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CAN GAME THEORY HELP TO MITIGATE WATER CONFLICTS IN THE SYRDARYA BASIN?

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Abstract

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This paper focuses on methods to resolve the ongoing conflict between countries in the Syrdarya Basin, namely Kyrgyzstan and Uzbekistan, over water allocation. It addresses the problem by using the cooperative games framework. It identifies difficulties of choosing the most suitable solution to the Nash bargaining problem under the current circumstances and also reveals complications that may obstruct negotiations on water allocation. The latter is done by using a simplified model from a different subject field which explains why the negotiations have sequential character. The Kalai-Smorodinsky solution is recommended as optimal in the concrete situation because it takes into account efficiency of water use of the involved parties and its sequential use leads to a Pareto-optimal outcome. Also a compromise between the Kalai-Smorodinsky and dictator solutions can be considered for the current case.

Keywords: water allocation problem, Syrdarya Basin, negotiations, game theory, cooperative games, Nash bargaining problem, Kalai-Smorodinsky solution

INTRODUCTION

Since Hardin (1968) and Ostrom (1990) it has been established that the sustainable use of common-pool natural resources, such as water, requires cooperation among users. It is generally felt that the problem of water scarcity is not so much physical scarcity, but inefficient use and vested interests, in particular in case of the world's many international rivers (Houba, 2008). While many countries do coordinate their water uses, international disputes do occur. Unfortunately, they cannot be resolved by international water law because in essence it only states that the countries involved should mutually agree on sharing the river through negotiations, and it is left in the middle how to resolve disputes over the allocation of water (Houba *et al.*, 2014). Countries sharing water resources often proceed to negotiations regarding water allocation issues in order to settle their arguments. During such negotiations the use of appropriate tools, such as game theory, which will provide assistance to the opponent parties in terms of scenarios quantification and simulation processes, is an essential component towards conflict resolution.

The reason for focusing on the water allocation problem is the recent events in the Central Asian region, in particular the failure to construct hydrofacilities on rivers in the Syrdarya Basin. Central Asian region is an area where interests of the individual countries collide in many spheres and one of the most severe problems is disputes over water resources in the whole Aral Sea Basin. The geopolitical role of water is likely to only rise. The further decreasing availability of water in the region is becoming a factor that slows down economic and social development of the involved countries which leads to worsening of the political situation. The problem of water allocation in Central Asia is not only burning but it also has a potential of explosion of the tense interstate relations.

The countries divide into two groups depending on their geographical characteristic – water-rich upstream and water-poor downstream states. Kyrgyzstan and Tajikistan belong to the first group, and Uzbekistan, Turkmenistan and (southern part of) Kazakhstan to the latter. The conflicts over water allocation have escalated since the Soviet Union and its water management institutions and financing collapsed.

This article focuses on methods to resolve the ongoing conflict between Kyrgyzstan and Uzbekistan in a wider context of disputes over water allocation. This conflict attracted a lot of attention this year thanks to the failure to construct the Kambarata hydropower plant and the upper-Naryn cascade in Kyrgyzstan due to disagreement with the Russian investor Rusgidro regarding financial issues (Izvestia, 2016). Large dam projects in Kyrgyzstan are provoking negative reactions from downstream Uzbekistan. Reliable water supply for farmers in Uzbekistan is crucial. It is important to bear in mind that the country is extremely sensitive to changes in water availability due to population density; population growth and food demand will not decrease in the future. On the other hand, the abundant water resources of Kyrgyzstan, together with favourable topography, make the country exceptionally rich in hydropower potential.

In 1998 an agreement between Kyrgyzstan, Uzbekistan and Kazakhstan (Tajikistan joined in 1999) on water use of the Syrdarya Basin resources was concluded. This agreement provides for mutual supplies of electric power, fuel and energy resources to settle water and energy relations among the involved countries (Antipova *et al.*, 2001). Parties are obliged to, inter alia, consider building new hydrofacilities and dams together (Agreement on the Use of Water and Energy Resources of the Syr Darya Basin, 1998). In 2008, however, the riparian countries of the Syrdarya basin could not come to an agreement regarding the rational use of river water. Kyrgyzstan, Uzbekistan and Kazakhstan could not reach a consensus whether Syrdarya is or is not a transboundary river, as it was claimed by Tashkent. Kyrgyzstan was opposed since the status of a transboundary river would limit Kyrgyzstan's possibilities to construct dams and hydropower plants. Such measures would have to be agreed with Uzbekistan which has repeatedly expressed its negative attitude to Kyrgyzstan's plans.

The current challenge consists in coordinating the management of cascades of reservoirs, both operating and planned, which are located in Kyrgyzstan. Of particular importance is the handling of trade-offs between water use for downstream irrigation in summer and non-consumptive use for upstream energy production in winter (Bernauer and Siegfried, 2012). Since both countries benefit from using water, compensations are necessary to encourage the upstream country to give up water. The solution of the problem of water allocation aimed at its efficient utilization and determining subsequent compensations is an extremely complicated task, which can lead to a number of conflicts. The origin of the problem is possible to quite exactly describe using mathematical apparatus, particularly game theory.

The goal of this paper is, in the context of the water allocation problems in Central Asia, to show what mathematical tools can be used to identify problems in this subject area and what the possibilities of overcoming such problems are, i.e. of reaching an agreement. Specifically the following issues are covered:

- demonstrate how the how tools of the cooperative game theory can be utilized;
- use new findings associated with the identification of "snag" when negotiating about optimal resource allocation and subsequent compensations in a different subject field (financial markets) to solve the water allocation problem which will further enable to formulate practically relevant recommendations.

MATERIALS AND METHODS

As we have pointed out above water allocation negotiations are complicated, conflicting, and agreement is often difficult to reach. From this point of view it is apparently positive that construction of big hydroenergetic projects in Central Asia has been postponed because they could significantly worsen the situation between the involved countries in the near future. Time was gained to investigate a wider scale of methods to find an agreement, and to involve different methods including game theory. The situation in the Syrdarya Basin as described in the previous section is the basis for our models. We consider a potential investor willing to construct and fund hydrofacilities in Kyrgyzstan. Such investor would be interested in a stable regional situation taking into account Uzbekistan's position of a regional power; he would therefore promote equal negotiation conditions for both countries and strive for a reasonable solution. Using this concrete case is important for understanding how the game theory can contribute to real world situations. The application is presented in an intelligible form so that it can clarify the models and solutions even to a person not experienced in game theory.

Before going deeper in the game theory itself, we are going to mention the influence of human behaviour to emphasize the complicated nature of the negotiation process. Some of the obstacles during negotiations in such situations are described by behavioural economics. The case, where each party overestimates its requirements, behavioural economics indicates as a demonstration of extreme thinking, i.e. thinking which overrates its own position and places maximalist requirements. This is why each party understands the arguments of the counter party with difficulties, because they are extremely distant from his point of view. What is for one party an insufficient concession, it is for the other party an exaggerated concession, although it is all about the same thing.

Another reason why one party (A) is not willing to accept even justified arguments of the counter party (B) is cognitive dissonance, because accepting such argument would mean that A was wrong. So party A will not accept arguments of party B not because the argument is invalid but because A does not want to admit his own mistake. B's reaction is a further clarification of his argument which, paradoxically, leads to further rejection by A (see for instance Kruger and Dunning, 1999; Ariely, 2008; Kahneman, 2012).

A powerful tool to understand the root of the problems in negotiations on water allocation is offered by game theory. Contrary to behavioural economics which sees the core of the problems in imperfections of human behaviour (the discipline reveals, classifies and evidences that these are standard situations), game theory is based on the assumption of rational human behaviour, and reveals precisely describable roots of the problems that occur during negotiations. Since the 1940s, game theoretic models have been applied to various aspects of water management, such as decisions on cost and benefit allocation in multi-objective multi-use water projects, conflicts and joint management of irrigation projects, management of groundwater aquifers, hydropower facilities, urban water supplies, wastewater treatment plants, and transboundary water disputes (Dinar and Hogarth, 2015). Game theoretic results may help riparian countries to narrow down their differences, and thus to form a basis for negotiation. They also help riparian countries to understand the sources of their negotiation power (Wu, 2001).

Game theory can be described as the mathematical study of the interactions among decision-makers whose decisions taken affect inevitably all the involved parties and that often result in conflicts. A solution concept is defined in game theory as the methodology of solving conflicting situations by estimating the equilibrium point of the conflict. The most popular solution concept of modern game theory is Nash equilibrium when each strategy is the best response to the other players' strategies. At the point of Nash equilibrium all players profit most (i.e., have high payoffs), taking into account all possible moves of the counter-players (Eleftheriadou and Mylopoulos, 2008).

Game theory can consider cooperation between the players and include the possibility of estimating and comparing the consequences of other player's actions towards the counter-players. So in the case where the players have a possibility to conclude binding agreements about what choices they make before they choose a strategy, it is called a cooperative game. The player can cooperate but does not have to. They will cooperate only if it is beneficial for them, which means that cooperation will provide both players with higher payoff than if they do not cooperate (Dlouhý and Fiala, 2009). An important milestone for the cooperative game theory development is works by John Nash (Nash, 1950).

Several water resource problems have been modelled using cooperative game theory; a comprehensive review was made by Parrachino *et al.* (2006), and most recently by Dinar and Hogarth (2015) who provide an overview of the development in cooperative game theory solutions with regard to water issues. Especially the distribution of water from internationally shared rivers has received attention in recent years. The source of potential conflict is that water consumed by an upstream country reduces the volume of water available for a downstream country.

Ambec and Sprumont (2002) address this problem by modelling it as a cooperative game on the set of riparian countries. They translated the principles from international water law into axioms. They ask how the water should be allocated and what money transfers should be performed. This model was further elaborated by Ambec and Ehlers (2008), van den Brink *et al.* (2010, 2014), Wang (2011), Béal *et al.* (2013) or Ansink and Houba (2014). There are many studies using the game theory such as case studies of river basins. Rogers (1969) applied game theoretic approach to the disputed Ganges Brahmaputra Basin that involved different water uses by India and Pakistan, suggesting a range of strategies of cooperation offering significant benefits to each. The more recent works include studies of the Nile River Basin (Wu, 2001), the Jordan River Basin (Luterbacher and Wiegandt, 2002), the Euphrates and Tigris (Kucukmehmetoglu and Guldmen, 2004), the Nestos/Mesta River Basin (Eleftheriadou and Mylopoulos, 2008), the Orange Senqu River Basin (Siehlow *et al.*, 2011), the Mekong River Basin (Houba *et al.*, 2012) or the Aral Sea Basin (Ambec *et al.*, 2013). Some authors took into account specific conditions in context of water distribution. Ansink and Ruijs (2008) investigated the effects of climate change and the choice of a sharing rule on stability of a water allocation agreement. Several studies have addressed the issue of flow variability for two common sharing rules for water allocation, proportional allocation and fixed flow allocation (Ambec *et al.*, 2013).

The problem of water allocation between Uzbekistan and Kyrgyzstan can be understood as a Nash bargaining problem within the cooperative game theory framework. We assume that there is a set of feasible agreements that could be concluded by them, and a disagreement point when the players do not agree on any cooperation. The players strive for finding a better solution than the one in the disagreement point (Dlouhý and Fiala, 2009). We consider three trivial axioms of the bargaining problem that must be met in the given subject field as follows: individual rationality (neither player should get less in the bargaining solution than he could get in the event of disagreement), collective rationality (Pareto optimality) and feasibility (the solution is within the set of feasible payoffs).

The compensation can be understood as a determination of price for a unit of a respective resource which is allocated between the players. In other words, if we determine the amount of compensation, we know what the price of the water unit is. If we determine the price of unit, we know the amount of compensation.

The problem of using the cooperative game theory to resolve the problem of water allocation lies in the fact that determining the amount of compensation requires a solution of the Nash bargaining problem. This is not unambiguous. There are several approaches that are more or less suitable for a certain case but there is no general rule that would give an answer to the question, which approach is suitable for a particular situation. In the case of cooperative games, the possible agreement on the solution focuses on the features and properties of the solution which are often expressed in terms of axioms. The axioms try to incorporate the fairness features in the solution. It is important to mention that there are not any universal fairness criteria and that there are several competing concepts. The judgment on solution fairness is therefore a subjective process which may depend on a specific game formulation.

The Nash solution (Nash, 1950), the Raiffa sequential solution (Raiffa, 1953) or the Kalai-Smorodinsky solution (Kalai and Smorodinsky, 1975) are among the best known solutions. Nash came up with a list of properties an ideal bargaining solution function is expected to satisfy and then proved that there exists a unique solution that satisfies all of these properties. This solution is known as the Nash bargaining solution.

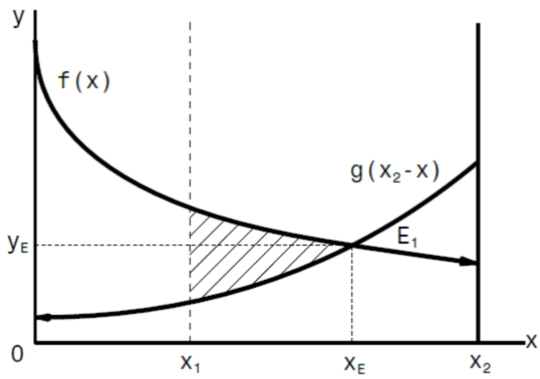
However, in the current situation we suggest the Kalai-Smorodinsky solution which we will discuss in more detail and which we consider more suitable in case it satisfies certain properties. We will also refer to some other game theory solutions, such as the Kalai egalitarian solution (Kalai, 1977) or the dictator solution (see e.g. Forsythe *et al.*, 1994).

The problem is not only to select the most suitable model which itself is a question that may lead to disagreement between the parties since the models give different results and give preferences to or disadvantage one party or another. Another interesting and important problem that got called a "snag" during negotiations was pointed out by Černík and Valenčík (2016) when solving a question of optimal distribution of financial resources and subsequent compensation in the field of financial markets (see also Červenka *et al.*, 2015). Although it is a task from a different subject area, the mathematical model is suitable to reveal one of the key problems in the water allocation field as shown in the next chapter. Recommendations for future negotiations on water allocation can be formulated based on the model.

RESULTS

We assume a model with two parties (the two riparian countries in our case). Each of them disposes of opportunities to use water and at the same time they dispose of a certain water reserve or a possibility to influence the allocation of such water reserve. Combining a certain amount of water and an opportunity to use water results in a certain revenue.

We will assume that both parties will maximize their future revenue which in other words means they will use water units they dispose of according to their rate of return. The function of the marginal revenue from each next unit of water which both parties dispose of is therefore a non-increasing function in its whole domain. We will assume that the functions of the marginal revenue from used water units of both parties are continuous where the minimum of one of the functions is smaller than the maximum of the other function, and the maximum of the first function is greater than the minimum of the second function, see Fig. 1.



1: *Supply and demand of water units*
Source: own creation based on Červenka *et al.*, 2015

In Fig. 1, x_1, $x_2 - x_1$ are the amounts of water units that both players dispose of; y is the future revenue in marginal values, $f(x)$, $g(x)$, resp. $g(x_2 - x)$ nonincreasing continuous functions of the marginal revenue, $g(x)$ is modified due to a more suitable graphic demonstration of the situation.

Arrows on functions $f(x)$ and $g(x_2 - x)$ express which direction the water units of both parties are gradually used; the domain of both functions is a closed interval from 0 to x_2.

$E_1(x_E, y_E)$ is a point where $f(x) = g(x) = f(x_2 - x) = g(x_2 - x)$, in this point all water units of both parties are used according their rate of return.

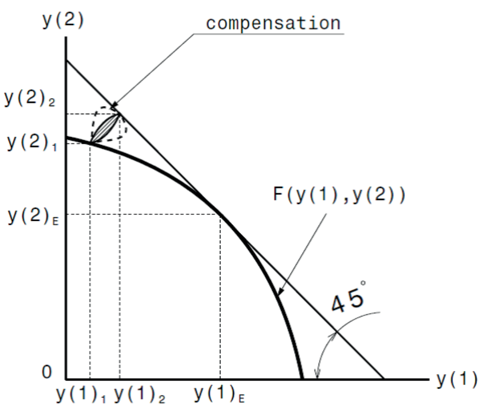
The hatched area shows the size of the maximum possible Pareto improvement as a result of negotiations, where one party gives up part of his water resources for the other one to use.

The total revenue of the first economic party (and similarly of the other) is defined:

$$\int_0^{x_1} f(x)d(x) = \int_{x_1}^{x_2} f(x_2 - x)d(x)$$
$$\int_0^{x_1} g(x)d(x) = \int_{x_1}^{x_2} g(x_2 - x)d(x)$$

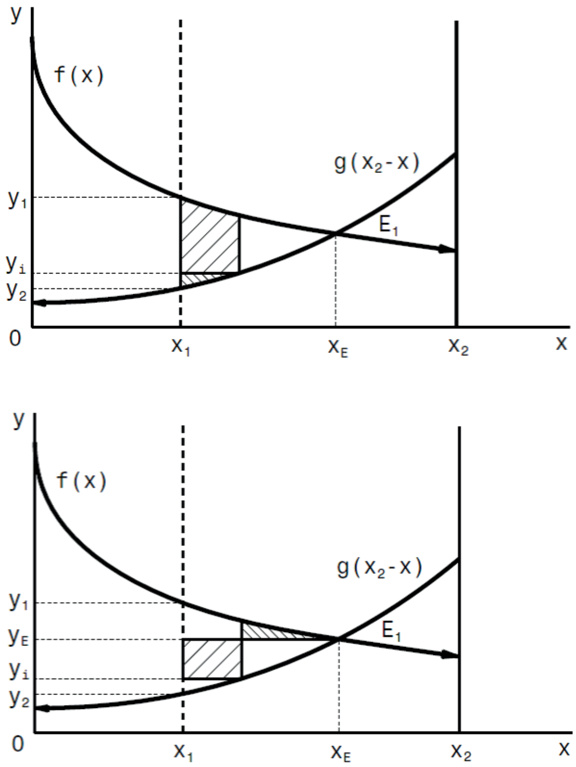
In the case when the price of water unit is determined by the parity of marginal revenues, i.e. $f(x) = g(x)$, water units of both players will be used according to their rate of return. The amount of compensation of the party who provided the other party with water to make use of it, will be $y_E(x_E - x_1)$.

In terms of mathematical analysis, the problem seems to be resolved. Problem, however, lies in the fact that each party can have a maximum revenue different from the revenue in the point *E* in Fig. 1. This means that we have to transform the negotiations into the Nash bargaining problem. Transforming the model into a cooperative game will show other assumptions. Since we enter the realm of game theory, we will call the parties "players" and we will use the term "payoffs" for revenues. A certain distribution of payoffs between the players corresponds to every point in the closed interval from *0* to x_2. Let's determine:
$y(1)$ as a total payoff of the first player
$y(2)$ as a total payoff of the second player
If x oscillates from 0 to x_2, all feasible combinations of payoffs are at $F(y(1), y(2))$,
where $y(1) = \int_0^x f(x)d(x), y(2) = \int_x^{x2} g(x_2 - x)d(x)$, see Fig. 2.



2: *The feasible payoffs frontier*
Source: Černík and Valenčík, 2016
Legend:
starting point if $x = x_1$ is $(y(1)_1, y(2)_1)$
point $(y(1)_E, y(2)_E)$ is the point of maximum sum of payoffs
point $(y(1)_2, y(2)_2)$ are payoffs of the players after compensation in case where all Pareto improvements are exploited

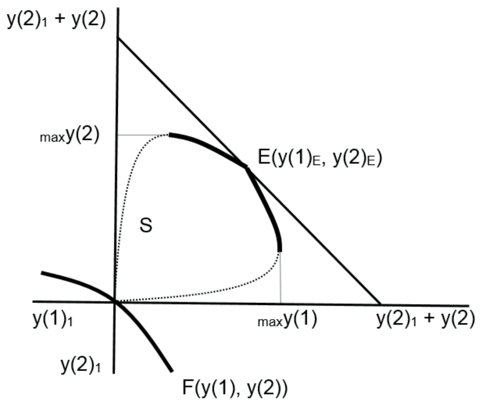
Fig. 2 demonstrates that the payoffs of both players increased, which corresponds to what is shown in Fig. 1. If both players achieved in the point $(y(1)_2, y(2)_2)$ the maximum payoff with water prices oscillating in Fig. 3 in a closed interval from y_1 to y_2, the assumption of individual rationality would be enough to consider the point $(y(1)_2, y(2)_2)$ an intuitively acceptable solution of the respective cooperative game. It is so in the case where the set of compensations is defined with the solid curve (Fig. 2). It does not have to be the case, however, see Fig. 3.



3: *Players' payoffs in case of changing prices of water*
Source: own creation based on Červenka *et al.*, 2015

The first figure shows the increase of the payoff of the first and second player at the price of water y_i. The figure below shows a change that would happen if the water price changed from y_i to y_E. The payoff of the first player would decrease in the given case compared to the payoff of the second player. This is a very important moment. It shows that the assumption of individual rationality is not enough to find a definite solution. It is therefore suitable to transform this problem to the Nash bargaining problem. The set of compensations (the set of feasible solutions) is in this case defined by dashed line in Fig. 2. We have encountered a phenomenon that can be called a "snag", as identified by Černík and Valenčík (2016). In this context it would be useful to explain why such term is used. All Pareto improvements are exploited in the point E_1 (Fig. 3). This point, however, does not have to be the result of negotiations. Each player may for example require maximum payoff and from this position derive his negotiations, and thus such a snag occurs. If this is an upstream player (country) who can control the whole runoff and there are no other influences, he can enforce a solution when he gets maximum payoff. This solution is called a "dictator" solution and it can be found quite often, e.g. when in times of low runoff a hydropower plant owner retains all water to subsequently generate energy and is not interested what happens to fish downstream in the river bed.

From the next figure (Fig. 4) it will be obvious why the problem we have just encountered can be called a "snag" and subsequently a sequential solution of the problem is necessary. It significantly complicates the negotiation process. Let's analyse the problem in detail and see an enlarged part of Fig. 2, where the area of compensations is plotted.



4: *Payoffs of the players under changing prices of water*
Source: own creation based on Černík and Valenčík, 2016
Legend:
S is a set of possible distribution of payoffs in the case where $_{max}y(1)$ and $_{max}y(2)$ are bigger than $y(1)_E$ and $y(1)_E$

If we mark an inversion function to function $y = f(x)$ as $x = f^{-1}(y)$ and similarly $x = g^{-1}(y)$ an inversion function to function $y = g(x)$, then the values of the Pareto improvement are (as functions of y, that in this case represent the price of water):

$$\Delta y(1)=\int_{x_1}^{x_i} f(x)d(x)-y_i\,(x_i-x_1) \text{ where } x = f^{-1}(y)$$

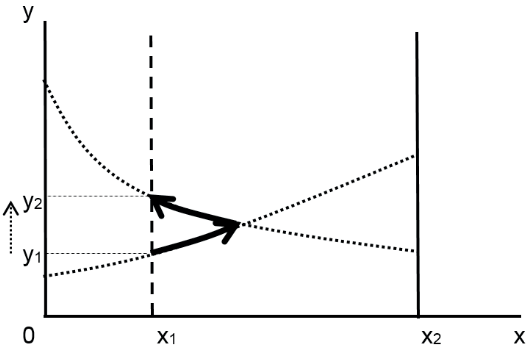
$$\Delta y(2)=y_i\,(x_i-x_1)-\int_{x_1}^{x_i} g(x_2-x)d(x) \text{ where } x = g^{-1}(y)$$

Respective functions of Pareto improvement are shown in Fig. 4. In the general case, $_{max}y(1)$ and $_{max}y(2)$ are bigger than $y(1)_E$ and $y(1)_E$ (as in Fig. 4). The bargaining set (a set of feasible payoffs) is limited by the dotted line. The bold line indicates points where the axioms of individual rationality, collective rationality and feasibility axiom are met. Situations where these three axioms are satisfied correspond to the character of the case we are analysing.

To complete the picture, a figure of marginal values demonstrates the above described situation.

If the price of resource (water) rises from the value y_1 to y_2, the points of maximum feasible combination of payoffs will move along the bold lines in the direction of the respective arrows.

The situation described in Fig. 4 is a typical Nash bargaining problem. It has several trivial solutions:



5: *The players' maximum payoffs in a figure demonstrating marginal value functions*
Source: own creation based on Červenka *et al.*, 2015

- the dictator solution when one of the players reaches the maximum improvement of his payoff compared to the initial situation
- the egalitarian solution where both players reach the same improvement
- the utilitarian solution where the sum of payoffs is maximized

Nowadays a number of other non-trivial solutions and their combinations to the Nash bargaining problem are known, for example:

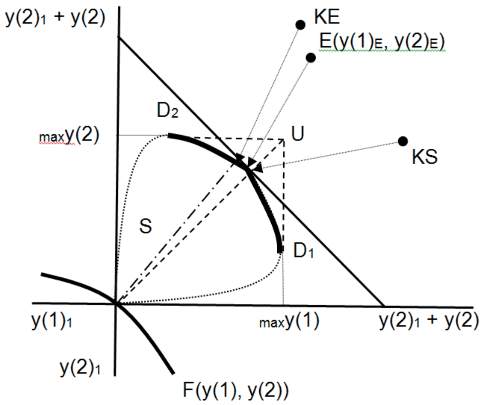
- the Nash solution, where the product of payoffs is maximized (this solution has a number of remarkable qualities which are, however, not suitable for the current case);
- the Raiffa sequential solution which could be used in a modified form;
- the Kalai-Smorodinski solution which is derived from maximum payoffs; its application in the current subject field can be considered.

Only the utilitarian solution enables to exploit all Pareto improvements. Players or one of the players do not have to have any reason to accept such solution, or rather they can push through a different solution, more favourable for them. That is why that in the current situation a double snag occurs during negotiating water allocation and compensations from the perspective of the most efficient use of water.

1. A snag linked to the question which solution of the Nash bargaining problem to choose because game theory does not provide with any general guideline, there are several possible approaches for each given situation.
2. A snag related to the question how to continue in negotiating in case a certain solution has been chosen and such solution does not give a Pareto-optimal result, i.e. part of water is not used in the most efficient way.

We have also mentioned problems of human errors during decision-making as pointed out and described by behavioural economics. Since this is not the core of the current topic, we have only mentioned it as a fact complicating negotiations.

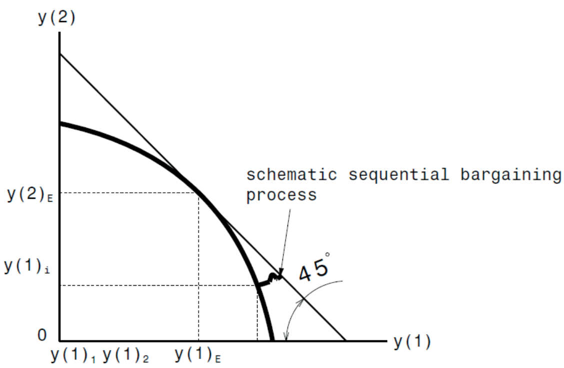
Some of the possible solutions of the bargaining problem are shown in the following figure.



6: *Possible solutions to the bargaining problem*
Source: own creation based on Červenka *et al.*, 2015
Legend:
D_1, D_2 are dictator solutions
U is the utopian (infeasible) point of the maximum payoffs of both players, on the basis of which the Kalai-Smorodinsky solution is construed.
KS is the point of the Kalai-Smorodinsky solution.
KE is the Kalai egalitarian solution, which is derived from the intersection of the set complying with the axioms of individual rationality, collective rationality and feasibility with the 45-degree line (a dash-and-dot line in Fig. 6).
$E(y(1)_E, y(2)_E)$ is the already mentioned utilitarian solution (which represents the maximum sum of payoffs).

If the players choose any default solution of the Nash bargaining problem that is different from the utilitarian one, they can both further improve the situation in terms of efficiency. This way both players will gradually (sequentially) come closer to the point of Pareto-optimal outcome which is marked as E_1 in Fig. 1.

The following figure demonstrates what the sequential negotiation may look like.



7: *Possible sequential bargaining process*
Source: Černík and Valenčík, 2016

The figure above is illustrative. There are more solutions to the Nash bargaining problem, it depends which method is chosen.

DISCUSSION

There are many different approaches to the water allocation problem and each offers an innovative way of looking at it. Many of the authors employ the international water law, explain its stipulations with the tools of the game theory and further examine other principles to investigate how these affect the river sharing problem (e.g. Ansink and Houba, 2014; Houba *et al.*, 2014, Ambec and Ehlers 2008). Many authors (Abbink *et al.*, 2009; Ansink and Houba 2014; Houba *et al.* 2014) also take into account other factors such as transactions costs, political power, the variability and uncertainty of water flow or the probability of failure to cooperate. In contrast to that, our model is simplified; however, it offers another perspective of the water allocation problem with specific features. We focused on a solution that would fit the current situation in the Syrdarya Basin where the opportunity to construct hydrofacilities poses a threat to the downstream country and where a potential investor might play a role of a mediator. We applied a model from a different subject field that reveals what kind of complications are in the way of efficient resource use and why the negotiations have a sequential character.

Regarding problem of choosing a suitable solution of the Nash bargaining problem, we focus on the Kalai-Smorodinsky solution because we assume that there are certain prerequisites that favour this solution compared to others. The reasons will be explained below.

But let us look into one of the trivial solutions first. If the upstream country could arbitrarily (without any external limitations) dispose of the whole runoff, then the solution of the Nash bargaining problem would be a dictator solution, i.e. the upstream country would enforce water allocation corresponding to its maximum payoff.

However, it does not have to be the case. In the situation we are considering it is likely to encounter a situation when the entity that is able to carry out the construction of hydrofacilities (i.e. disposes of necessary technical and financial resources, for instance an investor from Russia or China) is not interested in any sort of dispute between the countries; an equal negotiation position of both countries (upstream Kyrgyzstan and downstream Uzbekistan) is desired. The investor can take up the role of an intermediary during the negotiations and can also increase the equality of parties. The symmetry axiom corresponds to the equal position of parties. Then the most suitable solution of the Nash bargaining problem would be the Kalai-Smorodinsky solution. Without going into detailed theoretical analysis of this question (which would need a separate discourse), we will give the reasons for this point of view:

- the Kalai-Smorodinsky solution takes into account the efficiency of water use of the involved parties;
- in the given context the monotonicity axiom should be satisfied in the following sense: if

the water resources increase, the situation of neither party will worsen;

- the sequential use of the Kalai-Smorodinsky solution during individual steps of negotiations on compensations relatively quickly leads to a Pareto-optimal outcome;
- a possible compromise between the Kalai-Smorodinsky solution and the dictator solution can be considered; it can be obtained by using weighted symmetry (to both parties' maximums a certain weight is assigned) which corresponds to the case when the bargaining power of one of the parties is stronger.

CONCLUSION

The original contribution of this paper when compared to previous related publications is the adaptation of the "snag" phenomenon as identified by Černík and Valenčík (2016) to the field of water allocation problems. The mathematical apparatus demonstrates an additional complication that we may encounter and answers the question how to continue in negotiations in case a certain solution has been chosen but it does not give a Pareto-optimal result (i.e. part of water is not used in the most efficient way). It implies that the process of negotiation has a sequential character. We can make another conclusion regarding the optimal solution to the Nash bargaining problem with concern to the parties' position before and during negotiations. If we assume that both parties have an equal position for the reasons cited in the previous section, a suitable solution of the Nash bargaining problem is the Kalai-Smorodinsky solution. As a rule this solution gives a result which is close to the optimum water allocation, resp. it leads to a relatively fast achievement of such optimum.

Game theory provides a useful framework for analysing the strategic decision-making of riparian states. However, the limits of the current study involve, first of all, the willingness of stakeholders to come to an agreement. This paper shows that an agreement can be reached and is beneficial to both parties. The theory, however, cannot enforce negotiations.

The next important step is to translate the language of game theory into a comprehensible form for the stakeholders. This approach is considered a priority; too intricate models may result in reluctance of their application in practice. From the practical point of view it is therefore desirable to advise the involved parties (countries) about the theoretical basis of the problem of water allocation negotiations and "snags" along the way. This can in the end appease the whole negotiating process and lead to more efficient solutions. We are well aware that the examined problem needs further elaboration and research. This paper aims to determine directions which can be taken and to demonstrate how concrete parameters of a real world problem inspire and give new incentives to theoretical research.

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