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Scope and Sustainability of Cooperation in Transboundary Water Sharing of the Volta River

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Scope and Sustainability of Cooperation in Transboundary Water Sharing of the Volta River

Abstract

The paper explores the scope and sustainability of a self-enforcing cooperative agreement in the framework of a game theoretic model, where the upstream and downstream country, Burkina Faso and Ghana respectively in the Volta River Basin, bargain over the level of water abstraction in the upstream. In the model we consider the case where the downstream country, Ghana, offers a discounted price for energy export to the upstream country, Burkina Faso, to restrict its water abstraction rate in the upstream. The paper examines the benefits and sustainability of such self-enforcing cooperative arrangements between Ghana and Burkina Faso given stochastic uncertainty in the river flow. The findings of the paper suggest that at the present condition, the marginal benefit of Burkina Faso from increasing the water abstraction is much higher than that of Ghana's marginal loss. However, the paper finds that if both countries' water abstraction rates are at a much higher level, then the marginal loss of Ghana increases phenomenally from similar increase in water abstraction rate by Burkina Faso. Under such circumstances, there is an opportunity for Ghana to provide side payments in terms of discounted export price of power in order to motivate Burkina Faso to restrict water abstraction.

Key words: Bargaining, Cooperation, Transboundary, Uncertainty, Volta River Basin

Kurzfassung

Die vorliegende Studie untersucht den Rahmen und die Nachhaltigkeit einer selbstbestimmten Kooperationsvereinbarung im Rahmen eines Spieltheorie-Modells, in dem sich die flussauf- bzw. flussabwärts liegenden Länder des Voltabeckens, Burkina Faso und Ghana, über das Maß der Wasserentnahme aus dem oberen Flussbecken verhandeln. In dem Modell wird der Fall betrachtet, in dem das flussabwärts liegende Land, Ghana, dem flussaufwärts gelegenen Burkina Faso einen ermäßigten Energieexportpreis anbietet, um dessen Wasserentnahme einzudämmen. Die Studie untersucht den Nutzen und die Nachhaltigkeit derartiger Vereinbarungen zwischen Ghana und Burkina Faso, wobei zufällige Schwankungen der Abflussmengen berücksichtigt werden. Die Ergebnisse der Studie zeigen, dass unter den gegenwärtigen Voraussetzungen Burkina Fasos Grenzgewinn durch eine erhöhte Wasserentnahme viel höher ist als der dadurch in Ghana zu verzeichnende Grenzverlust. Jedoch wird auch gezeigt, dass im Falle einer bereits höheren Wasserentnahme beider Länder eine weitere Steigerung der Wasserentnahme in Burkina Faso in vergleichbarem Maße zu erheblich höheren Grenzverlusten in Ghana führen würde. Unter solchen Umständen gäbe es für Ghana die Möglichkeit, Anreize in Form reduzierter Energieexportpreise anzubieten, um Burkina Faso zu einer Eindämmung seiner Wasserentnahme anzuregen.

Scope and Sustainability of Cooperation in Transboundary Water Sharing of the Volta River

1 Introduction

The issue of cooperation in transboundary water sharing is receiving increased attention in international scientific research over the last two decades. It has been realized that cooperation in water sharing is essential in attaining economic and social development in the regions where water is scarce.

It is evident from review of past transboundary water sharing cases that a record of cooperation has consistently dominated water relating conflicts over the last half of a century, when thousands of water related cases were resolved cooperatively (Wolf 2001). But the relevant issue is why the upstream countries find cooperation to be attractive if they do not care about the welfare of the downstream countries. One plausible reason is that potential gains from cooperation have consistently outweighed water's conflict-inducing characteristics and induced these countries to opt for cooperative solutions (Netanyahu 1998).

Bennett (1998) has demonstrated that even under conditions of limited scope of cooperation, there is a possibility of attaining bilateral or even multilateral agreement on international river basin management, through "linking" the water allocation negotiations to outcomes in non-water issues of mutual interest to the parties. In a paper, Bennett (1998) has linked the water allocation issue between Uzbekistan and Tajikistan with air pollution abatement, and found that issue linkage can lead to an enhanced bargaining set where the players have an opportunity to cooperate and gain (Carlo 2005). In another case, Netherlands linked the issue of water allocation in the Meuse River with Belgium on the issue of navigation on the Sceldt River (Ansink 2008).

The following paper is concerned with the allocation of Volta river water between the upstream and downstream countries, Burkina Faso and Ghana respectively; and the influence of a non- water issue linkage on water allocation between these countries in the Volta River Basin. We have identified that in this case, the issue linkage to water sharing could be hydropower export from Ghana to Burkina Faso.

Ghana and Burkina Faso comprise nearly 90 % of the Volta Basin area, and is dependent on the freshwater availability to a great extent in meeting the water demand of the economy (Van de Giesen *et. al* 2001). However the pattern of water demand in these two countries follows different trajectories. The upstream country, Burkina Faso, is dependent on freshwater from the Volta River to meet primarily the agricultural water demand; while in the downstream Ghana, the main water user is hydropower generation, which accounts nearly 73% of the total electric generation in the latter country. Currently, water withdrawal rate to meet agricultural, domestic and industrial water demand in Ghana is 1.73 per cent compare to 6.15 per cent in Burkina Faso (FAO 2005).

Higher water abstraction in the upstream can reduce water inflow in Lake Volta located in the downstream Ghana. It could affect hydro-electric generation at Akosombo Dam, thereby hurting the growth of the economy of the country. This could be one of the reasons that has restricted Ghana's water abstraction for other purposes in its upstream. However, the Government of Ghana has projected the agricultural water demand to increase five fold in the next two decades (MWH 1998).

Increasing demand for water coupled with higher uncertainty in the water flow has been a potential source of water conflict between Ghana and Burkina Faso. In 1998, the conflict between the two countries exacerbated when low water levels in the dam resulted in the reduction of the generating capacity by half and caused major energy crisis in Ghana.

Ghana accused Burkina Faso of constructing dams in the upstream as reservoirs for irrigation water; and thus the latter country's higher water consumption was suspected of being the main cause of reduced water levels at the Akosombo Dam (Niasse 2005). Burkina Faso, however, denied such Ghana's claim and cited low rainfall and natural variability of water flow as the main causes for the reduction in river flow.

The pertinent question is whether higher water abstraction in the upstream Burkina Faso can lead to lower water availability in Lake Volta, where hydropower is generated for Ghana with the help of Akosombo Dam. Van de Giesen *et al* (2001) claims that irrigation development activities can create an impact in the water availability in the downstream; though, it is difficult to capture such influence.

The amount of irrigable area in Burkina Faso is much higher than that of Ghana, estimated at 160 000 ha (Sally 1997). The amount of water that could be used for irrigation in Burkina Faso is approximated to be around 10% of the water inflow to downstream Lake Volta. In the recent past, Burkina Faso had already built two large dams and some 1500 small dams in the upper basin of the Volta River (Niasse 2005). Moreover, Burkina Faso has plans of building three more large dams on the tributaries of the Volta within its territory for water supply to its capital, Ouagadougou. While these trends seem to support the claims that Burkina Faso's investments in water infrastructures could be the main cause of water deficits in the lower Volta, there are also opposite views suggesting that Burkina Faso has little to do with the reduced flow in Ghana (Andreini *et. al* 2000, Niasse 2005).

Still both countries, in principle, have agreed to cooperate given the potential risk of conflict, while the manner of cooperation is still in the planning process (Lautze et. al 2005). In this perspective, the GLOWA Volta Project funded by the German Government aims to develop a decision support system for the assessment, sustainable use and development of the Volta basin water resource. The project attempts to promote and help both countries in designing a transboundary cooperation mechanism. The paper, stemming from the GLOWA Volta Project, explores the feasibility and sustainability of cooperative arrangements with the objective of encouraging a self-enforcing water sharing cooperation between the two countries.

The challenge in establishing a sustaining cooperative agreement is greater here, especially in the absence of a 'super natural body' or 'third party' to enforce a cooperative agreement. Netanyahu (1998) views that sustainability of an agreement in the long run depends on both sides possessing sufficient retaliatory actions (credible threats) to make continued cooperation and sustaining the agreement.

There were several attempts to initiate a self-enforcing cooperative agreement between the two countries. One such attempt was made when Ghana offered Burkina Faso with energy in order to prevent the country from unilateral diversion of water. Giancarlo (2001) argues that when policy issues are separable, for instance water and energy here, linking them in a grand international agreement could facilitate policy cooperation by reallocating enforcement power.

The paper is an attempt to examine the benefits and sustainability of water sharing agreements with issue linkage to energy trade. In this paper we try to develop, and apply, an analytical framework for evaluating the scope of bilateral cooperation in the management of water resources in the Volta River Basin.

A model is structured in the framework of Rubenstein's alternating offer game model, where the upstream and downstream countries bargain over the level of water abstraction rate in the upstream. In the model, the downstream country, Ghana offers a discounted price for energy export to the upstream country, Burkina Faso, for more water in the downstream. Each country offers a proposal in alternating periods until a proposal is accepted.

The basic principle in negotiation in an alternating offer model is to produce a sequence of moves such that the subsequent alternatives are preferred by other country to the previous ones (Carlo 2005).Each year the countries face scarcity of water and they can re-negotiate about the level of water abstraction rate in the upstream and the associated side payments. Such repeated bargaining can guarantee an efficient outcome solution with the potential to deter deviation.

The structure of model presented here is different from the standard Rubinstein's offer model. In Rubinstein's model, each player gets the share of a good after an agreement is reached and the good is used only once. But in the model here, water is consumed or used each period, and thus allows the possibility of deviation from the agreement.

The paper also considers the variability in water flow that may influence the sustainability of the agreement. When water flow is deterministic, there exists perfect information about the upstream country's action. If there is a deviation from the agreement by the latter country, the downstream country retaliates immediately and the agreement breaks down. However, in the case with stochastic variability in the flow of water, it is difficult for the downstream country to infer with certainty about the flow of the river, and thus it may behave differently.

Consideration of the assumption of uncertainty in water flow makes sense as the effect of climate change on ecosystem may increase the variability of water flow in future. Wider variability in the water flow with frequent extreme conditions, like flood and drought, can increase the likelihood of water conflict, and induce countries to deviate from the existing agreement and engage in unilateral diversion of water. In the framework of Green and Porter (1984) model with imperfect price information, we explore the sustainability of agreement in the case of stochastic variability of water.

The paper is structured as follows. The next section outlines the water sharing between the upstream and the downstream country without any agreement. Section 3 discusses the energy demand of Burkina Faso. The next section presents the bargaining model of water sharing with possibility of deviation from the agreement. In the subsequent section, we present the simulation results, and finally the conclusion summarizes the main findings and results of the paper.

2 Water Allocation between Ghana and Burkina Faso

This section of the paper is concerned with the allocation of Volta River water between Ghana and Burkina Faso. Burkina Faso is the upstream country and has the upper riparian right to unilaterally divert water, while Ghana is a downstream country where the freshwater availability depends on the water usage of the upstream country. We denote the countries by subscript i= B, G , where B and G denote Burkina Faso and Ghana respectively. Let W_B be the annual total renewable fresh water resources in Burkina Faso. In the model, we assume that the water flow in the upstream is stochastic. The uncertainty in the flow of water can be attributed to environmental changes in the headwaters of the rivers as a result of climate variability and change. As an example of stochastic dependence in the flow of water, low rainfall or a hot summer may simultaneously lower W_B and raise the marginal benefit of water for both countries. The total renewable fresh water resources, W_{Bt}, at time period t can be represented by

$$W_{Bt} = \overline{W}_B + \varepsilon_t , \qquad (1)$$

where $\overline{W_B}$ is the long run average water resource available in Burkina Faso and ε_t is the stochastic variable factor.

The total per capita fresh water utilization in each country is denoted by w_i.The freshwater utilization depends on the degree of appropriation of the expected (E) total available resource. Considering the rate of water utilization of a country as α_i, the total per capita freshwater utilization in Burkina Faso can be exhibited in the form of mathematical equation as

$$w_B = \alpha_B E(W_B) . \qquad (2)$$

The water availability in the downstream Ghana depends on the water consumption in the upstream, w_B and rainfall, R, that the river picks up and added to its volume while flowing. The water availability in Ghana can be represented as $W_G = (1-\alpha_B - \theta)E(W_B) + E(R) + E(X)$ where θ is the proportion of water that flows from Burkina Faso to neighboring country Benin andTogo; and X is the amount of water that flows from Cote d'Ivoire and Togo to Ghana. The water withdrawal in Ghana, w_G, can be expressed as

$$w_G = \alpha_G E(W_G) = \alpha_G \left[(1-\alpha_B - \theta)E(W_B) + E(R) + E(X)\right]. \qquad (3)$$

The inflow of water to the Lake Volta denoted by $w_{Akasambo}$, can be represented as

$$w_{Akasambo} = (1-\alpha_G)W_G = (1-\alpha_G)\left[(1-\alpha_B-\theta)E(W_B)+E(R)+E(X)\right]. \quad (4)$$

Consider the benefit of water consumption of the countries as $B_i = B(w_i, x_i)$ for i= *B, G,* where w_i is water utilization and x_i is an indicator for all other inputs. The benefit B_i is inclusive of agricultural, industrial and hydrological profits. The benefit function is assumed to be strictly concave for all possible values of w_i and x_i.

The cost function of withdrawing water from the River and distribution is $C = C(\alpha_i) = C(w_i / E(W_i))$ which is assumed to be increasing and convex for all values of α.

In the absence of any agreement, Burkina Faso chooses the 'economically potential' rate of water utilization that maximizes its own net benefit.

Burkina Faso's maximization problem is as follows max $NB_B = B_B(w_B, x_B) - C_B(\alpha_B)$ given

$$w_B = \alpha_B E(W_B). \quad (5)$$

The solution of the above maximization problem is $\alpha^*{}_B = \alpha(W_B, x_B)$ which is determined at the point where marginal benefit of water withdrawal is equal to the marginal cost of water withdrawal. However, the current rate of water withdrawal, which is a function of government resources, policy parameters, could be less than

$\alpha^*{}_B$.

Similarly Ghana also chooses its optimal water withdrawal α^*_G by maximizing the net benefit $NB_G = B_G(w_{Akasambo}, w_G, x) - C_G(\alpha_G)$ given

$$w_G = \alpha_G E(w_G) = \alpha_G\left[(1-\alpha_B)E(W_B)+E(R)\right] \text{ and}$$

$$\alpha^*{}_B = \alpha(W_B, x_B). \quad (6)$$

From the first order condition of the above problem, we derive the slope of the reaction function of Ghana to an arbitrary change in the rate of water withdrawal by Burkina Faso using the implicit function theorem. The reaction function is derived as follows

$$\frac{\partial \alpha_G}{\partial \alpha_B} = -\frac{\dfrac{\partial^2 B_G}{\partial \alpha_G \partial \alpha_B}}{\dfrac{\partial^2 NB_G}{\partial \alpha^2_G}} = \frac{\left[\dfrac{\partial^2 B_G}{\partial w^2_G} - \dfrac{\partial^2 B_G}{\partial w^2_{Akasambo}}\right]E(W_B)}{\dfrac{\partial^2 NB_G}{\partial \alpha^2_G}}. \quad (7)$$

The above expression suggests that for an increase in α_B, diverted by Burkina Faso in the upstream, Ghana will react by increasing water withdrawal if the rate of decrease in marginal benefit from an increase in water inflow in the Lake Volta is lower than that of the increase in water withdrawal for consumptive usage $\left[\left|\frac{\partial^2 B_G}{\partial w^2{}_{Akasambo}}\right| < \left|\frac{\partial^2 B_G}{\partial w^2{}_G}\right|\right]$. However, the rate of increase in α_G for any increase in α_B will increase at a decreasing rate since the marginal cost of water abstraction will be increasing at increasing rate. After a certain point, Ghana could find it increasingly difficult to respond and raise the water withdrawal rate. As water becomes increasingly scarce in the economy, the government would exploit less accessible sources of fresh water through appropriating and purchasing a greater share of aggregate economic output, in terms of dams, pumping stations, supply infrastructure etc (Barbier 2000).This leads to higher marginal cost and at a certain point, prohibits the country from making further investment in tapping water resource. One such instance is the proposed Bui dam in Ghana, which was shelved periodically as the project was not the least cost option. Such situation may lead Ghana to be more dependent on Burkina Faso for availability of water.

If α_B is sufficiently high and the rate of decrease in marginal benefit from an increase in water inflow in the Lake Volta is higher than that of the increase in water withdrawal for consumptive usage in Ghana , then the latter country will reduce or restrict α_G for an increase in α_B. Under such circumstances Ghana may face a trade off of water use between agriculture and hydropower.

3 Energy Demand of Burkina Faso

In this paper, as we are analyzing the issue linkage of water allocation and hydropower with the provision that Ghana exports energy to Burkina Faso, it is pertinent to discuss about the energy demand of Burkina Faso.

Burkina Faso’s electric power consumption is just 3% of that of Ghana’s, and was 205 GWh in 1997. However, Burkina Faso‘s power demand is increasing at 6% per annum. The main sources of electricity in 1995 were imported oil (61 per cent), and hydropower met the remaining demand (39 per cent). With rising oil prices, reduction in energy cost is a priority for Burkina Faso. Hydropower, on the other hand, although the cheapest source of electricity has a maximum technical limit and economic feasible potential estimated at 75 MW only.

Given increasing demand, Burkina Faso has few options left in meeting them. First, Burkina Faso may try to be self-sufficient in energy by constructing new hydropower dams and thus increasing hydropower potential. This requires external funding. However, in the past, international financial institutions were reluctant to finance new reservoirs in Burkina Faso as economic evaluations of these projects were negative (Barbier, Bruno 2007). Second, Burkina Faso may continue to import power from Cote d’Ivoire. The electric power transmission system of Cote d’Ivoire is connected to its neighbor, Burkina Faso, on the west by a 226-kV transmission line. In 2002, Côte d’Ivoire exported 111 GWh of electricity (worth about $5.46 million) to Burkina Faso. Third, Burkina Faso may buy power from Ghana. In the past, Ghana has supplied electric power to Burkina Faso in the north through a low voltage distribution network. Ghana has already proposed to sell higher amount of hydropower which may be transmitted through the planned high voltage transmission system between Ghana and Burkina Faso (ISSER 2005).

In the analysis, we consider that Ghana offers power to Burkina Faso at a discounted price as an incentive to get an assured supply of water from Burkina Faso. In transboundary water sharing, there are several instances where a downstream country provides the upstream country side payments to deter unilateral diversion of water (Ansink 2008).[1]

Here the side payment is in the form of discounted price of electric power. The next section analyses the bargaining between the two countries on the discount price of power and the level of water abstraction rate in Burkina Faso.

[1] The Indus Water Treaty between India and Pakistan included a one-time £ 62 million lump-sum payment by India to Pakistan (Beach et al. 2000). Also in the Lesotho Highlands Water Project South Africa pays € 24 million to Lesotho (LHDA 2005).

4 Bargaining on Water and Energy

A general game theoretic is structured here in the framework of Rubenstein's alternating offer game model, where the countries Burkina Faso and Ghana bargain over the share of water diverted from the upstream. As part of the agreement, Burkina Faso may not increase the water abstraction rate further which will allow Ghana to get assured supply of water.[2] On the other hand, Ghana supplies power to Burkina Faso at a discounted price to prevent Burkina Faso from diverting water unilaterally. We describe the amount of hydropower to be exported from Ghana to Burkina Faso as H^{GB}. We assumed that the amount of electric power that Burkina Faso decides to be imported from Ghana is exogenously fixed. If $p_H^{\pm}$ and p_H denote the actual price and discounted price of hydropower respectively, the gains to Burkina Faso from power import can be represented as $S = (p_H^{\pm} - p_H)H^{GB}$. If the gain from import of power from Ghana is sufficient then Burkina Faso would agree to forgo additional planned diversion of water in the upstream. The countries in alternate periods make offer (α_B, p_H) which includes both the rate of water withdrawal and the gain in the import of hydropower.

The time line of the game is as follows: Burkina Faso proposes to restrict the water withdrawal to α_B for a monetary gain *S*. Ghana can accept the proposal or reject. If Ghana accepts the proposal, an agreement is struck, where every year it provides hydropower at a discounted price $\overline{p}_H$; while Burkina Faso restricts it rate of water withdrawal at $\overline{\alpha}_B$. The agreement continues until one of the country deviates.

If Ghana rejects the offer, Burkina Faso continues to unilaterally divert water in the upstream and the game continues to second period where Ghana proposes another set of offers. The game continues infinitely until a proposal has been accepted.

The game has two layers. First, the country's decision problem is to choose an equilibrium offer so that the other country accepts it. If the offer is accepted, an agreement is struck. Secondly, after an agreement is reached, each country chooses either to maintain or deviate from the agreement.

Using backward induction, we first derive the optimal conditions under which the countries maintain the agreement or to defect. Assuming that an equilibrium offer is accepted and an agreement reached, we demonstrate the conditions under which the strategies of the countries are a sub-game perfect equilibrium (SPE). Then given the SPE strategies of the country after an agreement is struck, we determine the equilibrium offers of the countries. A sub-game perfect equilibrium will be again employed to characterize such outcome of the game.

[2] We assume that Burkina Faso can increase its water abstraction rate; however from a political point of view it is difficult to decrease its water utilization through decrease in the water withdrawal rate.

We consider the case where water flow is stochastic. We also assume that water flow in each period is independently and identically distributed. Since the water flow in each period is independently distributed, uncertainty in water flow does not affect the bargaining process explicitly. But it will affect the sustainability of a reached agreement.

In the analysis we illustrate the influence of uncertainty in water flow on the sustainability of the agreement once reached. Suppose an equilibrium offer $(\overline{\alpha}_B, \overline{p}_H)$ is accepted and an agreement is reached. The expected payoffs of Burkina Faso and Ghana in each period are represented as $E(NB^B(\alpha_B, W_B)) + S$ and $E(NB^G(\alpha_B, W_B)) - S$ respectively.

The game begins in the collusive phase where both the countries play according to the agreement. Burkina Faso diverts $\overline{\alpha}_B$ share of water in the upstream while Ghana pays $\overline{S} = (p'_H - \overline{p}_H)H_{GB}$ amount of side payments in terms of discounted price for the export of hydropower.

However in any year, the downstream country, Ghana may get lower amount of water. The lower water availability in the downstream could stem either from higher abstraction of water in the upstream by Burkina Faso or extremely low water flow caused by natural factors. Ghana could devise a mechanism to reduce the cost of such uncertainty. It could trigger a non-cooperation phase using a tail test i.e. it starts if the water inflow in the Lake Volta of Ghana, $w_{Akasambo}$ falls under some threshold level, $\hat{w}_{Akasambo}$. The tail test emerge from Ghana's belief that if water inflow falls below $\hat{w}_{Akasambo}$, then the chance of Burkina diverting more water in the upstream is high. The value of the threshold level is exogenously chosen by Ghana.

The non cooperation phase continues for a time period T during which Ghana pays no discount. The time period, T, of the punishment phase can a priori be finite or infinite, and is chosen optimally by Ghana. At the end of the non-cooperation phase, the countries revert to the collusive phase where Ghana charges only $\overline{p}_H$ discounted price for hydropower trade.[3] Given the distribution of water, the probability of the temporary breakdown of the agreement can be derived as

$$P(w_G \le \hat{w}_{Akasambo}) = P(\alpha_G\left[(1-\alpha_B-\theta)W_B + E(R) + E(X)\right] \le \hat{w}_{Akasambo})$$

$$= P(W_B \le \frac{\hat{w}_{Akasambo} - (1-\alpha_G)\left[E(R)+E(X)\right]}{\alpha_G(1-\alpha_B-\theta)}) = F\left[\frac{\hat{w}_{Akasambo} - (1-\alpha_G)\left[E(R)+E(X)\right]}{\alpha_G(1-\alpha_B-\theta)}\right] = \pi(\alpha_B)$$

and $\frac{\partial \pi}{\partial \alpha_B} > 0$. (8)

[3] There are examples which illustrate such non-cooperation phase in the agreement. In 1948, India diverted water away from Pakistan's irrigation canals, breaking the 1947 "Standstill Agreement", and there has been a four-year gap before renegotiations again began (Ansink 2008). Again, in the Euphrates basin, the 1987 security protocol between Turkey and Syria which guaranteed Syria an annual average minimum flow of 500 cubic meters per second did not last long as Turkey continued the construction of a large-scale irrigation project. However after 5 years another follow up agreement came up. In the analysis, for analytical simplicity, we avoid the possibility of a separate negotiation process after the non-cooperation phase. In the model the countries continue with the same agreement after the non-cooperation phase.

If Burkina Faso plays cooperatively, the probability of breakdown of the treaty is $\pi(\overline{\alpha}_B)$. As $\frac{\partial \pi}{\partial \alpha_B} > 0$, higher deviation of water by Burkina Faso will increase the chance of breakdown of the agreement.

Suppose both the countries play cooperatively. Burkina Faso will earn $NB^B(\overline{\alpha}_B, W) + \overline{S}$ in the first period. Due to bad shock, the water flow can fall below the threshold level. Given Ghana's strategy, Burkina Faso knows that for the next T periods, Ghana would give no discount to the price of power ($S = 0$) with probability $\pi(\overline{\alpha}_B)$. In the next period, water flow could also be higher than threshold level $\hat{w}_G$ and Ghana would give discount to power purchase and play cooperatively with probability $1 - \pi(\overline{\alpha}_B)$. If Ghana plays uncooperatively giving no discount to power in the next T periods, then the collusive phase will be reverted where it will start giving discounts $(p_H = \overline{p}_H)$ again. The present value of Burkina Faso payoff with cooperation, V_C^B, will be

$$V_C^B = E\left[NB^B(\overline{\alpha}_B, W_B)\right] + \overline{S} + (1 - \pi(\overline{\alpha}_B))\delta^B V_c^B + \pi(\overline{\alpha}_B)\delta^B\left[\left(1 - \left(\delta^B\right)^T\right)V_{NC}^B + \left(\delta^B\right)^T V_c^B\right]$$

where V_{NC}^B is the discounted value of Burkina Faso payoff under non cooperation and $V_{NC}^B = \frac{E\left[NB^B(\overline{\alpha}_B, W_B)\right]}{1 - \delta^B}$. δ^B is the discount factor of Burkina Faso reflecting the patience of the country.

Amplifying, we can write the above expression as

$$V_C^B = \frac{E\left[NB^B(\overline{\alpha}_B, W_B)\right]\left[1 - \delta^B + \pi(\overline{\alpha}_B)\delta^B\left(1 - \left(\delta^B\right)^T\right)\right] + \overline{S}(1 - \delta^B)}{\left[1 - (1 - \pi(\overline{\alpha}_B))\delta^B - \pi(\overline{\alpha}_B)\left(\delta^B\right)^{T+1}\right](1 - \delta^B)} \quad (9)$$

If Burkina Faso chooses to defect from the beginning, then it will increase the water abstraction rate and plays $\alpha_B > \overline{\alpha}_B$. Burkina Faso also knows that if it defects, then the probability of the breakdown of the treaty also increases. However, as long as water inflow to the Lake Volta is above the threshold level, the agreement will be sustained. It is only possible if the water flow is high enough and Ghana cannot detect the deviation. If Burkina Faso defects for a given level of water abstraction, α_B^d, then the present value of its payoff under defection, V_d^B, will be

$$V_d^B = \frac{E\left[NB^B(\alpha_B^d, W_B)\right]\left[1 - \delta^B + \pi(\alpha_B^d)\delta^B\left(1 - \left(\delta^B\right)^T\right)\right] + \overline{S}(1 - \delta^B)}{\left[1 - (1 - \pi(\alpha_B^d))\delta^B - \pi(\alpha_B^d)\left(\delta^B\right)^{T+1}\right](1 - \delta^B)} \quad (10)$$

Burkina Faso will not deviate if $V_c^B \geq V_D^B$. Solving for δ^B we derive the condition as $\delta^B \geq \tilde{\delta}^B(\alpha_B^d, T, \overline{\alpha}_B, \overline{S})$. It suggests that Burkina Faso should be sufficiently patient (higher discount factor) for not to deviate from the agreement.

If Burkina Faso deviates, it chooses the optimal share of water for water abstraction, $\alpha_B^d(T)$ to maximize the expected payoff from deviation given the flow of water.

$$MaxV_d^B = \frac{E\left[NB^B(\alpha_B^d, W_B)\right]\left[1-\delta^B + \pi(\alpha_B^d)\delta^B\left(1-\left(\delta^B\right)^T\right)\right] + \bar{S}(1-\delta^B)}{\left[1-(1-\pi(\alpha_B^d))\delta^B - \pi(\alpha_B^d)\left(\delta^B\right)^{T+1}\right](1-\delta^B)}$$

It will choose the optimal $\alpha_B^d(T)$ such that the expected marginal benefit from defection is equal to the expected marginal cost of defection in terms of higher risk of the breakdown of the treaty.[4] The optimal level of water abstraction for defection depends on the time, *T*, during which Ghana will play non-cooperatively. Given Burkina Faso's best response, Ghana chooses the optimal strategy in the first period after an agreement is struck. Ghana knows that if $\delta^B \geq \tilde{\delta}^B(\alpha_B^d, T, \bar{\alpha}_B, \bar{p}_H)$, Burkina Faso will have lesser chance to deviate, and hence its problem is to choose the optimal period for non-cooperation such that the latter country maintains the agreement. The expected payoff of Ghana will be

$$V_c^G = \frac{E\left[NB^G(\bar{\alpha}_B, W_B)\right] - \bar{S} + p\delta^G\left(1-\left(\delta^G\right)^T\right)V_{NC}^G}{1-(1-\pi(\bar{\alpha}_B))\delta^G - \pi(\bar{\alpha}_B)\left(\delta^G\right)^{T+1}}$$

where V_{NC}^G is the discounted value of Ghana's payoff under non-cooperation and

$$V_{NC}^G = \frac{E\left[\left[NB^G(\bar{\alpha}_B, W_B)\right]\right]}{1-\delta^G}.$$

δ^G is the discount factor of Ghana signifying the tolerance level of the country in maintaining the agreement. (11)

Ghana chooses the optimal duration of non-cooperation $T(\alpha_B^d)$ to maximize the expected payoff V_C^G subject to $\delta^B \geq \tilde{\delta}^B(\alpha_B^d, T, \bar{\alpha}_B, \bar{p}_H)$. The optimal duration of non-cooperation, T, chosen by Ghana can be finite or infinite. Infinite value of optimal T implies that if the water level falls below the threshold level at the given period, then the cooperation permanently ends. Given the response functions, $\alpha_B^d = \alpha_B^d(T)$ and $T = T(\alpha_B^d)$, both the countries simultaneously decide about the optimal $\tilde{\alpha}_B^d$ and $\tilde{T}$.

If $\delta^B \geq \tilde{\delta}^B(\bar{\alpha}_B, \bar{p}_H, \tilde{\alpha}_B^d, \tilde{T})$, Burkina Faso will have less incentive to deviate and will play cooperatively in the current and subsequent periods. Knowing that Burkina Faso will not deviate given high discount factor; Ghana optimal strategy will be to play cooperatively. But a bad shock can cause the water consumption of Ghana to fall below the threshold level $\hat{w}_{Akasambo}$ triggering a temporary breakdown of the agreement for $\tilde{T}$ period where Ghana stops paying the side payment and Burkina Faso unilaterally diverts a fixed amount of water.

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[4] Due to theoretical complexity involved, we avoid solving the first order conditions. However, the results of the optimization are provided in the simulation results section.

We are now in a position to derive the equilibrium offers of the countries. Each country offers a proposal in alternating periods and if a proposal is rejected in a given round, the game continues to next round where again a proposal is offered. If the offer is accepted, an agreement is struck and Burkina Faso would not deviate provided $\delta^B \geq \tilde{\delta}^B(\overline{\alpha}_B, \overline{p}_H, \tilde{\alpha}_B^d, \tilde{T})$ for an offer $(\overline{\alpha}_B, \overline{p}_H)$. Here, the country's decision problem is to choose an equilibrium offer so that it is accepted by the other country. A sub-game perfect equilibrium is again employed to characterize the outcome of the game.

To solve a sub-game perfect equilibrium in an infinitely repeated game, we have to employ a different technique. Because the game would go on infinitely, there is no such last step to begin the process of backward induction.

To characterize a SPE of the game, we need to specify few assumptions

A1: Stationarity: In equilibrium, the country makes the same offer whenever it has to make an offer. We restrict to stationary paths i.e. $(\alpha_{Bt}, p_{Ht}) = (\alpha_B, p)$ for $\forall t$

A2: No Delay: Whenever a country has to make an offer, her equilibrium offer is accepted by the other player.

If the countries perpetually disagree then the expected payoff of country i (i= B, G) will be $E\left[NB^i(\alpha^*_{B_B}, W_B)\right]\frac{1}{1-\delta^i} = B^i$. The payoff pair, $\left(B^B, B^G\right)$, from perpetual disagreement are obtained by the countries if each country always rejects any offer made to her. This is called the impasse point. Country i can always get a payoff $V^i(\alpha_B, p_H)$ by always asking an offer (α_B, p_H) and always rejecting all other offers given $V^i(\alpha_B, p_H) = B^i$. The 'impasse point payoff' may differ if there are chances of breakdown of the negotiation.

There are several exogenous reasons for a negotiation process to breakdown. One factor could be the possibility of import of gas from Nigeria, which could meet a large proportion of energy demand in Ghana. Under such circumstances, Ghana may depend less on hydropower from Akosombo Dam. On the other hand, Burkina Faso might be interested in construction of hydropower dam with the help of international donor's fund. This factor can also erode Burkina Faso's interest in the negotiation of water issues. The fear of the breakdown of the negotiation may induce both countries to reach an agreement early and influence the outcome of the model.

Consider the probability that the negotiation continues to the next round as q and the probability of breakdown of the agreement as 1-*q*. If the chance of negotiation breaking down is permanent and the countries perpetually disagree, then the expected payoff of country i (i=B, G) will be

$$\left[(1-q)E\left[NB^i(\alpha^*_B, W_B)\right] + q(1-q)\delta^i E\left[NB^i(\alpha^*_B, W_B)\right] + q^2(1-q)\delta^{i2} E\left[NB^i(\alpha^*_B, W_B)\right].+...\right].$$

$$= E\left[NB^i(\alpha^*_B, W_B)\right]\frac{1-q}{1-q\delta^i} = B^i \qquad (12)$$

The result also supports Rubenstein findings (Rubinstein 1984): if $\delta \rightarrow 1$ the fear of breakdown rather than the time cost of bargaining is the dominant consideration, then the disagreement point is close to ($E\left[NB^i(\alpha_B^*,W_B)\right]$). If the probability of breakdown is zero or $q \to 1$ then the disagreement is close to zero for both the countries and the time preference for bargaining will act as an incentive to reach an agreement.

As the countries make delay in making a successful negotiation, the probability of breakdown increases. If we assume that an agreement outcome is always preferable over a breakdown outcome, the country will have incentive to reach an agreement earlier. In any SPE of the game, each country's payoff should be greater than or equal to B^i.

During the negotiation, Burkina Faso chooses an optimal offer (α'_B, p'_H) maximizing $V_c^B(\alpha_B, p_H)$ subject to $V_c^G(\alpha_B, p_H) = E\left[NB^G(\alpha_B^*,W_B)\right] + \delta^G\left[V_c^G(\alpha''_B, p''_H)\right]$ where (α''_B, p''_H) is the equilibrium offer of Ghana.

Similarly, Ghana chooses an optimal offer (α''_B, p''_H) maximizing $V_c^G(\alpha_B, p_H)$ subject to $V_c^B(\alpha_B, p_H) = E\left[NB^B(\alpha_B^*,W_B)\right] + \delta^B\left[V_c^B(\alpha'_B, p'_H)\right]$ and $\delta^B = \tilde{\delta}^B((\alpha_B, p_H))$ where (α'_B, p'_H) is the equilibrium offer of Burkina Faso.

The game has a unique SPE for unique values of (α'_B, p'_H) and (α''_B, p''_H) if Burkina Faso always offers (α'_B, p'_H) and always accepts an offer (α_B, p_H) and does not deviate if and only if $V_c^B(\alpha_B, p_H) \geq E\left[NB^B(\alpha_B^*,W_B)\right] + \delta^B\left[V_c^B(\alpha'_B, p'_H)\right]$ where $\delta^B \geq \tilde{\delta}^B((\alpha_B, p_H))$ Ghana always offers (α''_B, p''_H) and always accepts an offer (α_B, p_H) if and only if $V_c^G(\alpha_B, p_H) \geq E\left[NB^G(\alpha_B^*,W_B)\right] + \delta^G\left[V_c^G(\alpha''_B, p''_H)\right]$.

If Burkina Faso and Ghana are indifferent between the offers (α'_B, p'_H) and (α''_B, p''_H) and assumptions A1-A2 holds then, we get a SPE achieved at the first stage of the game.

The outcome of the negotiation and the sustainability of the agreement depend to a large extent on time preferences of the countries. The negotiating countries' time preferences can be either symmetric or asymmetric. However, here Ghana could be more impatient than Burkina Faso as it faces more excess demand of water than the latter country. Moreover, lack of water in the downstream would hurt the economy of Ghana severely. If such consequences are taken into account then Ghana may pay a higher compensation or side payments to the upstream country to reach an agreement. Burkina Faso may be also more impatient, if it faces an increasing demand to meet the power shortage.

When countries have asymmetric preferences, one country can have a larger share of the 'cake' relative to the other. It is reasonable to assume that the outcome of the game obtained by a country in the unique SPE reflects its bargaining power. Thus a country's bargaining power is increasing in her discount factor and decreasing in opponent country's discount factor. In this game, if either Ghana or Burkina Faso does not wish to accept any particular offer, and instead would like to make a counter-offer then it is free to do so, but has to incur the cost of waiting. The smaller the discount factor, the smaller is such cost. The country with a lower discount factor will be impatient and is likely to reach the agreement quickly. In this process, the country may need to compensate the relatively patient country for reaching an agreement more quickly and as a result receive a lower benefit.

If the upstream Burkina Faso has a higher discount factor, it will not deviate once an agreement is struck. But if it is more patient than Ghana, then it can ask for a higher discount price for electric power or retain a larger share of W_B for itself. It is like a scissor problem for Ghana.

Ghana may prefer Burkina Faso to be relatively impatient, as it would help Ghana to reach an agreement earlier. But if Burkina Faso is impatient, then the chance of deviation after an agreement is struck is higher. It means that either Ghana has to pay higher discounts for energy or demand a lower level of water diversion in the downstream to induce Burkina Faso to accept an agreement. This also resolves the problem of deviation, as with higher compensation Burkina Faso will have lesser chance to deviate. Uncertainty in the flow of water will affect the equilibrium offers of the countries. If Ghana is not willing to pay higher side payments then it will settle for lesser share of water, and then the chance of breakdown of the agreement will be high. The agreement will be sustaining if Ghana demands a higher share of water and pays higher discounts to compensate Burkina Faso.

5 Simulation Results

In this section, we present the result of the theoretical model using simulation techniques. We have used @ Risk software to simulate, employing the Latin Hypercube sampling technique.[5] Table 1 shows the parameters values, distribution function and the method used in computation of the important variables and parameters. The key variables involved in the simulation are Burkina Faso's water abstraction rate and Ghana's discounted price on power supply to Burkina Faso.

Using Best Fit @ Risk Software and empirical data, we determine the distribution function of the water availability in the Volta River Basin. Simulation results suggest that the stochastic variable, W_B, is best fitted with a lognormal distribution with mean and standard deviation 13 and 5 respectively. Based on the distribution function, we compute the probability of the breakdown of the treaty. The simulations of expected net benefits of Burkina Faso and Ghana, E(NB^B) and E(NB^G) respectively, were conducted in both cases of with and without the agreement. This in turn allows us to evaluate the optimal offers of each country accepting the agreement based on their potential gain.

Table 1: Description of variables and parameters of the model

Variables/ Parameters	Description	Assumptions
H^{GB}	Amount of hydropower exported from Ghana to Burkina Faso.	We have assumed that Burkina Faso will import a fixed amount of power. $H^{GB} = 150GWH$. This is based on the projection of hydropower import of Burkina Faso (Obeng 2004)[6]
$p_H^{\pm}$	Actual price of Hydropower.	0.6-0.8 million rupees per GWH (ISSER 2005)
p_H	Discounted price of hydropower.	Discounted price of power ranges between 0 to 0.6 million rupees. It is chosen optimally in the model.
S	Side payments made to Burkina Faso by Ghana in Bargaining.	$S = (p_H^{\pm} - p_H)H^{GB}$. The value of S ranges between 0 to 9 million dollars.
W_B	Annual total renewable fresh water resources in Burkina Faso expressed in cubic km.	W_B follows lognormal distribution with mean 13 and standard deviation 5. It is determined from the Best Fit @ Risk Software and empirical data from Aquastat(FAO 2005).

[5] The Latin Hypercube technique requires fewer model iterations to approximate the desired variable distribution than the simple Monte Carlo method, and ensures that the entire range of each variable is sampled. In the simulation, more than 10,000 iterations are used.

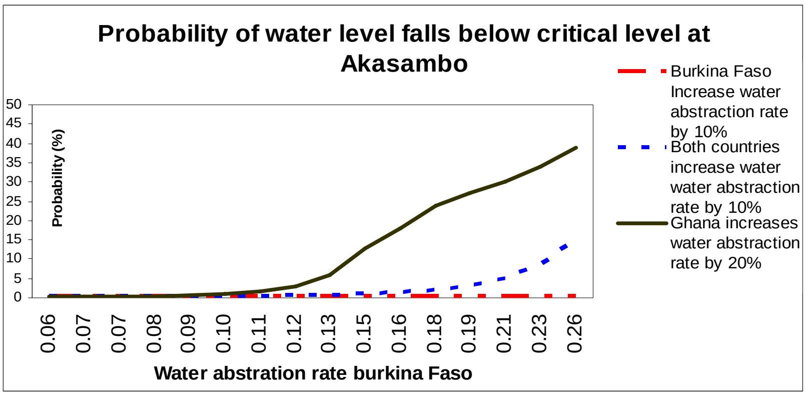
[6] We have considered import demand as fixed for analytical simplicity. Further work can be done by assuming demand for power as a function of price. It could influence the scope of negotiation as well as the bargaining set.

R	Rainfall.	The internal resource available is 29.5 cubic km. Source FAO 2005. We consider that R follows lognormal distribution with mean 29.5 and standard deviation 10.
X	Inflow of water from Togo and Cote d'Ivoire to Ghana.	The Inflow of River flow to Ghana is estimated as 14 cubic km (FAO 2005). We assumed that the X follows lognormal distribution with mean 14 and standard deviation 10.
θ	Proportion of water in Burkina Faso that flows out to Togo.	We consider θ be equal to 0.5. Source FAO
α_B^0	Actual /current water withdrawal rate of Burkina Faso.	The current level of water abstraction rate in Burkina Faso $\alpha_B^0 = 0.065$ Source FAO 2005
α_B^d	Water withdrawal rate of Burkina Faso in case of deviation.	Optimal water withdrawal rate $\tilde{\alpha}_B^d$ of Burkina Faso in the case of deviation has been chosen optimally in the model. $\tilde{\alpha}_B^d = .3$ It is based on the irrigated potential of the country of 165,000 ha.
$\alpha^*{}_G$	Water abstraction rate of Ghana.	The current level of water abstraction rate of Ghana is 0.078. Given the water demand of Ghana of nearly 4 cubic km, we have estimated the maximum potential water abstraction rate as 0.1.
T	Time period during non cooperation.	The time period during non cooperation is chosen optimally in the model as $\tilde{T} = 1.3 years$
NB^B	Net benefit of Burkina Faso without treaty conditions.	$NB^B = 3E(w_B)$^0.5 The benefit function is based on the profit level of water consumption in Burkina Faso as estimated by Obeng-Asiedu (2004) using optimization model in GAMS. The profit of Burkina Faso was calculated as 58 million US dollars from 336 million cubic meters. The concavity of the benefit function with a power of (1/2) is chosen for analytical simplicity.
NB^G	Net Benefit of Ghana without treaty conditions.	$NB^B = 1.45E(w_B)$^0.5 $+ P(w_{Akasambo} > \hat{w}_{Akasambo})(20E(w_{Akasambo} \mid w_{Akasambo} > \hat{w}_{Akasambo})$^0.5 $+ P(w_{Akasambo} \leq \hat{w}_{Akasambo})(20E(w_{Akasambo} \mid w_{Akasambo} \leq \hat{w}_{Akasambo})$^0.5 The benefit function of Ghana is similarly calculated using Obeng-Asiedu (2004) estimate, which shows that Ghana has generated an agricultural, rural and urban profit of 26 million dollars from 271 million cubic of water, and a profit of hydropower generation of 98 million. We have modified the expected profit from hydropower by incorporating the uncertainty in the water inflow into Lake Volta. The concavity of the benefit function with a power of (1/2) is chosen for analytical simplicity.
$\hat{w}_G$	Threshold level below which if the water consumption level falls then the agreement breaks down.	The threshold level is chosen as 37.5 cubic km. It is chosen based on the given demand of water at the Lake Volta. Source: (MWH 1998).
δ^B	The discount factor of Burkina Faso.	We have assumed the discount factor of Burkina Faso to be 10%.[7]
δ^G	The discount factor of Ghana.	We have considered Ghana discount factor as 15%.

[7] The assumption on the values of discount factors of both Ghana and Burkina Faso has been made based on values in the region as mentioned in other literatures (Starkey 1990).The difference between the Burkina Faso and Ghana 's discount factor is based on the difference in their GDP level.

Figure 1 illustrates the results of the simulation, which explains the relationship between probabilities of water inflow that could fall below the critical level at Lake Volta and different degrees of water abstraction of Ghana and Burkina Faso. The Figure suggests that if Burkina Faso increases the water abstraction by 10%, and Ghana's water abstraction rate remains at the current level, then the probability of water inflow falling below the critical level of 37.5 cubic km is minimal. However, under similar conditions if Ghana increases the water abstraction level by 20% then the probability increases phenomenally for similar increase in Burkina Faso's water abstraction rate at a higher level.

Figure 1: Probability of water inflow falls below critical level of 37 cubic km under levels of water abstraction rate of Ghana and Burkina Faso.



The marginal loss and benefit of Ghana and Burkina Faso respectively at different levels of water abstraction rate of Burkina Faso are described in Figure 2. It shows that if Ghana maintains its current proportion of water abstraction, marginal benefits of Burkina Faso from increase in its water abstraction rate are much higher than that of Ghana's marginal loss. If Ghana also increases water abstraction, then initially the marginal loss becomes negative as higher water abstraction brings more profit. However, the marginal loss of Ghana increases sharply as the probability of water inflow falling below the critical level also increases. On the other hand, Burkina Faso's marginal benefit from an increase in water abstraction decreases and becomes equal to Ghana‘s marginal loss.

Under such circumstances, there is an opportunity for Ghana to induce Burkina Faso to restrict water withdrawal by providing the latter country side payments in terms of discounted export price of power.

Figure 2: Marginal cost of Ghana and Marginal benefit of Burkina Faso under different levels of levels of water withdrawal of Ghana and Burkina Faso.

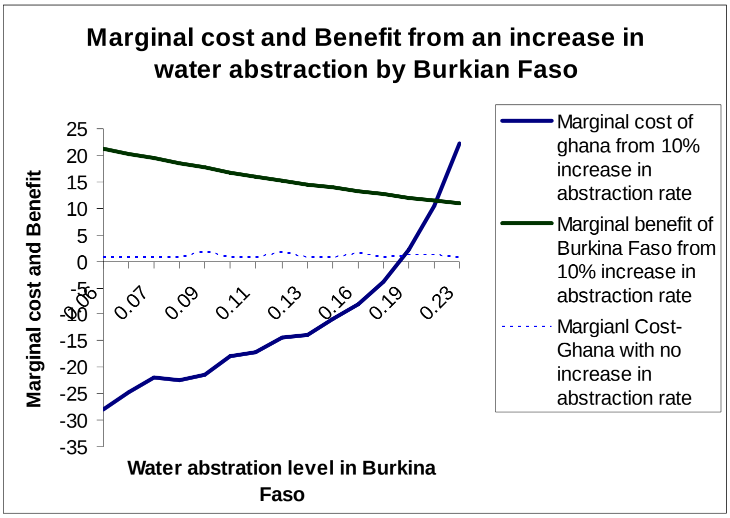


Table 2 describes Ghana's and Burkina Faso's gains from different offers in terms of the price discount in power export and percentage reduction in the proportion of water withdrawal of Burkina Faso from its optimal level. The Table also shows Burkina Faso's chance of deviation and the probability of water inflow falling below the critical level at different offers of the countries. The discount factors of Burkina Faso and Ghana are assumed to be 10% and 15% respectively, which implies that Burkina Faso is less patient than Ghana.

The results indicate that Burkina Faso would gain more from higher water withdrawal in the upstream and with lower discount on the price of power .On the contrary, Ghana would gain more by offering higher discount and asking Burkina Faso to restrict its water withdrawal at a higher level. However, in such case Burkina Faso's chance of deviation will increase. Optimal results suggests that Ghana would offer close to 78% power discount for restricting Burkina Faso at 15% less than its optimal water abstraction under no agreement case. It will reduce the probability of water inflow falling below the critical level significantly from 25% to 7% .The gains to Ghana would increase by around 2% with lesser chance of deviation of Burkina Faso from the agreement if the latter country's discount factor increases to 15% from 10%.

Table 2: Ghana and Burkina Faso's gain from different equilibrium offers.

Ghana's discount on power (%)	Burkina Faso abstraction rate less than the optimal rate (%)	Ghana Gain (%)	Burkina Faso Gain (%)	Probability that the water level falls below the critical level at Akosombo (%)	Burkina Faso's Chance of deviation from the treaty (%)
92	25	12.1	1.1	5.8	Positive
85	18	10.2	3.4	6.7	Positive
78	15	9.3	4.1	7.1	Close to zero
65	13	7.6	5.2	8.5	Negative
56	11	5.1	6.6	9.2	Negative
49	9	4.3	7.2	11.0	Negative
44	8	3.4	8.1	14.1	Negative
35	5	2.9	9.6	17.9	Negative
25	3.7	1.1	10.2	19.7	Negative
20	2.9	0.4	11.2	21.6	Negative

Note: Here we have considered the discount factor of Ghana and Burkina Faso as 15% and 10% respectively.

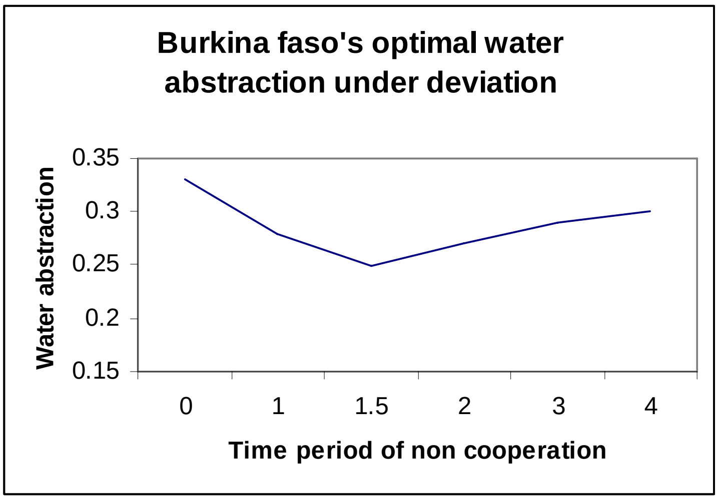
We attempt to evaluate the countries' gains given different probabilities of breakdown of the negotiation, and it is illustrated in Table 3. The negotiation may break down by either Ghana or Burkina Faso due to some exogenous factors. If the risk of breakdown is permanent and countries perpetually disagree then it might reduce the potential gain from not having an agreement and it may induce the countries to reach an agreement earlier. The probabilities of breakdown of negotiation are chosen arbitrary, here, to evaluate the change in gains. Results suggests that for a similar increase in the probability of breakdown of negotiation by either Burkina Faso or Ghana , the latter country's gain from an early agreement increases more than that of Burkina Faso. It implies that the potential gains of such agreement to Ghana is much higher than to Burkina Faso, and if there is a chance of breakdown of the negotiation, Ghana will try to reach an agreement earlier by offering higher discounts to Burkina Faso.

In the theoretical model, we have derived the response function of Burkina Faso to choose the optimal abstraction rate for deviation with respect to Ghana's optimal time period for non-cooperation. The simulation results suggest that Burkina Faso will choose a higher level of water abstraction rate for deviation if Ghana chooses a lower time period for non-cooperation. However the rate of abstraction for deviation decreases with increase in T. The response function $\frac{\partial \alpha_B^d}{\partial T} < 0$ implies that if Ghana increases the period for noncooperation, *T*, then the losses for Burkina Faso from non-cooperation will increase, and it will deviate less from the agreement. It reaches minimum when T is 1.5 years and after that, further increase in T will create disincentive for Burkina Faso to maintain the agreement and induces the country to increase the level of water abstraction rate for deviation and $\frac{\partial \alpha_B^d}{\partial T} > 0$.

Table 3: Ghana and Burkina Faso's gain from treaty given different probabilities of breakdown of negotiation

Probability of breakdown of negotiation by Ghana.	Probability of breakdown of negotiation by Burkina Faso.	Ghana Gain from an early agreement (%)	Burkina Faso Gain from an early agreement (%)[8]
0	0	9.3	4.1
0	0.25	11.9	4.1
0.25	0	9.3	4.3

Figure 3: Optimal water abstraction of Burkina Faso under deviation given different time periods for non cooperation



Overall, the simulation results presented above indicate that under the present condition, there would be no gain for Ghana to enter into any such agreement as the marginal loss from an increase in water abstraction rate of Burkina Faso will be negligible compared to the latter country's marginal benefit. However, such cooperative agreement makes economic sense if both the countries have higher water abstraction rate. In such case, Burkina Faso's marginal benefit would decrease and Ghana's marginal cost will increase from further increases in water abstraction rate of Burkina Faso. It will lead to a situation where Ghana could gain by offering side payments and restricting Burkina Faso from further increases in water abstraction rate.

[8] We have considered that Ghana gives 80% discount on power and Burkina Faso restricts 15% less than optimal level of water abstraction rate.

Discount factors of both the countries are also critical elements which can influence the outcome of the model. Higher discount factor can reduce Burkina Faso's deviation from an agreement. However, it can delay the agreement as it will take longer time to accept such agreement. On the other hand, a lower discount factor can induce Burkina Faso to accept an agreement earlier, but the chance of deviation also increases. We hypothesized in the previous section that to make a sustaining agreement in a shorter time, Ghana may offer higher side payments to Burkina Faso. However, given the present structure of the side payments in the form of discounts, the simulation results indicate that the scope is limited. In the future, if Burkina Faso discount factor increases with development, then it will resolve Ghana problem.

6 Concluding Comments

The aim of the paper was to examine the scope of a self-enforcing issue-linked water sharing agreement between upstream and downstream countries of Burkina Faso and Ghana respectively. Such self-forcing agreement could lead to sustainable outcome as countries take into consideration the chance of deviation while negotiating for an agreement.

The paper incorporates the uncertainty of water flow and evaluates the risk of breakdown of agreement. The paper also answers the relevant question whether Burkina Faso's higher water abstraction can influence the water inflow in the Lake Volta, and repeat the situation as in 1998 when low water inflow affected the hydropower generation dramatically. Currently the probability of such event is around 1%, but could change drastically, if the countries start abstracting much higher proportion of water for irrigation and other purposes. This situation is likely in the near future, given that the demand for water is predicted to increase several folds in 2020 (see Appendix Figure). However, at the same time Ghana requires hydropower from the Akosombo Dam, which could produce power at a much lesser cost. In such circumstances, it could be worthwhile for Ghana to negotiate with Burkina Faso for restricting further increase in water withdrawal in the upstream. Burkina Faso could also gain from such agreement. Currently, Burkina Faso's water withdrawal is several times higher than Ghana's. At a later stage, the marginal benefit from further increases in its water abstraction could start to decrease. Also, with the demand of power increasing at 6% per annum and with limited potential to augment the power supply, Burkina Faso may rely more heavily on Ghana's hydropower export to meet the energy power demand. With both the countries gaining, such kind of issue-linked water agreement can guarantee a pareto improvement, and can facilitate the water sharing agreement between the two countries to be sustained in the long run.

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