The Potential Benefits of Informal Agreements in Transboundary Water Resources

Antonio Lloret

Instituto Tecnológico Autónomo de México

Río Hondo 1, Col. Progreso Tizapán, México, D.F., México, 01080

Tel. +52 (55) 5628 4000

Abstract

Many freshwater resources are located across national boundaries where governments must rely on institutional schemes to manage their shared resources. These schemes are formalized by institutional agreements that usually operate in uncertain hydrologic and variable socio-demographic conditions. Should the rate of change of the conditions governing the natural resource be faster than the rate at which formal institutions adapt, the chance of conflicts among governments is likely to increase. Flexible formal institutions are desirable, but the transaction costs associated with change makes the process of negotiation, implementation, and renegotiation of formal agreements unlikely. Thus users rely on other institutional schemes, namely informal agreements, which are policy instruments used by governments to overcome crises, uncertain events, or variable conditions not always considered in formal agreements. This paper develops a cooperative model to measure the potential joint benefits of establishing informal agreements and shows that informal agreements have net joint benefits that are greater

than or equal to the joint net benefits of formal agreements. The analytical method is illustrated with historical data from the Colorado River. The main results suggests that informal agreements increase joint net benefits on average by 4.4% and by as much as 30% when there is strong variability in water flow.

Key words: Informal agreements, formal agreements, transboundary water resources, Colorado River, uncertainty.

Introduction

Governance of transboundary water resources requires a thorough understanding of both institutions and the interplay of formal and informal agreements. Many freshwater resources are located across national boundaries, thus nations must rely on institutional schemes of cooperation to manage their shared resources. Governments formalize these schemes with institutional agreements such as treaties. Treaties are not isolated institutions that operate independently; rather, treaties are just one part of a complex array of formal agreements, both domestic and international, that govern transboundary water resources and that merit deeper analysis.

Transboundary river basins are subject to variable hydrologic conditions that often have large inter-annual variability. When the rate of change of the conditions governing the natural resource

is faster than the rate at which formal institutions adapt, the chance of domestic and international disputes is likely to increase.

While flexible formal institutions are desirable, the transaction costs associated with negotiation, implementation, and renegotiation, as well as the power structure among countries, make them static. One alternative to make agreements more flexible is to create informal agreements. Informal agreements are policy instruments used by governments to overcome crises, uncertain events, or variable conditions including water flow variability or changes in demand and supply of the resource that are not always considered in formal agreements. Informal agreements are part of a vast domain of policy instruments used at all levels of government. These agreements may vary in their form, from joint declarations or tacit understandings to soft law and social norms.

This paper develops a method of analysis of the significance of informal agreements for water resources and extends our knowledge of the interaction between formal and informal agreements. In particular, this paper (1) creates a model for calculating the optimal allocation of water resources among governments; (2) proves that informal agreements have greater than or equal net benefits than those of formal agreements (assuming that governments maximize their joint utility); and (3) applies the model using empirical data from the Colorado River. I use the Water Treaty of 1944 between Mexico and the United States to examine the potential gains in net benefits due to establishing informal agreements.

Section one sets out the problem and previous research; section two develops the analytical model; and section three illustrates the analytical model with an empirical case study. Finally I close with conclusions and directions to consider for future research. Further, this method can be adapted to analyze other transboundary water basins.

Problem and previous research

When two or more countries share a water basin, they have to work jointly in terms of economic development, infrastructural capacity, management and the resolution of political differences (Wolf *et al.*, 2003a). Tensions are likely to arise when countries gain asymmetric benefits from the use of water resources. Possible ways of reducing these tensions include joint management, institutional building, preventive diplomacy and joint welfare maximization. (Wolf *et al.*, 2003b).

The spatial distribution of surface water in the world includes 263 international basins (Wolf *et al.*, 2003a; Giordano & Wolf, 2003). Most international basins are shared between two countries, but some are shared by more than two nations and up to seventeen. The complexity of Transboundary water resources requires that cooperation and joint management be reflected in institutional arrangements.

In transboundary water resources, models of cooperative behavior are more common than non-cooperative models (Dinar *et al.*, 1992). I use a model of cooperation with characteristics of

game theory models. Under the rubric of game theory, players behave rationally and their decisions take into account those of other countries. Also, countries have very well defined objectives and have built expectations over their behaviors. An assumption of the model is that the joint net benefits of the whole basin are preferred over the single benefits of a country and an agreement leads to cooperative gains. Modeling transboundary water resources with a cooperative scheme is appropriate, since bargaining situations already entail some cooperative behavior. Furthermore, it is common in most basins that countries exchange water flow information for the development of the basin and to have adequate infrastructure to make the best possible use of the resource. That several institutions already embrace joint management schemes to manage transboundary water resources indicates that cooperation between countries exist. Examples include: the International Water and Boundaries Commission between US and Mexico; the International Joint Commission between US and Canada; the International Commission on the Protection of the Danube River with multiple nations in Europe; and the Nile River Basin Initiative. All these institutions work to ensure that countries work cooperatively to manage their shared water resources. Moreover, the cooperation amongst countries that share a basin and already have an agreement in place allows for better outcomes for the region as a whole.

Nevertheless, despite the growing number of treaties in the last fifty years, detailed analysis of international water agreements by Wolf and colleagues (Wolf *et al.*, 2003a; Wolf *et al.*, 2003b; Giordano & Wolf, 2003) show that water allocation between riparian states is rarely reflected in water treaties and, in those cases in which the agreements specify quantities, they often allocate

water in fixed amounts[1]. Further, many treaties ignore hydrological variation and probable changes in values and needs of the river basin. They also found that: "the likelihood and intensity of conflict rises as the rate of change [of socioeconomic conditions or hydrologic conditions] within the basin exceeds the institutional capacity to absorb that change," and that most of the disputes (86%) involve issues of water quantity and water infrastructure.

More flexible formal institutions thus offer a solution (Dietz *et al.*, 2003; Kilgour & Dinar, 2001). Changing or redesigning formal agreements, however, is not always feasible; often the transaction costs associated with renegotiation exceed the net benefits from the renegotiated formal agreements. In the next section I discuss an alternative analytical tool that may help to address some of the problems found in transboundary water resources.

Informal Agreements

Establishing informal institutions offers one alternative to formal institutions which adapt slowly to change. Informal institutions are policy instruments used among nations, regions or states within a country. Informal institutions take several forms, from basic oral or tacit communications to joint declarations or written rules and statements. The main characteristic that makes institutions informal is that they lack the full authority, given by a legislative body such as congress, of the government they represent (Lipson, 1991).

[1] 157 Transboundary water related treaties have been negotiated and signed worldwide between riparian nations.

Informal agreements are broad in scope and can take many forms. In its simplest form, an informal institution can be a memorandum of understanding between two nations that outlines policy directives to solve a conflict, for instance a trading dispute. In its most complex form, an informal institution is a social norm that has evolved over time and that induces some type of behavior; examples include non-written norms in cattle grazing, fisheries harvested by cooperatives, or people queuing for tickets in a movie theatre (North, 1990a; Ostrom, 1990; Young, 2002). For the purpose of this research I limit my analysis to those informal agreements in transboundary water resources that are used to solve one very particular issue. For example, in the context of water resources, an informal agreement would be an oral agreement between two nations to address the problems of an extended drought.

Informal agreements may be analyzed in two dimensions. The first dimension refers to the level of government that creates the agreements and the second dimension refers to the form of expression. The level of government at which decisions are taken limits the impact of the informal agreements in national policy. Informal agreements in the first dimension could be created at the highest level of government, like a head of state, and become a credible, although not formalized, sign of policy intention. In lower level bureaucracies or state agencies, informal agreements are less effective as they may reflect merely administrative procedures and not policy prescriptions.

The second dimension is the form in which governments express informal agreements. Informal agreements can take the form of elaborated written documents, joint communications, or oral or

tacit bargains. Written informal agreements tend to be more detailed and as such may contain more detailed considerations of a policy recommendation, which thus are more likely to be followed. Oral or tacit agreements, in contrast, may simply reveal an intention or perhaps a promise by some official regarding a policy (Lipson, 1991).

In matters of international law, transboundary water resource agreements rarely have binding conditions that limit behavior. Almost any country can breech its agreement without penalty. However, most countries abide by formal agreements mainly as a matter of reputation; informal agreements are generally less reliable and convincing because a country's reputation is not as much at stake (Lipson, 1991; Sigman, 2002; Tesler, 1980)

Informal agreements have the advantage over formal agreements of being more easily created and renegotiated, and thus less costly to abandon than more formal agreements. This flexibility is useful if there is variability or uncertainty about the future benefits under a formal agreement, which is the case of transboundary water resources.

A water agreement made by a government may be sustained over time depending on how well the agreement accommodates uncertain events. When an agreement allows for asymmetry in benefits between countries, it will likely be unsustainable, mostly because of the transaction costs involved in the renegotiation process. Under such circumstances, informal agreements may serve as policy directives to address changes due to uncertain events or to reduce some asymmetries, at least temporarily, at a lesser transaction cost (Lipson, 1991; Tesler, 1980).

Informal institutions are not free mechanisms; they have their own particular transaction costs, such as those associated with the lack of full enforcement or noncompliance. An additional potential cost of informal agreements arises from their informal status: generally less visible and prominent than formal agreements, informal agreements can thus obscure political intentions. On the other hand, however, the potential transaction costs of informal agreements can be outweighed by the potential gains of speed and simplicity inherent in a narrower scope (Lipson, 1991).

Transaction costs increase in the international arena because of a variety of factors including the power structure between countries, information asymmetries, and enforcing mechanisms. Cooperative schemes, when successful, help reduce transaction costs, but only when institutions are path dependent (North, 1990b)[2]. That is, renegotiation in each period may increase transaction costs when current agreements are independent of previous ones.

Informal agreements in international relations can exist as alternatives to or substitutes for formal agreements, and as such they can stand alone and last indefinitely (Lipson, 1991). For the purposes of my analysis, I consider informal agreements as temporary solutions used within an overarching framework established by a formal agreement, with similar characteristics to those formal agreements but without its framework.

[2] Path dependence means that history matters; previous institutional arrangements are not independent of one another.

When transaction costs are considered in renegotiation, then it is necessary to evaluate whether the benefits of renegotiation outweigh the benefits of doing nothing. Transaction costs can be fixed or variable depending on the issue being negotiated.

A closely related case to informal agreements is that of issue linkages or political strategies. These issues have been used as mechanisms to enhance cooperation and add flexibility to the bargaining process in the creation of formal institutions (Fischhendler *et al.*, 2004; Fischhendler & Feitelson, 2003). Issue linkages may be mechanisms to adapt to uncertain events, but tend to be nested in the formal agreements. For the scope of my analysis, I do not consider issue linkages as informal agreements.

Institutional Efficiency and Economic Performance

Economists generally analyze efficient allocation of transboundary water resources with optimization models that provide preferable and efficient solutions (Ambec & Sprumont, 2002; Bennett *et al.*, 2000; Booker & Young, 1994; Dinar & Wolf, 1994). Economic theory suggests that an optimal allocation is feasible as long as transfers are admissible. Water, however, is physically difficult and therefore expensive to transfer because of infrastructure and conveyance limitations, domestic reallocation, institutional capacity, and complex water rights. Nevertheless, water transfers have been suggested as one of the feasible solutions to alleviate water scarcity (Burness & Quirk, 1980; Colby, 1990).

From the institutional perspective, the efficiency of international agreements takes many forms and is not restricted to optimization models. Young and his colleagues (Young *et al.*, 1999) suggest several types of approaches to measure efficiency: normative, legal, political and economic. There are also measurement concepts that try to evaluate international regimes based on optimal economic performance, actual performance, and counterfactual performance (Helm & Sprinz, 2000).

This paper does not address effectiveness as an isolated concept. Rather, it models informal institutions to show that institutional arrangements can adapt to changing conditions or uncertain events. It shows that informal agreements in transboundary water resources may provide a feasible solution to the higher transaction costs associated with the renegotiation involved in formal agreements.

Analytical Model

This section develops an analytical model to show that informal agreements are policy instruments that serve as temporary solutions.

I proceed as follows: first, I develop a model to measure the potential joint benefits of informal agreements relative to the joint benefits of formal agreements, assuming that governments' decisions are to maximize their nations' joint welfare; second, I prove that informal agreements have greater than or equal net benefits to those of formal agreements; and third, I illustrate my

analytical method empirically with historical data from the Colorado River. The cooperative model I use is commonly used in the cooperative game theory literature (Parrachino *et al.*, 2006). I borrowed the basic setup for the formal agreement from Bennett et al (Bennett *et al.*, 2000), who estimate a fixed compact for the Colorado River.

Model

Definition 1:

a) There are two countries sharing a river; an upstream country and a downstream country.

b) All water originates upstream.

c) Governments' decisions are to maximize joint welfare equal to the sum of the net benefits of each country.

Let W = a random variable that represents the total yearly water flow available for the upstream country. The random variable is independently and identically distributed across time.

$f(W)$ = the probability density function of W.

X_u = upstream consumption of water.

X_d = downstream consumption of water.

$U_u(X_u) = U_u(W - X_d)$ = the upstream country's net benefits, assumed to be strictly concave with $U_u'(X_u) > 0$ and $U_u''(X_u) < 0$

$U_d(X_d)$ = the downstream country's net benefits, assumed to be strictly concave with $U_d'(X_d) > 0$ and $U_d''(X_d) < 0$.

q = The weight or bargaining parameter given to the upstream country.

The model identifies the water flow relationship to each country. Sharing takes place when the upstream country does not consume the entire volume available and instead passes some of it to a downstream country by means of a treaty or a formal agreement. For each period, W (the total flow volume from the river without withdrawals) must satisfy $0 \le X_u + X_d \le W$. In the absence of treaties or other arrangements, the upstream country will consume $X_u \le W$, which maximizes its utility before sharing any water with a downstream country. To make the problem tractable, I use a quadratic benefit function of the form $U_i(X_i) = a_i X_i + b_i X_i^2$ with the restriction of $b_i < 0$ and $a_i \ge -2b_i X_i$ to ensure non-negative marginal benefits and concavity.

The Formal Agreement

I model a fixed allocation scheme to show the gains of informal agreements over formal agreements. The rationale to limit the analysis to a fixed allocation (and not to include variable allocation schemes) is that the case study is based on a fixed allocation as a result of the appropriative doctrine (Burness & Quirk, 1980), and also because in most international agreements, allocations among riparian countries are fixed. The literature suggests, however,

that variable scheme agreements have greater benefits than fixed allocation schemes and are more flexible (Kilgour & Dinar, 2001, 1995).

Formally, the formal agreement is then a rule agreed upon by the upstream user to release a fixed quantity to the downstream user. Suppose that two countries negotiate a fixed quantity $\tilde{X}_d$ for the downstream country that maximizes the expected joint net benefits $E[J(W - X_{d,} X_d, W)]$.

The problem is then:

$$\max_{X_d} E[qU_u(W - X_d) + U_d(X_d)] = \int_0^\infty [qU_u(W - X_d) + U_d(X_d)] f(W) dW \qquad (1)$$

Using the quadratic net benefit function from definition 1, the maximization problem can be restated as:

$$\max_{X_d} E\left[q\, a_u (W - X_d) + q\, b_u (W - X_d)^2 + a_d X_d + b_d X_d{}^2\right]$$

The derivative of the expected net joint benefits with respect to X_d is:

$$-q\, a_u X_d - 2q\, b_u (W - X_d) + a_d + 2b_d X_d = G_F(W, X_d)$$

Since W is a random variable the problem is to choose $\tilde{X}_d$ that satisfies

$$\int_0^\infty G_F(W, X_d) f(W) dW = 0$$

With solution:

$$\tilde{X}_d = \frac{q\, a_u - a_d + 2q\, b_u E(W)}{2[q\, b_u + b_d]} \qquad (2)$$

where

$$E(W) = \int_{-\infty}^{\infty} W f(W) dW$$

and the joint net benefits are:

$$J(\tilde{X}_d, W) = qU_u(W - \tilde{X}_d) + U_d(\tilde{X}_d) \quad (3)$$

That is the policy that becomes the formal agreement and one has to compare it with the informal agreement.

The Informal Agreement

The informal agreement is a temporary fixed allocation agreed upon by the upstream user to the downstream user. It is a one-time policy based on the optimal allocation X_d^* that maximizes joint net benefits given a realization of the random variable W. The problem is to maximize the joint net benefits $J[W - X_d, X_d, W]$ and the maximization problem is:

$$\max_{X_d} [qU_u(W - X_d) + U_d(X_d)] \quad (4)$$

With solution:

$$X_d^*(W) = \frac{q\,a_u - a_d + 2q\,b_u W}{2[q\,b_u + b_d]} \quad (5)$$

The joint utility is:

$$J(X_d^*(W), W) = qU_u(W - X_d^*(W)) + U_d(X_d^*(W)) \quad (6)$$

That is the policy that becomes the informal agreement and one has to compare it with the formal agreement.

Proposition 1[3]**:** The joint net benefits of an informal agreement are always greater than or equal to the joint net benefits of a formal agreement for any realization of W. That is:

$$J(X_d^*(W), W) \geq J(\tilde{X}_d, W)$$

Corollary 1.1: The joint net benefits of an informal agreement are equal to the joint net benefits of a formal agreement when the realization of the random variable W is equal to $E(W)$.

Corollary 1.2: As the deviation from the mean of the random variable increases, the joint net benefits of the informal agreement increase.

Proposition 1 shows that the potential gains of establishing informal agreements are positive when no transaction costs are included and Corollary 1.1. shows that the gains have a positive relationship to the variability of flow. In the next section I illustrate the results from the analytical model using empirical data from the Colorado River.

[3] Proofs are left at the appendix for ease of reading

Case Study: The Colorado River

The Colorado River passes through 2,334 km of mountains and deserts and drains 629,100 km². It supplies water to over 25 million people and helps to irrigate 14,164 km^2 of farmland. The Colorado River shares a border of 35.4 km with Mexico and ends in the Gulf of California (Sea of Cortez). The watershed is divided into upper and lower basins and it is shared by two countries, the United States and Mexico. The upper basin is shared by the states of Utah, Wyoming, Colorado and New Mexico, whereas the lower basin is shared in the U.S. by the states of California, Arizona and Nevada, and the last user is Mexico. The Colorado River Compact of 1922 allocates 9.25 cubic kilometers (7.5 million acre-feet) annually each to the upper and lower basins in the United States. The 1944 Water Treaty allocates an additional 1.85 cubic kilometers (1.5 million acre-feet) to Mexico.

These formal institutions, together and other numerous agreements, contracts, and court decisions are known as the "Law of the River" and shape the institutions on the river.[4] The Colorado River is perhaps one of the most regulated rivers in the world, with multiple diversion points, reservoirs, canals and infrastructure projects that reach all users in the basin. These formal institutions create an interesting and yet complicated case of analysis that shows that

[4] The formal agreements that shape the institutions of the river are the Colorado River Compact, the Boulder Canyon Project Act, the California Seven Party Agreement, the 1944 Mexican Water Treaty, the Upper Colorado River Basin Compact, the Colorado River Storage Project, the Arizona v. California Supreme Court Decision and the supplemental and consolidated decrees, the Colorado River Basin Project Act, the Long Range Operating Criteria, the definite solution of salinity in Minute 242 and the Colorado River Basin Salinity Control Act.

there is room for improvement for the allocation of the river and that suggests ways to cope with uncertain events and variable conditions.

Data

I analyze the period from 1950 to 2006 using publicly available data from: the Bureau of Reclamation (Burec); the US Geological Service (USGS); and the International Boundary and Water Commission (IBWC). I consider a shorter period because of the lack of information about the amount of water that reached the ocean in the early years of the 1944 Water Treaty.

I use two available data sets, as shown in Figure 1 below. The series in dark is based on river flow at 20 gauge stations along the river. The data are calculated directly from the USGS database on water surface and are aggregated in yearly terms.[5] The lack of variability in these data is due to the various restrictions imposed by the formal agreements. These institutional schemes have a greater impact on the river as a result of numerous reservoirs, diversion points, and infrastructure projects aimed to serve the demand of multiple users along the basin. I named the series the "Controlled Flow."

[5] http://waterdaa.usgs.gov/nwis/sw (last visited June 1, 2010)

The data set in light is based on a simulation by the Colorado River Forecasting Service and is publicly available at the Bureau of Reclamation.[6] This data set represents the natural flow of the river at each station without institutions, a counterfactual (Prairie & Callejo, 2005). The data set is used by the Burec to develop models used for medium and long-term policy planning on the Colorado River. The distinction is important because I use these data to model the decisions taken by the upstream country and the downstream country as to how much water to allocate to the downstream country in each year.

[Insert Figure 1. Colorado River Flow about here]

Water Use

Water use by country is shown in Figure 2 below. A close look at the graph shows that the increase in use over time in the U.S. corresponds to a relatively constant use by Mexico. The peaks in water use by Mexico correspond to storage of Morelos Dam in the 1950's and to a rise in levees during the early 1980's along with excess rainfall in those wet years. The dotted line represents the water allocated to Mexico and it is precisely that graph which I try to model. It includes the decisions by both governments based on the formal and informal agreements in place.

[6] http://www.usbr.gov/lc/region/g4000/NaturalFlow/current.html (last visited June 1, 2010)

The Treaty of 1944 calculated Mexico's water usage as the difference between the water allocated by the U.S. to Mexico and the water that reached the ocean. The water that reached the ocean was measured by the site of the last gauging station at the Southern International Boundary (SIB) as reported by the IBWC. The SIB is the last source of information about the flow of the river (Cohen, 2005).

Another important distinction (comparing Figures 1 and 2) is that the Water Treaty of 1944, a formal agreement, is not binding to the U.S. In fact, once the U.S. knows how much water to expect in a given year, the decision is how much water to store, allocate and use. The U.S. has never decided to reduce its own consumption in order to meet the terms of the formal agreement with Mexico.

A weakness of my analysis, however, is that water usage for each country may be endogenously determined by the amount of water that each country has received over time, and thus may not appropriately represent the real demand. To address this problem in part, I use the same benefit functions for formal and informal agreements; nevertheless, improvement in determining the demand functions is necessary.

[Insert Figure 2. Colorado River water allocation and use by country about here]

Benefit Functions

The next step in the analysis is to find the benefit functions for each country. I build on the models derived by (Booker & Young, 1994) that estimated the economic benefits of interstate and intrastate markets along the Colorado River. They derived non-linear benefit functions by direct observation of the major users in the basin. I used their benefit functions and aggregated them across users to find a single net benefit function for the US and finally fitted a quadratic function to match it to the specification of my analytical model.

I approximated the benefit function for Mexico using the economic benefits of the neighboring irrigation district of Imperial Valley in the U.S.[7]. The Mexican counterpart, the Mexicali-San Luis irrigation district, is mostly irrigated by Colorado River water. These two irrigation districts have similar soils and grow similar crops. Under the assumption that the only difference between the districts is that the former belongs to the US and the latter to Mexico, I use the same benefit function but weighted by the number of irrigated acres in Mexico compared to the irrigated area in Imperial Valley, which is about 43%. Next, I fit the benefits function into a quadratic form. I assume that Mexico is capable of using more water than that it receives through the formal agreement.[8]

[7] Mexican economic benefits were not part of the Booker and Young model.

The net benefits for each country are:

$$U_{USA}(X) = 108.79X - 0.0029X^2$$
$$U_{Mex}(X) = 76.44X - 0.0057X^2 \quad (7)$$

The social welfare function is equal to the sum of the benefit function for both US and Mexico. The social welfare function has an additional parameter q pre-multiplying the U.S. benefit function; q is the bargaining power parameter that represents an additional weight to the benefits of the upstream country relative to the benefits of the downstream country.

Under full cooperation, one expects this parameter to be equal to one, in which case each benefits function will reflect their real economic value. A value for q greater than one means that the social planner places more weight on the upstream country's value relative to the economic benefits of the downstream country, suggesting a sign of non-cooperative behavior. Later in this section I estimate the bargaining parameter and show the behavior of the bargaining parameter over time.

Results of the Empirical Model

[8] These are strong assumptions that may not represent accurately Mexico's economic benefits and improvement in this direction is necessary.

In this section I model the informal agreements and compare them to the existing agreements to find the gain from establishing informal agreements. I previously mentioned that the current allocation to Mexico embeds in it the informal and formal agreements. The intention of the model is then to replicate such allocation. I modeled the informal agreement with equation (5) above. Since the parameter q is unknown, I estimate it through an optimization routine to find the minimum squared error of the difference between the modeled informal agreement and the existing informal agreement. The results of the modeled informal vs. the existing informal agreements are show in Figure 3[9] below.

[Insert Figure 3. Modeled Informal Agreements about here]

Next, I use the modeled informal agreements to calculate the net joint benefits of the modeled informal agreements as well as the joint net benefits of the existing informal agreements. In Figure 4 I graph in dark the current joint benefits and in light the modeled joint benefits. My results show that on average my model overestimated the net joint benefits by about 5.5% relative to the net joint benefits of the existing informal agreements. The difference between the agreements is graphed with the dotted line. There is a large difference in the modeled benefits vs. the existing benefits due to strong variability in the series during the extremely wet periods of the early 1980's. Without this, the difference between the modeled benefits and the existing benefits averages out at 2%.

[9] The modeled informal results underestimate the current informal by about 7% on average.

[Insert Figure 4. Modeled and Current joint net benefits of informal agreements about here]

I consider the modeled informal agreements a good fit for the existing informal agreements and use it to compare the net benefits of the existing formal agreements. Figure 5 below shows in dark the formal agreement joint net benefits and in light the joint net benefits of the informal agreements. The dotted line represents the benefit gain of the informal agreements compared to the formal agreements.

Figure 5 shows empirically what Proposition 1 and Corollary 1.2 in the analytical section aimed to prove: one, that informal agreements always have higher than or equal joint net benefits than formal agreements; and two, that net joint benefits increase with the variability of water flow. This suggests that informal agreements, under uncertain conditions and variability of water flow, may be considered a good alternative to formal agreements. This is especially the case when formal agreements do not have provisions that can accommodate variable and uncertain conditions. Moreover, my results suggest that establishing informal agreements increases joint net benefits by 4.4% on average, and that when there is strong variability in water flow the gain in joint net benefits may be as much as 30%.

[Insert Figure 5 Comparison of joint net benefits about here]

In the next section I briefly discuss two additional results that are worth of further analysis and that are based on the assumptions of the model developed: The transaction costs and the bargaining power.

A note on the potential gains when considering transaction costs

The previous analyses considered that the benefit functions from establishing informal agreements were net of transaction costs; however, it is a strong assumption even if the renegotiation costs were small relative to the renegotiation transaction costs of formal agreements. Renegotiation costs will likely impact the benefits of establishing informal agreements and will change the optimal allocation in of the benefits without transaction costs.

To measure the impact of how transaction costs reduce the benefits of establishing informal agreements, consider a fixed transaction cost for any negotiation that takes place to establish informal agreements. If that fixed cost is greater than or equal to the benefits of establishing an informal agreement, then countries will stick to the formal agreement. Variable transaction costs can also be considered in the model by simply including the costs in the objective function and maximizing the optimal joint benefit function.

Analysis of the Bargaining Parameter

My results show that the value of q that minimizes the sum of squared errors between the current informal and modeled informal agreements takes the value of 1.23, meaning that the upstream country, in this case the U.S., has more power than the downstream country. This result is intuitively correct since the country that controls flow is expected to have more power.

Figure 6 shows in dark a constant line equal to 1.23 as well as a constant dotted line equal to one that suggests the theta of full cooperative behavior. The light line describes the modeled behavior of the bargaining parameter over time that shows how for each period the bargaining power changes depending on water flow.

I have superimposed the flow of the river to show how flow has affected the bargaining parameter. From inspection, one can see that the bargaining parameter changed dramatically during the early 1950's and early 1980's. In the former period, Mexico built a storage dam for its allocation of waters from the formal agreement. In the early 1980's there was strong flow variability and the bargaining parameter moved erratically like in the early 2000's when there was a drought. This implies that Mexico had more power than the U.S, since Mexico received its full allocation when perhaps it should have received less water resources under the informal agreement.

Finally, one additional remark: from 1990 onwards the bargaining parameter is greater than the optimal estimated by the model. This suggests that the U.S. is increasingly placing more weight on its economic benefits, perhaps because of longer droughts (1988-1992), but also because use in the U.S. has been steadily increasing, as shown in figure 2 above.

[Insert Figure 6. Behavior of bargaining parameter over time about here]

Conclusions

In this paper I model the concept of informal agreements as policy instruments to solve temporary problems and help formal agreements adapt to uncertain and variable conditions. My analysis, in the context of transboundary water resources, shows that informal agreements have greater net benefits than formal agreements. I illustrate this empirically with historical data from the Colorado River. Further, I show that the joint net benefits from informal agreements are larger when there is strong variability in water flow, and thus that informal agreements may be used as temporary solutions if the formal agreement do not have provisions to accommodate changes in variability.

When I illustrated my methodology with historical data from the Colorado River, I found that informal agreements have on average a gain of 4.4% in joint net benefits relative to formal agreements, and that this gain can be as much as 30% when there is strong variability of flow. I found that the upstream country has a bargaining parameter ***1.23***.

While this analysis may oversimplify the actual behavior of the countries in such complex issues such as sharing a river, it models in a simple yet tractable manner the interaction of countries and allows us to understand how formal agreements may be enhanced by establishing informal agreements.

Establishing informal agreements has policy implications: since these agreements are temporary solutions to uncertain events, formal institutions are likely to be sustained for extended periods

of time. Informal agreements may enhance cooperation between countries given the problems that arise with the complexity of managing large river systems.

In addition, informal agreements can work as an overarching framework for formal agreements, at once facilitating the negotiation of particular provisions in the formal agreements and proposing temporary solutions for unresolved and uncertain events. Rarely do formal agreements account for the uncertainty and variability of the resource. Thus the formal agreements may act as an umbrella institution or framework institution that considers general provisions for how the resource should be managed and who ought to manage the resource. Once the formal agreement empowers an organization directly to oversee and manage the resource, then the organization may establish informal agreements as it see fit.

This paper has implications for future research: (1) to understand better the institutions that govern transboundary water resources in the context of both formal and informal institutions; (2) to use a dynamic model rather than static model to show how countries interact over time; (3) to analyze other types of formal agreements, such as variable formal agreements where countries sign over proportions of water flow, and (4) to include auto correlated time series since decisions of allocation of flows between countries are not necessarily independent of previous years flow (Salas, 1993).

Acknowledgements

This work has been possible with the financial support of University of California, UC-MEXUS and CONACYT , Asociación Mexicana de Cultura, A.C. and Instituto Tecnológico Autónomo de Mexico. All errors remain my own.

Appendix: Proofs of Proposition 1 and corollaries 1.1 and 1.2.

Proposition 1: The joint net benefits of an informal agreement are always greater than or equal to the joint net benefits of a formal agreement for any realization of W. That is:

$J(X_d^*(W),W) \geq J(\tilde{X}_d,W)$

Proof:

Take the results in (6) above from the informal agreements and (3) above from the formal agreements and let $X_d^*(W)$ be the function that maximizes $J(X_d,W)$ and let $\tilde{X}_d$ be the value that maximizes $E[J(X_d,W)]$. If $X_d^*(W) \neq \tilde{X}_d$ then plugging in $\tilde{X}_d$ in the value function is not optimal since the only value that optimizes $J(X_d,W)$ is $X_d^*(W)$ therefore

$J(X_d^*(W),W) \geq J(\tilde{X}_d,W)$.

QED

Corollary 1.1: The joint net benefits of an informal agreement are equal to the joint net benefits of a formal agreement when the realization of the random variable W is equal to $E(W)$.

Proof:

If and only if $W = E(W)$ then $X_d^*(W) = \tilde{X}_d$ from results (3) and (6) above and

therefore $J(X_d^*, W) = J(\tilde{X}_d, W)$.

QED.

Corollary 1.2: As the deviation from the mean of the random variable increases, the joint net benefits of the informal agreement increase.

Proof:

Let $z = |W - E(W)|$ be the absolute value of the deviation from the mean of the random variable and $X_d^*(W)$ be the unique optimal function that maximizes $J(X_d^*, W)$. If $J(X_d^*, W)$ is twice differentiable, concave and increasing in W then, from Proposition 1, it follows that $J(X_d^*, W)$ is also increasing in z.

To show that $J(X_d^*, W)$ is twice differentiable:

$$J(X_d^*, W) = q\, a_u (W - X_d^*) + q\, b_u (W - X_d^*)^2 + a_d X_d^* + b_d X_d^{*2}$$

By inspection the function is twice differentiable.

To show that $J(X_d^*, W)$ is concave:

We have previously assumed that the net benefit functions $U_u(W - X_d)$ and $U_d(X_d)$ are strictly concave. We assume that W and X_d are in the domain of $U_u(\cdot)$ and $U_d(\cdot)$ respectively. Since X_d^* is one of the many possible values that the X_d can take then X_d^* is in the domain of the function $U_u(\cdot)$ and $U_d(\cdot)$. Thus $U_u(W - X_d^*)$ and $U_d(X_d^*)$ are also concave functions. Since a property of concave functions is that the sum of concave functions is also concave then $J(X_d^*, W) = U_u(W - X_d^*) + U_d(X_d^*)$ is also concave.

To show that $J(X_d^*, W)$ is increasing in W:

I start by showing that the informal agreement is increasing in W and then use such result to show that the joint benefit function is also increasing in W.

Rewrite the informal agreement as $X_d^* = A + BW$ where $A = \frac{qa_u - a_d}{2[qb_u + b_d]}$ and $B = \frac{q b_u}{q b_u + b_d}$.

Take the first derivative $X_d^{*\prime}(W) = \frac{\partial X_d^*}{\partial W} = B$. Since B is always positive, the informal agreement is increasing in W. Moreover $0 \le B \le 1$.

Now, to show that the joint benefit function is also increasing in W take

$J[X_d^*(W), W] = q\,a_u[W - X_d^*(W)] + q\,b_u[W - X_d^*(W)]^2 + a_d[X_d^*(W)] + b_d[X_d^*(W)]^2$ and check that the first derivative $\frac{\partial J[X_d^*(W), W]}{\partial W}$ is positive.

$$\frac{\partial J[X_d^*(W),W]}{\partial W} = q\,a_u[1 - X_d^{*\prime}(W)] + 2q\,b_u\{W - WX_d^{*\prime}(W) - X_d^*(W) + X_d^{*\prime}(W)X_d^*(W)\} + a_d X_d^{*\prime}(W) + 2b_d X_d^*(W) X_d^{*\prime}(W)$$

Substitute $X_d^{*\prime}(W) = B$ and rearrange

$$\frac{\partial J[X_d^*(W),W]}{\partial W} = q\,a_u[1-B] + 2q\,b_u\{W - WB - X_d^*(W) + X_d^*(W)B\} + a_d B + 2b_d X_d^*(W)B > 0$$

$$= q\,a_u(1-B) + 2q\,b_u[W - X_d^*(W)](1-B) + a_d B + 2b_d X_d^*(W)B > 0$$

Under the restriction of $b_i < 0$ and $a_i \geq -2b_i X_i$ rearrange to get:

$$q\,a_u(1-B) - 2q\,b_u[W - X_d^*(W)](1-B) + a_d B - 2b_d X_d^*(W)B > 0$$

$$q\,a_u(1-B) + qa_u[W - X_d^*(W)](1-B) + a_d B + a_d X_d^*(W)B > 0$$

Since all terms are positive and since $0 \leq B \leq 1$ then $\frac{\partial J[X_d^*(W),W]}{\partial W} > 0$ therefore the joint benefit function is increasing in W if and only if the restriction $b_i < 0$ and $a_i \geq -2b_i X_i$ holds.

Proposition 1 shows that the quadratic joint net benefits of the informal agreements are greater than or equal to the joint net benefits of the formal agreement. Since the joint net benefits of the informal agreement are increasing in W, then it follows that the joint net benefits are increasing in $z = |W - E(W)|$.

QED.

Figures for The Potential Benefits of Informal Agreements in Transboundary Water Resources

Antonio Lloret

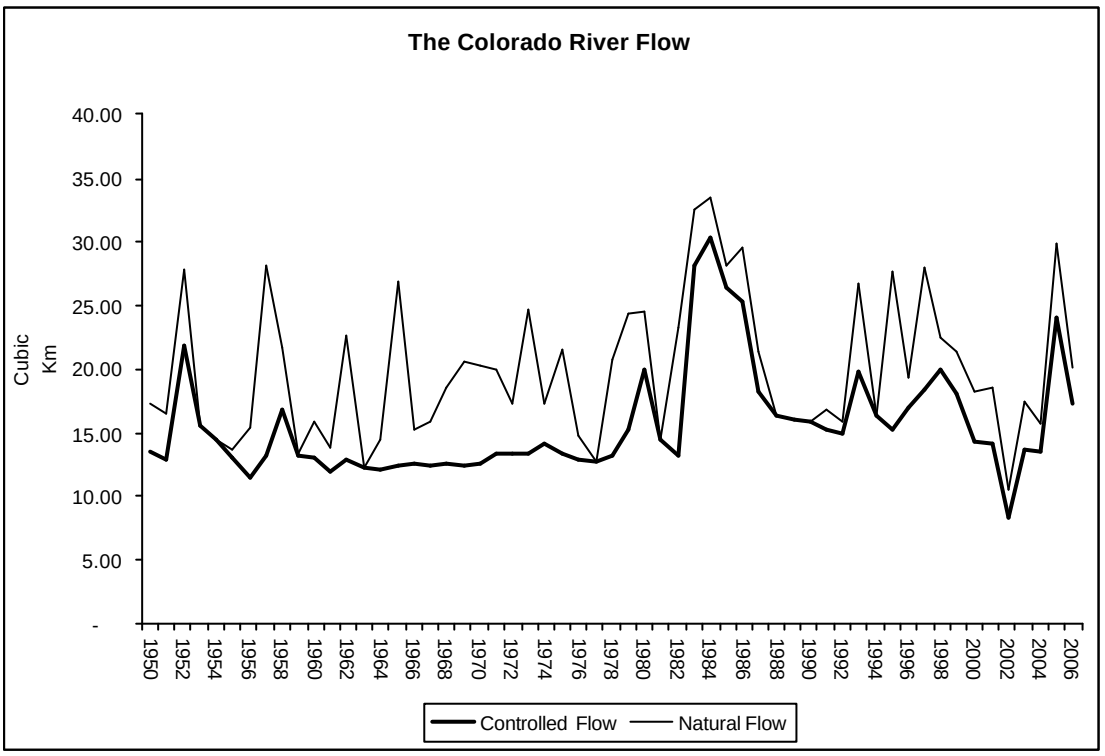

Figure 1. Colorado River Flow.

Source USGS, Bureau of Reclamation and IBWC

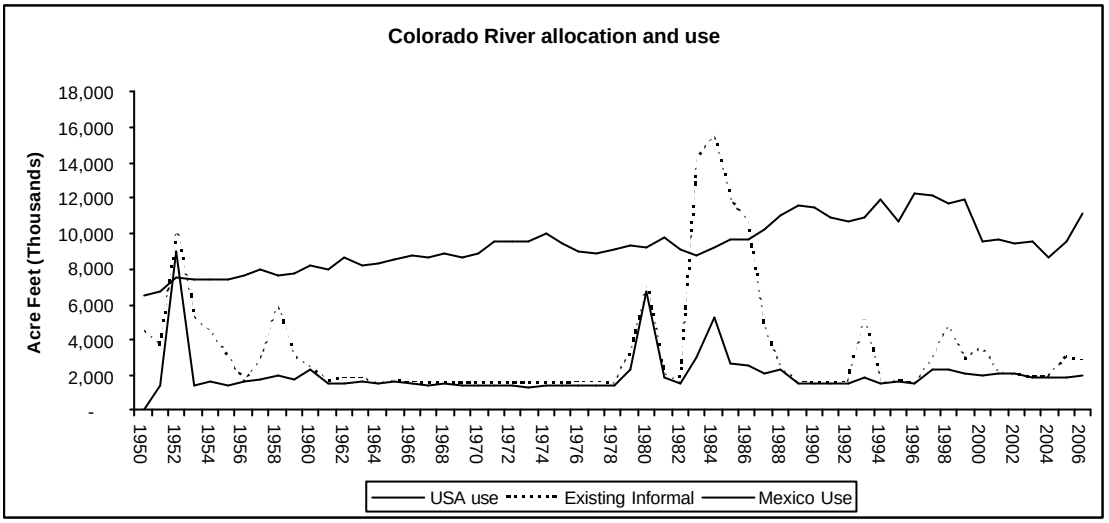

Figure 2. Colorado River water allocation and use by country.

Source USGS, Burec, IBWC

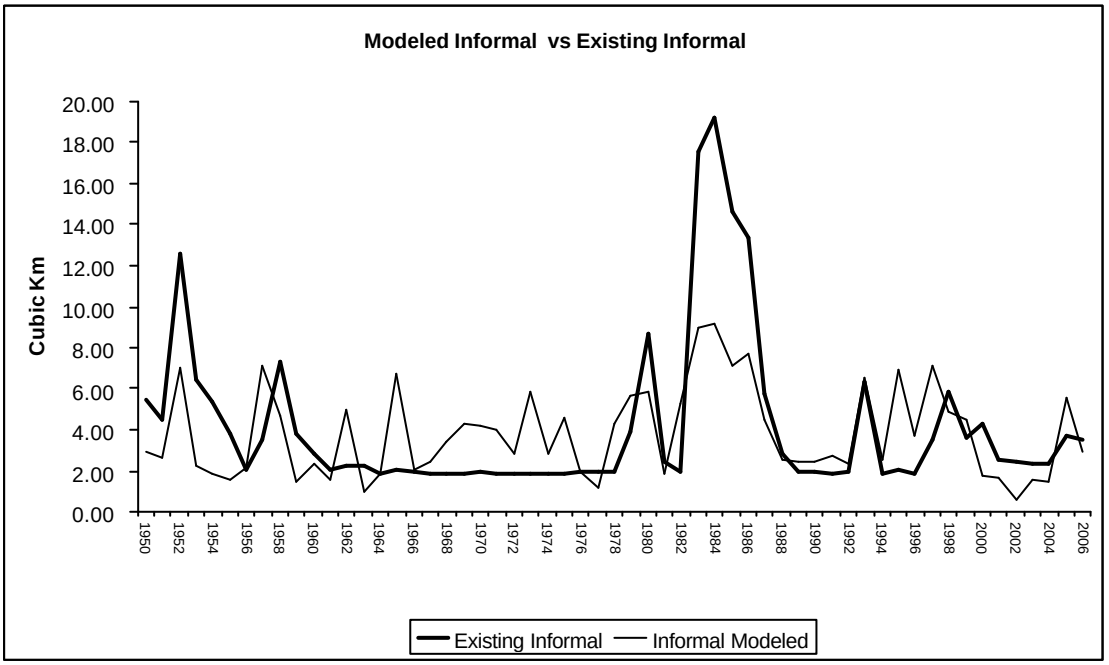

Figure 3. Modeled Informal Agreements

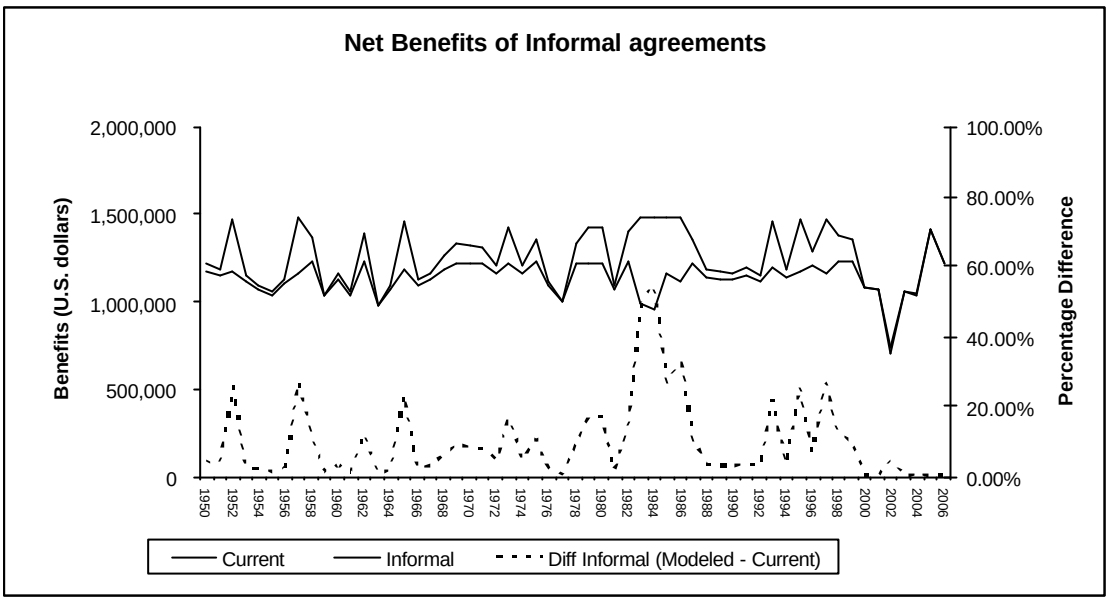

Figure 4. Modeled and Current joint net benefits of informal agreements.

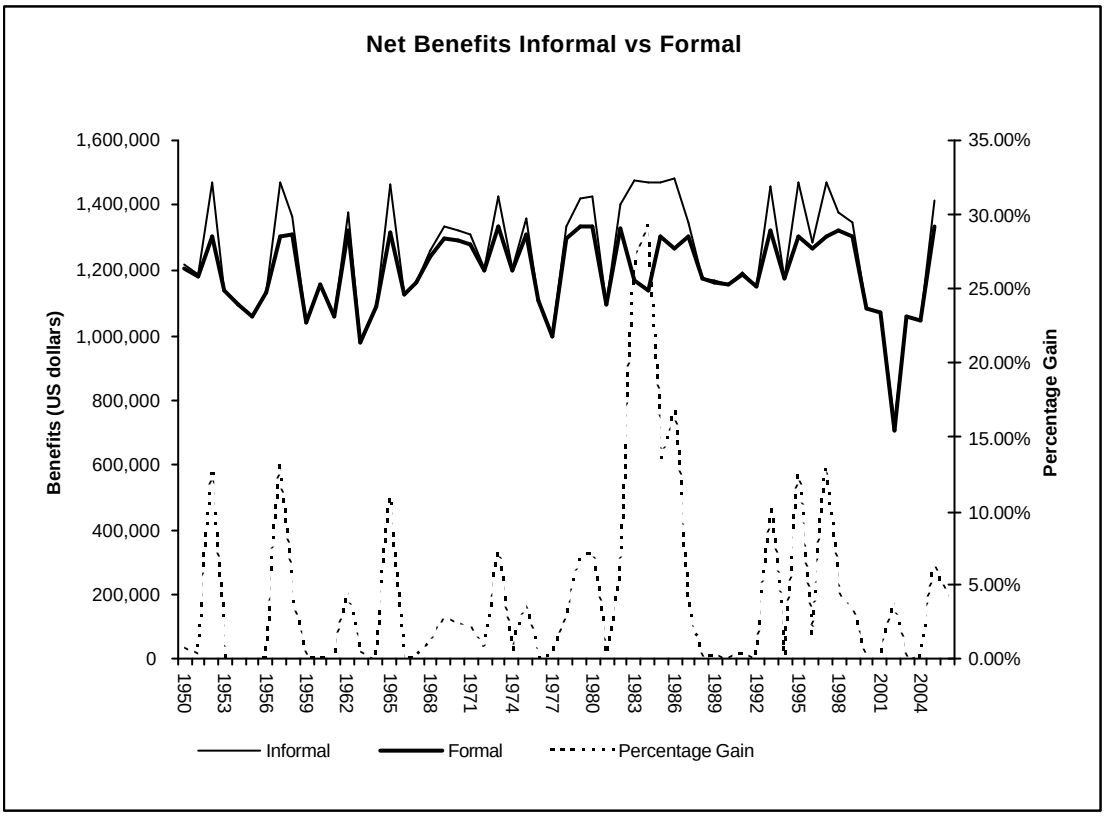

Figure 5. Comparison of joint net benefits.

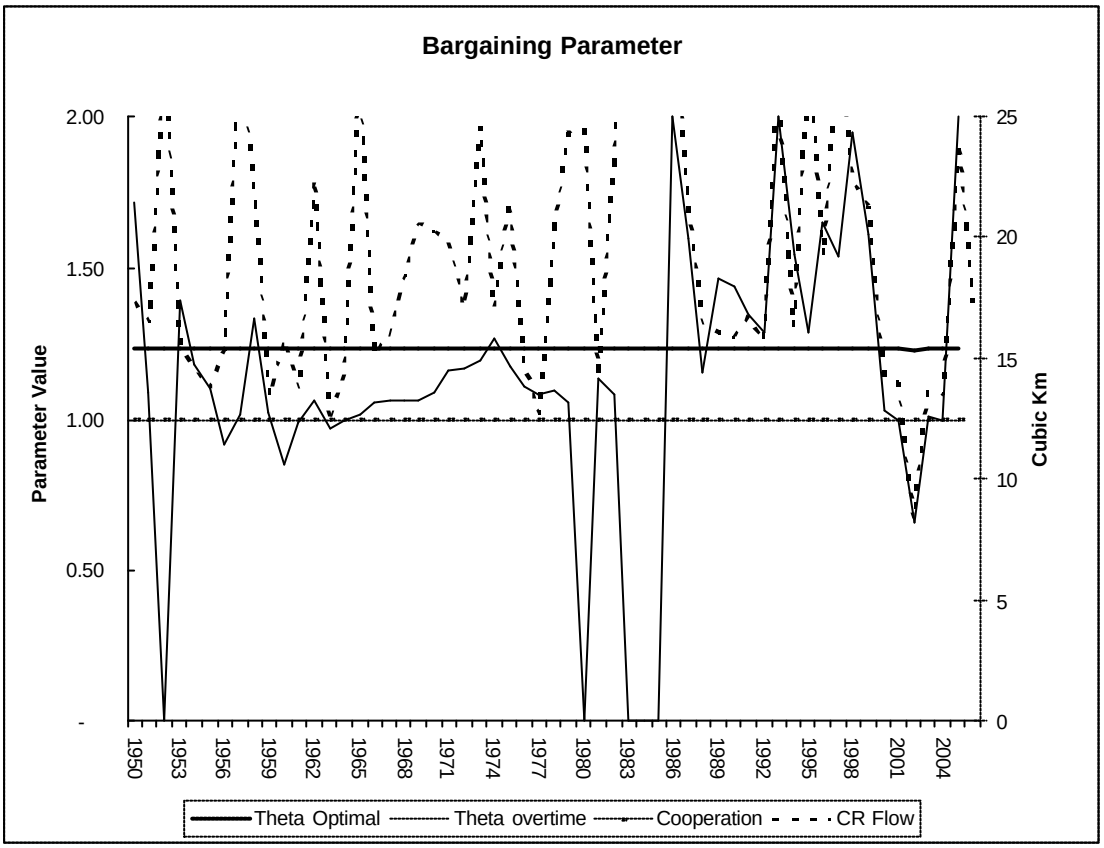

Figure 6. Behavior of bargaining parameter over time

References

Wolf, A. T., Yoffe, S. B., & Giordano, M. (2003a). International Waters: identifying basins at risk. *Water Policy*, 5, 29-60.

Wolf, A. T., Stahl, K., & Macomber, M. F. (2003b). Conflict and cooperation within international river basins: The importance of institutional capacity. *Water Resources Update*, 125.

Giordano, M. A., & Wolf, A. T. (2003). Sharing Waters: Post-Rio international water management. *Natural Resources Forum*, 27(2003), 163-171.

Dinar, A., Ratner, A., & Yaron, D. (1992). Evaluating Cooperative Game Theory in Water Resources. *Theory and Decision*, 31(1), 1-20.

Dietz, T., Ostrom, E., & Stern, P. C. (2003). The Struggle to Govern the Commons. *Science*, 302, 1907-1912.

Kilgour, D. M., & Dinar, A. (2001). Flexible Water Sharing within an International River Basin. *Environmental and Resource Economics*, 18, 43-63.

Lipson, C. (1991). Why are some International Agreements Informal? *International Organization*, 45(4), 495-538.

North, D. C. (1990a). *Institutions, Institutional Change and Economic Perfromance.* Cambridge, United Kingdom: Cambridge University Press.

Ostrom, E. (1990). *Governing the Commons. The Evolution of Institutions for Collective Action*: Cambridge University Press.

Young, O. (2002). *The Institutional Dimensions of Environmental Change: Fit, Interplay and Scale*. Cambridge Massachusetts: MIT Press.

Sigman, H. (2002). International Spillovers and Water Quality in Rivers: Do Countries Free ride? *The American Economic Review*, 92(4), 1152-1159.

Tesler, L. G. (1980). A Theory of Self-Enforcing Agreements. *The Journal of Business*, 53(1), 27-44.

North, D. C. (1990b). A Transaction Cost Theory of Politics. *Journal of Theoretical Politics*, 2(4), 355-367.

Fischhendler, I., Feitelson, E., & Eaton, D. (2004). The Short and Long Term Ramifications of Linkages Involving Natural Resources: The U.S.-Mexico Transboundary Water Case. *Envionment and Planning C*, 22(5), 633-650.

Fischhendler, I., & Feitelson, E. (2003). Spatial Adjustment as a Mechanism for Resolving River Basin Conflicts: U.S.-Mexico case. *Political Geography*, 25(5), 547-573.

Ambec, S., & Sprumont, Y. (2002). Sharing a River. *Journal of Economic Theory*, 107, 453-462.

Bennett, L. L., Howe, C. W., & Shope, J. (2000). The Interstate River Compact as a Water Allocation Mechanism: Efficiency Aspects. *American Journal of Agricultural Economics*, 82(4), 1006-1015.

Booker, J., & Young, R. (1994). Modeling Intrastate and Interstate Markets for Colorado River Water Resources. *Journal of Environmental Economics and Management*, 26(1), 66-87.

Dinar, A., & Wolf, A. T. (1994). International Markets for Water and the Potential for Regional Cooperation: Economic and Political Perspectives in the Western Middle East. *Economic Development and Cultural Change*, 43(1), 43-66.

Burness, H. S., & Quirk, J. P. (1980). Water Law, Water Transfers, and Economic Efficiency: The Colorado River. *Journal of Law and Economics*, 23(1), 111-134.

Colby, B. G. (1990). Transactions Costs and Efficiency in Western Water Allocation. *American Journal of Agricultural Economics*, 72(5), 1184-1192.

Young, O., Levy, M. A., & Osherenko, G. (1999). The Effectiveness of International Environmental Regimes. In: Young, O., ed. *The Effectiveness of International Environmental Regimes. Causal Connections and Behavioral Mechanisms*. Cambridge, Massachusetts: The MIT Press, pp. 1-32.

Helm, C., & Sprinz, D. (2000). Measuring the Effectiveness of International Environmental Regimes. *Journal of Conflict Resolution*, 44(5), 630-652.

Parrachino, I., Zara, S., & Patrone, F. (2006). Cooperative Game Theory and its application to Natural, Environmental and Water Resource issues: 1. Basic Theory. *World Bank Policy Research Working Paper 4074*. Washington D.C.: World Bank.

Kilgour, D. M., & Dinar, A. (1995). Are Stable Agreements for Sharing International River Waters Now Possible? Washington D.C.: The World Bank.

Prairie, J., & Callejo, R. (2005). Natural Flow and Salt Computation Methods: Calendar years 1971-1995. In: Reclamation, B. o., ed: Bureau of Reclamation. U.S. Department of the Interior, p. 112.

Cohen, M. (2005). Understanding Flows Through the Remnant Colorado River Delta: Recommendations for Stream gage Sites and Data Collection. Boulder, Colorado: Pacific Institute, p. 13.

Salas, J. D., ed. (1993). *Analysis and Modeling of Hydrologic Time Series*. New York: McGraw-Hill Professional.