The Aral Game

Objectives

This assignment on Negotiation and Cooperation includes several components. First is a set of *in-class negotiation sessions* between the Aral Sea upper and lower basin players. The negotiation sessions are aimed at demonstrating the concepts of asymmetry of information and power, and the importance of flexibility in infrastructure adjustment to changing water-supply conditions. Second is use of a *hydro-economic optimization model* that feeds into a *cooperative game theory allocation solution and stability assessment*. The model simulates varying states of nature (climate change), possible investments to alleviate water infrastructure and management, and several institutional arrangements in the basin that affect the likely level of cooperation over water.

By first working through the negotiation stage students will be better prepared to understand the positions of the players in the game vis-á-vis the main cooperation parameters (water quantities allocated and prices). After that, they are better able to assess the stability of various regional arrangements, as reflected in the cooperative game theory solutions. Students consider negotiation under various states of nature, investment options, and regional institutional arrangements. This allows them to understand the external parameters and rigid institutions and infrastructure of the players, and how these factors affect the solution and its stability. The impact of climate change on the region is simulated via inter-annual variation of the reservoir inflow—a simple characterization of climate change impact on the hydrology of the basin.

The Aral Sea Basin

The Aral Sea Basin is comprised of part of Kazakhstan, Tajikistan, Turkmenistan, Uzbekistan, and most of the Kyrgyz Republic (see Figure 1). The climate in the northern part of the basin is continental, whereas the southern part is subtropical. The high mountain areas are humid with annual precipitation ranging from 800–1600 mm. Water resources in the region are mainly surface water formed in the eastern mountain ranges. Reliable base flow in the major rivers of the Aral Sea basin, the Syr Darya, and the Amu Darya is provided by snowmelt from extensive permanent snow fields and glaciers, mostly during the spring and early summer thaw.

The Amu Darya flows 2,540 km from the Pamir Mountains, through the Kara Kum desert, to the Aral Sea. Its average annual flow ranges from 109.9 to 58.6 billion m^3. The Syr Darya stretches some 2,200 km from the Naryn River in Kyrgyzstan through the Fergana Valley, the Hunger Steppe, and the Kyzyl Kum desert, finally reaching the Aral Sea. It has an annual flow ranging from 51.1 to 23.6 billion m^3. These two rivers account for about 90% of the region's annual river flow and their waters irrigate roughly 75% (by area) of Central Asia's agriculture.

About 77% of the runoff in the Aral Sea basin originates in the high mountains of Tajikistan and Kyrgyzstan who use about 15% of that water. Afghanistan contributes about 10% of the inflow to the Amu Darya. Water demands in Central Asia are dominated by agriculture, with irrigated agriculture accounting for more than 90% of the total use, with the bulk of that being in Uzbekistan, Turkmenistan, and Kazakhstan.

Figure 1. Location of Aral Sea Basin in Central Asia. Source: CAWater (2015)

The Central Asia republics depend on the Amu Darya and Syr Darya for drinking water, irrigation, and hydroelectric power. In the upstream nations, Kyrgyzstan and Tajikistan, the rivers are utilized mostly for hydroelectric power, especially during winter months, while in the downstream nations, Turkmenistan, Kazakhstan, and Uzbekistan, the rivers are used for agricultural purposes, mostly in the summertime.

Central Asia's agricultural expansion and population growth in the second half of the twentieth century placed a great strain on the region's water resources. Since 1960 the population in the basin has grown from 13 million to more than 40 million people, water diversions have increased from 60 to 105 billion m^3, and irrigated lands rose from 4.5 million ha[1] to just over 8 million ha. As a result of the large-scale diversions of water necessary to irrigate these lands, the Aral Sea lost half of its surface area and two-thirds of its volume and became an environmental disaster area. In addition, inefficient irrigation systems and mismanagement of irrigation water diversions resulted in elevated water and soil salinity levels with consequent widespread environmental degradation and diminished agricultural productivity.

The main water and energy infrastructure in the region was developed when Central Asia was a centrally administered area of the Soviet Union and resources were shared and costs were subsidized. This has not been the case since the countries achieved independence in 1991. The past two decades have seen the development of greater national self-sufficiency and governance, while at the same time a decline in social and economic integration among the republics.

Given the great dependence of the Central Asian economies on irrigated agriculture, the issue of water allocation, in both quantity and timing, is a major factor in the development of the republics and a source for conflict. Agreements on the use of the region's shared water resources are in a formative stage of development and negotiation, and the ongoing process of regional cooperation between the countries in water management is a major factor in the long-term security of the region.

The Principles of the Aral Game

To simplify the timing-quantity and energy-water conflict in the basin we designed the game so that it is based on a subset of the rivers and riparian states in the Aral Sea Basin (i.e., the Syr Darya basin and two or three of its four riparian countries, see Figure 2). The three player states in this simplified representation of the basin are Kyrgyzstan (Kg), Uzbekistan (Uz), and Kazakhstan (Kz). The game assesses possible arrangements of water releases from the Kyrgyz-owned Toktogul reservoir and their impact on the welfare of the players.

[1] 1 hectare (ha) = 10,000 m^2

Figure 2. Syr Darya basin. Source: http://www.icwc-aral.uz/bwosyr.htm

The reservoir was built in the Soviet period to operate in a mode designed to optimize irrigation water deliveries in the summer growing period, with minimal releases in the winter. Surplus electricity generated by summertime irrigation releases was to be transmitted to neighboring regions. In return for receiving electricity and irrigation water, the downstream regions sent electric power and fuels (natural gas, coal, and fuel oil) back to Kyrgyz for winter heating. This situation changed drastically when independent states were established in Central Asia in 1991. Because of complications in intergovernmental relations and account settlements between the countries, the introduction of national currencies, and increasing prices of oil, coal, and natural gas, the compensation by the other Republics of wintertime fuels and electricity to Kyrgyz in exchange for irrigation water releases was reduced drastically. This created a winter heating crisis in Kyrgyzstan. As a result, wintertime releases were increased from Toktogul reservoir for hydroelectric generation, and this threatened to deplete reservoir storage during use in dry summer (irrigation) periods.

To alleviate these problems, the Syr Darya basin countries negotiated an agreement on the use of water and energy resources of the Syr Darya Basin (known as the Bishkek agreement) that was signed in 1998. Under the agreement, compensation is paid for Kyrgyz compliance with a Toktogul-release schedule that takes into account both Kyrgyz winter energy needs and Uzbek and Kazak summer irrigation water demands. Hegemony is an issue in this situation since Kyrgyzstan, the upstream riparian, controls (to some extent) the flow from Toktogul (and owns the storage infrastructure). Therefore, a cooperative agreement is the objective of the game.

Structure of the Negotiation and Cooperation Game Assignments

The flowchart of the set of negotiation-cooperation assignments can be seen in Figure 3. Below we discuss separately the structure of the negotiation games and the cooperation games. We start with the negotiation game assignments using a simplified setup of only two players (upstream and downstream) that have to agree on compensation for the water to be released either in the summer or in the winter. Then we move to the cooperation game sessions with two, more elaborate, assignments that incorporate aspects such as climate impacts on the water availability and possible investments to improve the water management in the basin.

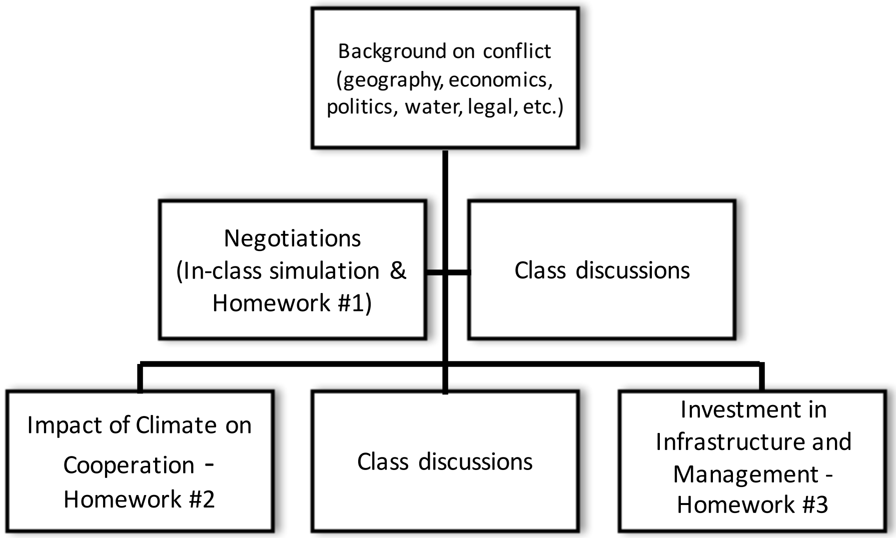

Figure 3. Sequence of simulation sessions on negotiation and allocation for the Aral Game.

The Assignments

In-Class Assignment – Simulating a Negotiation Process in the Aral Sea Basin

This assignment is based on in-class negotiation sessions. The setting is based on the amount of water inflow and storage in Toktogul Reservoir, reported for the period 1911–2012 (Figure 4). There are upstream and downstream players who differ in their desired use of the water. The negotiation sessions include three in-class scenarios and one homework assignment. The variable to be decided by negotiation is the price that the downstream player will pay the upstream player for releasing water in the summer for irrigation use.

In-class negotiations are conducted under a very short time schedule (15 minutes each). The first session simulates a situation where the players have very little information about the flow (Scenario A below). The second session simulates a situation where only one party has full information about the flow (Scenario B below). The third session simulates a situation where both players have full information about the flow (Scenario C below). The objectives are to demonstrate the value of information and information asymmetry.

The class will be divided into a number of negotiating teams of either 5 or 7 students, depending on the overall size of the class. The negotiating teams are to try and enter into an agreement that yields a positive payoff for each team. This is an expected outcome from a rational negotiator. The negotiating teams will select a chief negotiator and split the remaining members into the upstream and downstream parties. The chief negotiator will lead the decision process between the negotiating parties. The chief negotiators must carefully manage their teams' time or the teams may leave the negotiation table with no payoff.

Background

The year is 1992. The Soviet Union collapses. The newly independent nations, previously members of the Soviet Union, have to take charge of natural resources they now share. The Kyrgyz (upstream) and Uzbek (downstream) nations share the Basin. The Kyrgyz use the water for production of hydropower where the net value of each m^3 stored and run through the turbines at Toktogul reservoir is 0.074 $US/$m^3$. The Uzbeks use the water for irrigation of cotton, where the net value of each m^3 of water applied on the cotton fields of Uzbekistan is 0.0754 $US/$m^3$. The inlet to Toktogul reservoir is the measuring station where water flow is recorded. You represent the Uzbek or Kyrgyz nation in the water allocation negotiations.

The Assignment

The negotiations will have three scenarios, A, B, and C (shown below). You are to conduct a negotiation under each scenario and report the results to your government. What is the annual net payoff you can offer your government? You have 15 minutes for each negotiation scenario. Water not included in a treaty is lost. A no-treaty outcome means that your payoff is 0. You need to negotiate a mechanism to allocate the annual flow between the Kyrgyz and Uzbek nations in order to maximize the payoff in the decade period 2003-2012.

A. The following information is available to *both* parties:
   i. The long-term mean annual flow at Toktogul is 11,799 million m^3/yr (but *not* the detailed annual flows for the period of record).
   ii. Once allocated to a player, each unit (m^3) of water can be used by that player without affecting the other one. Water that is not allocated cannot be captured and used by any player.
   iii. No further consideration is needed.

B. The following information is available to *only* the Kyrgyz delegation:
   i. The recorded flow information in Figure 4 is available.
   ii. Same additional aspects as in Scenario A (i – iii).

C. The following information is available to *both* Kyrgyz and Uzbek delegations.
   i. The recorded flow information in Figure 4 is available to both players.
   ii. Same additional aspects as in Scenario A (i – iii).

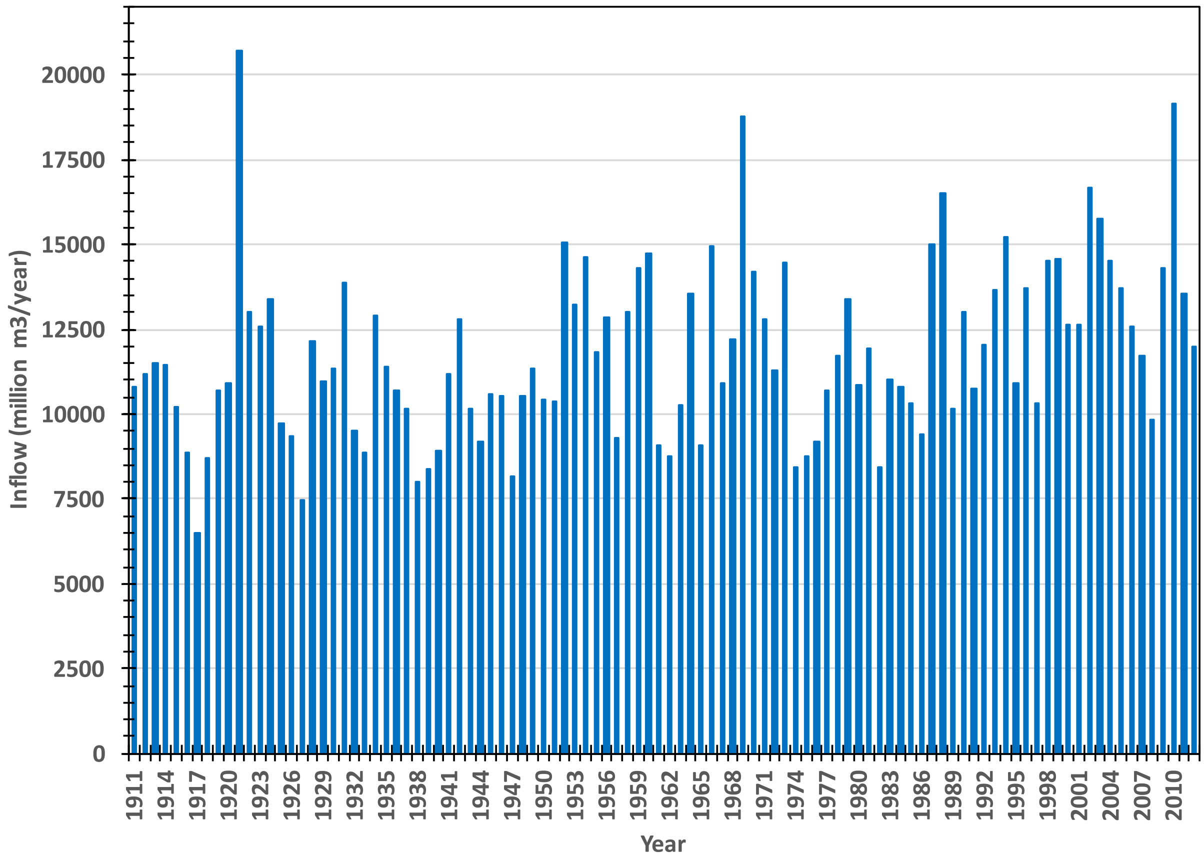

Figure 4. Annual inflow to Toktogul reservoir (1911–2012).

Homework Assignment 1 – Mediation in the Negotiation Process

Homework Assignment 1 builds on the class simulations, except that instead of developing negotiation skills and techniques, you will play the role of mediator. You are supposed to come up with a solution that will be accepted by the parties to the negotiation. The objectives are twofold: first, to have you recognize and to quantify the value of information about water flow; and second, to put the calculations into a hydro-political framework where you use terminology from earlier parts of the class in in your report to the negotiating parties.

This assignment allows you to quantitatively compare between states of nature and availability of information. You should consider the difference between allocation decisions that are based on long-term mean parameter values versus allocations based on annual data in terms of player payoffs. The difference between ‘‘with information’’ and ‘‘without information’’ is the value of information. How can this be interpreted as a benefit of cooperation?

Background

The year is again 1992. The Soviet Union collapses. The nations, previously members of the Soviet Union, have to take charge of natural resources they now share. The Kyrgyz and Uzbek nations share the Aral Sea Basin. The Kyrgyz use the water for production of hydropower where the net value of each m^3 stored and run through the turbine is 0.074 $US/$m^3$. The Uzbek use the water for irrigation of cotton, where the net value of each m^3 of water applied on the cotton fields of Uzbekistan is 0.0754 $US/$m^3$. Toktogul is the measuring station where water flow is recorded. You represent the Uzbek or Kyrgyz nation in the water allocation negotiations.

Once allocated, each unit of water can be used by each riparian state without affecting the other one. No further consideration is needed. The information that is available to you is also available to the parties to the negotiation.

This assignment is intended to focus on suggested allocations, payoffs calculations, positions of parties, and you are expected to persuade the parties that the allocation should be adopted as the basis for a treaty.

The Assignment

Provide a water allocation regime under the following two scenarios (states of information):

A. The long-term mean annual flow at Toktogul is 11,799 million m^3/yr.

B. The recorded annual flow information for the years 1911–1992 is available in Figure 4. The average inflow is 11,799 million m^3/yr, the standard deviation of inflow is 2,539 million m^3/yr, the minimum inflow is 6,525 million m^3/yr, and the maximum inflow is 20,725 million m^3/yr.

For each scenario A and B:

1. Present your proposed allocation and explain it;
2. Calculate the expected payoff to each of the negotiating parties, Kyrgyz and Uzbek, over the period 1993–2002;
3. Assess the value of having additional annual flow data (as in Scenario B) rather than long-term means (as in Scenario A).
4. Discuss the possible reactions by each of the parties; and
5. Prepare your argument as a mediator, including aspects of equity, efficiency, int'l law, etc. You need to make the case why the parties should adopt your proposal.

Homework Assignment 2 – Impact of Climate on Cooperation

Homework Assignment 2 utilizes the regional allocation game. It is based on the background provided earlier and on the hydro-economic optimization model highlighted in Appendix 2 of the text (Dinar et al., 2013 as updated in the handout for this class.). Teams of students conduct the analyses in the assignment.

In the assignment each team will:

- prepare and justify scenarios,
- modify certain parameters in the game dataset,
- run the scenarios using hydro-economic optimization model,

- interpret the results from the optimization phase,
- incorporate them into a cooperative game theory spreadsheet interface.

The spreadsheet interface calculates the Shapley value, tests whether or not a core exists and calculates the Loehman power and stability indices and the Straffin and Heaney index of propensity to disrupt from a coalition. Students should detect the impact of various parameters, such as climate change and infrastructure improvement, on the nature of the allocation solution (efficiency, equitability, stability).

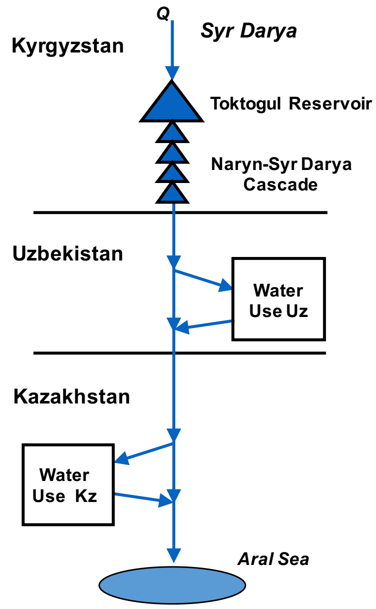

Figure 5. Illustration of the Aral Basin shared between three countries: Kyrgyzstan, Uzbekistan and Kazakhstan.

For each run of the hydrology-economic optimization model a results table for each coalition (Kg), (Uz), (Kz), (Kg, Uz), (Kg, Kz), (Uz, Kz), (Kg, Uz, Kz)[2] is generated. Table 1 presents the results for the grand coalition (Kg, Uz, Kz) under average inflow conditions. These values are then used in the spreadsheet to calculate the Shapley allocation. In doing so the characteristic function of each coalition is calculated and a check is made to see if the core exists for the game and if the Shapley value is in the core. In addition, the Loehman power index and the Straffin and Heaney index propensity to disrupt index are calculated by the spreadsheet. The students should interpret their results and draw some general conclusions from the trends observed in the analyses. Plot the results of regional payoff against available water flow to see the cooperation-climate relationship difference in cases of high water-scarcity and in water-abundant scenarios. How important a player is Kyrgyzstan in the Aral Game?

[2] Kg = Kyrgyzstan, Uz = Uzbekistan, Kz = Kazakhstan

Table 1. Results for the Grand Coalition {Kg, Uz, Kz} under average inflow conditions.

Country	Category	Unit	Amount
Kg	Foregone energy cost	million $	337
	Hydro-energy cost	million $	134
	Deficit energy cost	million $	130
	Compensation received	million $	130
	Total energy cost	million $	134
	Total energy benefit	million $	203
Uz	Available area	1000 ha	1603
	Irrigated area	1000 ha	732
	Agricultural Profit	million $	549
	Water Delivered	million m^3	8123
	Surplus Energy from Kg	million $	97
	Compensation to Kg	million $	65
	Total Benefit	million $	581
Kz	Available area	1000 ha	1017
	Irrigated area	1000 ha	880
	Agricultural Profit	million $	528
	Water Delivered	million m^3	11224
	Surplus Energy from Kg	million $	97
	Compensation to Kg	million $	65
	Total Benefit	million $	560
Aral Sea	Inflow	million m^3	4490
Coalition			
{Kg}	Value	million $	224
{Uz}	Value	million $	111
{Kz}	Value	million $	107
{Uz, Kz}	Value	million $	817
{Kg, Kz}	Value	million $	796
{Uz, Kz}	Value	million $	219
{Kg, Uz, Kz}	Value	million $	1345

Background

This assignment is concerned with the water flow in the Syr Darya Basin and its likely impact on the regional economies and the stability of possible agreements. We are interested in the impact of water availability on cooperation in the basin, using all possible concepts from our class.

The Assignment

Simulations

The inflows to Toktogul reservoir are shown in Figure 4. A "flow duration curve" (showing the probability of a flow larger than a particular value) is given in Figure 6. From this figure you can see that high flows are unlikely (low probability) and low flows are quite likely (high probability).

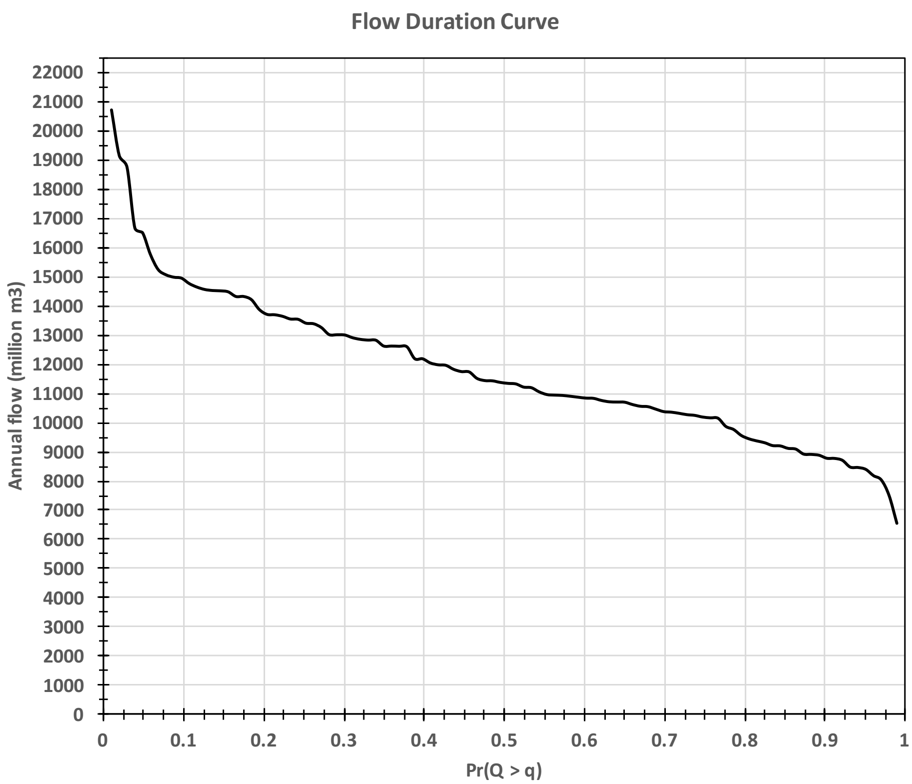

Figure 6. Flow duration curve for Toktogul inflow.

There are five climatic scenarios we will refer to (see Table 2):

1. Very Dry Year Scenario (drought year);
2. Dry Year Scenario;
3. Average Year Scenario (Base Run);
4. Wet Year Scenario;
5. Very Wet Year Scenario (flooding year).

Table 2. Flows and Probabilities of Toktogul Inflow

Condition	**Representative inflow (million m^3/yr)**	**Probability of inflow**
Very dry	8378	0.15
Dry	10162	0.20
Average	11348	0.30
Wet	13466	0.20
Very wet	16134	0.15

Analyses

1. For each scenario, report in a table the following items (you can a single table for all scenarios):
    a. A short description of the parameters used

   b. The values of the Grand Coalitions
   c. The energy produced
   d. The land under irrigation in each country
   e. The water in storage in Toktogul reservoir: Beginning and end of year
   f. The water used by each riparian
   g. The water going to Aral Sea

2. For each scenario suggest and calculate two allocations of the regional payoff (Grand Coalition) from use of the water:
   a. The Shapley allocation
   b. Any other allocation you can come up with.

3. Discuss (using concepts from international law, negotiation, and cooperation theories) the allocations in 2a and 2b above relative to the Stability of the agreement (using Loehman and Straffin and Heaney indexes).

4. In a final discussion, compare the five scenarios in terms of the impact of climate on the economy and on the stability of a possible agreement in the Aral Basin. Try to introduce (calculate) the likelihood of very dry, dry, average, wet, very wet years and incorporate it into your discussion.

Homework Assignment 3 — The Role of Investment in Infrastructure and Management

In climates that have abundant water supply, Toktogul Reservoir on the territory of Kyrgyzstan fills and more water cannot be stored behind the dam and must be spilled, thus limiting the ability of Kyrgyzstan to benefit from the water. However, water that spills from the reservoir is used by Uzbekistan and Kazakhstan. What are the consequences of this on regional options for future cooperation? This is addressed in the Homework Assignment 3 of the Aral Game by adding an investment option to the set of possible cooperation interventions in the region. The two types of investments are: (1) increasing the reservoir capacity; and (2) increasing irrigation efficiency by moving to irrigation technologies that reduce runoff. In Homework Assignment 3, you are expected to introduce and analyze the impact of investment decisions aimed at improving water infrastructure and management.

Background

This assignment is concerned with future prospects for the regional economy and livelihood of the people in the Aral Sea Basin. This is also the concern of the international community and you are part of an International Panel (IP) that evaluates possible cooperative arrangements and regional development for the region.

The IP has identified the year 2026 as its target planning of the Aral Basin cooperative arrangements.

Two major processes will affect the basin:

1. *Deterioration of irrigation infrastructure*: The irrigation infrastructure deteriorates and this is reflected in two ways.
    a. The productivity per irrigated hectare ($/ha) decreases.
    b. The return flows increase, meaning that a big portion of the water applied to fields is not utilized efficiently and is lost as return flows.

2. *Population growth*: It is expected that the population in 2026 will increase by 15% causing a similar increase in the domestic energy demand of Kyrgyzstan.

The European Union (EU) has pledged a loan to increase the total capacity of Toktogul Reservoir by 10%. To pay off this loan, the Hydro Energy Cost is increased to 0.0015 $US/kWh. This increase in cost of production will be reflected also in the price to purchase energy.

The United States Agency for International Development (USAID) has also pledged assistance for new irrigation technologies and canal lining that will decrease water needs for irrigation (per hectare) by 10% for both Uzbekistan and Kazakhstan, will increase agricultural production (Profit) by 20% per hectare for Uzbekistan and by 25% per hectare for Kazakhstan and will reduce return flow coefficients for Uzbekistan from 0.4 to 0.3 and for Kazakhstan from 0.4 to 0.2. The IP calculated that the cost of the irrigation system investment would be paid by Uzbekistan and Kazakhstan at the rate of $25 per irrigated hectare.

The Assignment

The IP has to:

1. Use the average climate scenario for the flow data (Figure 4).
2. Recalculate the relevant coefficients for the Aral Game model.
3. Assess several alternative regional arrangements (coalition benefit allocations) and come up with two alternate regional cooperative arrangements for negotiation.

Analyses

1. Explain your calculations of all the coefficients that have to be re-estimated (or recalculated).
2. Explain the regional cooperative arrangements you want to simulate and suggest to the riparian states.
3. Report on the following for each of the simulations (in one table if possible):
    a. Short justification of the simulations selected
    b. Short description of the parameters used
    c. Coalitional values
    d. Energy produced
    e. Land under irrigation
    f. Water in Storage: Beginning and end of year.
    g. Water used by each riparian
    h. Water going to the Aral.
4. For each simulation suggest and calculate the Shapley Value allocation.
5. Discuss (using concepts from international law, negotiation, and cooperation theories) the stability of the agreement, using Loehman and Gately indexes.
6. Prepare < 1-page policy note for your presentation of the alternatives and the IP recommendation to the heads of states that will meet on November 17, 2016 at 12:30 pm.