Sharing a River: A Bilateral Mekong River Basin Management[1]

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ABSTRACT

The Mekong River (MR) is shared by six countries: China, Myanmar, Thailand, Laos, Cambodia, and Vietnam. Over the years there have been both conflict and cooperation on managing the water resources to meet population growth, climate change and the desire for economic development. Currently, the MR Committee (MRC) has weak policy instruments. This paper exploits an axiomatic bargaining approach to examine how China and the MRC might negotiate effective joint management. We investigate what welfare improvements arise from strengthening the MRC and propose an alternative offering for the MR's joint management that is preferable to the status quo from the perspective of all nations. We show that there are little gains from cooperation unless international institutions provide a budget to promote cooperation with China. Alternatively, strengthening the MR Committee has the potential to achieve large welfare improvements.

Keywords: transboundary river basin, Mekong River, optimization, Nash bargaining solution.
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I. INTRODUCTION

The Mekong River (MR) is the major water source in Southeast Asia, flowing through or forming the border of six countries: China, Myanmar, Laos, Thailand, Cambodia, and Vietnam. The MR is not only the source of food, water, and transport for over 70 million people from over 90 distinct ethnic groups, the river basin is also home to over 1,300 species of fish, creating one of the most diverse fisheries in the world (Campbell, 2009; Osborne, 2010). Over the years there has been conflict and cooperation on water resource management to accommodate for population growth, climate change and the desire for economic development. Although the four downstream nations in the Lower Mekong (Thailand, Laos, Cambodia, and Vietnam) signed the 1995 Agreement[2] and formed the Mekong River Committee (MRC) to promote development and management of the river and its resources in a sustainable manner (MRC, 2005), the "sustainable development" provision remains largely ambiguous due to the lack of a legal framework and procedural elements for management (Phillips et al, 2006; Bearden, 2009; 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).

The literature on water resources management, based on game theory approaches (Dinar et al, 1992; Dinar and Dinar, 2003; Madani, 2010 and references therein), shows that sharing the total economic benefits from cooperation among the river basin countries, if it is attainable, gives rise to Pareto improvement where every country is better off and none is worse off. This implies that one may hope to bring "agreement" and thereby cooperation on how mitigate conflicts over water. In most transboundary water resource sharing problems, allocation outcomes are not primarily determined by economic considerations but also by the distribution of political and bargaining power. Water, in this sense, accrues more often simply to the most powerful riparian state within a basin. For the Mekong river, developments that are taking place in upstream and the tributaries are expected to affect the downstream communities at different levels. Moreover, China has unquestionably the most power. Much of the debate among the member countries can be related to operating current dams and plans for drastic expansion of dam capacity. Therefore, there is a need for stable arrangements of a sustainable nature that will satisfy all countries involved.

This paper exploits an axiomatic bargaining approach (i.e. Nash, 1950; Roemer, 1988; Thoyer et al., 2001) to examine how the MRC 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 (the MRC formed by Thailand, Laos, Cambodia, and Vietnam).[3] We consider the following major economic issues in the MRB: building infrastructure for industrial and households' water use; dam capacity for hydropower generation and mitigating flood damage; irrigated agriculture; and saltwater

[2] The "Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin" was signed in 1995, and it is known as the 1995 Agreement.

[3] Due to the topographical fact that the Mekong is of only limited importance to Myanmar (roughly 2%, of the Mekong River drains from the portion of the basin that resides in Myanmar), we distinguish two regions, namely China and the MRC. Each region acts in its own specific ways to solve the issues of planning, developing, allocating, distributing and protecting their water resources.

intrusion in the estuary during the dry season. The highly centralized Chinese government has more grip on its water economy than the fragmented and less effective management by the MRC. One research issue is what the benefits of improved river management by the MRC and its associated governments are. Since basin-wide joint management did not develop in the MRB, the question is whether an international aid should be aimed at strengthening the MRC's management or providing extra financial incentives to widen the agenda for joint management. The aim of this paper is to deal with these issues in a bargaining framework and to propose an alternative offering in MRB's joint management that is preferable to the current situation for all nations.

The paper is organized as follows. The next section presents the basic model that extends the framework of Haddad (2010) in which dam capacity is endogenous. Some theoretical insights of the model, concerning the disagreement point, the applied bargaining solution and decentralized water prices, are presented in section 3. These results are embedded within the terminology of Houba (2008). Section 4 discusses numerical calculations of our model for the MRB and analyses the opportunities that can enhance effective regional cooperation under different scenarios including financial accounts and decentralize water prices. Concluding remarks and directions for further research 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 or countries, denoted by $i = 1, 2$ and region 1 lies upstream of region 2. Each region has the option to build dam capacity, denoted by D_i. It is used as infrastructure to provide end users such as industry and households with water, it is also used for hydropower generation and to store water from the wet season, denoted by y_i, for usage in the dry season. Due to evaporation losses, only $\delta_i y_i$, $\delta_i \in (0, 1)$,[4] 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 consumers: 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

Following Haddad (2010), our model represents building dam capacity and hydropower generation in each region. We then extend it by adding water uses, 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

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

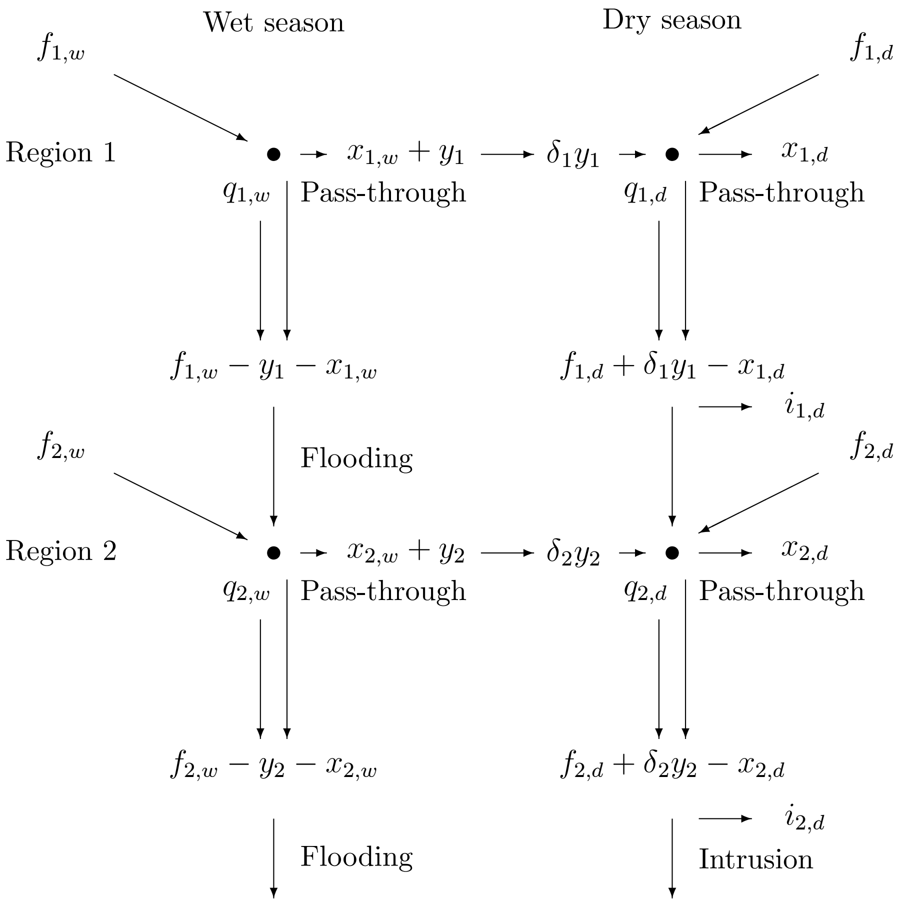

Figure 1: Seasons, locations and water uses in the river basin.

dam $o_{1,w}$ consists of $q_{1,w}$ and pass-through that runs directly to downstream and 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 capacity D_1) or runs to downstream. This imposes $i_{1,d} \leq o_{1,d}$. Formally, upstream's water balances[5] are given by

$$x_{1,w} + y_1 + q_{1,w} \leq f_{1,w}, \tag{1}$$
$$x_{1,w} + y_1 + o_{1,w} = f_{1,w}, \tag{2}$$
$$x_{1,d} + q_{1,d} \leq f_{1,d} + \delta_1 y_1, \tag{3}$$
$$x_{1,d} + o_{1,d} = f_{1,d} + \delta_1 y_1, \tag{4}$$
$$i_{1,d} \leq o_{1,d}. \tag{5}$$

In Figure 1, both $o_{1,w}$ and $o_{1,d}$ are expressed as the residuals from inflow minus water use.

[5] This formulation extends the model for optimal hydropower generation in Haddad (2010) to include the necessary infrastructure for industrial and households' 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 $i_{2,d}$ 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.

Cost 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 seasons. 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 $c_i \cdot D_i$. 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 $c_i y_i$. 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 $c_{2,d}(o_{2,d} - i_{2,d})$, a convex function $c_{2,d}(\cdot)$ with $c'_{2,d}(\cdot) < 0$. 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 we lacked data on costs and there is a constant river flow from Tonle Sap in Cambodia to the estuary that minimizes salt water intrusion.[6]

As will be clear from 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

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

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

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

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 e.g. Binmore et al. 1986, and Houba, 2007, 2008).

[6] Personal communication with professor Daene McKinney.

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 government with weak instruments. For that reason, we will 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.[7] 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 $u_1(x_{1,w}, x_{1,d}, q_{1,w}, q_{1,d}, i_{1,d}, D_1, t_1, o_{1,w}, o_{1,d})$. After substituting out the flow variables $o_{1,w}$ and $o_{1,d}$ from (2) and (4), we obtain the following program for upstream:

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

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 a 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,

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

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

$$\max_{x_{2,w},x_{2,d},q_{2,w},q_{2,d},D_2,y_2} v_{2,w}\ln(x_{2,w}) - c_{2,w}x_{2,w} + v_{2,d}\ln(x_{2,d}) - c_{2,d}x_{2,d} + h_{2,w}\ln(q_{2,w}) + h_{2,d}\ln(q_{2,d}) - c_2 D_2, \tag{19}$$

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

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

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

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,

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

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 play an important role in the Nash bargaining solution, which we are about to introduce. For this solution, we characterize the transfers and relate these to the budget 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 has more bargaining or political power than downstream.

The asymmetric Nash bargaining solution is given by the unique maximizer of the following program:

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

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

A novel aspect that we implement in the latter program is the role of international aid or external budget $b \geq 0$. For that reason, we derive how the external budget b accrues to upstream and downstream through the the negotiated transfers.

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

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

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

where $w_i(\cdot) = u_1(\cdot) - t_i$ 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 due to substitution effects. What the magnitudes of the direct and indirect effects are, will be investigated in our numerical application to the MRB.

IV. NUMERICAL ANALYSIS FOR JOINT MRB MANAGEMENT

In this section, we perform our numerical analysis. First, we discuss the benchmark using the 1995 data. After that, we present the results for the case without cooperation where we distinguish between upstream and downstream, respectively. These results form the disagreement levels used in the Nash bargaining solution.

Benchmark

The yearly water inflows and the water withdrawals for households and industry use, i.e., the so-called consumptive use, are given in Table 1. 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. From this ratio, we can easily obtain the water inflows in both seasons.

	Water availability	Consumptive use
Upstream	2812	500
Downstream	1492	104

Table 1: Water availability and consumptive use (in km^3).
Source: Adapted from Ringler (2001).

Table 2 shows the economic value created from different types of water use in the two regions. Yunnan province of China is one of the poorer areas in China, which is reflected by the low total economic value in this region. The economic value generated downstream is the aggregate over the MRC members. The ratio of value of one type of water and the total profit of all water use reflects the relative importance or the weight of that particular type of water use in the economy.

	Upstream	Downstream
Irrigation	20	893
Consumptive use	11	159
Hydropower incl. fisheries	0.05	589
Wetlands	0	134
Total	31	1778

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

To calibrate the model, we use the ratio of the profit for each category of water use and the total profit in Table 2 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 households and industry in wet and dry season. Further, we assume some values for the reserving costs, flooding costs, dam-building costs and irrigation costs to make the model completely-specified. As mentioned before, we set the costs of salt water intrusion equal to zero. This allows us to solve this model numerically and obtain results on water allocation to each type of water use, the possible expanding dam capacity and the shadow prices for each type of water. This roughly reflects or replicates the current situations in both regions.

Upstream

In the absence of cooperation, each region maximizes its own economic value. For upstream, we implemented optimization program (18) and solved it numerically. Table 3 presents upstream's water balances under the non-cooperative scenario. In such an economy with the given technologies (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, upstream region (China) uses 329 km^3 water for consumptive use (domestic and industry), reserves 649 km^3 of water for irrigation in the dry season as its first priority, and distributes a small amount of hydropower (2 km^3 water) according to the marginal values of these usages. The water outflows to the downstream in the wet season is 1552 km^3, and in dry season is 0 km^3. *The economic value of water use for the upstream region in this noncooperative scenario is* 316 *million US$.*

Water balances upstream	Wet	Dry
Precipitation	2530.800	281.200
Reserved water	649.159	-649.159
Consumptive use	329.337	170.674
Hydropower generation	1.534	759.686
Outflow from dams	1552.304	759.686
Irrigation		759.686
Outflow to downstream	1552.304	

Table 3: Upstream's water balances (in km^3).

Table 4 presents the results on upstream's shadow prices under no cooperation. Under the current water inflows and existing technologies, the irrigation sector has a very high shadow price, which means this is a demanding part of water use in the dry season for China. Given the reserving costs, China cannot reserve more than 649 km^3 of water in wet season. The shadow price of the consumptive use in wet season is zero implying that there is sufficient water for this purpose. The shadow price of water for consumptive use in the dry season is non-zero (0.2 million US$) anymore, implying that there is water scarcity. The shadow price of water for hydropower generation in wet season is very large, because the existing capacity of dams is very small in upstream region. Therefore, it is more efficient to reserve water for irrigation in dry season than using water for hydropower generation in wet season. Furthermore, the high shadow price of hydropower water in the wet season also explains the need for expanding dam capacity under the given building costs, because it can achieve the highest profit. The shadow price of hydropower water in dry season is zero because water is reserved for irrigation and pass through the dam before it reaches agricultural users.

	Wet	Dry
Consumptive water	0.0	0.2
Hydropower water	105.0	0.0
Irrigation water	0.0	55.0

Table 4: Upstream's shadow prices per water usage under no cooperation in million US$.

Downstream

Downstream users take the outflow from upstream (1552 and 0 km^3 in wet and dry season respectively) as an externality. We implemented river basin management under weak and strong governance. For weak governance, we implement optimization program (19) and (20), then we sequentially solve these in the stated order, and as a final step we compute (21). Strong governance required to implement optimization program (18) after making the appropriate adjustments mentioned just after (21). Table 5 presents downstream's water balances under weak and strong governance. Since more externalities (at the regional level only) are internalized under strong governance than under weak governance, and therefore under strong governance, there will be 333.4 km^3 less water outflow from the dam in the wet season to mitigate flood damages, because strong governance internalizes externalities. This is accomplished by storing 294.7 km^3 of water and encouraging more consumptive use 38.7 km^3. For the same reason, hydropower generation is reduced by 124.8 km^3 in the wet season under strong governance. The stored water is used to increase hydropower generation in the dry season and to increase irrigation. 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, increased hydropower generation and irrigation in the dry season.

Water balances downstream	Weak governance		Strong governance	
	Wet	Dry	Wet	Dry
Precipitation	1342.8	149.2	1342.8	149.2
River flow from upstream	1552.3		1552.3	
Water availability	2895.1	149.2	2895.1	149.2
Reserved water	1.0	−1.0	295.7	−295.7
Consumptive use	37.2	21.1	75.9	28.1
Hydropower generation	456.1	129.1	331.3	416.8
Outflow from dams	2856.9	129.1	2523.5	416.8
Irrigation		129.1		416.8
Outflow to the estuary	2856.9		2523.5	

Table 5: Downstream's water balances (in km^3).

Table 6 presents the results on the shadow prices. The shadow price in the wet season for domestic and industry use in downstream region is also zero, implying that they have sufficient water for this purpose. They reserve 296 km^3 water for dry season because they can use if for irrigation. The shadow price of hydropower in the dry season is zero because water is reserved for irrigation although it pass through the dam first for hydropower generation. As such, *the economic value of downstream is* 422.8 *and* 467 *million US$ under weak and strong governance, respectively.* So, the economic costs of weak government are 44.2 *million US$.*

	Wet	Dry
Consumptive water	0.0	79.5
Hydropower water	100.0	˜.0
Irrigation water	0.0	70.5

Table 6: Downstream's shadow prices per water usage under no cooperation (in million US$)

Existing and the expansion of dam capacity is presented in Table 7. Downstream region has a higher dam capacity (494 km^3) in the current situation, compared to a capacity of 4 km^3 in upstream region. Upstream prefers to expand its dam capacity considerably. Under weak governance, there is no expansion of dam capacity in the Lower Mekong, but under strong governance there would be but it is relatively smaller compared to upstream's expansion (209 versus 975 km^3). Besides, this also leads to the lower relative shadow price of hydropower water in wet season with respect to the irrigation water in downstream than in upstream, because downstream users have a higher coefficient for hydropower generation in their value function.

Dam Capacity	Upstream	Downstream	
		Weak governance	Strong governance
Existing	4.5	494.3	494.3
Expansion	975.5	0	208.6
Total	980.0	494.3	702.9

Table 7: Dam capacity under no cooperation (in km^3).

Note that we calibrated the model with data from 1995, a time when China did not have much dams installed in the MR, and that China started to expand dam capacity rapidly after. By now, it is claimed that China has already completed three dams with an aggregate dam capacity of 40.0 km^3 and plans another thirteen dams in the near future (Osborne, 2010). Our model predictions therefore reflect the long-term development already going on in China and that China is able to carry out without the cooperation with downstream. Whether all legal rights of downstream are respected is a different matter that we omit. Downstream has already installed many dams and its expansion is more modest. Under weak governance expansion has even reached its maximal level.

If there is no cooperation or water basin agreement, the two regions only care about their own economic values and allocate water use according to their value functions. The upstream users will not consider the externality they generate upon the downstream users and the downstream users just take this externality as given in their economic activities. This is not economically efficient because water is in principle not used to the possibly highest value. We are now turning to show how cooperation through bargaining can achieve the more efficient use of water in the river basin, i.e. obtaining higher economic values in two regions. The economic value of upstream is 316 million US$, while the downstream are 422.8 million US$ and 467 million US$ under weak and strong governance.

Cooperation

In the bargaining model, the two regions have the possibility of bargaining aiming to achieve the highest cooperative profit. We implemented optimization program (22) and ran four scenarios, depending upon upstream's bargaining power of α being .5 and .75, and the exogenous budget b being 0 or 100 million US$. The simulated solutions for $\alpha = .5$ and $\alpha = .75$ almost coincide with those for the situation describing non-cooperation whenever $b = 0$, and we forego presenting the water balances for these cases. Also for $b = 100$, the bargaining solution for both α's coincides, and we report the one for $\alpha = .75$ since upstream China has more political power than downstream.

	α	b	Upstream	Downstream
No cooperation			316.000	467.000
Cooperation	.5	0	316.014	467.086
	.5	100	367.509	518.509
	.75	0	316.045	467.022
	.75	100	393.263	492.754

Table 8: Economic values for no cooperation and four scenarios of cooperation (in million US$).

We only consider the strong governance case of the downstream for the cooperation regime. Table 8 reports the regions' economic values for each of these four scenarios and the situation with no cooperation. Without an exogenous budget to promote cooperation, our simulations reveal a lack of incentives to reach agreement: The gains from cooperation are simply too small. This might explain why upstream China and the Lower Mekong fail to even negotiate joint river basin management. If so, an exogenous budget has to provide such incentives. Indeed, an budget of $b = 100$ million US\$ provides the incentives for cooperation. The party with the most bargaining power will attract most of the gains from cooperation, which is upstream China in case of the MRB. Also, Proposition 1 indicates that China receives a share α of the budget b plus something else. We investigate these numbers in Table 9.

	Effect	Upstream	Downstream	Total
$\alpha = .5$ $b = 100$	Transfer	65.594	34.406	
	Indirect effect	-14.099	17.017	
	Net value effect	51.495	51.423	102.92
$\alpha = .75$ $b = 100$	Transfer	91.349	8.651	
	Indirect effect	-14.131	17.081	
	Net value effect	77.218	25.732	102. 95

Table 9: Economic value gains attributed to transfers and indirect effects (in million US\$)

The indirect effect is equal to the total increase in economic value (from no cooperation to b is 100 million US\$) minus the transfer received. We observe that upstream receives the lion share of the exogenous budget provided by the international organizations, but in order to get the transfer upstream has to implement costly policies that benefit downstream. The sum of indirect effects is a modest 2.9 million US\$ when compared to the budget of 100 million US\$. For equal bargaining power, the increase in economic value is split almost equally, but about one third of downstream's gains from cooperation come from changes in water management. For unequal bargaining power, upstream gets about a share of α of the joint value increase. The indirect effects are relatively modest for upstream, but are about two thirds of downstream increase in economic value.

Dam Capacity	Upstream		Downstream	
	No coop.	Cooperation	No coop.	Cooperation
Existing	4.5	4.5	494.3	494.3
Expansion	975.5	1234.3	208.6	137.9
Total	980.0	1238.8	702.9	632.2

Table 10: Dam capacity of the MRB (in km^3). Cooperation: $\alpha = .75$ and $b = 100$.

Table 10 reports the expansion of dam capacity under the noncooperative and cooperative situation for $\alpha = .75$ and $b = 100$. Upstream expands and downstream contracts its planned dam capacity. The main reason is that upstream dams prevent flooding twice and water stored for upstream hydropower can also be used later either for hydropower generation, consumptive use or irrigation. Therefore, downstream has less reason to build dam capacity for flood prevention, only as infrastructure for hydropower generation and consumptive use.

Water balances upstream	No cooperation		Cooperation	
	Wet	Dry	Wet	Dry
Precipitation	2530.800	281.200	2530.800	281.200
Reserved water	649.159	−649.159	906.643	−906.643
Consumptive use	329.337	170.674	329.337	170.674
Hydropower generation	1.534	759.686	2.812	1017.170
Outflow from dams	1552.304	759.686	1294.820	1017.170
Irrigation		759.686		759.686
Outflow to downstream	1552.304		1294.820	257.484

Table 11: Water balances upstream (in km^3). Cooperation: $\alpha = .75$ and $b = 100$.

We discuss upstream's water balances first. From Table 11, we conclude that consumptive use and hydropower generation in both seasons and irrigation in the dry season remain at their satiation levels and that the main difference concerns the storage of water that increases by 39.7% from 649.159 to 906.643. The reduced outflow in the wet season mitigating flood damages in both regions is 257.48, which is a reduction of the river flow by 16.6%. 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. Delays 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.

Water balances downstream	No cooperation		Cooperation	
	Wet	Dry	Wet	Dry
Precipitation	1342.8	149.2	1342.8	149.2
River flow from upstream	1552.3		1294.8	258.0
Water availability	2895.1	149.2	2637.6	407.2
Reserved water	295.7	−295.7	225.0	−225.0
Consumptive use	75.9	28.1	75.9	28.1
Hydropower generation	331.3	416.8	331.3	604.1
Outflow from dams	2523.5	416.8	2336.7	416.8
Irrigation		416.8		416.8
Outflow to the estuary	2523.5		2336.7	187.3

Table 12: Water balances downstream (in km^3). Cooperation: $\alpha = .75$ and $b = 100$.

We continue by discussing downstream's water balances. From Table 12 we conclude that consumptive use in both seasons, hydropower generation in the wet season, and irrigation in the dry season remain at their satiation levels. Hydropower generation in the dry season increases because the increased inflow from upstream in this season increases water availability in the dry season. 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 reduced river flow coming from upstream mitigates flood damages and makes the need for downstream to reduce those damages by storing water less pressing. This is another reason why downstream stores less water under joint river basin management. So, we observe less river flow in the wet season and an increase in river flow during the dry season.

V. CONCLUDING REMARKS

Transboundary water resources are often a cause for conflict among riparian entities and negotiations over water among 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, climate change) such as the Mekong River situation. This paper explore alternative offerings for the MRB. Though the MRC's task is to promote development and management of the river and its resources in a sustainable manner, it lacks a legal framework and procedural elements to make such management a success. Furthermore, efficient river basin management requires the cooperation by all countries in the basin, including China.

Exploring axiomatic bargaining approach in the form of the asymmetric Nash bargaining solution to the MRB, our numerical analysis indicates that the gains from cooperation are rather insignificant and that China and the MRC have insufficient incentives for joint river basin management. These results may explain the current practice in which China and Myanmar are willing to be the observers of the MRC and not involved in other cooperation with the MRC. Yet, many perceive current practice as insufficient to meet sustainability of the river. International institutions, such as the World Bank or Asian Development Bank, might promote cooperation by enlarging the surplus in case agreement on cooperation would be reached.

Our numerical analysis also shows that an exogenous budget provides stronger incentives for cooperation in the MRB because it offsets the small gains from cooperation. Without the exogenous budget an alternative offering may be to forget about such cooperation. Instead, China and the MRC could develop their part of the basin, where downstream has to adapt to China's future development path in order to be sustainable in the near future. The MRC, therefore, has to obtain a solid legal framework with strong procedural elements that can implement river basin management. Our finding shows that the welfare gains from strengthening the MRC are substantial, and might offer an attractive road map that is independent of "unwilling" China.

Some of the usual caveats apply to our analysis. Despite the presence of the MRC, China is a country that reluctantly discloses data about its national policies. Also for the MRC, good data to feed economic models is hard to find. Our model is calibrated based upon these data limitations. Also the spatial and temporal scale of our numerical model allows further improvement. Since the four member countries forming the MRC are lumped together, it would be preferable to disaggregate these countries in order to further investigate where unanimity for cooperation can be found. For that reason, we regard our analysis as a first step in developing models that take these issues seriously.

APPENDIX: PROOF OF PROPOSITION 1

Define $w_i(\cdot) = u_1(\cdot) - t_i$, then the Lagrangian function is given by

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

The first-order conditions are given by

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

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

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 and $t_1 + t_2 = b$, we obtain from

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

that (23) and (24).

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