An Integrated Engineering and Economic Analysis of the Columbia River Treaty Renegotiation using Game Theory

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Principal Investigator: Michael Brady
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Projective Objectives

The Columbia River Treaty (CRT), signed between Canada and the United States, has been in effect since 1964. Three dams were constructed in Canada to meet these goals (Mica, Duncan, and Keenleyside). Canada took a lump sum payment for 30 years of their share of the hydropower from the U.S. to pay for dam construction. The existing treaty focuses on the management of dam operations for flood control and hydropower generation. This reflected the costs of floods in places like Portland, Oregon in 1948, and the growth in manufacturing in energy intensive industries in the region like aircraft manufacturing. Irrigated agriculture was also spreading quickly following the Columbia Basin Project.

Either country can exit or initiate renegotiation starting in 2024 with a ten year advance notice, and both countries are in the process of reviewing options. There is a great deal of uncertainty over the future of the CRT because of the changes in the regional economies within the CRB over the last 50 years. The population of Washington grew from 2.3 million in 1950 to about 7 million currently. The regional economy has diversified significantly from heavy industries like manufacturing and natural resource extraction (e.g. timber). Seattle's economy now focuses on software, information technology, and services. Firms such as Amazon, Microsoft, and Costco are all headquartered in the area. The environmental amenities provided by the region's ecosystems plays an important part in the ability of these firms to recruit the most talented workers from other parts of the country. This has resulted in increased pressure to manage lakes and rivers in a way that enhances ecosystem health. The rehabilitation of fish runs and reservoirs for boating, for example, is often at odds with flood control and hydropower. Drawing down reservoirs in the winter allows for additional storage capacity in the spring if it is needed to prevent flooding. However, lower river levels impede fish passage, and low lake levels can persist into the mid-summer if snowmelt is late which hurts boating recreation. Tribes have also become more politically active in asserting their rights over fisheries and water. Climate change is also expected to impact dam operations by reducing winter snowpack and increasing spring rainfall. This amounts to a loss in natural water storage that provides in-stream flow at periods of peak demand that would need to be replaced with man-made storage if objectives are to be met in the future. Water scarcity problems have also grown in Eastern Washington where irrigated agriculture is the primary economic driver for many parts of the state. Managing dams for flood control and hydropower does move the hydrograph from spring to summer to the benefit of irrigators. However, winter drawdown of reservoirs can reduce in-stream flows in summer if late winter snow and spring rain is less than expected. Energy generation has also changed due to the large scale deployment of wind power generators throughout the region.

The dimensionality of the problem of managing dams and reservoirs on the Columbia River from the headwaters in Canada out to the Pacific Ocean between Oregon and Washington has increased substantially since the Columbia River Treaty was signed due to changes in the regional economy. There are now a number of stakeholder groups with a strong interest in changing how the system is managed in both Canada and the U.S. With this many dimensions to management it becomes difficult to account for all the costs and benefits to changes in management to either country. A systematic approach is required to quantify impacts from changing management and to understand how potential changes may cause abandonment of the current treaty or a willingness to renegotiate.

To this end, we develop an integrated engineering and economic analysis of the renegotiation of the Columbia River Treaty using a game theoretic bargaining framework. The economic portion will consist of an accounting of costs and benefits associated with different reservoir management regimes and an analysis of treaty negotiation within a game theoretic bargaining framework. The engineering analysis will consist of the use of reservoir model to simulate the impact of different reservoir management regimes on various outcomes including flood control, hydropower generation, irrigation, and recreation.

The development of game theory revolutionized the analysis of strategic interactions. Since its founding in the mid-20th Century it has become a foundational tool in economics and political science for understanding decision making in a wide range of contexts that involve strategic behavior, including a number of trans-boundary water agreements. Game theory accounts for the fact that parties give priority to their own objectives, and also recognize that others do the same and take that fact into account. This often does not result in the best system-wide outcome (Madani, 2010). By taking an integrated engineering-economic approach, we can more accurately account for the impact of changes in policy on the hydrological system and those who benefit from it. *Analyzing the CRT using the tools of game theory in an integrated engineering-economic study will identify an agreement that (1) both countries are likely to agree to, (2) that will leave both countries better off compared to the current agreement or to a withdrawal from the treaty, and (3) will be based on realistic estimates of the impact of changes in dam operations on the hydrograph of the Columbia River.* The logic model below shows how the different components of the study fit together to provide scientifically objective research aimed at maximizing the societal benefits generated by the Columbia River system in Canada and the USA.

1. Objectives

- Provide an accurate accounting of the costs and benefits to the USA and Canada that would result from changing reservoir operation objectives from current objectives to likely alternative(s).
- Construct a realistic game theoretic model of the renegotiation of the Columbia River Treaty.
- Using game theoretic equilibrium concepts, answer the following questions:
    - Is either country likely to withdraw without renegotiation from the current agreement?
    - Is there is an agreement structure that leaves both countries better off compared to the current treaty?
    - How can the negotiation process be designed to increase the chance of maximizing societal benefits from the Columbia River system in both countries?

While the environment within which this treaty operates is complex, the small number of treaty participants lends itself well to an analysis of country-specific objectives, potential strategies, and their payoffs. As such, a game-theoretic modeling approach provides a promising framework for understanding potential outcomes.

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Background on Game Theory's Relevance to Resource Allocation Problems

For modeling the allocation of water resources, a typical socio-economic approach is to rely on optimization models that focus on strategies like transferable water rights (water markets) as a way to maximize social welfare. This approach is well-suited to situations where a single entity has primary authority over water resources. For example, in Washington the Washington Department of Ecology is the primary regulatory agency that oversees water issues in the state. They are not forced to reach agreements with other entities like the Washington State Department of Agriculture. This approach breaks down when there are two or more entities that have legal authority over different parts of a system where one is not subservient to the other. When this is the case a game-theoretic approach is preferable. An optimization will not account for the fact that Canada holds most of the storage capacity on the Columbia River while most of the benefits from flood control, hydropower, and irrigation are accrued in the USA.

Bargaining models have been used to analyze trans-boundary negotiations over water resources since the 1960s. Game theory provides a systematic framework for taking account of biophysical and socio-economic conditions of each country when trying to identify solutions to complex resource allocation problems. Bogardi and Szidarovsky (1976) showed how to find equilibrium solutions for water management aimed at addressing a range of problems including environmental protection, irrigation systems, water quality management, and multi-purpose water management systems. The World Bank has argued for a greater use of game theory to improve trans-boundary water agreements because this approach helps determine when an agreement is likely to emerge and signals how negotiations can be designed to improve the process (World Bank Policy Research Working Paper No. 3641). Game theory has been used to study conflict resolution over trans-boundary water resources across the globe including India (Rogers, 1969; Kilgour and Dinar, 2001), the Great Lakes (Becker and Easter 1995), Mexico and the USA (Fisvold and Caswell, 2000), the Middle East (Kucukmehmetoglu and Guldmen, 2004; Madani and Hipel, 2007), Africa (Wu and Whittington, 2006; Elimam, 2008), and Central Asia

(Sheikhmohammady and Madani, 2008).

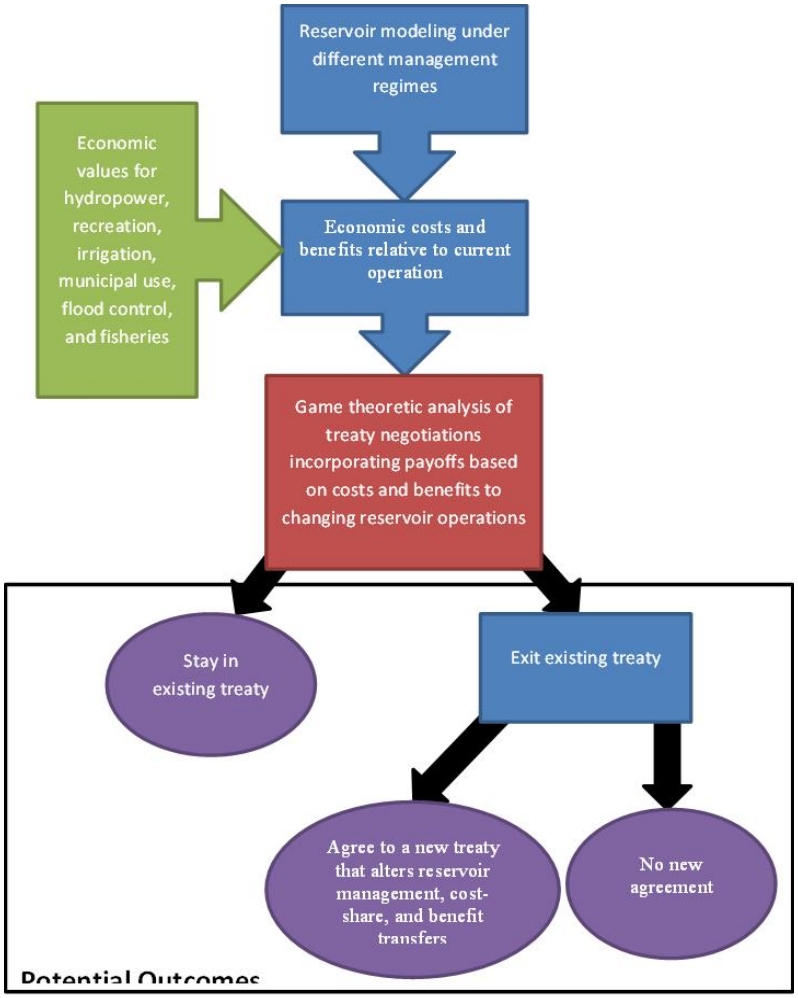

Figure 1. Logic model for the research that connects the reservoir modeling to economic costs and benefits that are then analyzed using game theory to identify the potential for withdrawal and renegotiation of the existing treaty.

The most well-known game theory example is the Prisoner's Dilemma (PD), which captures some of the characteristics of trans-boundary water negotiations and can be used to demonstrate the usefulness of the approach. The lesson from the PD is that the best strategy for each individual does not result in the best possible outcome, where the best outcome refers to the payoffs that could be reached if cooperation was possible. Consider a crime committed jointly be two people that are subsequently held for questioning. The partners in crime get a light sentence if neither confesses. Both are offered plea deals so that if they confess and indict their partner they are freed and their partner serves the longest possible prison sentence. If both confess then they do not need either plea deal and each serves a medium length prison sentence. A dominant strategy exists where one person is better off pursuing a particular strategy no matter what the other person does. The PD game is shown below in Figure 2 in matrix form where the values represent length of prison term. It can be shown that each suspect has a dominant strategy. Suspect 1 is better off confessing no matter which strategy Suspect 2 takes because 0<1 and 6<10. The same holds for Suspect 2 given Suspect 1's actions. Therefore, both suspects confess and get six years in prison even though they would have been better off if they could have coordinated and not confessed.

Figure 2. Prisoner's Dilemma Payoff Matrix

		Suspect 2 Don't Confess	Confess
Suspect 1	Don't Confess	1, 1	10, 0
	Confess	0, 10	6, 6

Values are prison terms in years (Player 1, Player 2).

While the PD is a highly stylized game it shows that the best strategy for one party depends on the best strategy for the other party, and vice versa. It also shows in a very simple example why system-wide optimal outcomes, or pareto-optimal outcomes, are often not achieved. This can be due to barriers to coordination, such as is the case when agreements cannot be enforced, or to political or legal constraints that can eliminate many solutions. For example, many developing countries have argued that fairness dictates that richer countries bare all the costs of climate change mitigation because they are responsible for a majority of emissions in the last 200 years. Also, the Reagan Administration stipulated that Mexico and the USA split costs of water treatment facilities for border towns 50/50, which prevented the ability of the two countries to reach an agreement that would allow the facilities to be built (Frisvold and Caswell, 2000).

The negotiation of the CRT fits well into a game theoretic framework because the costs and benefits of pursuing various objectives are not evenly shared by Canada and the USA without some compensation. Also, the fact that both are sovereign nations means that there are political barriers to cooperation because there is no unified actor that has ultimate say over decisions. Another challenge is that stakeholder groups in both countries often seek to restrict the policy space to exclude strategies that are counter to their interest. Game theory provides a mathematically rigorous framework for organizing and accounting for how all these factors influence negotiations. Most importantly, game theory is not simply a *descriptive* tool for explaining why two parties fail to reach an agreement that leave both better off. Instead, game theory is a *prescriptive* tool that can be invaluable for identifying mutually beneficial outcomes in complex multi-dimensional bargaining situations. Game theory also helps identify what obstacles may prevent reaching a mutually beneficial agreement, and also aids in improving negotiations by ruling out agreements that are not feasible.

2. Modeling of Streamflow Routing and Reservoir Operations

Modeling of streamflow routing and reservoir operations is accomplished by using a suite of models. The variable infiltration capacity (VIC) hydrologic model sums the runoff and baseflow contributrions from each grid-cell included in the area of study. These contributions are routed downstream using linearized St. Venant's equations (Lohmann et al. 1996; 1998).

Monthly routed streamflow is then an output of VIC into the Columbia River Simulation Model (ColSim). ColSim accounts for physical characteristics of the CRB water management system such as type of reservoir (storage or run-of-river), diversions, and return flows. ColSim can also model reservoir operating policies (Hamlet and Lettenmaier 1999). These are rule curves that are a function of objectives including flood control, hydropower, in-stream flow targets, out-of-stream withdrawals for agricultural and municipal uses, and recreation. ColSim is well-suited to analyzing the impacts of changes in the weights placed on objectives of dam operations, which is the focus of this study.

The third component to the engineering modeling is HEC-ResSIM, which provides information on power generation and reservoir storage. While ColSim captures changes in operation at a system-wide level, HEC-ResSIM provides a more detailed summary of the relationship between reservoir storage and power generation. Also, HEC-ResSIM employs a graphical user interface that allows the user to define rule-based operations. VIC provides information on streamflows. Rules are based on within-year forecasts of volume from April to August.

Simulating future hydrological flows account for climate change given the multi-decadal lifespan of most trans-boundary water agreements. Future temperature and precipitation conditions are from the Hadley Centre's HadCM3 general circulation model. We will use the B1 emission scenario. Climate scenarios are incorporated via the baseflow estimates in VIC. There is a very large of potential reservoir management regimes that could be employed. The cost of simulating each regime is significant so only a limited number of runs can be handled

3. Economic Impact of Changes in Reservoir Modeling

The streamflow routing and reservoir operations modeling quantifies the impact of changes in dam operations on the outcomes of interest. In this study the outcomes we will focus on are floods, hydropower generation, out-of-stream uses including irrigation and municipal demand, recreation, and fish habitat. Given the limited scope of the proposal, economic values associated with each use will be derived from existing estimates. The scope will also prohibit considering general equilibrium impacts that account for the effect of a change in one sector on the output of all other sectors. Future values will be forecasted based on expected changes in the regional economy and climate.

4. Game Theoretic Analysis

The bargaining analysis between the USA and Canada is based on the payoffs that each receives under different agreements that are defined by reservoir management objectives and transfers between them. The current agreement is defined by reservoir management that seeks to reduce the chance of floods and also maximize hydropower generation. To compensate Canada for storage operations on their dams 50% of the value of potential hydropower generation is awarded. This defines the current "no change" scenario. While defining the full set of alternatives is part of the research project the option of "no treaty" will be included. Solutions to game theory problems depend critically on payoffs under no cooperation. The "no treaty" scenario assumes that both Canada and the USA manage their dam operations to their own interests recognizing that the other will do the same.

The type of game that is the best fit for the CRT negotiations is a **cooperative game** because a treaty allows for enforcement of binding agreements. Costly enforcement of agreements can make the assumption of a cooperative game problematic. However, dam operations are fairly transparent and legal costs are likely to be relatively low compared. It is also fitting to assume that any treaty is binding given the durability of the existing treaty despite controversy over the equity and efficiency of the arrangement.

For comparison, a coordination game is relevant when two parties are attempting to agree to non-binding actions like in the case of the Kyoto Protocol to address climate change. A cooperative game structure is also designed to consider whether some constraint will prevent the two parties from reaching a binding agreement. In the case of the CRT there are potentially a number of such constraints. Tribes have become much more active in seeking to exert their fisheries rights since the first treaty was negotiated. Setting a minimum standard on in-stream flows at certain times of the year to maintain fish runs reduces the number of pathways to an agreement. There are many other examples of how domestic law can constrain the treaty choice set.

Following similar studies, the bargaining process will be modeled as a **sequential game** which reflects the realities of the political process. In a sequential game one party makes an offer and the other either accepts or rejects and can then make a counteroffer. Another benefit of the sequential game structure is that it has been shown that the outcome is approximated by the Nash solution (Binmore et al., 1986). The **Nash solution** (Nash 1953) maximizes the product $N=\left[u_m-u_m^*\right]\left[u_n-u_n^*\right]$ where u_m and u_m^* are the payoffs, as a function of terms being bargained over, to country *m* under an agreement and with no agreement, respectively. The Nash solution to a cooperative game is pareto-efficient which guarantees that there is no other agreement that could make one party better off without making the other worse off. This requirement lends the model results credibility that countries are (1) likely to be agree to the conditions, and (2) will not prefer some other agreement more. The assumption of **full information** can also be made given the history of information sharing under the existing treaty about the benefits to each country from different outcomes.

A complex part of modeling the negotiations will be to look at how stakeholder groups in each country are likely to form coalitions to politically pressure for particular standards. Coalition formation is always an important part of modeling cooperative games. Constructing a model of stakeholder influence will be part of the initial economic analysis that is aimed at reducing the number of feasible treaties that will be the basis of the reservoir model runs. This part of the game will also be an important part of the final game theoretic analysis that incorporates payoffs based on the reservoir model runs.

Status of Work

This project has received a no-cost extension to complete this work. Work to date includes:

- Reviewed existing reports analyzing the benefits and costs of the Treaty to existing parties.
- Collected data on the positions of stakeholder groups in the US and Canada in regards to staying in the existing Treaty or renegotiating a new Treaty based on discussions at public meetings.
- Collected data on historical hydropower production and value.
- Developed a game theoretic model to analyze the "Canadian Entitlement" relative to a predicted equilibrium outcome from a negotiating process in terms of the distribution of benefits and costs.

Remaining Work

- Additional time is needed to integrate the economic modeling with the reservoir modeling (ColSim) needed to analyze the effect of changes in dam operations with in-stream flows at different points in the year.
- A more complete analysis of the incentives of all stakeholder groups not active in the negotiation of the original treaty are needed including tribes, agriculture, and recreation.

Outputs

The work modeling done to date is being presented at the 2014 UCOWR-NIWR-CUAHSI Conference on "Water Systems, Science, and Society Under Global Change held June 18-20 at Tufts University, Medford, MA.

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