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A joint management approach to the Mekong River Basin

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Abstract. The Mekong River is shared by six Asian countries. Over the years there has been both conflict and cooperation on managing the water resources to meet population growth, climate change and the desire for economic development. This paper exploits an axiomatic bargaining approach to examine how China and the Mekong River Commission (MRC) might negotiate effective joint management. We show that there are significant welfare gains from cooperation in this region; an exogenous budget provides stronger incentives for cooperation; and the MRC should be extended to include all affected nations for sustainable management and future development. The economic costs of the current weak governance and its effects on the negotiated joint management are discussed..

Key Words: Joint River-Basin Management, Transboundary River, Nash Bargaining Solution, Optimization, Mekong River.

JEL codes: C71,C72,D62.

I. INTRODUCTION

Management of water resources is seen to be a critical global issue in the twenty-first century and the Mekong River, the world's tenth-longest river and the seventh-longest in Asia, is no exception as being one of the least developed transboundary rivers in the world. As the major water source in Southeast Asia, flowing through or forming the border of six countries: China, Myanmar, Laos, Thailand, Cambodia, and Viet Nam, the Mekong River (MR) is not only the source of food, water, and transport for over seventy million people from over ninety distinct ethnic groups, the river basin is also home to over thirteen-hundred species of fish, creating one of the most diverse fisheries in the world (Campbell, 2009; Osborne, 2010). Over the years there have been conflict and cooperation on water resource management among diverse riparian nations to accommodate for population growth, climate change and the desire for economic development. Moreover, the operation of existing dams and many plans for drastic expansion of dams increase tensions due to the upstream's constructions have been affecting downstream communities at various levels. Therefore, there is a need for increasing cooperation in a stable and sustainable manner.

In April 1995, a Mekong River Basin Treaty (known as the 1995 Agreement on the Cooperation for the Sustainable Development) has been signed by four Lower Mekong nations, which established the Mekong River Commission (MRC), to "promote and coordinate sustainable management and development of water and related resources for the countries' mutual benefit and the people's well-being" (MRC, 2005). The two upper states of the MRB, China and Myanmar, became dialogue partners to the MRC in 1996. The 1995 agreement brought a change of identity for the organisation previously known as the Mekong Committee, which had been established in 1957 as the Committee for Coordination of Investigations of the Lower Mekong Basin - the Mekong Committee.

The MRC is supporting a joint basin-wide planning process with the four countries, called the Basin Development Plan, which is the basis of its Integrated Water Resources Development Programme. The MRC is also involved in fisheries management, promotion of safe navigation, irrigated agriculture, watershed management, environment monitoring, flood management and exploring hydropower options. No longer under the umbrella of other organisations, the management responsibility of the Commission is in the hands of its four Member Countries; Cambodia, Lao PDR, Thailand and Viet Nam. However, nearly over one and a half decade since the treaty was signed, the "sustainable development" provision remains largely ambiguous due to the lack of a legal framework and procedural elements for management by the MRC (Phillips et al., 2006; Bearden, 2010; Osborne, 2010). Water allocation is one of the increasingly important interdependency concerns in the Mekong River Basin (MRB), and is a source of tensions between the countries that share it (Campbell, 2009).

From an economic point of view, joint management of the MR should be aimed at achieving Pareto efficiency and sharing the total economic benefits from efficiency among the riparian countries such that each one is better off. In reality, most transboundary-river disputes are not primarily solved by economic considerations but rather by the distribution of political, military and bargaining power. Water and its economic gains, in this sense, accrue more often simply to the most powerful riparian state within a basin. Recent concerns about increasing the efficiency of water resources utilizations have centered on economical optimal water allocation at the river basin level (McKinney et al., 1999).

For the MR, although the "dialogue partners" China and Myanmar slowly but steadily increased their (non-binding) participation in the various forums of the MRC, it is at present unthinkable that either would join the MRC in the near future. In addition, the governments of Cambodia, Laos, and Thailand are currently contemplating plans to build eleven big hydropower dams on the river's lower mainstream. If built, the lower Mekong dams would block major fish migrations and dramatically change the Mekong forever, placing at risk the food security and income of millions of people. Hence, to save the Mekong, there is a need for "the process where riparians cooperate in optimising and equitably dividing goods, products and services connected directly or indirectly to the water course or arising from the use of its water" and the river basin organisations need to find sustainable financing mechanisms to support the core functions for management of the basin (MRC, 2010).

This paper examines how all riparians in the Mekong might achieve effective development. Taking the 1995 Agreement as a benchmark, we view the MRB as a transboundary water resource shared by two regions: upstream (China) and downstream (i.e. MRC formed by Thailand, Laos, Cambodia, and Vietnam).[1] Our aim is to investigate the welfare effects arising (i) from strengthening the governance of the MRC with and without cooperation with China; (ii) from joint management of the MRC and China; and (iii) how improved governance by the MRC before it negotiates would change the welfare distribution of joint management. We adopt a game theoretic approach as advocated in the literature on water resources management (Dinar et al., 1992; Dinar and Dinar, 2003; Madani, 2010 and references therein). In particular, we use an axiomatic bargaining framework (i.e. Nash, 1950; Kalai, 1977; Roemer, 1988; Thoyer et al., 2001), in which an international transfer of funds from international institutions can be incorporated to provide stronger incentives for joint management of resources. The MR and its economic livelihood then is modelled by extending the single-dam framework of Haddad (2010), in which dam capacity and its operation are both endogenous, to a double-dam framework embedded in a simple river structure with two regions. We also distinguish two seasons (wet and dry seasons) and some other economic activities than just hydropower generation to analyse the welfare changes from non-cooperation to cooperation situations.

We consider the following major economic issues in the MRB: dam capacity for hydropower generation and mitigation of flood damage, industrial and households' activities, irrigated agriculture, and the environmental services or damages (i.e. wetland benefits or damage from saltwater intrusion in the estuary during the dry season). In addition, it is believed that the highly centralized Chinese government has more grip on its water resources than the fragmented MRC with its less effective management. We will analyse the implications of both equal and unequal bargaining power when a joint management approach is proposed. Currently, the cooperation between upstream and downstream regions is unthinkable and the MRC has weak policy instruments. For analysing welfare and the implication of strengthening the MRC's governance, we consider both weak and strong governance structures in our framework. Particularly, the current situation represents "weak" governance in which the different water users maximize their own profits sequentially without taking into account externalities they cause, while the strong governance is represented as a situation where the MRC's regional welfare will be optimized. This allows us to compare the welfare gains from the MRC's improved river management.

The paper is organized as follows. The next section presents our model. Some theoretical insights of the model, concerning the disagreement point and the applied bargaining solution are presented in section 3. Section 4 discusses a case study for the MRB. It presents the simulation results, including water quantity

[1] Myanmar is not party to the 1995 agreement (roughly 2% of the MR drains from the portion of the basin that resides in Myanmar).

accounts and economic values, under different scenarios. Recommendations and concluding remarks follow in the last section.

II. MODEL FRAMEWORK

Our model respects the physical hydrological basin-reality with a unidirectional water flow from upstream to downstream. Total basin-wide water available is determined by total-wide precipitation or water (in)flows. We distinguish two seasons: the wet season (w) and the dry season (d), and two regions: denoted by $i = 1, 2$, where region 1 lies upstream of region 2. Following Haddad (2010), each region has the option to build dam capacity, denoted by D_i. In our model, however, dam capacity is not only used for hydropower generation and storing water from the wet season (denoted by y_i) for usage in the dry season, but also serves as the necessary infrastructure to provide end users such as industry and households with water. Due to evaporation losses, only $\delta_i y_i$, $\delta_i \in (0, 1)$,[2] can be used in the dry season. Water availability, including inflows and river flows, determine water usage in each region $i = 1, 2$ and each season $\tau = w, d$. Water users within the same region are aggregated into three categories of representative water users: Industry and households, hydropower generators and agriculture irrigators. Transboundary flows from upstream to downstream are sensitive to changes by upstream's water use and storage management.

The Water Balances

As mentioned, our model incorporates endogenous dam capacity for multiple usages in each region. We extend it further by adding irrigation as water use and costs of flood damage and saltwater intrusion. The river basin in space and time is presented in Figure 1.

In the wet season w at region 1, inflow $f_{1,w}$ can be spent on water use by industry and households $x_{1,w}$, storage y_1 for the dry season, hydropower generation $q_{1,w}$ that is reusable further downstream, and pass-through by the dam to downstream. River outflow from the dam $o_{1,w}$ consists of $q_{1,w}$ and pass-through that runs directly to downstream. River outflow might cause flood damage. In season d, at region 1, inflow $f_{1,d}$ and the fraction of stored water $\delta_1 y_1$ can be spent on water use $x_{1,d}$, hydropower generation $q_{1,d}$ that remains available further downstream, and pass-through by the dam to downstream. River outflow from the dam $o_{1,d}$ can be used either for irrigation $i_{1,d}$ in the upstream region (assuming an irrigation infrastructure that is independent of dam capacity D_1) or runs to downstream. This imposes $i_{1,d} \leq o_{1,d}$. Formally, upstream's water balances[3] are given by

$$
\begin{aligned}
x_{1,w} + y_1 + q_{1,w} &\leq f_{1,w}, && (1)\\
x_{1,w} + y_1 + o_{1,w} &= f_{1,w}, && (2)\\
x_{1,d} + q_{1,d} &\leq f_{1,d} + \delta_1 y_1, && (3)\\
x_{1,d} + o_{1,d} &= f_{1,d} + \delta_1 y_1, && (4)\\
i_{1,d} &\leq o_{1,d}. && (5)
\end{aligned}
$$

In Figure 1, both $o_{1,w}$ and $o_{1,d}$ are expressed as the residuals from inflow minus water use. Dam capacity D_1 at region 1 imposes the restrictions

$$
\begin{aligned}
x_{1,w} + y_1 + q_{1,w} &\leq D_1, && (6)\\
x_{1,d} + q_{1,d} &\leq D_1. && (7)
\end{aligned}
$$

In the wet season w at region 2, inflow $f_{2,w}$ and $o_{1,w}$ can be spent on water use by industry and households $x_{2,w}$, storage y_2 for the dry season, hydropower generation $q_{2,w}$ that is reusable further downstream, and pass-through by the dam to downstream. River outflow from the dam $o_{2,w}$ might cause flood damage before flowing into the estuary. In the dry season d at region 2, inflow $f_{2,d}$, stored water $\delta_2 y_2$ and net inflow $o_{1,d} - i_{1,d}$ received from upstream can be spent on water use $x_{2,d}$, hydropower generation $q_{2,d}$ that remains available, and pass-through by the dam. River outflow from the dam $o_{2,d}$ can be used either for irrigation $i_{2,d}$

[2] Haddad (2010) assumes a single location and that there are no evaporation losses, i.e. $\delta_i = 1$, $i = 1, 2$.

[3] This formulation extends the model for optimal hydropower generation in Haddad (2010) to include the necessary infrastructure for industrial and households' water use.

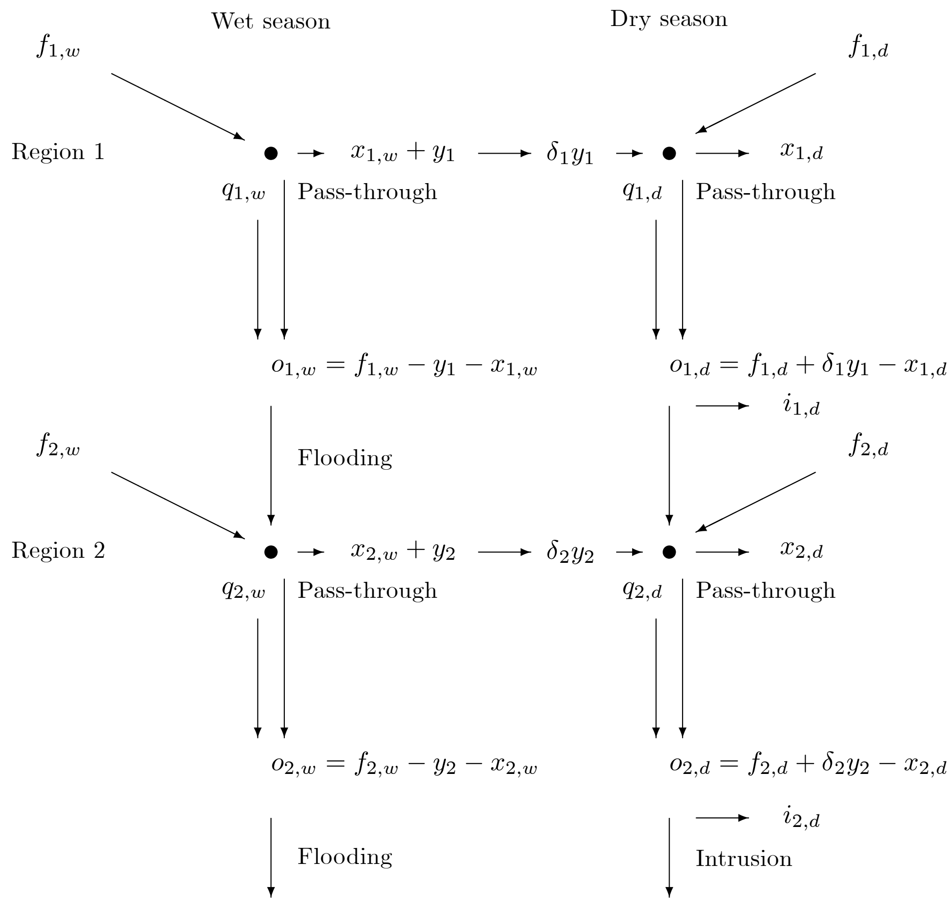

Figure 1: Seasons, locations and water uses in the river basin.

in the own region or left to combat saltwater intrusion in the estuary before flowing into the sea. Formally, the water balances are given by

$$
\begin{aligned}
x_{2,w} + y_2 + q_{2,w} &\leq f_{2,w} + o_{1,w}, && (8)\\
x_{2,w} + y_2 + o_{2,w} &= f_{2,w} + o_{1,w}, && (9)\\
x_{2,d} + q_{2,d} &\leq f_{2,d} + \delta_2 y_2 + o_{1,d} - i_{1,d}, && (10)\\
x_{2,d} + q_{2,d} + o_{2,d} &= f_{2,d} + \delta_2 y_2 + o_{1,d} - i_{1,d}, && (11)\\
i_{2,d} &\leq o_{2,d}. && (12)
\end{aligned}
$$

Dam capacity D_2 at region 2 imposes the restrictions

$$
\begin{aligned}
x_{2,w} + y_2 + q_{2,w} &\leq D_2, && (13)\\
x_{2,d} + q_{2,d} &\leq D_2. && (14)
\end{aligned}
$$

This completes the description of the water balances.

Costs and Benefits

There are three water users that create economic value. Consumptive uses by industry and households in both regions permanently remove amounts of water in the wet and dry season. The economic value of consumptive use $x_{i,\tau}$ in region i in season τ is given by the logarithmic value function $v_{i,\tau} \ln(x_{i,\tau}) - c_{i,\tau} x_{i,\tau}$, which is a concave function with satiation point $\bar{x}_{i,\tau} = v_{i,\tau}/c_{i,\tau} > 0$. Both, $x_{1,w}$ and $x_{1,d}$ are externalities for downstream, as is storage y_1. The net benefits from hydropower $q_{i,\tau}$ in region i in season τ are given by the logarithmic benefit function $h_{i,\tau} \ln(q_{i,\tau})$. The net benefits from irrigation $i_{i,d}$ in region i in season d are $a_{i,d} \ln(i_{i,d}) - \kappa_{i,d} i_{i,d}$, which is also a concave function with satiation point $\bar{\imath}_{i,d} = a_{i,d}/\kappa_{i,d} > 0$. Following Haddad (2010), the costs of building dam capacity D_i of water in region i are $c_i D_i$. These costs include the annuities of the capital costs and the operating and management costs. The operating costs of storing y_i of water are $\hat{c}_i y_i$. Storing water is costly in three ways: building capital, operating costs and evaporation losses.

River flows also involve costs associated with flooding in the wet season and saltwater intrusion in the estuary. The costs of flood damage are $c_{i,f} \cdot (o_{i,w} - \bar{o}_{i,w})$, where $\bar{o}_{i,w} \geq 0$. In the dry season, outflow $o_{2,d} - i_{2,d}$ to the estuary combats saltwater intrusion with costs $c_{2,d} \cdot (o_{2,d} - i_{2,d})$, with $c_{2,d} < 0$. The costs decrease when more fresh water flows into the estuary. We regard irrigation $i_{2,d}$ as irrigation at elevated inland plots that are immune to saltwater intrusion, and irrigation on plots at the lowest parts of the delta can be included as benefits in the costs function for saltwater intrusion. In our simulation, we left out costs for saltwater intrusion because lacking data and assume that there is a constant river flow from Tonle Sap in Cambodia to the estuary that minimizes salt water intrusion.

As shown in Figure 1, upstream's decisions impose externalities on downstream's water availability. These externalities are positive in case upstream stores more water in the wet season, i.e. less flood damage downstream, and negative in case upstream's decisions reduces downstream's water inflow in the dry season, i.e. increased water scarcity and more saltwater intrusion. This extends the negative externalities of water scarcity in Ambec and Ehlers (2008) to a combination of positive and negative externalities. To overcome these externalities, we assume that international aid provides a budget $b \geq 0$ such that each location i obtains a (possibly negative) transfer t_i and

$$t_1 + t_2 \leq b, \tag{15}$$

where the $\leq$ expresses that the regions are free to dispose some fraction of b. We regard transfers as representing either money or some tradable produce.

Upstream's utility function $u_1(x_{1,w}, x_{1,d}, q_{1,w}, q_{1,d}, i_{1,d}, D_1, t_1, o_{1,w})$ is given by

$$\begin{aligned} &v_{1,w} \ln(x_{1,w}) - c_{1,w} x_{1,w} + v_{1,d} \ln(x_{1,d}) - c_{1,d} x_{1,d} + h_{1,w} \ln(q_{1,w}) + h_{1,d} \ln(q_{1,d}) + \\ &a_{1,d} \ln(i_{1,d}) - \kappa_{1,d} i_{1,d} + t_1 - c_1 D_1 - \hat{c}_1 y_1 - c_{1,f}(o_{1,w} - \bar{o}_{1,w}) \end{aligned} \tag{16}$$

and downstream's utility function $u_2(x_{2,w}, x_{2,d}, q_{2,w}, q_{2,d}, i_{2,d}, D_2, t_2, o_{2,w}, o_{2,d})$ is given by

$$\begin{aligned} &v_{2,w} \ln(x_{2,w}) - c_{2,w} x_{2,w} + v_{2,d} \ln(x_{2,d}) - c_{2,d} x_{2,d} + h_{2,w} \ln(q_{2,w}) + h_{2,d} \ln(q_{2,d}) + \\ &a_{2,d} \ln(i_{2,d}) - \kappa_{2,d} i_{2,d} + t_2 - c_2 D_2 - \hat{c}_2 y_2 - c_{2,f}(o_{2,w} - \bar{o}_{2,w}) - c_{2,d}(o_{2,d} - i_{2,d}). \end{aligned} \tag{17}$$

This completes the description of costs and benefits of water use.

III. MODEL SPECIFICATION

In this paper, we explore an axiomatic bargaining approach in the form of the asymmetric Nash bargaining solution (for details, see e.g. Nash, 1950). This solution maximizes an objective function that depends upon the region's utilities, the so-called disagreement point, and bargaining weights reflecting the relative power between the regions. The Nash bargaining solution allows an underpinning by the strategic alternating-offers model in Rubinstein (1982) (for details, see Binmore et al., 1986, and Houba, 2007, 2008).

The Disagreement Point

The disagreement point plays an important role in the Nash bargaining solution. In the MRB, upstream China is a highly centralized economy with a strong government, whereas downstream's MRC can be regarded as a rather politically-divided institution with weak instruments. For that reason, we assume that upstream maximizes its own regional welfare and internalizes its own regional externalities but not the downstream region's externalities. For downstream, we assume river management is ineffective in the sense that end users and dam operators in this region optimize their own benefits without taking into account any externalities at all.[4] Hence, we treat the model as a game in normal form and take its unique Nash equilibrium (NE) as the disagreement point. Due to the directional manner of externalities in which upstream influences downstream but not vice versa, we may solve the Nash equilibrium sequentially similar as in e.g. Ambec and Ehlers (2008). First, the upstream region maximizes its regional welfare, then downstream's dam operator solves his decision problem before downstream's agricultural sector solves its irrigation problem. The last two agents do not take into account any externalities they cause, which represents river management with weak governance. After having derived the disagreement point, we investigate the Nash bargaining solution.

Region 1 has a river basin management with strong policy instruments that internalizes its own regional externalities. This region's objective function is given by the function $u_1\left(x_{1,w}, x_{1,d}, q_{1,w}, q_{1,d}, i_{1,d}, D_1, t_1, o_{1,w}, o_{1,d}\right)$. After substituting out the flow variables $o_{1,w}$ and $o_{1,d}$ from (2) and (4), we obtain the following program for upstream:

$$\begin{aligned} d_1 = \max_{x_{1,w},x_{1,d},q_{1,w},q_{1,d},i_{1,d},D_1,y_1} \; & v_{1,w}\ln\left(x_{1,w}\right) - c_{1,w}x_{1,w} + v_{1,d}\ln\left(x_{1,d}\right) - c_{1,d}x_{1,d} + \\ & h_{1,w}\ln\left(q_{1,w}\right) + h_{1,d}\ln\left(q_{1,d}\right) + a_{1,d}\ln\left(i_{1,d}\right) - \kappa_{1,d}i_{1,d} \\ & -c_1 D_1 - \hat{c}_1 y_1 - c_{1,f}\left(f_{1,w} - x_{1,w} - y_1\right), \end{aligned} \tag{18}$$

s.t.

$$\begin{array}{lcll} x_{1,w} + y_1 + q_{1,w} & \leq & f_{1,w}, & (p_{1,w}) \\ x_{1,d} + q_{1,d} & \leq & f_{1,d} + \delta_1 y_1, & (p_{1,d}) \\ i_{1,d} & \leq & f_{1,d} + \delta_1 y_1 - x_{1,d}, & (\lambda_{1,d}) \\ x_{1,w} + y_1 + q_{1,w} & \leq & D_1, & (\mu_{1,w}) \\ x_{1,d} + q_{1,d} & \leq & D_1, & (\mu_{1,d}) \end{array}$$

where all symbols between brackets denote shadow prices. The maximal welfare is region 1's disagreement point in the negotiations for joint river basin management.

The politically-divided downstream region with weak instruments is modelled by two agents that sequentially take decisions. The first agent decides the dam capacity for the joint use of industrial and households' water use and hydropower generation. The second agent decides on irrigation. These agents do not take into account external effects, or to put it differently, no policy to price externalities is present in the downstream region. Given Nash equilibrium quantities $o_{1,w}^{NE}$, $o_{1,d}^{NE}$ and $i_{1,d}^{NE}$ for upstream, the downstream dam-building agent solves

$$\begin{aligned} \max_{x_{2,w},x_{2,d},q_{2,w},q_{2,d},D_2,y_2} \; & v_{2,w}\ln\left(x_{2,w}\right) - c_{2,w}x_{2,w} + v_{2,d}\ln\left(x_{2,d}\right) - c_{2,d}x_{2,d} + \\ & h_{2,w}\ln\left(q_{2,w}\right) + h_{2,d}\ln\left(q_{2,d}\right) - c_2 D_2 - \hat{c}_2 y_2, \end{aligned} \tag{19}$$

s.t.

$$\begin{array}{lcll} x_{2,w} + y_2 + q_{2,w} & \leq & f_{2,w} + \delta_2 y_2 + o_{1,w}^{NE}, & (p_{2,w}) \\ x_{2,d} + q_{2,d} & \leq & f_{2,d} + \delta_2 y_2 + o_{1,d}^{NE} - i_{1,d}^{NE}, & (p_{2,d}) \\ x_{2,w} + y_2 + q_{2,w} & \leq & D_2, & (\mu_{2,w}) \\ x_{2,d} + q_{2,d} & \leq & D_2, & (\mu_{2,d}) \end{array}$$

where all symbols between brackets denote shadow prices. Also $o_{1,w}^{NE} > 0$ seems realistic for the MRB, and therefore, $D_2 < f_{2,w} + o_{1,w}^{NE}$ seems appropriate. The dam operator's optimal management induces equilibrium river flows $o_{2,w}^{NE}$ and $o_{2,d}^{NE}$ from the dam. Then, the downstream irrigation sector, who is most downstream of all water users, solves

$$\max_{i_{2,d}} a_{2,d}\ln\left(i_{2,d}\right) - \kappa_{2,d}i_{2,d}, \;\text{ s.t. }\; i_{2,d} \leq o_{2,d}^{NE} \qquad \left(\lambda_{2,d}\right). \tag{20}$$

This program can be solved straightforwardly as optimal irrigation is $i_{1,d} = \min\left\{\bar{\imath}_{1,d}, o_{1,d}^{NE}\right\}$.

[4] From a technical point of view, we demonstrate two different ways of modelling regions. In essence, any combination of weak and strong governance can be modelled, such as either both have weak governance, both have strong governance or the opposite case with upstream having weak governance and downstream strong.

Downstream's disagreement utility is given by the sum of the utilities of its two agents utilities and deducting the costs of flooding and saltwater intrusion. Formally,

$$\begin{aligned} d_2 &= v_{2,w}\ln\left(x_{2,w}^{NE}\right) - c_{2,w}x_{2,w}^{NE} + v_{2,d}\ln\left(x_{2,d}^{NE}\right) - c_{2,d}x_{2,d}^{NE} + h_{2,w}\ln\left(q_{2,w}^{NE}\right) + h_{2,d}\ln\left(q_{2,d}^{NE}\right) + \\ &\quad a_{2,d}\ln\left(i_{2,d}^{NE}\right) - \kappa_{2,d}i_{2,d}^{NE} - c_2 D_2^{NE} - \hat{c}_2 y_2^{NE} - c_{2,f}o_{2,w}^{NE} - c_{2,d}\left(o_{2,d}^{NE} - i_{2,d}^{NE}\right). \end{aligned} \tag{21}$$

This is the disagreement point under ineffective regional water management.

The case of effective river management by downstream would be similar to upstream's optimal river management defined (18), but after changing all subscripts 1 into 2 and include the costs of saltwater intrusion. Comparing the difference between both solutions provides an estimate for the welfare loss of downstream's ineffective river basin management, which is one issue of interest in our study.

The Nash Bargaining Solution

The regions' disagreement levels, as introduced above, play an important role in the Nash bargaining solution. We assume that there is a possibility of an international transfer of funds from international institutions to provide stronger incentives for cooperation. For this solution, we characterize the transfers and relate these to the funds and the solution's other variables.

Formally, we denote $\alpha \in [\frac{1}{2}, 1)$ as upstream's bargaining weight and $1-\alpha \in (0, \frac{1}{2}]$ as downstream's weight. The bargaining weights reflect that upstream (China) has more bargaining or political power than downstream (the MRC). The asymmetric Nash bargaining solution is given by the unique maximizer of the following program:

$$\max_{\substack{(u_1,u_2)\geq(d_1,d_2);u_1,u_2,t_1,t_2;\\ x_{1,w},x_{1,d},x_{2,w},x_{2,d},q_{1,w},q_{1,d},q_{2,w},q_{2,d},q_{1,d},i_{1,d},i_{2,d};\\ D_1,D_2,y_1,y_2,o_{1,w},o_{1,d},o_{2,w},o_{2,d}}} \left(u_1 - d_1\right)^{\alpha}\left(u_2 - d_2\right)^{1-\alpha}, \tag{22}$$

$$\begin{aligned} &\text{s.t.} \\ u_1 &\leq (16)\,, && (v_1) \\ u_2 &\leq (17)\,, && (v_2) \\ t_1 + t_2 &\leq b, && (p_m) \\ &\text{and (1)-(15).} \end{aligned}$$

A novel aspect that we implement in the latter program is the role of international aid given by b. For that reason, we derive how the external budget accrues to upstream and downstream through the negotiated transfers.

Proposition 1 *The Nash bargaining solution implies transfers given by*

$$t_1 = \alpha b + \alpha\left(w_2(\cdot) - d_2\right) - (1-\alpha)\left(w_1(\cdot) - d_1\right), \tag{23}$$

$$t_2 = (1-\alpha)b + (1-\alpha)\left(w_1(\cdot) - d_1\right) - \alpha\left(w_2(\cdot) - d_2\right), \tag{24}$$

where $w_1(\cdot) = (16) - t_1$ and $w_2(\cdot) = (17) - t_2$ denotes region i's utility in the Nash bargaining solution.

This result shows that the negotiated transfers depend upon the exogenous budget $b \geq 0$ provided by the international organizations. The stronger region, here by assumption upstream, obtains the lion share of the external budget. This is, however, only the direct effect of the external budget, and there are also indirect effects. To see this, note that αb and $(1-\alpha)b$ push the players' utilities u_1 and u_2 upward in the Nash product and this changes the marginal contributions of the utilities to the Nash product. Therefore, the optimal allocation also adjusts.

IV. NUMERICAL ANALYSIS FOR JOINT MRB MANAGEMENT

In this section, we present our numerical results for the MRB's joint management under different scenarios. First, we present our baseline or benchmark that represents the most realistic scenario for the disagreement point. The baseline consists of the model simulation results based on the 1995 data where we assume that downstream has weak governance without cooperation with upstream. Then, we present the results on economic values, water balances and shadow prices under non-cooperation between upstream and downstream and also for the case in which downstream has strong governance, which shows the implication of the MRC's governance structure in terms of economic costs. Next, we discuss the results for several scenarios of upstream and downstream cooperation: with weak or strong downstream governance representing the disagreement point, different levels of bargaining power, and with or without an exogenous budget. This provides information on the implications of cooperation under various scenarios.

Benchmark

The yearly water inflows due to precipitation and the water withdrawals for industrial and households' use, i.e., the so-called consumptive use, are given in Table 1. Upstream withdraws 17.8 per cent of available water inflows and downstream only 7.0 per cent.

Table 1: Yearly water inflows and water withdrawal in 1995 (in km^3).
Source: Adapted from Ringler (2001).

	Water inflows	Water withdrawal
Upstream	2812	500
Downstream	1492	104

The Mekong River is known for its huge seasonal variability with the ratio of 9:1 for water availability in the wet and dry seasons. Using this ratio, we can easily obtain the water inflows in both seasons. Table 2 shows the economic values generated from different types of water use in the two regions.

Table 2: Profits from different types of water uses in million US$.
Source: Adapted from Ringler et al. (2004).

	Upstream	Downstream
Irrigation	20	893
Industrial & households	11	159
Hydropower incl. fisheries	0.05	589
Wetlands	0	134
Total	31	1778

The upstream region of the MRB is mainly situated in Yunan province of China. The economic value generated downstream is the aggregate of the MRC members. The ratio of the profit of one type of water and the total profit of all water reflects the relative importance or the weight of that particular type of water in the economy.

To calibrate the model, we use the profit ratio of each category of water to generate the coefficients of the value functions for both upstream and downstream region. Besides, we also use the water withdrawal in 1995 as the benchmark for the total consumptive use of industry and households. Furthermore, we assume some values for parameters of reserving costs, flooding costs, dam-building costs and irrigation costs to make the model completely specified. Lacking data, we set the costs of saltwater intrusion equal to zero also because there is a constant river flow from Tonle Sap in Cambodia to the estuary that already mitigates saltwater intrusion. This allows us to solve this model numerically and obtain results on water allocation to each type of water use. For calibration, we adjust the parameter for reserving costs in numerical simulation such that the model results reflect the current water use. The baseline results including the possible expanding dam capacity and the shadow prices for each type of water will be detailed below.

Upstream under non-cooperation

In the baseline scenario there is no cooperation. Upstream maximizes its own economic value (or welfare) subject to its regional water balances, which is program (18). Table 3 presents the water balances for both regions and the scenarios of non-cooperation and cooperation. We discuss the column non-cooperation for upstream first. In such an economy with the given technologies, hydrological parameters and value functions, the river flow to downstream in the wet and dry season are 1552 and 0 km^3, respectively. In the wet season, the upstream region uses 329 km^3 of water for consumptive use of industry and households, reserves 649 km^3 for irrigation (or other use) in the dry season as its first priority, and distributes a small amount for hydropower (1.5 km^3 water) according to the marginal values of these usages.

One can easily see from Table 3 that without cooperation, roughly two-thirds of water inflow (1552 of 2530 km^3) flows to downstream, which may cause downstream flooding in the wet season. In the dry season, however, no water flows to downstream causing drought and increases sea water intrusion. This does not count on the river flow to the estuary in reality where the continuous release from the lake Tonle Sap maintains a considerable flow. Of course, tributaries and the natural storage capacity of Tonle Sap are unmodelled. Also water traveling 4200 km^3 along the MR takes time and delays are not captured in our simple framework.

Table 3: Water balances under non-cooperation in two seasons (in km^3).

Water use	Upstream		Downstream (Weak)		Downstream (Strong)	
	Wet	Dry	Wet	Dry	Wet	Dry
Water inflow (Precipitation)	2530.8	281.2	1342.8	149.2	1342.8	149.2
River flow from upstream	—	—	1552.3	0.0	1552.3	0.0
Water availability	2530.8	281.2	2895.1	149.2	2895.1	149.2
Reserved water	649.2	-649.2	1.0	-1.0	295.7	-295.7
Consumptive use	329.3	170.7	37.2	21.1	75.9	28.1
Hydropower generation	1.5	759.7	456.1	129.1	331.3	416.8
Outflow from dams	1552.3	759.7	2856.9	129.1	2523.5	416.8
Irrigation	—	759.7	—	129.1	—	416.8
Outflow to downstream/estuary	1552.3	0.0	2856.9	0.0	2523.5	0.0

The shadow prices of the constraints (1)-(7) under non-cooperation are shown in Table 4. The shadow prices of outflow, which are associated to (2) and (4), reflect upstream's marginal costs and benefits of the altered volumes of river flow. These prices reflect the negative flood damage in the wet season, and the positive benefit from upstream's irrigation in the dry season that is directly linked to the shadow prices of irrigated agriculture, i.e., (5). Under the current water inflows and existing technologies, the irrigation sector upstream has a high shadow price, which means this is a demanding part of water use in the dry season for upstream. These prices reflect that, even under regionally-optimal management, upstream has a clear incentive to decrease flood damage and increase irrigation. Furthermore, the shadow prices of dam capacity, which are associated to (6) and (7), explain the benefit of further expanding dam capacity in the wet season under the given building costs, and there is no such benefit of further expanding dam capacity for economic activities in the dry season. Given the costs of reserving water, upstream does not want to reserve more than 649 km^3 in the wet season. These shadow prices do not allow to disentangle the marginal benefit of consumptive use by industry and households from the marginal benefits from hydropower generation. The net benefits of expanding dam capacity in the wet season drive expansion. Finally, the shadow prices of water availability, which are associated to (1) and (3), reflect that there is water scarcity in the dry season, but no such scarcity in the wet season (because (1) is nonbinding).

Table 4: Shadow prices of the constraints in baseline (non-cooperation) in \$/m^3.

Water use	Upstream		Downstream (Weak)		Downstream (Strong)	
	Wet	Dry	Wet	Dry	Wet	Dry
Water availability	0.0	0.2	0.0	265.5	0.0	79.5
Dam capacity	105.0	0.0	72.6	0.0	100.0	0.0
Outflow	-150.0	54.8	0.0	0.0	-150.0	70.5
Irrigation water availability		54.8		339.0		70.5

Downstream under non-cooperation

Water outflow, from upstream to downstream, is an externality for downstream, and downstream has to take it as given. In order to check the welfare gains from better governance by the MRC, we solve the downstream problem under weak and strong governance. Weak governance, which is the current situation, means that there is no joint management between the dam operator and the agricultural sector for internalizing regional externalities. First, the Nash equilibrium is obtained by maximizing the dam operator's value function (i.e. in (19)) and then solving the problem of the agricultural users (as in (20)). For strong governance, the equilibrium is obtained by maximising the regional welfare subject to the constraints of water balances similar to (18).

As shown in Table 3, under strong governance there will be 333.4 km^3 less water outflow from the dam in the wet season than under weak governance (i.e. 2523.5 versus 2856.9 km^3), which mitigates flood damages, because strong governance internalizes some externalities at the regional level. This is accomplished by storing 294.7 km^3 more water and encouraging more consumptive use of 42.3 km^3 water. For the same reason, hydropower generation is reduced by 124.8 km^3 (from 456.1 to 331.3 km^3) in the wet season under strong governance to reduce flood damage. The stored water is used to increase hydropower generation and irrigation in the dry season. So, the economic costs of dam building, storing water and less hydropower generation in the wet season are compensated by reduced flood damages and increased consumptive use in the wet season, and by increased hydropower generation and irrigation in the dry season.

The shadow price of the constraints (8)-(14) under non-cooperation and for both weak and strong governance are also shown in Table 4. Under strong governance, the shadow prices cancel each other out, similarly as we have seen for upstream. Under weak governance, however, dam operators will not be rewarded for reducing flood damage or for increasing the amount of water available for irrigation. This is reflected in the shadow prices for outflow that are zero. The lack of economic incentives for dam operators under weak governance are an additional 333.4 km^3 of flood volume and 287.7 km^3 less water available for irrigation than would have been achieved under strong governance. In the dry season the prices for water availability and irrigation under weak governance are higher than under strong governance implies that water scarcity is reduced by stronger governance.

Table 5 shows the existing dam capacity and the potential expansion under the non-cooperation situation. Downstream has more dam capacity (i.e. 494 km^3), compared to a capacity of 4.5 km^3 in the upstream region (recall that this refers to over 15 years ago). This is probably due to the fact that there is much longer distance over the river, many tributaries to the main river flow, and more countries in the Lower Mekong. Upstream has the potential to expand its dam capacity considerably for its economic development. Under weak governance, there is no expansion of dam capacity in the Lower Mekong because the MRC provides insufficient incentives for the dam operators to do so, but under strong governance there would be a potential expansion (209 km^3) although it is relatively small compared to upstream's expansion (975 km^3). The expansion downstream could internalize the LMR's regional externalities. This also leads to a lower relative shadow price of hydropower generation downstream than upstream in the wet season (100 versus 105 as in Table 4).

Table 5: Existing dam capacity and expansion potential under non-cooperation (in km^3).

Dam Capacity	Upstream	Downstream	
		Weak governance	Strong governance
Existing	4.5	494.3	494.3
Expansion	975.5	0.0	208.6
Total	980.0	494.3	702.9

Note that we calibrated the model with data from 1995 when upstream China did not have much dams installed in the MR. China has started to expand dam capacity rapidly since then, and has completed three dams with an aggregate capacity of 40.0 km^3 and planned to build thirteen dams in the near future (Osborne, 2010). Our model results show the long-term development trend already going on in China, although we are aware that our results may overestimate these developments because our model does not place any cap on the maximal physically-feasible dam capacity related to landscape considerations. Although downstream has also already built many dams, its expansion potential in the future from an economic point of view may be relatively modest. Under weak governance, it has even reached its maximal level and no expansion will occur.

If there is no cooperation or water basin agreement, the two regions only care about their own economic values and allocate water according to their value functions. The upstream users will not consider the externalities they generate upon downstream users and the downstream users just take this externality as given in their economic activities. This is not economically efficient because water is not used to the possibly highest value (see Table 6). *Without joint management, the economic value of upstream is 316.1 million US$, while downstream's value are 190.0 million US$ and 234.2 million US$ respectively under weak and strong governance.* The economic costs of weak governance without cooperation with China, therefore, are 44.2 million US$ for the LMR. We are now turning to show how cooperation through bargaining can achieve the more efficient use of the river basin, i.e. obtaining higher economic values in two regions.

Upstream-downstream Cooperation

In the bargaining model, the two regions have the possibility of bargaining aiming to achieve the highest cooperative profit. We run the model for four scenarios with upstream's bargaining power α being 0.5 and 0.75, and the exogenous budget b being 0 or 100 million US$. Table 6 shows the economic values for the upstream and downstream region under different scenarios when downstream governance is weak or strong.

Table 6: Economic values for non-cooperation and four scenarios of cooperation under weak and strong governance (in million US$).

	Scenarios		Upstream		Downstream	
	α	b	Weak downstream	Strong downstream	Weak downstream	Strong downstream
Non-cooperation			316.092	316.092	189.977	234.161
Cooperation	0.5	0	459.152	437.060	333.037	355.129
	0.5	100	509.152	487.060	383.037	405.129
	.75	0	530.687	497.549	261.502	294.640
	.75	100	605.687	572.549	286.502	319.640

From Table 6 we can observe three findings. *First*, there are large welfare gains from cooperation for both regions but the size and distribution depends upon the bargaining power and the international transfers. For equal bargaining power and no international transfers, the gain for upstream is 143.1 million US$ (i.e. from 316.1 to 459.2 million US$), and 121.0 million US$ (316.1 to 437.1 mission US$) depending on whether disagreement is characterized by weak or strong downstream governance respectively. Under equal bargaining power, upstream and downstream equally split the net gains. Stronger governance by downstream increases this region's disagreement outcome and this improves its bargaining position at the expense of upstream. Similarly, unequal bargaining power (e.g. 0.75) increases this region's welfare by 71.5 million US$ in case of no international transfers (from 459.2 to 530.7 million US$) and by 96.5 million US$ with such transfers (i.e. from 509.2 to 605.7 million US$). For downstream, this region's welfare decreases by these amounts. *Second*, more bargaining power for upstream is beneficial to upstream at the expense of downstream, which is in accordance with bargaining theory. Or, bargaining power determines the distribution of the welfare gains from cooperation.

Third, we estimate the economic costs for downstream if weak governance instead of strong governance determines the consequences of disagreement in the negotiations. Comparing the two disagreement outcomes (Table 6), one can easily see that the economic costs of weak downstream governance under non-cooperation are 44.2 million US$. These are the costs if upstream would refuse to negotiate joint management of the MR, as is currently the case. If upstream would start the negotiations before downstream could realize strong governance, then the economic costs for downstream of reaching less favourable agreement would reduce to 22.1 million US$ and 33.1 million US$ under equal and unequal bargaining respectively. These losses are lower for the following reason. Weak governance by downstream would have a net gain of joint management that is 44.2 million US$ higher when compared to the net gain that could be realized under strong governance. Of this net gain, depending on the distribution of bargaining power, either half or one quarter would accrue to downstream anyway under joint management. So, downstream only looses the fraction that accrues to upstream, which is less than the 44.2 million US$. Nevertheless, downstream would be better off by either 22.1 or 33.1 million US$, depending upon upstream's bargaining power, if it first strengthens its governance before entering the negotiations with upstream.

It is believed that upstream (China) has more political power than downstream, and we have argued that an international budget would provide stronger incentives to manage the MRB jointly. We also demonstrated that the MRC would gain from strong governance in two ways: It improves efficiency without an agreement with upstream China. And if strong governance is achieved before downstream starts negotiations with upstream, then it negotiates a more favourable distribution of the joint welfare gains. Hence, in what follows, we will report and discuss the results on dam capacity and water balances under cooperation for the scenario of $\alpha = 0.75$, $b = 100$ and weak downstream governance.

The water balances are reported in Table 7, where we added non-cooperation to facilitate comparisons. Under cooperation if downstream has weak governance, upstream will decrease the water flow to downstream in the wet season tremendously from 2.812 to 1219.8 km^3, and increase the water flow to downstream in the dry season to 657.8 km^3 mainly through reserving water, which mitigates flooding in the wet season and water scarcity in the dry season for downstream. Therefore the consumptive use increases under cooperation. The storage of water by upstream increases more than three times from 649.2 to 2007.2 km^3. Consequently, the river flow increases in the dry season. This increase does not cause flood damages and it mitigates water scarcity in the dry season. Of course, water traveling 4200 km along the MR takes time and delays are not captured in our simple framework. Also tributaries and the natural storage capacity of Tonle Sap, which generates a positive flow to the estuary, are not modelled. Delays and other changes to our model may partly undo the positive effects of water storage by upstream in the wet season, as do natural bounds that limit the maximal physically-feasible dam capacity. These issues are left for future research.

Table 7: Water balances under non-cooperation and cooperation in two seasons (in km^3).

	Non-cooperation		Cooperation	
	Wet	Dry	Wet	Dry
Upstream				
Water inflow (Precipitation)	2530.8	281.2	2530.8	281.2
Reserved water	649.2	-649.2	2007.2	-2007.2
Consumptive use	329.3	170.7	520.8	210.9
Hydropower generation	1.5	759.7	2.8	2077.5
Outflow from dams	1552.3	759.7	2.8	2077.5
Irrigation	—	759.7	0	1419.7
Outflow to downstream	1552.3	0.0	2.8	657.8
Downstream (weak governance)				
Water inflow (Precipitation)	1342.8	149.2	1342.8	149.2
River flow from upstream	1552.3	0.0	2.8	657.8
Water availability	2895.1	149.2	1345.6	807.0
Reserved water	1.0	-1.0	0.1	-0.1
Consumptive use	37.2	21.1	125.7	38.9
Hydropower generation	456.1	129.1	621.9	748.9
Outflow from dams	2856.9	129.1	1219.8	768.3
Irrigation	—	129.1	0	768.3
Outflow to estuary	2856.9	0.0	1219.8	0

Table 8 reports the expansion of dam capacity under the non-cooperative and cooperative situation. Both regions will increase their dam capacity (from 980 to 2530.8 km^3 for upstream and from 702.9 to 747.8 km^3 for downstream) and more dams will be built upstream. The main reason is that in our simple modelling of water balances upstream dams prevent flooding for both upstream and downstream, and water stored for upstream in the wet season can be used either for hydropower generation, or consumptive use or irrigation in the dry season. Therefore, it is less efficient for downstream to build more dams for flood prevention, and only its benefits for hydropower generation and the consumptive use of industry and households drives the expansion of dams.

Table 8: Dam capacity (in km^3), cooperation $\alpha = .75$ and $b = 100$.

Dam Capacity	*Upstream*		*Downstream (weak governance)*	
	Non cooperation	Cooperation	Non cooperation	Cooperation
Existing	4.528	4.528	494.256	494.256
Expansion	975.501	2526.272	208.577	253.499
Total	980.029	2530.800	702.933	747.755

Under cooperation the consumptive use by industry and households, the hydropower generation downstream in the dry season increases because the increased inflow from upstream in this season increases water availability. Water storage is costly not only in terms of dam capacity, but also in operating costs. For these reasons, the increased river flow is used to generate hydropower. The flooding is reduced because less than half of water flows out to the estuary (from 2856.9 to 1219.8 km^3). The reduced river flow coming from upstream mitigates flood damages and reduces the need of storing water under joint river basin management.

V. RECOMMENDATIONS AND CONCLUDING REMARKS

Transboundary water resources are often a cause for conflicts among riparian entities and negotiations over water among several sovereign nations are typically difficult. Smaller and weaker countries are suffering most because they have neither the political clout nor the economic strength to achieve their goals (Kirmani and Le Moigne, 1997). Negotiations on the allocation of a water resource (or the benefits from using it) are more difficult when one does not know in advance how much water supply or demand will be generated under future conditions (e.g. population growth, economic activities, and climate change) such as in case of the Mekong River. Following an axiomatic bargaining approach in the form of the asymmetric Nash bargaining solution, this paper shows that the welfare gains from strengthening the MRC are substantial.

Our numerical analysis indicates that the gains from cooperation are significant and that both China and the MRC have incentives for joint river basin management. Such cooperation is a win-win situation. The MRC, therefore, should obtain a solid legal framework with strong procedural elements that can implement river basin management. Even without cooperation, China will expand its dam capacity but this does not internalize upstream-downstream externalities. Strengthening downstream governance would increase the bargaining position of the LMR countries by improving their disagreement outcome and thus achieve higher benefits in cooperation to the MRB. In addition, we demonstrate that an exogenous budget in the form of international aid provides stronger incentives for cooperation in the MRB. Our numerical results also show that if bargaining power distorts a fair distribution of the welfare gains because welfare will mostly accrue to the stronger region, then the external funds would also be unequally divided. In this case, we may also need international imposed restrictions with respect to the distribution of such funds. The first policy measure, therefore, is to establish a legal framework including effective procedures for river management by the MRC. Furthermore, efficient river basin management requires the cooperation of all countries in the MRB, including China and Myanmar.

Another important policy issue is to find ways to implement the efficient joint management of our simulations. It is important to strengthen the cooperation among all nations, rather than only the local MRC in the Lower Mekong. This can begin with assistance to foster common perceptions, which should include the sharing of official data on water resources by all six nations. A wider MRC including China and Myanmar would avoid conflict between upstream and downstream. If there is a wider and stronger MRC, including upstream, the welfare gains are larger. This implies the future development of MRC should include all six nations along the river for a common development and opportunities. Hence, cooperation should start with a common perception of the status quo situation including a mutual acceptance of aspects like the presence of claims to water, perceived property rights and official water use data (c.f. Ansink, 2009). Consequently the negotiation process on the specifications of a water allocation agreement or on a jointly supported principle for water sharing can begin.

Some of the usual caveats apply to our analysis. We use data from 1995 for numerical analysis due to data limitations, although the current situation has been changed considerably since that time. This obviously raises some issues about accuracy of the model results and the interpretation of the quantitative results. Next, the spatial and temporal scale of our numerical model needs further improvement. Since the four member countries forming the MRC are lumped together, it would also be preferable to disaggregate these countries in order to further investigate conditions productive of unanimity. For that reason, we regard our analysis as the first step in developing models that provide some insights into the joint management opportunities in the MRB. For future analysis, we need to consider expansion of the membership of the MRB management. The MRC is not a solid organization yet, which might give more insights into the effectiveness of management of the local MRC or the joint management of all countries along the river.

As a final remark, we mention that the developed framework is generally applicable to transboundary rivers that are shared among two riparian countries. As such, it is directly applicable to the recent political tension between downstream Pakistan and upstream India over dam construction in several tributaries of the Indus River (The Economist, 2011).

APPENDIX: PROOF OF PROPOSITION 1

Redefine (16) and (17) as $w_1(x_{1,w}, x_{1,d}, q_{1,w}, q_{1,d}, i_{1,d}, D_1, o_{1,w}) + t_1$ and $w_2(x_{2,w}, x_{2,d}, q_{2,w}, q_{2,d}, i_{2,d}, D_2, o_{2,w}, o_{2,d}) + t_2$ respectively. Then, we can rewrite the first two constraints of (22) as $u_i - t_i \leq w_i(\cdot)$, $i = 1, 2$. Ignoring the constraints (1)-(15), we have the Lagrangian function given by

$$\begin{aligned}
&(u_1 - d_1)^{\alpha} (u_2 - d_2)^{1-\alpha} \\
&-\upsilon_1 [u_1 - t_1 - w_1(x_{1,w}, x_{1,d}, q_{1,w}, q_{1,d}, i_{1,d}, D_1, o_{1,w})] \\
&-\upsilon_2 [u_2 - t_2 - w_2(x_{2,w}, x_{2,d}, q_{2,w}, q_{2,d}, i_{2,d}, D_2, o_{2,w}, o_{2,d})] \\
&-p_m [t_1 + t_2 - b],
\end{aligned}$$

where we maximize over u_1, u_2, t_1, t_2 and the shadow prices. The first-order conditions are given by

$$\begin{aligned}
u_1 :& \quad \alpha (u_1 - d_1)^{-(1-\alpha)} (u_2 - d_2)^{1-\alpha} - \upsilon_1 = 0, \\
u_2 :& \quad (1-\alpha)(u_1 - d_1)^{\alpha} (u_2 - d_2)^{-\alpha} - \upsilon_2 = 0, \\
t_1 :& \quad \upsilon_1 - p_m = 0, \\
t_2 :& \quad \upsilon_2 - p_m = 0,
\end{aligned}$$

$$\begin{aligned}
\upsilon_1 [u_1 - t_1 - w_1(x_{1,w}, x_{1,d}, q_{1,w}, q_{1,d}, i_{1,d}, D_1, o_{1,w})] &= 0, \\
\upsilon_2 [u_2 - t_2 - w_2(x_{2,w}, x_{2,d}, q_{2,w}, q_{2,d}, i_{2,d}, D_2, o_{2,w}, o_{2,d})] &= 0, \\
p_m (t_1 + t_2 - b) &= 0.
\end{aligned}$$

From these conditions, we obtain

$$\alpha (u_1 - d_1)^{-(1-\alpha)} (u_2 - d_2)^{1-\alpha} = (1-\alpha)(u_1 - d_1)^{\alpha} (u_2 - d_2)^{-\alpha} = \upsilon_1 = \upsilon_2 = p_m > 0,$$

because Pareto inefficiency of the Nash equilibrium underlying d_1 and d_2 implies that the first two terms will be positive. These two terms combined with $t_1 + t_2 = b$ imply

$$\alpha (w_2(\cdot) + b - t_1 - d_2) = (1-\alpha)(w_1(\cdot) + t_1 - d_1)$$

from which (23) and (24) follow directly.

REFERENCES

Ambec, S., and L. Ehlers (2008). Sharing a river among satiable agents. *Games and Economic Behavior* **64**, 35-50.

Binmore, K., A. Rubinstein, and A. Wolinsky (1986). The Nash bargaining solution in economic modeling.*Rand Journal of Economics*, **17**, 176–188.

Bearden, B.L. (2010). The Legal Regime of the Mekong River: A look back and some proposals for the way ahead. *Water Policy* **12** (6): 798-821

Campbell, I. (2009). *The Mekong: Biophysical Environment of an International River Basin*. Elsevier.

Dinar S. and A. Dinar (2003). Recent Developments in the Literature on Conflict and Cooperation in International Shared Water. *Natural Resources Journal,* **43**, 1217-1287.

Haddad, M.S.(2010). Capacity choice and water management in hydroelectricity systems. *Energy Economics* 33, 168-177.

Houba, H. (2007). Alternating offers in economic environments.*Economics Letters* 96, 316-324.

Houba,H. (2008). Computing Alternating Offers and Water Prices in Bilateral River Basin Management. *International Game Theory Review* 10, 257-278.

Kalai, E. (1977). Nonsymmetric Nash solutions and replication of 2-person bargaining. *International Journal of Game Theory* 6: 129–133.

Kirmani, S. and G. Le Moigne (1997). Fostering Riparian Cooperation in International River Basins: The World Bank at Its Best in Development Diplomacy. *World Bank Technical Paper*, No 335.

Madani K. (2010). Game Theory and Water Resources. *Journal of Hydrology* 381, 225- 238.

McKinney, D.C, Cai, X, Rosegrant, M.W, Ringler, C. and C.A. Scott (1999) *Modeling water resources management at the basin level. Review and future directions*. International Water Management Institute, Colombo, Sri Lanka.

MRC (2005). Overview of the Hydrology of the Mekong Basin. Executive Summary. *Mekong River Commission*, Phnom Penh, Cambodia.

MRC (2010) Strategic Plan 2011-2015, *Mekong River Commission for sustainable development,* Vientiane, Lao PDR

Nash, J. (1950). The bargaining problem.*Econometrica*, 18, 155-162.

Osborne, M. (2010). The Mekong River under Threat. *The Asia-Pacific Journal,* January 11, 2010.

Phillips, D.J.H., M. Daoudy, J. Öjendal, A. Turton and S. McCaffrey (2006). T*rans-boundary Water Cooperation as a Tool for Conflict Prevention and for Broader Benefit-sharing*. Ministry for Foreign Affairs, Stockholm, Sweden.

Ringler, C.(2001). Optimal Water Allocation in the Mekong River Basin. *ZEF-Discussion Papers On Development Policy*, No. 38.

Ringler, C., J. von Braun and M.K. Rosegrant (2004). Water policy analysis for the Mekong River Basin. *Water International* 29, 30-42.

Rubinstein, A. (1982). Perfect equilibrium in a bargaining model.*Econometrica*, 50, 97–109.

The Economist (2011), Unquenchable thirst, Vol. 400 Issue 8760, 27-29.

Thoyer, S., S. Morardet, P. Rio, L. Simon, R. Goodhue, and G. Rausser (2001). A bargaining model to simulate negotiations between water users.*Journal of Artificial Societies and Social Simulation* 4,2–20.