,000 (32,868,833)	$578,700 ($5,084,519)	$553,785 ($4,865,617)
One-year average supply	1,500,000	55,000	16,256,250 (16,256,250)	$26,433,405 ($26,433,405)	$14,277,333 ($14,277,333)
Five-year average supply	1,500,000 (300,000 per year)	275,000 (55,000 per year)	2,756,000 (13,001,502)	$801,756 ($3,781,961)	$1,076,421 ($5,077,584)
Ten-year average supply	1,500,000 (150,000 per year)	550,000 (55,000 per year)	1,068,750 (9,390,154)	$108,729 ($955,308)	$180,067 ($1,582,092)
One-year high supply	1,500,000	0	4,905,000 (4,905,000)	$27,509,660 ($27,509,660)	$4,605,912 ($4,605,912)
Five-year high supply	1,500,000 (300,000 per year)	0	981,000 (4,627,474)	$792,604 ($3,738,790)	$681,316 ($3,216,646)
Ten-year high supply	1,500,000 (150,000 per year)	0	490,500 (4,309,586)	$189,534 ($1,668,268)	$211,221 ($1,855,812)

Note: The equilibrium shadow price of water, λ_e, is $32.25 acre-feet for the low water supply scenario, $11.20 acre-feet for the average water supply scenario, and $3.27 for the high water supply scenario.

[a] The first value reported represents the cost/benefit of compensation in the first repayment year and the parenthetical values represent the NPV of compensation over the entire contract length, using a 3% discount rate.

the optimal combination of water and dollar repayment that maximizes the collective welfare of both countries. In the absence of Coasian negotiations, Mexico is contractually obligated to divert the entire 300,000 acre-feet of the DID's water supply each year to satisfy the repayment contract. This repayment scheme imposes a heavy compensation cost on Mexico's DID, and the net cost of much of the water released by Mexico exceeds the net economic value the released supplies will produce in agricultural production in the LRGV.

Under the Coasian approach, Mexico annually repays 34,000 acre-feet of the deficit in water. At this water repayment level, the net marginal benefit of deficit water releases in agricultural production is equal for both countries at a value of $32.25 per acre-foot, the equilibrium shadow price, λ_e. After Mexico repays 34,000 acre-feet of the deficit in water, Ω_e in Figure 2, the DID's remaining water supply is 266,000 acre-feet ($W_M - \Omega_e$) and the effective water shortage level in the LRGV is decreased from 810,000 to 776,000 acre-feet ($W_{US} - \Omega_e$). Repaying more than Ω_e of the deficit in water imposes a greater net marginal cost on Mexico than the net marginal benefit to the United States. If each acre-foot of the residual contract obligation, $\Omega - \Omega_e$, (300,000–34,000) is repaid at the equilibrium

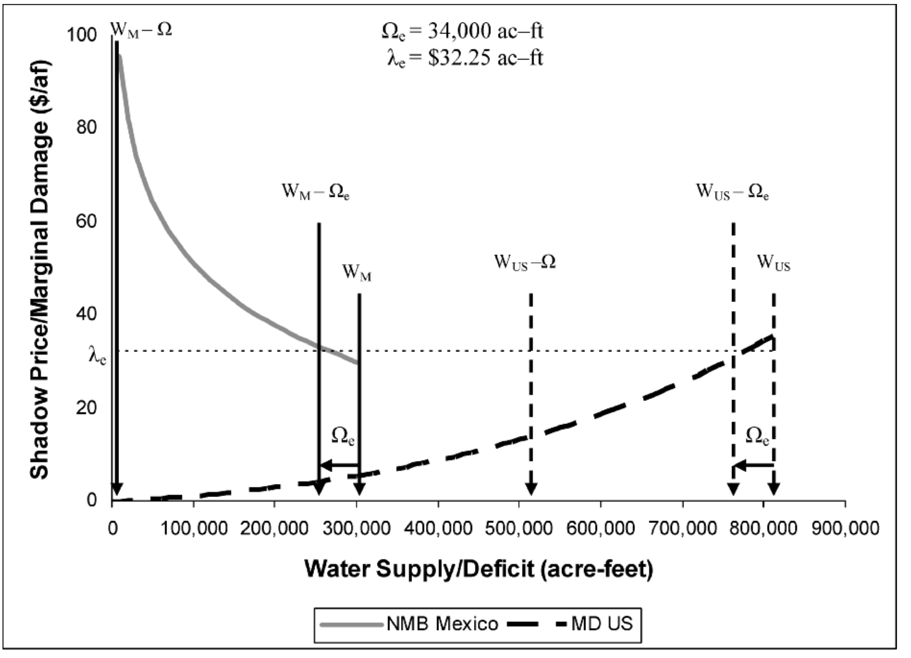

Figure 2. Coasian Solution: Five-Year Deficit Repayment Policy, Low Water Supply

shadow price value, λ_e, the lump sum dollar payment is λ_e *[$\Omega - \Omega_e$], and Mexico's compensation cost is less than if Mexico exclusively repaid in water. Conversely, the U. S. net economic benefit is greater than when compensation is exclusively paid in water. Over the 5-year contract, the annual net Coasian gains to the United States and Mexico, respectively, are $2.7 million and $5.1 million. As reported in Table 3, the net present values for the Coasian gains over the 5-year contract are $12.5 million for the United States and $24.1 million for Mexico. Equations 4 and 5 are respectively used to calculate the net gains to the United States and Mexico.

U.S. Net Gains

$$
\begin{aligned}
&= \lambda_e * \{\Omega - \Omega_e) \\
&- \int_{w_{US}-\Omega}^{w_{US}-\Omega_e} [1{,}387.69 \\
(4) \quad &- .00091(w_{US}) + .00113(d * w_{US}) \\
&- 83.8338(\ln(d * w_{US})) \\
&- .4365\left(\sqrt{d * w_{US}}\right)\Big] dw_{US}
\end{aligned}
$$

Mexico Net Gains

$$
\begin{aligned}
&= \int_{w_M-\Omega}^{w_M-\Omega_e} [320.5757 \\
(5) \quad &- 22.6263 * (\ln(w_M))]\, dw_M \\
&- \lambda_e * (\Omega - \Omega_e)
\end{aligned}
$$

Where:

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

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

Ω = total water deficit or annual contracted water repayment value.

In Equation 4, the annual net gain to the United States is computed as the difference between the value of the dollar payment made to the United States and the net economic value the water, if delivered to the LRGV, would have produced in agricultural production in the LRGV. Conversely, as shown in Equation 5, the net gain to Mexico's DID is the net economic value the nonreleased water

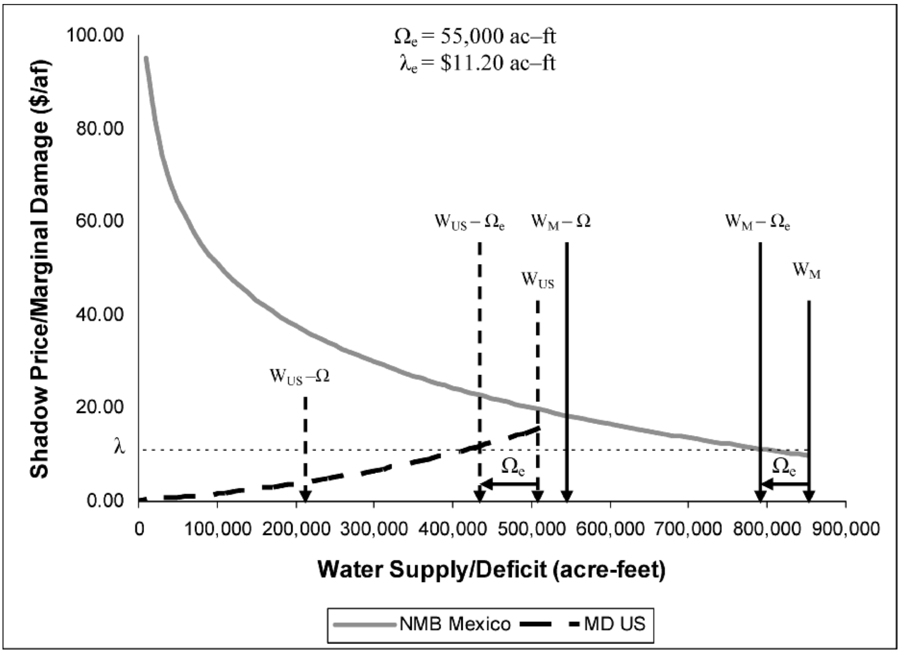

Figure 3. Coasian Solution: Five-Year Repayment Policy, Average Water Supply

would produce in agricultural production less the dollar compensation payment made to the United States.

Five-Year Repayment with Average Water Supplies

Figure 3 portrays the Coasian solution with average water supply conditions in each country. With average water supplies, the LRGV has an initial water allocation of 900,000 acre-feet for irrigation use, and Mexico's DID initial water supply is 850,000 acre-feet (W_M). Under these conditions, the MD_{US} curve extends only to 510,000 acre-feet (W_{US}), and the NMB_M curve has a length of 850,000 acre-feet before any water repayment. The NMB_M values for the first 300,000 acre-feet are identical to their values for the low water supply condition and the additional 550,000 acre-feet of length represent the additional net economic value the additional water supplies when efficiently used would produce in Mexico's DID. The MD_{US} curve length is shorter because under an average water supply level, the water supply shortage for agriculturally used water in LRGV is reduced to 510,000 acre-feet, the difference between the maximum annual quantity of water that could be productively used in the LRGV under average weather conditions (1.41 million acre-feet) and the initial LRGV water supply of 900,000 acre-feet.

After Mexico makes the annual required 300,000 acre-feet (Ω) contract payment the residual agricultural water deficit in the LRGV is 210,000 acre-feet and is labeled $W_{US} - \Omega$, and the DID water supply is $W_M - \Omega$ (550,000 acre-feet) as shown in Figure 3. Similar to the low water supply scenario, the optimal Coasian water repayment level, Ω_e, is much smaller than the contractual requirement. The optimal repayment level is 55,000 acre-feet, which equates the shadow price of the deficit water in both countries at $11.20 per acre-foot ($\lambda_e$). The equilibrium shadow price is lower for the average water supply condition than the low water supply condition due to the decreasing net marginal benefit of water in agricultural use in each country. After optimal Coasian water compensation is paid, the DID water supply is 795,000 acre-feet ($W_M - \Omega_e$) and the residual agricultural shortage in the LRGV is 455,000 acre feet ($W_{US} - \Omega_e$).

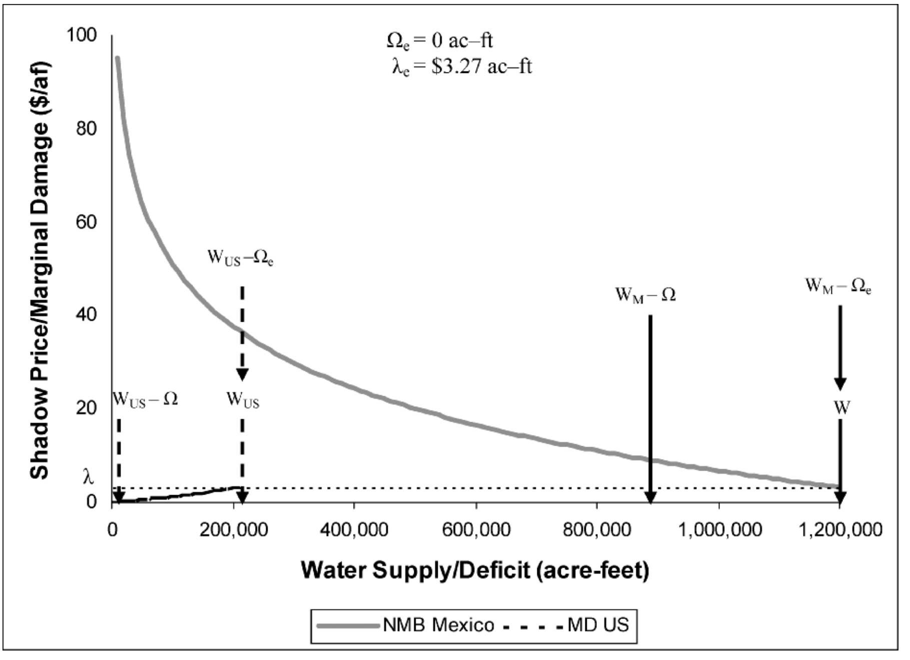

Figure 4. Coasian Solution: Five-Year Deficit Repayment Policy, High Water Supply

Mexico would compensate the United States with a lump dollar sum payment equal to λ_e*[$\Omega - \Omega_e$] for the nondelivered water. Under the 5-year repayment plan Mexico annually releases 55,000 acre-feet of water to the United States for a total water repayment of 275,000 acre-feet. As reported in Table 3, over the 5-year contract, the net present values for the Coasian gains are $5.1 million for the United States and $3.8 million for Mexico.

Five-Year Repayment with High Water Supplies

The Coasian solution with high water supplies in each country is illustrated in Figure 4. With high water supplies, 1,200,000 acre-feet of water is available in the LRGV and Mexico's DID initial water supply level is also 1,200,000 acre-feet. Mexico's net marginal benefit curve is now 1,200,000 acre-feet long (W_M), four times longer than under the low water supply condition. The first 850,000 acre-feet of the NMB_M curve is identical to the curve used in the average water supply scenario and the additional 350,000 acre-feet of length reflect the additional net economic value the additional water will generate in agricultural production in Mexico's Rio Conchos Basin. In contrast, the MD_{US} curve now has a length of only 210,000 acre-feet (W_{US}), nearly four times shorter than its length under the low water supply condition. The length reduction reflects the fact that under high water supply levels the maximum water shortage for agriculturally used water the LRGV is only 210,000 acre-feet (1,410,000–1,200,000) in a given year. After Mexico repays 300,000 acre-feet of the deficit, the DID's remaining water supply is 900,000 acre-feet ($W_M - \Omega$) and the LRGV water shortage is 0 ($W_{US} - \Omega$).

With high water supplies in each country, Mexico's net marginal benefit curve (NMB_M) is located entirely above the U.S. net marginal damage curve (MD_{US}) as shown in Figure 4. The shadow price, λ, for the last unit of water used in Mexico's DID (the 1,200,000th acre-foot) is $3.274 and exceeds the shadow price for the first acre-foot of marginal damage avoided when the first acre-foot is repaid in the LRGV ($3.273). In this circumstance, Ω_e is equal to 0, and the efficient Coasian outcome is for compensation to be entirely paid in dollars at the net marginal value of \$3.27 per acre-foot. The annual cash payment made to the U.S. is $\lambda_e * \Omega$ (\$3.27 * 300,000) over the five-year contract repayment period. The net present values for the Coasian gains, are \$3.2 million for the United States and \$3.7 million for Mexico.

Empirical Results

Table 3 reports the net benefits to the United States and Mexico under the Coasian approach for the nine combinations of three repayment time horizons and three initial water supply levels relative to identical repayment contracts that require repayment be made exclusively in water. Also reported are the dollar and water compensation values for each Coasian 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 acre-feet for the low water supply scenario, \$11.20 per acre-foot for the average water supply scenario, and \$3.27 per acre-foot for the high water supply scenario. The greater the initial water supply is in each country, the lower the net marginal benefit and cost of water repayment.

The empirical results are based on a deterministic static analysis with compensation taking place in one, or multiple time periods, with no consideration how current use might affect the value of water storage options. The major limitation of performing a static analysis in one time period, or multiple time periods, is that the value of water stored over time is not estimated. A methodological extension would be to incorporate U.S. and Mexico reservoir storage capacity into the analysis and estimate how the net marginal benefit and marginal damage functions change in a dynamic decision making framework. In the absence of storage, this analysis made the assumption that the United States would not receive economic value for any deficit repayments that caused the LRGV supply level to exceed 1,410,000 acre-feet in a given year.

Policy Implications

After examining the net marginal value of water in each region and accounting for expected delivery losses, the United States and Mexico could have negotiated a more efficient agreement by agreeing to repay the water debt over multiple years and using a Coasian bargaining approach. When the repayment time horizon is extended beyond one year and payment is made exclusively in water, U.S. compensation value increases and Mexico's compensation cost decreases relative to repaying the entire deficit in water within one year as per the negotiated settlement. Moreover, for a given repayment contract length and water supply condition, additional net benefits accrue to both the United States and Mexico when the two countries consider a negotiated outcome that allows repayment in dollars and water instead of exclusively in water. For example, relative to the negotiated one-year agreement, assuming average initial water supplies in both countries, the Coasian approach increases the U.S. value of repayment by 534% and reduces Mexico's cost of repayment by 60%.

The analysis focused on the optimal form of water repayment in the Rio Grande Basin, where water is allocated between the United States and Mexico. However, the Coasian approach can easily be extended to efficiently reallocate water supplies between two U.S. states, or regions, sharing a common fresh water resource in periods of drought. The Coasian approach clearly supports the economic efficiency of using water markets as an economic policy instrument to prescribe efficient water allocations and minimize the cost of water conflicts. Water markets would allow market forces to allocate water supplies to their highest economic value while adequately compensating sellers of those supplies above the benefits they would receive from the same unit of water. By marketing water, regions (or countries) have the flexibility to improve their respective economic welfare associated with the use of a shared water resource. Lack of well-defined property rights and allocation agreement ambiguity can lead to inefficient allocation of water resources. When water rights are clearly established, efficient reallocation trades can be generated annually to maximize the joint economic welfare of the trading regions.

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