Cooperative Decision Making in River Water Allocation Problems

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2013

Summary

This dissertation presents recent developments in the modeling of international river water allocation problems. Rivers, and the bodies of water they flow into, constitute the most important source of fresh water in the world. A river is called 'international' if it flows through at least two states. The water that flows in international rivers is used on a large scale in agriculture, industry and by households. In addition, rivers are used for fishing, transport, hydropower, recreation and waste discharge. It is not hard to imagine that the use of a river for this kind of activities can have negative consequences for downstream countries. Particularly in regions of water scarcity, consumption of large amounts of water by an upstream country can be disastrous for downstream countries.

Asymmetric dependence on a water resource, as in the above example, is often at the heart of disputes about the use of the resource. This is especially true for water resources of which the property rights are not clearly defined. In a national setting, disputes about property rights over water resources are usually settled through a country's legal system. In an international setting, though, there typically is no third party that is able to enforce agreements.

Global institutions, such as the United Nations, have tried to install binding rules on the use of water from international watercourses. While this, so far, has not resulted in binding international laws, it did help in establishing over 400 (bilateral) agreements between countries sharing transboundary water resources. These agreements, and the principles on which the articles in these agreements are based, are the subject of an extensive legal literature.

The literature on international watercourse law is one of the two main tools that is used in models that describe, prescribe and predict the allocation of water from international rivers. The other main tool is (cooperative) game theory.

A game theorist examines conflict and cooperation between a limited number of economic agents (players), in a mathematical model (game). In non-cooperative game theory it is assumed that the players in a game are not able to make binding agreements. In cooperative game theory players can make binding agreements and underlying strategic procedures that lead to these agreements are not taken into consideration. Instead, a cooperative game is formed by a set of players and a characteristic function that attributes to every coalition (group) of players a maximally achievable worth (amount of utility). Given such a cooperative game the emphasis is put on questions like: what coalition of agents is formed in the game? And, how is the worth of a coalition divided among the players of the coalition? A solution for a cooperative game is a function that attributes to every game a payoff to every player.

Since agreements on the use of international rivers are usually made between a small number of countries is it not strange that (cooperative) game theory is at the basis of a small, but growing, literature that models the distribution of water from international rivers.

In expanding this literature, this dissertation focuses on three goals. The first goal is to generalize an existing single-stream international river water allocation model to a model in which the river possibly consists of one main river with multiple tributaries and/or multiple distributaries. The second goal is to extend the same model to a model in which countries possibly consist of multiple water users (e.g., states, cities or individual water users). The third goal is to analyze the difference between the rival use of river water (once the water is consumed, it can no longer be consumed by others) and the non-rival use of river water (e.g., by polluting the water or its use in the generation of hydropower) in an international river water allocation model.

The study of these three goals has led to this dissertation which consists seven chapters. The first two of these have an introductory character. The last five contain the most new findings.

Chapter 1 gives a detailed summary of the existing literature on international watercourse law. It provides both a general introduction into the international river water allocation problem as well as a specific discussion of the principles of international watercourse law.

In Chapter 2 an introduction into cooperative game theory is provided by discussing various transferable utility games. Most of the game-theoretic concepts that are used throughout the dissertation can be found in this chapter. In addition, Chapter 2 discusses the major findings of the literature on cooperative decision making in international river water allocation problems. In this literature authors have combined the international water law principles of Chapter 1 with concepts from cooperative game theory. This combination has resulted in a class of models that, on the one hand, is quite technical, but on the other hand, provides clear insight into how certain principles from international watercourse law can be made operational in actual river water allocation problems.

In Chapter 3 the problem of sharing water among agents (countries) located from upstream to downstream along a single-stream river is considered. A number of (independence) axioms is introduced to characterize two new solutions and two solutions that were proposed in the literature discussed in Chapter 2. All four solutions are applied to the particular case that every agent along the river has constant marginal benefit of one up to a satiation point and marginal benefit of zero thereafter. In that case it follows that two of the solutions (one from the literature and a new one) can be implemented without monetary transfers between the agents.

Chapter 4 focuses on the first goal mentioned above by generalizing the model of Chapter 3 to a model in which the river now possibly has multiple springs. This means that there is a river that has several tributaries along which water users can be located. In this model two different assumptions on the benefit functions of the agents are considered. The first assumption leads to a type of cooperative game in which the agents always want to consume more water, the second to a different type of cooperative game in which each agents possibly has a satiation point, which can lead to externalities of coalition formation. For both games the class of weighted hierarchical solutions is proposed as a class of solutions satisfying the "TIBS" principle from international watercourse law.

Chapter 5 provides a strategic implementation of the class of weighted hierarchical solutions (a non-cooperative mechanism of which the unique subgame perfect Nash equilibrium payoffs correspond to the weighted hierarchical solution payoffs of the cooperative game).

Chapter 6 focuses on both the first and the second goal mentioned above by further extending the model of Chapter 3 and Chapter 4 to a model in which the river possibly consists of a main river with multiple tributaries and distributaries, and in which the agents are possibly composed of different water users. To take account of both the different water users within one country and the river that can have multiple springs and multiple sinks, transferable utility games in characteristic function form with both graph restricted communication and a priori unions are considered. Two new values for this type of games are introduced and characterized by applying the Shapley value to two associated transferable utility games in characteristic function form. In addition, a solution is proposed that is close to the class of solutions introduced in Chapter 4.

Chapter 7 is the last chapter and focuses on the third goal mentioned above. In this chapter a model is studied in which the agents do not directly consume the water from a river (so that this can no longer be used by others), but indirectly, by polluting it (so that it can still be used by others but is of lower quality). It turns out that total pollution in this model decreases when the agents along the river decide to cooperate. The resulting gain in social welfare can be distributed among the agents based on the property rights over the river. Using various principles from international watercourse law several ways are suggested to 'fairly' distribute the property rights and therefore the cooperative gain over the agents along the river.