Water sharing in Fergana Valley

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Abstract

This paper proposes a Social planner, Nash-Bargaining and Market-based allocations of water between Uzbekistan and Tajikistan, as well as the strategic interaction of those countries under serial monopoly setting. It is the first attempt to analyze water allocation from the part of the Syr-Darya river that flows through Uzbekistan to Tajikistan and back to Uzbekistan. Such geographical feature makes Uzbekistan both downstream and upstream country in relation to Tajikistan, which is uncommon for upstream-downstream problems. This work describes the equilibrium water consumption, prices, and transfers between two countries under Social planner and two decentralised water division mechanisms. Comparing solutions from the decentralised approaches, we can see that both market-based and Nash-Bargaining mechanisms allocate water in a Pareto optimal way. But these desired allocations are achieved through different magnitudes of transfers. Under the market solution, Uzbekistan receives the whole gain from the trade, while Tajikistan gains nothing. In contrast, Nash-Bargaining solution splits benefit from trade according to the bargaining power. Finally, water allocation is no longer Pareto efficient under serial monopoly setting: at least one county would set the price above the socially optimal level.

Contents

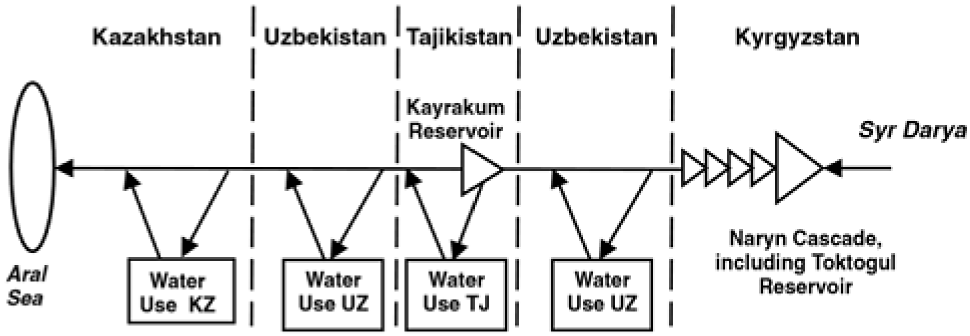
1 Introduction

Water in Central Asia plays a key role in the socio-economic development of its five nations (Kazakhstan, Kyrgyzstan, Uzbekistan, Tajikistan, and Turkmenistan). Nowadays, this region suffers from a number of water resources challenges that are shaped by the multitude of things, including science, economics, competing interests, and Soviet-era decisions. One of such issues is the problem of sharing Amu-Darya and Syr-Darya rivers. The major source of transborder river tensions is adversarial interests between upstream and downstream countries. Upstream countries (Kyrgyzstan and Tajikistan) use Syr-Darya's waters during winter in order to generate hydro-power electricity. However, this leads to water loss in summer for downstream countries (Kazakhstan, Turkmenistan, and Uzbekistan) who use water for irrigation. As a result, the agricultural system of downstream countries is in a stressful situation if too much water is used for hydro-power by upstream countries. The problem has its roots in Soviet-time policies. In Soviet times, the government applied a policy of high agricultural output, so the course of river flows were unnaturally changed to the fields of downstream countries. In order to offset the shortage of water of upstream countries, downstream countries had to provide supply of fuel. When the USSR collapsed in 1991 the two rivers (Amu- Darya and Syr-Darya) turned from domestic into international water systems. As a result, centralized water system was broken. Natural resources and electricity supplies from downstream to upstream countries declined drastically from 1991 onwards. So, after the breakdown of the Soviet Union five economies of the Central Asia were left with destroyed compensation system.

The situation is especially critical in the Fergana Valley region. The Fergana Valley spreads throughout Kyrgyzstan, Tajikistan, and Uzbekistan and rivers cross the borders of these countries approximately thirty times which makes water management even more complicated. In order to resolve disputes over Uzbekistan's priority in agriculture and Kyrgyzstan and Tajikistan's priority in generating electricity from hydro-power plants, Tajikistan and Uzbekistan signed an agreement in 2000, according to which Tajikistan receives fuel oil in exchange for more water for Uzbekistan. However, neither of the countries committed to the agreement afterwards.

The existing literature discusses the problem of Fergana Valley focusing on the relationship between Kyrgyzstan and Uzbekistan. However, little attention is paid to the hydro-power-irrigation conflict between Uzbekistan and Tajikistan. Moreover, there are some geographic features that make conflict between Tajikistan and Uzbekistan over Syr-darya river worth of attention: local geography permits water transfers from Uzbekistan to Tajikistan and from Tajikistan back to Uzbekistan (see the Figure 1). And since those countries located upstream usually have more power than their downstream members, it is ambiguous who is privileged in the given situation.

Figure 1: Syr-Darya water basin use



In this paper I propose a model of water distribution from upstream Uzbekistan (player 1U) into Tajikistan (player 2) and back to downstream Uzbekistan (player 1D). I study the social planner, Nash-Bargaining, market solution concepts, and also serial monopoly setting to find demand of water, prices and transfers of resources between Uzbekistan and Tajikistan under different interaction scenarios. Generally, there are different methods the scholars propose and analyze to resolve the water management problems, some of which are found to be effective, while others not. For instance, the traditional approaches to water management, such as interventionist [1] and market-based [2]one, have proved to be ineffective (Carraro et al, 2007). These methods are criticized for the failure to account

[1]under this approach the central authority controls water distributions

[2]water is allocated due to water trades, no control from the third party

for the transboundary nature of water, difficulties in transportation of water, uneven distribution of water in time and space and etc. There are some works (Demeke et al, 2013; Rausser and Simon, 1992) that advocate another approach to water management – negotiation approach. Those works claim that negotiated decisions are easier to adapt to local conditions [3].

Overall, this paper distinguishes from other papers due to the following. The upstream-downstream water quantity issue usually divides the states into two groups: suppliers (upstream countries) and consumers (downstream countries). For instance, the solution to the water sharing problem is when the dominant strategy of the upstream country is not to cooperate [4], while downstream country's dominant strategy is to cooperate. This is because of the linearity of the river direction: river flows from the upstream country to the downstream and no other way around. This model, however, considers the case when Syr-Darya river crosses Uzbekistan twice - flow from Kyrgyzstan into Uzbekistan, through Tajikistan, and back into Uzbekistan. Relative to Tajikistan, Uzbekistan consists of two parts – upstream and downstream. Therefore, the upstream Uzbekistan has incentive to cooperate with Tajikistan in order to make sure that Tajikistan cooperates with downstream Uzbekistan in return. In this model Tajikistan can be consumer (consumes water from upstream Uzbekistan) and supplier (sells water to downstream Uzbekistan) at the same time.

[3]They are not conflicting with national sovereignty, for instance

[4]to divert water in non-agreeable way

2 Literature Review

There are some works (Provencher and Burt, 1994; Supalla et al, 2002) that criticize the interventionist and market methods of water allocation among different countries. Thus, Provencher and Burt (1994) found that the central control approach and property rights approach are sub-optimal with risk-averse firms. Even though these approaches focus on efficient exploitation of ground water, they fail allocating water based on real-life issues. Similar conclusions are obtained by Supalla et al (2002) who apply auction theory to allocate water resources from Platte river between three states sharing it.

At the same time, the methods of negotiation are found to be more effective. Thus, Ambec and Sprumont (2000) developed a model of international water allocation with side payments. Authors characterize decentralized behavior (market with tradable water rights) and non-cooperative bargaining. They found non-cooperative bargaining rules that lead to optimal water allocation. Rausser and Simon (1992) proposed a non-cooperative multilateral bargaining model in which strategic behavior is explained through offer and counter-offer method. Adams et al. (1996) apply the Rausser-Simon model to water negotiations in California, while Simon et al. (2003) apply it to water negotiations in France. Simon et al. (2003) simulation results are in line with predictions of Rausser-Simon model: increasing the weight of one group (in the model there are one farmer group, two environmental groups, and water manager) makes this group and groups with similar preferences better off. Adams et al. (1996) also proposed the framework of water negotiation and found that the higher disagreement payoff of one group, the more bargaining power this group has.

When water resources are transboundary, especially in the problems of sharing an international river, countries experience a number of problems. Firstly, countries' well-being depends on actions of other countries through the quantity or quality of water. Secondly, agreements over water allocations should be voluntary and not conflicting with national sovereignty (Carraro et al, 2007).

Bennet et al. (1998) proposed a framework where two players negotiate over two issues, one of which is water issue. The model is applied to the Aral Sea water conflicts, particularly to the water sharing problem between Tajikistan and Uzbekistan. There are two games played by these countries: in the first one Tajikistan decides whether to develop the Amu Darya river to gain additional water, whereas Uzbekistan has to decide whether or not to support rebel groups in Tajikistan; in the second game, Tajikistan has to decide whether to abate air pollution affecting Uzbekistan or not, while Uzbekistan has to decide whether to subsidize abatement activities in Tajikistan. The authors found that if the games were played separately, the outcome would be inefficient, but if two games were played in a nested way, both Uzbekistan and Tajikistan would be better off.

Richards and Singh (1996) develop a 2-level game of two countries bargaining over water allocation using framework of Nash-bargaining solution. In their model country has a domestic negotiation over water allocations and international negotiations. The countries initial allocation of water (domestic and international) are assumed to be inefficient. In Richards and Singh's model, there are several alternative (simultaneous and sequential) cooperative bargaining games, and those games varies according to the level of utility countries gain from disagreement. The outcome corresponds to disagreement utility as well: the greater is the disagreement payoff, the stronger is the bargaining position of the group or country. This result is in line with Adams et al (1996) finding. Richards and Singh (1996) work shows, that if within and across country negotiations over water allocation were made at the same time, the result differs from the case when two levels of negotiations were made sequentially. The result is important in understanding why there is often disagreement not only over water allocations, but even over the method of negotiation about water allocations. A key finding in their model is that commitment to domestic negotiations can improve the bargaining position at the international level.

Ansink and Weikard (2008) proposed a model in which countries have overlapping claims to water and the conflict over water is revealed through contested property rights to water. In the model countries may prefer to engage in conflict, hoping for a favourable settlement of the bargain through a third-party intervention instead of bargaining an efficient allocation. If the intervention fails, conflict may occur. Thus, the likelihood of third-party intervention can prevent water trade.

Gately (1974) develops a framework of the assignment of both the electricity and its cost of production among Indian states that can split hydroelectric plants. The paper pays attention to the problem of optimal and acceptable division of the gains from cooperation and calculates the costs of providing power to the region of the case study under different degree of cooperation.

Jorgensen and Zaccour (2001) define a method of sharing a benefit gained when two states or regions decided to coordinate their policies to diminish downstream pollution. The benefit from cooperation is the difference between the joint payoff and the disagreement payoff. In order to split the benefit from coordination, the inter-temporal decomposition scheme for the total side payment was offered.

3 Model set up

In this section the model set up of water sharing between Uzbekistan and Tajikistan is provided. There are two players in the model: player 1 (Uzbekistan) and player 2 (Tajikistan). Suppose that those two players have some utilities from water consumption. Player 2 uses water resources for hydro-power plants to generate electricity, while player 1 is engaged in agriculture. Consider the allocation of river water between those two players. Suppose initially each country is endowed with some amount of water $\overline{W}_i$. The part of Uzbekistan which is located upstream relative to Tajikistan has an opportunity to divert water to Tajikistan. Denote the amount of water diverted to Tajikistan to be W_2^u. Water from Tajikistan flows into downstream Uzbekistan. Finally, downstream Uzbekistan can only receive water from Tajikistan but cannot divert it to anywhere else (actually, downstream Uzbekistan diverts water to Kazakhstan, but its out of the scope of this paper). Apart from the water player 1 and player 2 consume some amounts of the numeraire good, Y_1 and Y_2, respectively. The notations can be summarised in the below:

- W_i - the amount of consumed water by player i

- $\overline{W}_2$ - the endowment of water of player 2 (Tajikistan).

- W_2^U - the amount of water diverted to Tajikistan from upstream Uzbekistan

- $\overline{W}_1 = \overline{W}_{1D} + \overline{W}_{1U}$ - player 1's (Uzbekistan's) endowment of water from upstream ($\overline{W}_{1U}$) and downstream part ($\overline{W}_{1D}$)

- $\overline{W}$ - the total endowment of water. $\overline{W} = \overline{W}_1 + \overline{W}_2$.

- Y_i - the consumed numeraire commodity by player i

- $\overline{Y_i}$ - the endowment of numeraire commodity of player i.

Also, assume that the water consumption is feasible and nonewasteful. So, the sum of water consumption by each player must be equal to the total water endowment:

$$\overline{W} = W_2 + W_{1D} + W_{1U} \tag{1}$$

The feasibility constraint (1) indicates that the sum of water demands from player 1 and player 2 should be equal to the total endowment of water $\overline{W}$. Regarding player 1, it is clear that the demand of water represents the forgone water resources used for irrigation. Player 2, on the other hand, does not consume water directly, since ideally water used in hydro-electricity should not be lost, it should pass to downstream consumers. However, in reality downstream consumers receive less amount of water than supposed to, since water evaporates from reservoirs. Water evaporation from reservoirs could be one of the major causes of flood or drought conditions (Demeke et al, 2013). Water evaporation depends on several factors, such the height of hydropower plant, the size of reservoir area, and climate conditions. But the intensity of energy generation from plants significantly increases evaporation (Sommers, 2004). So in this paper water demand by player 2 is an amount of evaporated water resulted by high intensity of energy generation.

Folowing Gately (1974) irrigation utility increases with water in decreasing way. Generally, hydro-power output is proportional to flow of water multiplied by height difference between where the water enters into the hydro system and where it leaves it (Campbell, 2010). So in this model the utility from generating hydro-power linearly depends from consumed water (W_2). The utility functions of upstream player 1, downstream player 1, and player 2 are represented by:

$U_1(W_{1U}, W_{1D}, Y_1) = \sqrt{W_{1U}} + \sqrt{W_{1D}} + Y_1$ - utility of the player 1

$U_2(W_2) = cW_2 + Y_2$ - utility of the player 2

Suppose initially, player 1 and player 2 consume endowed levels of water and numeraire good. However, it is possible that upstream player 1 wants to divert some of the water resources to downstream player 1 (because of weather conditions irrigation becomes more efficient in downstream Uzbekistan, for instance). Or upstream player 1 wants to sell water to player 2 to consume more numerarire good. This paper aims to investigate all optimal cases of water transfers between two countries under negotiation (Nash-Bargaining) and market solutions.

Richards and Singh (1996) in their paper assume that initial allocations of water is sub-optimal, because of changing circumstances of populations and economic conditions. They denote the deviation payoff as the payoff from initial amount of water. Following Richards and Singh (1996) I assume that deviation utilities are the utilities from consuming endowed level of water. The deviation utilities of player 1 and player 2 are the following:

$D_1 = \sqrt{\overline{W}_{1U}} + \sqrt{\overline{W}_{1D}} + \overline{Y}_1,$

$D_2 = c\overline{W}_2 + \overline{Y}_2$

The optimal allocation of water can be expressed as:

$U_1(W_{1U}^*, W_{1D}^*, Y_1^*) = \sqrt{W_{1U}^*} + \sqrt{W_{1D}^*} + Y_1^* = \sqrt{W_{1U}^*} + \sqrt{W_{1D}^*} + \overline{Y}_1 + t$

$U_2(W_2^*, Y_2^*) = cW_2^* + Y_2^* = cW_2^* + \overline{Y}_2 - t$

Here t denotes wealth transfers from player 2 to player 1, defined as the difference between equilibrium and endowment amount of the numeraire good Y:

$t = Y_1^* - \overline{Y}_1$ - transfers of player 1 (Uzbekistan)

$-t = Y_2^* - \overline{Y}_2$ - transfers of player 2 (Tajikistan)

4 Social Planner Solution

The focus of this paper is to analyse the efficiency of two decentralised water allocation mechanisms, so I provide firstly the social planner solution. In the model there are two countries, Uzbekistan (player 1) and Tajikistan (player 2), two types of goods, water (W_{1D}, W_{1U} for downstream player 1 and upstream player 1, respectively, W_2 for player 2) and a numeraire good (Y_1 for player 1 and Y_2 for player 2). Suppose there is a benevolent social planner whose maximisation problem is the following:

$$\max_{W_{1D},W_{1U}} \sqrt{W_{1D}} + \sqrt{W_{1U}} + cW_2 + \bar{Y} \tag{2}$$

subject to constraints:

$$W_{1D} + W_{1U} + W_2 = \overline{W}$$

$$W_2 \geq 0$$

$$W_{1U} \leq \overline{W}_{1U}$$

$$W_{1U} + W_2 \leq \overline{W}_{1U} + \overline{W}_2$$

The social planner is an omniscient institution that would allocate the entire available water amount in the most efficient manner. In the above situation the social planner seeks to maximize the sum of benefits of both upstream and downstream Uzbekistan and Tajikistan in the Fergana Valley region from selling and buying water, subject to the water availability constraint. So, the utility functions of upstream player 1, player 2 and downstream player 1 enter the objective function of the social planner. The constraints tell that upstream Uzbekistan can at maximum consume $\overline{W}_{1U}$ as it cannot receive water from downstream parts. Tajikistan is able to both receive and divert water, and downstream Uzbekistan can only receive water. Now I focus on the situation when water is diverted from upstream player 1 to player 2 and further to downstream player 1. Apart from this there is a number of cases to the solution to this problem, which are described in Appendix1. They capture different scenarios, such as the draught caused by over-consumption of water by Upstream player 1, or over-flooding of downstream player 1.

Suppose that $\overline{W}_{1U} \geq \frac{1}{4c^2}$; $\overline{W}_{1D} \leq \frac{1}{4c^2}$; $\overline{W} \geq \frac{1}{2c^2}$.

In order to efficiently allocate water resources, the social planner will equate the marginal benefits of each country from water consumption. Since both upstream and downstream player 1 have similar utilities from water consumption and player 2's utility differs, maximisation problem dictates to allocate the equal amount of water between upstream and downstream player 1. Moreover, the greater the marginal utility water of player 2, c, the more water would be granted to player 2 and the less water to upstream and downstream player 1. The solution is the following:

$W_{1D} = \frac{1}{4c^2}$ - demand for water by player 1 downstream;

$W_{1U} = \frac{1}{4c^2}$ - demand for water by player 1 upstream;

$W_2 = \overline{W} - \frac{1}{2c^2}$ - demand for water by player 2.

So, theoretically the social planner achieves optimal allocation. In reality, it is questionable whether such an institution is feasible. Moreover, the social planner's decisions might not reflect the characteristics of the individual countries participating in a water allocation program. An individual country may be unwilling to take a part in a program developed by a social planner, which aims to maximize aggregate benefits. For instance, there could be different attitudes to risk between a country and a planner. These differences could result in partial compliance, and create an incentive to deviate in order to achieve a higher level of personal benefits.

5 Nash-Bargaining solution

To begin with, suppose that there are negotiations between players and reallocation of water is possible. The asymmetric Nash Bargaining solution is used in order to capture the difference in the bargaining power. α denotes the bargaining power of player 1 (Uzbekistan). If α is greater than $\frac{1}{2}$ than player 1 has more bargaining power than player 2. D_{1U} and D_{1D} denote disagreement payoffs which two players obtain if they cannot agree on the distribution of final payoffs between them. The disagreement payoffs are payoffs from consuming endowed amount of water.

Following Nash (1950), the maximisation problem is:

$$\begin{aligned} \max_{U_1,U_2} \quad & (U_1 - D_1)^{\alpha}(U_2 - D_2)^{1-\alpha} \\ \text{s.t.} \quad & U_1 + U_2 \quad \leq \quad N \end{aligned} \tag{3}$$

where

$$N = \sqrt{W^*_{1U}} + \sqrt{W^*_{1D}} + \overline{Y}_1 + \overline{Y}_2 + cW^*_2 \tag{4}$$

N is the maximum total utility available, where W^*_{1U}, W^*_{1D}, and W^*_2 denote the optimal allocation of water.

Solution to the maximisation problem (3) gives us utilities from water consumption for player 1 and player 2. Player 1's utility is:

$U_1 = (1 - \alpha)D_1 + \alpha(N - D_2)$

Substituting the expression (4) instead of N gives us the following:

$U_1 = (1 - \alpha)(\sqrt{\overline{W}_{1D}} + \sqrt{\overline{W}_{1U}}) + \alpha(\sqrt{W^*_{1D}} + \sqrt{W^*_{1U}}) + \alpha c(W^*_2 - \overline{W}_2) + \overline{Y}_1$

The same for the player 2:

$U_2 = \alpha D_2 + (1 - \alpha)(N - D_1)$

$U_2 = \alpha c\overline{W_2} + (1-\alpha)cW_2^* + (1-\alpha)(\sqrt{W_{1D}}^* - \sqrt{\overline{W}_{1D}} + \sqrt{W_{1U}^*} - \sqrt{\overline{W}_{1U}}) + \overline{Y}_2$

Solution from Social Planner problem gives W_2^*, W_{1U}^*, and W_{1D}^*

Let us assume again $\overline{W}_{1U} \geq \frac{1}{4c^2}$; $\overline{W}_{1D} \leq \frac{1}{4c^2}$; $\overline{W} \geq \frac{1}{2c^2}$:

$W_{1D}^* = W_{1U}^* = \frac{1}{4c^2}$, $W_2^* = \overline{W} - \frac{1}{2c^2}$

Then, solution to Nash-Bargaining problem can be written more explicitly as:

$U_1(W_{1D}^*, W_{1U}^*, Y_1^*) = (1-\alpha)(\sqrt{\overline{W}_{1D}} + \sqrt{\overline{W}_{1U}}) + \frac{\alpha}{2c} + \alpha c(\overline{W} - \overline{W_2}) + \overline{Y_1}$;

$U_2(W_2^*, Y_2^*) = \alpha c\overline{W_2} + (1-\alpha)c\overline{W} + \frac{1-\alpha}{2c} - (1-\alpha)(\sqrt{\overline{W}_{1D}} + \sqrt{\overline{W}_{1U}}) + \overline{Y_2}$

We also know that at the optimum allocation of water, transfers are the difference between optimum and endowment amount of numeraire good Y. Unlike the optimal amounts of water, however, the transfers are not uniquely determined. For instance the transfers obtained from Nash-Bargaining solution are different from those obtained from Market solution. Hence, $U_1(W_1^*, Y_1^*)$ can be expressed also as:

$U_1(W_1^*, Y_1^*) = \sqrt{W_{1D}^*} + \sqrt{W_{1U}^*} + \overline{Y_1} + t$

So transfers of player1 (Uzbekistan) are given by:

$t = (1-\alpha)(\sqrt{\overline{W}_{1D}} + \sqrt{\overline{W}_{1U}}) + \alpha c(\overline{W} - \overline{W_2}) + \frac{\alpha-2}{2c}$

So we found how transfers can help optimally divide water between two countries using Nash-Bargaining solution. Since the essential problem faced by the bargainers is that the initial allocation of water is suboptimal and there is a need to equate the marginal utilities of water for each player, such solution will not be feasible without some compensatory transfers. It should be noted that transfers obtained from the Nash bargaining solution depend on the deviation utilities of the players engaged in bargaining. Richards and Singh (1996) water transfers also depend on threat points (deviation utilities).

In order to see whether players are better of from the trade under Nash-Bargaining solution, let's calculate the gain from the trade $U_i^* - D_i$:

$U_1^* - D_1 = \alpha[c(\overline{W}_{1D} + \overline{W}_{1U}) - (\sqrt{\overline{W}_{1D}} + \sqrt{\overline{W}_{1U}}) + \frac{1}{2c}]$ - utility gain of player 1

$U_2^* - D_2 = (1-\alpha)[c(\overline{W}_{1D} + \overline{W}_{1U}) - (\sqrt{\overline{W}_{1D}} + \sqrt{\overline{W}_{1U}}) + \frac{1}{2c}]$ - utility gain of player 2

So, under NB solution total gain from the negotiation is divided among two players. And which player gains more depends on the bargaining power, α. If α is greater than $\frac{1}{2}$, then player 1 gains more than player 2. Anyway, both players are better off from the trade.

6 Market Solution

In the following analysis, let's assume that countries may engage in selling rights to their water endowments in the market place (say, on an annual basis or through longer term contracts). Let P_1 and P_2 be the price of the water sold by player 1 and player 2, respectively. In other words, player 2 buys water from upstream player 1 at the price of P_1 and sells it to downstream player 1 at the price of P_2. In the next section I introduce a serial monopoly setting where players can set the prices themselves. But for this moment assume that two players act as price takers. Since each player represents a country, not a concrete individual, we could assume that a player stands for a large number of identical consumers of the country.

Player 1's Maximisation Problem:

$$\max_{W_{1D}, W_{1U}, Y_1} \sqrt{W_{1D}} + \sqrt{W_{1U}} + Y_1 \tag{5}$$

s.t.

$$P_2 W_{1D} + P_1 W_{1U} + Y_1 \leq P_2 \overline{W}_{1D} + P_1 \overline{W}_{1U} + \overline{Y}_1 \tag{6}$$

$$W_{1U} \leq \overline{W}_{1U}$$

$$W_{1D} \geq \overline{W}_{1D}$$

Constraints are such that upstream player 1 cannot consume more than endowed amount of water and downstream player 1 cannot consume less than endowed amount of water. This is because upstream player 1 is unable to receive water from it's upstream part or player 2, while downstream player 1 is unable to send water to it's upstream part or Tajikistan.

Player 2's Maximisation Problem:

$$\max_{(W_2;Y_2)} cW_2 + Y_2$$

s.t.

$$P_1W_2^U + P_2W_2 + Y_2 \leq P_2\overline{W}_2 + P_2W_2^U + \overline{Y}_2$$

$$W_2^U \geq 0$$

$$W_2 \leq \overline{W}_2 + W_2^U$$

$$W_2 \geq 0$$

According to constraints player 2 could buy water from upstream player 1 and sell water to downstream player 1.

Under the assumptions that $\overline{W}_{1U} \geq \frac{1}{4c^2}$; $\overline{W}_{1D} \leq \frac{1}{4c^2}$; $\overline{W} \geq \frac{1}{2c^2}$ solutions are the following:

$W_{1D} = \frac{1}{4P_2^2}$; - water demand by downstream player 1

$W_{1U} = \frac{1}{4P_1^2}$; - water demand by upstream player 1.

Player 2 agrees to demand and supply any amount of water unless $P_1 = P_2 = c$

So, at the equilibrium, in which market clears and demand of water equals to supply, the optimal water consumption by each player are the following:

$$W_{1D} = \frac{1}{4c^2};\ W_{1U} = \frac{1}{4c^2};\ W_2 = \overline{W} - \frac{1}{2c^2}; \tag{8}$$

The central question of this problem is whether the outcome of the market allocation is Pareto optimal. From the social planner problem we know that the socially desired allocation is exactly the one we obtained above. Such allocation can be achieved with the following equilibrium transfers and prices:

$P_1 = P_2 = c$

$t = c(\overline{W}_{1D} - \frac{1}{4c^2}) + c(\overline{W}_{1U} - \frac{1}{4c^2})$ - transfers of player 1

For the player 2 transfers are the opposite sign of t. So, we found that market can deliver optimal allocation of water by an appropriate redistribution of wealth through transfers t. Since one of the commodities is a numeraire good, the optimal allocation can be achieved through wealth transfers. Note that the desired allocation could also be achieved by directly transferring endowments, but since our commodity is a water, it would be impractical.

Also, comparing results of social planner and market setting, competitive prices are equal to shadow prices on water resources constraints. So we can say that the prices of water reflect their marginal social values. The derivations see in the Appendix 2.

Finally, by comparing the gains from the trade it comes that, player 1 is better off from the trade, while player 2 is indifferent:

$U_1^* - D_1 = c(\overline{W}_{1D} + \overline{W}_{1U}) - (\sqrt{\overline{W}_{1D}} + \sqrt{\overline{W}_{1U}}) + \frac{1}{2c}$ - utility gain of player 1

$U_2^* - D_1 = 0$ - utility gain of player 2.

In other words, player 1 takes the whole gain from the trade.

7 Serial monopoly analysis.

In the previous section it was illustrated how the market clearing conditions allocated water in an efficient way. In this section, I consider the possible inefficiencies caused by the strategic interaction between two players. Suppose that instead of the prices that are determined by the market clearing conditions, both player 1 and player 2 set the level of price P_1 and P_2 to maximize their utility from water consumption. In a standard monopoly situation, member of the distribution channel typically adds a markup to the markups of all channel members above it, which leads to a double marginalization problem, where the prices would exceed the opportunity cost of water for the members. But here, since player 2 is not only a client of player 1, but also a seller, the interesting situation could occur. Intuitively, we can expect that player 1 anticipates that player 2 will markup the price P_2, so in order to guarantee enough water consumption for it's downstream part, it should not set too high price for water from it's upstream part.

For simplicity of the analysis let's assume $\overline{W}_{1D} = 0, \overline{W}_2 = 0$. This implies that $\overline{W} = \overline{W}_{1U}$, so initially all water resources are allocated in the upstream player 1. Let $W_2^u(P_1)$ be the amount of water player 2 buys from player 1. Player 1 solves the following maximisation problem:

$$\max_{W_{1D},P_1} \sqrt{\overline{W}_{1U} - W_2^u(P_1)} + \sqrt{W_{1D}} - P_2 W_{1D}(P_2) + P_1 W_2^u(P_1)$$

The objective function tells us that player 1 gains the utility from water consumption, receives $P_1 W_2^u(P_1)$ by selling water from it's upstream part and has to pay $P_2 W_{1D}$ in order to get water for it's downstream part. Solving this problem gives us optimal P_1, the price of water sold to player 2 and W_{1D}, optimal demand of water of downstream player 1. At the same time, Player 2's maximisation problem is:

$$\max_{W_2^u, P_2} \; c[W_2^u - W_{1D}(P_2)] + P_2 W_{1D}(P_2) - P_1 W_2^u$$

s.t.:

$$W_2^u - W_{1D} \geq 0$$

Player 2 maximises total utility with respect to W_2^u, the amount of water bought from player 1 and P_2, price of sold water. The objective function tells that player 2 gains utility from water consumption (electricity generation), earns $P_2 W_{1D}(P_2)$ from selling water to player 1 and pays $P_1 W_2^u$ for water from upstream player 1. To guarantee that player 2 has enough water resources to sell water to downstream player 1, the total utility is maximised subject to the above constraint.

Player 2 consumes the amount of water left after selling water to downstream player 1:

$$W_2 = W_2^u - W_{1D}$$

At the equilibrium market clears and demand of water should be equal to supply of water for both players. In Appendix 3 there is in detail the steps to solve the serial monopoly setting. The solution can be summarised in the following:

If $\overline{W}_{1U} < \frac{17}{16c^2}$:

$$P_1 = \frac{1}{4}\sqrt{\frac{17}{\overline{W}_{1U}}}$$

$$P_2 = \frac{1}{2}\sqrt{\frac{17}{\overline{W}_{1U}}}$$

$$W_2^{u*} = W_{1D}^* = \frac{\overline{W}_{1U}}{17}$$

$$W_{1U}^{*} = \frac{16\overline{W}_{1U}}{17}$$

For such case player 2 buys water only to resell it to downstream player 1. So, consumption of water, W_2, is equal to 0. And both players set prices grater than c.

If $\overline{W}_{1U} = \frac{17}{16c^2}$:

$$P_1 = c$$

$$P_2 = 2c$$

$$W_{1D}^{*} = \frac{1}{16c^2}$$

$$W_2^{u*} \in [\frac{1}{16c^2}; \overline{W_{1U}}]$$

$W_{1U}^{*} = \overline{W}_{1U} - W_2^{u*}$ and $W_2^{*} = W_2^{u*} - W_{1D}^{*}$

Calculating benefits from trade:

Suppose $\overline{W}_{1U} < \frac{17}{16c^2}$:

Player 1's benefit:

$U_1 - D_1 = \frac{(19-4\sqrt{17})\sqrt{\overline{W}_{1U}}}{4\sqrt{17}}$

Player 2's Benefit:

$U_2 - D_2 = \frac{\sqrt{\overline{W}_{1U}}}{4\sqrt{17}}$.

If $\overline{W}_{1U} = \frac{17}{16c^2}$:

Player 1's benefit is $\frac{19-4\sqrt{17}}{16c}$

Player 2's benefit is $\frac{1}{16c}$

Comparing solutions with market one we can deduce that:

- under serial monopoly at least one player sets the price of water above c, while under market setting both players set price equal to c

- Player 1's benefit is less under serial monopoly than under market setting.

- Player 2 benefits more under serial monopoly than under market one.

- Total benefit (the sum of benefits of player 1 and player 2) is greater under market solution.

8 Conclusion

In this paper I propose a model of water sharing between two members of Fergana Valley conflict, Uzbekistan and Tajikistan. I consider water distribution from upstream Uzbekistan (player 1U) into Tajikistan (player 2) and back to downstream Uzbekistan (player 1D). I apply social planner, Nash-Bargaining, market solutions, and also serial monopoly setting to find demand of water, prices and transfers of water resources between those two countries under different scenarios. Such scenarios include different weather conditions like flooding or drought in each of these countries.

In usual upstream-downstream agent problems, upstream agent has more power than the downstream one due to it's geographical advantage. However geographical position of the Fergana Valley is such that river flows through Uzbekistan to Tajikistan and back to Uzbekistan. Therefore, Tajikistan could be a buyer and seller of water resources from the same Uzbekistan simultaneously. This could result in interesting interactions between these countries.

One of the results of the model is that it is possible to achieve efficient water allocations between Uzbekistan and Tajikistan under market approach. Assuming that there exist prices of water resources, market can optimally deliver water from one country to another. This is especially crucial in Fergana Valley region, where rivers cross different countries (including Uzbekistan and Tajikistan) about thirty times, so that centralized planning would likely to fail.

However, comparing transfers from market-based and Nash-Bargaining approaches, we can see that they are not the same. Thus, under market-based approach there is a linear dependence on water endowments, while under Nash-Bargaining approach there is non-linear dependence. So, even though both approaches divide water optimally, they do it with different proportions. And comparing gains from the trade, Nash-Bargaining solution divides the gain from the trade by proportion α, which is the bargaining power of the country. In contrast, market solution splits gain unevenly as player 1 receives the whole gain and player 2 gains nothing. And comparing two approaches we can say that market one transfers gains from one player to another more unequally than NB approach.

Finally, serial monopoly setting shows that at least one country would set a price greater than socially optimal level. When Uzbekistan sells water at the socially optimal price level, its downstream part receives more water from Tajikistan. This is because Uzbekistan anticipates that Tajikistan will markup the price, so in order to prevent high price for its downstream consumption, it should not set too high price for it's upstream part. Comparing serial monopoly analysis with market one we can see that total benefit is less under the serial monopoly setting than under market one. It would be interesting to see in the future work the strategic interactions with other important parts of the chain of Fergana Valley conflict, such as Kazakhstan and Kyrgyzstan and add stochastic fluctuations to the model.

References

[1] Abbink, K., Moller, L.C. and O'Hara, S., 2005. *The Syr Darya River conflict: an experimental case* study (No. 2005-14). CeDEx Discussion Paper Series.

[2] Ambec, S. and Sprumont, Y., 2002. *Sharing a River.* Journal of Economic Theory,2(107), pp.453-462.

[3] Ansink, E. and Weikard, H.P., 2009. *Contested water rights.* European Journal of Political Economy, 25(2), pp.247-260.

[4] Bennett, L.L., Ragland, S.E. and Yolles, P., 1998. *Facilitating international agreements through an interconnected game approach: The case of river basins. In Conflict and cooperation on trans-boundary water resources* (pp. 61-85). Springer, Boston, MA.

[5] Bernauer, T. and Siegfried, T., 2012. *Climate change and international water conflict in Central Asia. Journal* Journal of Peace Research, 49(1), pp.227-239.

[6] Carraro, C., Marchiori, C. and Sgobbi, A., 2007. *Negotiating on water: insights from non-cooperative bargaining theory.* Environment and Development Economics, 12(2), pp.329-349.

[7] Demeke, T. A., Marence, M., Mynett, A. E. (2013). *Evaporation from reservoirs and the hydropower water footprint. proceedings from Africa,* 16-18.

[8] Gately, D., 1974. Sharing the gains from regional cooperation: A game theoretic application to planning investment in electric power. *International Economic Review, pp.195-208.*

[9] Jørgensen, S. and Zaccour, G., 2001. Time consistent side payments in a dynamic game of downstream pollution. *Journal of economic dynamics and control, 25(12)*, pp.1973-1987.

[10] Parrachino, I., Dinar, A. and Patrone, F., 2006. Cooperative game theory and its application to natural, environmental, and water resource issues: 3. application to water resources. *The World Bank.*

[11] Provencher, B. and Burt, O., 1994. A private property rights regime for the commons: The case for groundwater. American *Journal of Agricultural Economics, 76(4)*, pp.875-888.

[12] Rausser, G.C. and Simon, L.K., 1992. A noncooperative model of collective decision making: A multilateral bargaining approach.

[13] PRichards, A. and Singh, N., 1997. Two level negotiations in bargaining over water. *Springer, Boston, MA.*, p 257-273

[14] Supalla, R., Klaus, B., Yeboah, O. and Bruins, R., 2002. A GAME THEORY APPROACH TO DECIDING WHO WILL SUPPLY INSTREAM FLOW WATER *JAWRA Journal of the American Water Resources Association, 38(4)*, pp.959-966.

[15] Teasley, R.L. and McKinney, D.C., 2011. Calculating the benefits of transboundary river basin cooperation: Syr Darya Basin. *Journal of Water Resources Planning and Management, 137(6),* pp.481- 490.

9 Appendix 1

Here I provide different water allocation scenarios under flooding/drought weather conditions:

1. Suppose that $\overline{W}_{1D} > \frac{1}{4c^2}$; $\overline{W}_{1U} > \frac{1}{4c^2}$;

Then, solution to the maximisation problem of the social planner/market solution is the below:

$W_{1D} = \overline{W}_{1D}$; $W_{1U} = \frac{1}{4c^2}$; $W_2 = \overline{W}_2 + \overline{W}_{1U} - \frac{1}{4c^2}$

At the price of $P_1 = c$ upstream player 1 sells water to player 2, but player 2's hydropower station evaporates the whole amount of water, so downstream player 1 does not receive any amount of water from player 2. Equilibrium prices and transfers are given by:

$P_1 = c$;

$t = c(\overline{W}_{1U} - \frac{1}{4c^2})$;

2. The next situation occurs when player 1 upstream uses the whole endowment water for crops, so there is a drought of the water channel from player 1 upstream to player 2. Player 2 releases water from its own endowment to generate electricity and discharge some amount of it to player 1 downstream (part of water evaporates after electricity generation).

So upstream Uzbekistan does not sell water to Tajikistan, but Tajikistan sells water to downstream Uzbekistan at the price of c:

$$W_{1D} = \frac{1}{4c^2};\ W_{1U} = \overline{W}_{1U};\ W_2 = \overline{W}_2 + \overline{W}_{1D} - \frac{1}{4c^2}$$
$$\text{if } \overline{W}_{1D} \leq \frac{1}{4c^2};\ \overline{W}_{1U} < \frac{1}{4c^2};\ \overline{W} \geq \overline{W}_{1U} + \frac{1}{4c^2};$$

Equilibrium prices and transfers are:

$P_2 = c;$

$t = c(\overline{W}_{1D} - \frac{1}{4c^2});$

3. This is an extreme situation when the drought of water from player 1 is combined with total evaporation of water in player 2's hydro-power station. Here no one buys or sells in the market, both Tajikistan and Uzbekistan consume endowed amount of water. Hence, transfers are equal to 0:

$$W_{1D} = \overline{W}_{1D};\ W_{1U} = \overline{W}_{1U};\ W_2 = \overline{W}_2$$
$$\text{if } \overline{W}_{1D} > \frac{1}{4c^2};\ \overline{W}_{1U} < \frac{1}{4c^2};$$

Equilibrium transfers:

$t = 0$

4. Under this scenario player 2 diverts the whole amount of water, but player 1 upstream experiences a drought.

$$W_{1D} = \overline{W}_{1D} + \overline{W}_2;\ W_{1U} = \overline{W}_{1U};\ W_2 = 0;$$
$$\text{if } \overline{W} < \frac{1}{2c^2};\ \overline{W}_{1U} < \frac{\overline{W}}{2};$$

Equilibrium transfers and prices are:

$P_1 = \frac{1}{2\sqrt{\overline{W}_{1D}+\overline{W}_2}}$

$t = \frac{-\overline{W}_2}{2\sqrt{\overline{W}_{1D}+\overline{W}_2}}$

5. Finally, this the case when water flows from player 1 upstream through player 2 into downstream player1 without any loss of water. Player 2 water from the hydro-power station does not evaporate:

$$W_{1D} = W_{1U} = \frac{\overline{W}}{2} W_2 = 0;$$

$$\text{if } \overline{W}_{1U} \geq \frac{\overline{W}}{2}; \, \overline{W}_2 \geq 0;$$

Equilibrium transfers and prices are:

$P_1 = P_2 = \frac{1}{\sqrt{2\overline{W}}}$

$t = \frac{-\overline{W}_2}{2\sqrt{2\overline{W}}}$

10 Appendix 2

This section shows that the market price of water is equal to the shadow price.

From the maximisation problem (2) set up the Lagrangian for the social planner problem:

$L = \sqrt{W_{1D}} + \sqrt{W_{1U}} + cW_2 + \lambda_3(\overline{W} - W_{1D} - W_{1U} - W_2) + \mu W_2 + \lambda_1(\overline{W}_{1U} - W_{1U}) + \lambda_2(\overline{W}_{1U} + \overline{W}_2 - W_{1U} - W_2)$

The first order conditions are:

$$\frac{\partial L}{\partial x} = 0 \to \frac{1}{2\sqrt{W_{1D}}} - \lambda_3 = 0 \to \lambda_3 > 0$$

$$\frac{\partial L}{\partial y} = 0 \to \frac{1}{2\sqrt{W_1 U}} - \lambda_3 - \lambda_1 - \lambda_2 = 0$$

$$\frac{\partial L}{\partial z} = 0 \to c - \lambda_3 + \mu - \lambda_2 = 0$$

Since λ_3 is equal to 0, λ_1 and λ_2 are equal to c and these are the shadow prices for W_{1U} and W_{1D}, respectively.

From the maximisation problem (5) set up the Lagrangian for the market problem:

L=$\sqrt{W_{1D}} + \sqrt{W_{1U}} + P_2(\overline{W}_{1D} - W_{1D}) + P_1(\overline{W}_{1U} - W_{1U}) + \overline{Y}_1 + \alpha_1(\overline{W}_{1D} - W_{1U}) + \alpha_2(W_{1D} - \overline{W}_{1D})$

For $\overline{W}_{1U} \geq \frac{1}{4c^2}$; $\overline{W}_{1D} \leq \frac{1}{4c^2}$; $\overline{W} \geq \frac{1}{2c^2}$. the market solution is $P_1 = P_2 = c$

Hence, market prices are equal to shadow prices.

11 Appendix 3

This section derives the solution to the monopoly problem.

Player 1's maximisation problem:

$$\max_{W_{1D}(P2),P_1} \sqrt{\overline{W}_{1U} - W_2^u(P_1)} + \sqrt{W_{1D}} - P_2 W_{1D}(P_2) + P_1 W_2^u(P_1)$$

First order conditions give:

$$W_{1D}(P_2) = \frac{1}{4P_2^2}$$

$$P_1 = \frac{1}{2\sqrt{W_{1U}}} - \frac{W_2^u(P_1)}{W_2'^u(P_1)}$$

Player 2's maximisation problem:

$$\max_{W_2^u(P_1),P_2} c[W_2^u(P_1) - W_{1D}(P_2)] + P_2 W_{1D}(P_2) - P_1 W_2^u(P_1)$$

s.t.:

$$W_2^u(P_1) - W_{1D}(P_1) \geq 0$$

Set up the Lagrangian:

$$L = c[W_2^u(P_1) - W_{1D}(P_2)] + P_2 W_{1D}(P_2) - P_1 W_2^u(P_1) + \lambda[W_2^u(P_1) - W_{1D}(P_2)]$$

First order conditions give: $P_2 = 2P_1$

If $\lambda > 0$, then $W_2^u(P_1) = W_{1D}(P_2)$

if $\lambda = 0$, then $W_2^u(P_1) \in [W_{1D}(P_1); \overline{W}_{1U}$

$P_1 = c, P_2 = 2c$

At the equilibrium:

If $P_1 > c$:

$W_{1D} = W_2^u = \frac{1}{16P_1^2}$

From player 1's first order condition:

$P_1 = \frac{1}{2\sqrt{W_{1U}}} + \frac{P_1}{2}$, so $W_{1U} = \frac{1}{P_1^2}$

Since $\overline{W}_{1U} = W_{1U} + W_{1D} + W_2$,

$\overline{W}_{1U} = \frac{1}{P_1^2} + \frac{1}{16p_1^2} + 0 = \frac{17}{16P_1^2}$. From this we obtain solution:

For $\overline{W}_{1U} < \frac{17}{16c^2}$:

$$P_1 = \frac{1}{4}\sqrt{\frac{17}{\overline{W}_{1U}}}$$

$$P_2 = \frac{1}{2}\sqrt{\frac{17}{\overline{W}_{1U}}}$$

$$W_2^u * = W_{1D}^* = \frac{\overline{W}_{1U}}{17}$$

$$W_{1U}^* = \frac{16\overline{W}_{1U}}{17}$$

For such case player 2 buys water only to resell it to downstream player 1. So, consumption of water, W_2, is equal to 0. And both players set prices grater than c.

If $\overline{W}_{1U} = \frac{17}{16c^2}$:

$$P_1 = c,$$

$$P_2 = 2c$$

$$W_{1D}^* = \frac{1}{16c^2}$$

$$W_2^{u*} \in [\frac{1}{16c^2}; \overline{W}_{1U}]$$

$W^*_{1U} = \overline{W}_{1U} - W^{u*}_2$ and $W^*_2 = W^{u*}_2 - W^*_{1D}$

Calculating benefits from trade:

Suppose $\overline{W}_{1U} < \frac{17}{16c^2}$:

Player 1's benefit:

$U_1 - D_1 = \sqrt{\overline{W}_{1U} - W^{u*}_2} + \sqrt{W^*_{1D}} - P_2 W^*_{1D} + P_1 W^{u*}_2 - \sqrt{\overline{W}_{1U}}$

Substituting the solutions from the above we obtain:

$\frac{(19-4\sqrt{17})\sqrt{\overline{W}_{1U}}}{4\sqrt{17}}$ - benefit from trade of player 1

Player 2's Benefit:

$U_2 - D_2 = c(W^{u*}_2 - W^*_{1D}) + P_2 W^*_{1D} - P_1 W^{u*}_2$

Similarly, substituting the above optimal water consumption we get:

$\frac{\sqrt{\overline{W}_{1U}}}{4\sqrt{17}}$ - benefit from trade of player 2.

If $\overline{W}_{1U} = \frac{17}{16c^2}$:

Player 1's benefit is $\frac{19-4\sqrt{17}}{16c}$

Player 2's benefit is $\frac{1}{16c}$

Comparing solutions with market one we can deduce that:

- under serial monopoly at least one player sets the price of water above c, while under market setting both players set price equal to c

- Player 1's benefit is less under serial monopoly than under market setting. Assuming that $\overline{W}_{1U} = \frac{17}{16c^2}$ player 1 gets $\frac{25-4\sqrt{17}}{16c}$ under market setting which is a total benefit, since player 2 gets nothing.

- Player 2 benefits more under serial monopoly than under market one.

Total benefit is greater under market solution. Total benefit under serial monopoly is $\frac{20-4\sqrt{17}}{16c}$