Water Allocation between States in Inter Basin Water Transfer in India

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Abstract

In the following paper, we illustrate the proposed inter basin water transfer in India and attempt to do an *ex ante* analysis of the sharing of the transferred water between the donor and the recipient states. The paper identifies that one of the possible ways of water allocation could be market based, where through a commercial agreement water scarce states that receives transferred water pay the donor state a certain amount. Our results also indicate that such price based water transfer could lead to a most inefficient outcome. The donor states could charge a much higher price and the buyer would buy less amount of water. It would create large deadweight loss in the social welfare. The loss could increase further if there are many states in the middle between the donor and the ultimate beneficiary state.

The paper also investigates water allocation in a situation where the state cares about the welfare of the other states. We find that with better relationship, the middle state could divert higher proportion of water even if the head state shares less water with the middle state.

We also consider that political relations are crucial elements influencing the altruistic concerns of the states and thus in the determination of water allocation. We recognize the risk in benefit loss of water recipient states could stem from hostile political relationship between the donor and the recipient state. We have designed a penalty mechanism, which can deter the states from unilateral diversion of water in such cases, and facilitate to have an efficient allocation of water sustaining in the long run.

Key words: Inter-basin Water Transfer, Water allocation, Market Based Water Transfer, Political Economy.

1. Introduction:

India is no exception to the general global trend of rising demand for freshwater. In many regions of India, the amount of water available is already very limited. The gap between freshwater supply and demand in India may widen further in the coming century as a result of increasing consumption of water by a growing Indian population. However, the growing concern in India is about the spatial variation in water availability (see Appendix Table 1).

The spatial variations at river basin level, studied by Amarasinghe *et. al* (2005), shows that the Ganga-Brahmaputra-Meghna River Basins, which cover one-third of the total land area in India (Figure 1), are home to 44 percent of India's population, but drain more than 60 percent of the country's water resources. In contrast, the Peninsular River Basins, which cover 16 percent of the land area, have 17 percent of the population and drain only 6 percent of India's water resources (Amarasinghe *et. al* 2005).

(Insert Figure1)

As a consequence, severe regional water scarcity emerges in Peninsular India despite higher water availability in other parts of the country. Currently, India is planning to develop a national water grid as part of the National River Linking Project, and divert surplus water resources of the Himalayan Rivers to the water deficient Peninsular River basin. The notion of the linking of the rivers in the Subcontinent is an old one. In the 19th

Century, Sir Arthur Cotton had thought of a plan to link rivers in southern India for inland navigation. Though partially implemented, the idea was later abandoned. The proposal now has been taken up by India's National Water Development Agency (NWDA). NWDA has identified 30 links classified into Himalayan and Peninsular links. The Himalayan component consists of 14 links that involves transfers of 33 billion cubic meters of water from the Ganges-Brahmaputra-Meghna basins. The Peninsular component consists of 16 links which involves mainly the transfers from Mahanadi, Godavari, Krishna, Pennar, Cauvery river basin (NWDA, 2006). Amongst the Peninsular component, Mahanadi and Godavari has been considered as the sizeable surpluses, and it is proposed to transfer the surpluses of Mahanadi and Godavari river water to Krishna, Pennar and Cauvery river basins.

Creating new sources to augment water supply not only requires large investments but also effective institutions for allocating water (Bhaduri and Barbier 2008). River linking in such setting requires cooperation and coordination between the different states sharing the water. As rivers do not follow state boundaries in the federal democratic country, constructing an efficient water allocation mechanism is essential to avoid any inter state water disputes (Richards and Singh 2002, Bandopadhyay and Parveen 2003). Many policy makers argue that interlinking of rivers would multiply the intensity of conflicts between states (Iyer 2003). Some of the states have already voiced their concern against the river linking proposals¹.

¹ The states traversed under some of the prominent Peninsular Links area are shown in Appendix Table 2. Kerala, Bihar, West Bengal, Assam, Punjab, Chhattisgarh, and Goa have opposed the river-linking proposition. Gujarat, Karnataka, Andhra Pradesh, Orissa, and Maharashtra have only given a conditional agreement; that is, they have agreed to links where they would receive water but are opposed to those links where they would donate the water (Bandopadhyay and Parveen 2003).

The following paper analyzes the economic impact of allocating river water among states in India if the inter-linking of rivers project takes place. There are several ways in which transferred water can be allocated to meet the demand of the water scarce states. The approach considered here is a market-based water transfer, where through a contractual agreement the state that receives water makes a payment to the donor state.

Following Bhaduri and Barbier (2008), a general framework of a market-based water transfer model is developed for inter-linked river, where a water deficient state has the option to buy more water to meet its excess demand from a water surplus state. In addition to mitigating the water scarcity problem, a market based water transfer may also provide an incentive for an efficient water use within the states. This modelling approach and application differs from Bhaduri and Barbier (2008) in some crucial respects. First, we have applied the international river allocation modelling framework of Bhaduri and Barbier (2008) in the context of interstate river of a country. Second, Bhaduri and Barbier (2008) showed how water allocation between an upstream and downstream country is influenced if latter country has an outside option to buy water from a third country. However, in this paper we allow the possibility of direct water trade between upstream and downstream states in a country. Moreover, we extend the framework to three players (head, middle and tail) which gives scope to generalize some of the results, and apply in the context of water sharing among multiple players.

In the model, we determine the optimal share of water diversion between upstream and downstream states with the provision of the downstream states to buy surplus water from upstream. The state's decision regarding the amount of water to buy depends on the price of water and its relative availability. Given the reaction function of

the buyer, the donor state chooses the optimal price of water. Thus we will be able to investigate the conditions, which can induce the water deficient states to buy water at a given price. We employ the model to explore the hypothesis whether market based water transfer could lead to an optimal allocation of resources in the setting of inter basin water transfer.

We also address how water allocation between states in India will be different in a situation where a state cares about the welfare of other states. Many states care about the welfare of the other states and settle water allocation disputes among themselves. For instance, the dispute regarding the sharing of the Yamuna River among the states of Delhi, Haryana and Uttar Pradesh was resolved through consensual approach by conferences involving Chief Ministers of the states. In another case, Andhra Pradesh has agreed to supply Krishna River water to a reservoir in Tamil Nadu to meet its urban water demand.

In such cases, the decision on water allocation between the states will be similar to that of a social planner managing the whole river basin, and thus leading to an efficient water allocation. However, in many cases cooperative outcome may not be self enforcing by states, for instance, one of the larger disputes on interstate water dispute between Karnataka and Tamil Nadu over the waters of the Cauvery still rages on. A study conducted by Anand (2004) on Cauvery water dispute shows that the intensity of water dispute is higher when there is asymmetry in the political powers of the states. The resolution of water disputes also depend on political power relationship between the conflicting parties. Thus, political relationship and the altruistic concerns of the donor and

the recipient states might be related and play a vital role in water allocation. We extend the basic water-transfer model by allowing altruism between states.

We assume such altruism between states is determined by their political relationship. The paper explores different scenarios of political relationship and the corresponding altruistic concerns under which the states would allocate water after the river-linking project takes place. We consider the situations where cooperation between the states is possible, as well as situations of pure conflict when the allocation of water rights is at stake. The degree of power asymmetry, which relates to political relationship between the states, is an important element to understand whether a cooperative outcome will emerge or not. The paper illustrates the case of water allocation between head, middle and tail states – Orissa, Andhra Pradesh and Tamil Nadu respectively in the case of river linking. We discuss the outcome if there is no cooperation among states compared to a situation when water is allocated as planned by a social planner.

In case of hostile political relationship between the states, donor state could unilaterally divert water and result in an inefficient of water allocation. In such instances, intervention of the central autonomous authority can act as a threat point in water allocation decisions of the states. We design a mechanism, which could prevent the states to deviate in the case of hostile political situation and make the agreement of water sharing sustaining in the long run.

The remainder of the paper is structured as follows. In the next section, we develop a general model of interstate water allocation. In the third section, we derive the optimal allocation of water in the setting of market based water transfer. The fourth section describes the water sharing model with the help of a simple altruism model

determined by political relationship. Finally, the conclusion summarizes the main findings and results of the paper.

2. A Model of Interstate Water Sharing with River Linking

We consider first the case of allocating of river water between three states of a country. Suppose the river basins X , Y and Z are located in the states A , B and C respectively (see Figure 2). The river basins and the states are indexed as i ($i=X,Y,Z$) and j ($j=A,B,C$) respectively. After linking of rivers in the three basins, there is an opportunity to transfer water from the water surplus River Basin, X located in state A to the water deficient Basins Y and Z located in state B and C respectively. Due to local geography, however, surplus water from state A can only be transferred to state C through state B . We assume that the availability of water in river basin i ($i=X, Y, Z$) is w_i , and consider the flow of rivers in each river basin as non-stochastic for analytical simplicity. As the availability of water is invariant, the consumptive usage of water in state A is a function of the share of water α_A diverted by the latter state. Similarly, the consumptive usage of water in states B and C depend on the share of water α_A and α_B diverted by state A and B respectively. The share of water diverted α_A and α_B lies between 0 and 1. The contribution of α_A and α_B to the consumptive usage of water w_i , in state j ($j=A, B, C$) respectively can be represented by

$$w^A = (1 - \alpha_A)W_X; w^B = (1 - \alpha_B)[W_Y + \alpha_A W_X]; w^C = W_Z + \alpha_B(W_Y + \alpha_A W_X). \quad (1)$$

Consider an agricultural production function $q^j = f(w^j, x^j)$ for state $j = A, B, C$ where w^j is the amount of water usage and x^j is an indicator for all other inputs.² The production function is assumed to be strictly concave for all possible values of w and x .

[Insert Figure 2]

The cost function of withdrawing water from the river and for distribution is $c_w^j(w^j)$, and is assumed to be increasing and convex for all values of w . The marginal cost of other factors, c_x^j , is constant for all values of x . The price of the agricultural good is p^j , and is determined exogenously in the domestic markets of the states. The payoff of each state is represented by the aggregate profit of the agricultural sector.

Payoff functions of states j ($j=A, B, C$) is represented as

$$\pi^j = p^j q^j(w^j, x^j) - c_w^j(w^j) - c_x^j x^j \quad (2)$$

Prior to river basin linkage, each state maximizes the benefit function with respect to the water availability. As in State A water availability is sufficient to meet the water demand, it would withdraw water to meet their optimal water consumption needs. State A 's benefit will be maximized when the net marginal benefit of water consumption

, $\left[p^A \frac{\partial q^A}{\partial w^A} - \frac{\partial C_w^A}{\partial w^A} \right]$, is equal to zero. The solution to the maximization problem

is $w^{A*} = w^A(p^A, x^A)$ where the optimal amount of water usage by the state A depends on the price of agricultural good, p^A , and usage of other inputs for agriculture.

As we have assumed, the freshwater availability in the states B and C are limited, the water consumption in these two states would be determined by the water constraint.

² In main rivers basins involved in the river linking project, more than 90 % of water is used for agricultural purposes.

If the water availability constraint is non binding, then the solution to the problem would be $w^{j*} = w^j(p^j, x^j)$ $j=B, C$.

Measuring the *ex ante* amount of water needed for water deficient state j ($j=B, C$) to approximate the maximized profit when there is no scarcity of water, the excess demand of water to attain the profit maximizing optimum can be represented by

$$ED^j = w^j(p^j, x^j) - W_i \text{ where } i=Y \text{ and } X. \quad (3)$$

According to equation 3, equation excess demand for water, ED^j , arises when the state faces water scarcity, and is dependent on the agricultural price, p^j , and usage of other production factors, x^j of state j . In order to make the problem tractable, we consider factors influencing the excess demand to be exogenously determined, thus making the excess demand, ED^j , a function of water availability only.

Equation 3 allows us to consider how states B and C can meet its excess demand for water through transfers from a water abundant state. The water deficient states B, C can meet its shortage of water by transferring an amount of water, D^j . The range of D^C lies between zero, and ED^C and is the function of the share of water diverted by states A and B . D^C can be expressed as

$$D^C = \alpha_B [W_Y + \alpha_A W_X] . \quad (4)$$

As state B is the intermediary state and receives all the water from state A before it transfers to state C , state B can demand D^B amount of water for itself and state C . D^B could range between zero and $ED^B + ED^C$.

There are several ways in which water can be transferred to meet the water demand of the water scarce states. Transfer of water from one basin to another can be achieved either through a commercial agreement by which the state that receives water

pays the donor state a certain amount or a mutual consent arising from good political relationship between the states.

In the next section, a market-based water transfer model is formulated to determine the optimal amount of water transfer where a state has the opportunity to buy water from the relative water abundant state.

3. Market Based Water Transfer to the Water Scarce States

In this section, we formulate a game theoretic model where we determine the optimal amount of water transfer. In the model, the water scarce states have the “outside option” to buy water from the other states. State A is a water abundant state and can transfer water directly to state B , but due to local geography, water cannot be further transferred to state C directly from state A . It can only be transferred indirectly through state B . In that case where state B has the opportunity sell water to state C after buying water from state A .

Direct transfer of water entails a high cost, which may include building storage dams, canals or pipelines.

The cost of transferring water, T^j , can be expressed as $T^j = \bar{T}^j + t(D^k)$ where $(j=A,B)$ $(k=B,C)$ and $j \neq k$. (5)

In the above expression (5) $\bar{T}$ is the fixed cost of water supply and $t(D)$ is the variable cost of water transfer. We also assume the marginal cost of water transfer, $T'(D)$, is increasing. If state j ($j=A, B$) sets a price, r^j , for each unit of water transferred to state k , the payoff function of state A and B is represented by

$$\pi^A = p^A q^A(w^A, x^A) - c_w^A(w^A) - c_X^A x^A + r^A D^B - T^A(D^B) \quad (6)$$

$$\pi^B = p^B q^B(w^B, x^B) - c_w^B(w^B) - c_X^B x^B + r^B D^C - r^A D^B - T^B(D^C). \quad (7)$$

Figure 2 illustrates the case of water transfer. State C facing the price of water charged by state B will buy the desired amount of water, D^C . Similarly, state B observing the price charged by state A and anticipating the desired demand of water of state C , would buy an amount of water from state A .

State C 's payoff can be represented as $\pi^C = p^C q^C(w^C, x^C) - c_w^C(w^A) - c_x^C x^C - r^B D^C$ (8)

The sequence of the state's move is as follows

1. *State A sets the price of water transfer, r^A .*
2. *After observing the price r^A , state B chooses the amount of water to be bought from state A , D^B to meet its own water requirement and also to transfer the remaining water to state C at a price, r^B .*
3. *State C observes r^B and then chooses the desired amount of water D^C to be bought from state B .*

The presence of the transfer cost of water and the scarcity value of water are crucial to the outcomes of the model. This would induce states A and B to charge a monopoly price.

Proposition 1: *In a market based water transfer arrangement between three states, the state at the middle (state B) will charge a higher price to the state at the tail (state C) than the state at the head (state A) charges to the middle state.*

To solve the backward-induction outcome of the model, we first compute state C 's reaction to an arbitrary price of water charged in terms of water demanded by state $B, R^C(r^B)$. The problem can be expressed as³

$$\max_{D>0} \pi^C = p^C q^C(w^C, x^C) - c_w^C(w^C) - c_X^C x^C - r^B D^C \text{ subject to } w^C = W_Z + D^C.$$

The first order condition of the above problem can be expressed as:

$$p^C \frac{\partial q^C}{\partial w^C} \frac{\partial w^C}{\partial D^C} - \frac{\partial c_w^C}{\partial w^C} \frac{\partial w^C}{\partial D^C} - r^B = 0. \quad (9)$$

The above first order condition can be simplified to

$$p^C \frac{\partial q^C}{\partial w^C} - \frac{\partial c_w^C}{\partial w^C} - r^B = 0.$$

The above expression implies that state C will demand an optimal amount of water

transfer from state B when the net marginal benefit of water transfer $\left[p^C \frac{\partial q^C}{\partial w^C} - \frac{\partial c_w^C}{\partial w^C} \right]$ is

equal to its opportunity cost, r^B .

Solving equation 9 we can derive the demand function for excess water of state C ,

$$D^C = D(r^B). \quad (10)$$

Since state B can solve state C 's problems as well, state B will anticipate the amount of water bought given the reaction function, $D(r^B)$. Thus state B 's problem amounts to choosing the price of water transfer to state C and compute the amount of water demanded given an arbitrary price of water charged by state $A, R^B(r^A)$.

$$\max_{r^B, D^B>0} \pi^B = \max_{r>0} \left[p^B q^B(w^B, x^B) - c_w^B(w^B) - c_X^B x^B + r^B D^C - T^B(D^C) - r^A D^B \right]$$

subject to $D^C = D(r^B)$; $T^B = T + t^B(D^C)$ and $w^B = W^C + D^B - D^C$.

³ Here, the model is in the framework of Leontief's (1946) model of the relationship between a single firm and a single monopoly union.

The first order conditions are

$$D^C + r^B \frac{\partial D^C}{\partial r^B} = \frac{\partial D^C}{\partial r^B} \left[p^B \frac{\partial q^B}{\partial w^B} - \frac{\partial c_w^B}{\partial w^B} \right] + \frac{\partial t^B}{\partial r^B}. \quad (11)$$

$$p^B \frac{\partial q^B}{\partial w^B} - \frac{\partial c_w^B}{\partial w^B} - r^A = 0. \quad (12)$$

The above first order condition suggests that state B will charge a water transfer price such that the marginal revenue of water transfer $\left[D^C + r^B \frac{\partial D^C}{\partial r^B} \right]$ equals the marginal benefit forgone in domestic consumption $\frac{\partial D^C}{\partial r^B} \left[p^B \frac{\partial q^B}{\partial w^B} - \frac{\partial c_w^B}{\partial w^B} \right]$ and the marginal cost of water transfer $\frac{\partial t^B}{\partial r^B}$. The second expression implies that state B will demand an optimal amount of water transfer from state A when the net marginal benefit of water transfer

$$\left[p^B \frac{\partial q^B}{\partial w^B} - \frac{\partial c_w^B}{\partial w^B} \right] \text{ is equal to its opportunity cost, } r^B.$$

$$\text{Combining equation 11 and 12, we get } r^B - r^A - \frac{\partial t^B}{\partial D^C} = \frac{-D^C}{\frac{\partial D^C}{\partial r^B}} > 0. \quad (13)$$

The above expression suggests that if the marginal cost of water transfer is increasing and the demand for water transfer of state C is downward sloping, then state B will charge a higher price of water than state A .

Solving equations 11 and 12, we can derive the state B 's reaction function to price charged for water transfer by state A , which could be expressed as $D^B = D(r^A, D^C(r^B))$ and the price set for the water transfer to state C , $r^B = r(D^B(r^A))$.

Since state A can solve states B and C 's problems as well, state A should anticipate that the amount of water bought given the reaction function.

$$D^B = D(r^A, D^C(r^B)).$$

Thus state A 's problem amounts to

$$\max_{r^A > 0} \pi^A = \max_{r^A > 0} \left[p^A q^A(w^A, x^A) - c_w^A(w^A) - c_X^A x^A + r^A D^B - T^A(D^B) \right]$$

Subject to $D^B = D(r^A, D^C(r^B))$; $r^B = r(D^B(r^A))$, $T^A = T + t^A(D^B)$ and $w^A = W_X - D^B$.

The first order condition is

$$p^c \frac{\partial q^c}{\partial w^c} \frac{\partial w^c}{\partial D} \frac{\partial D}{\partial r} - \frac{\partial c_w^c}{\partial w^c} \frac{\partial w^c}{\partial D} \frac{\partial D}{\partial r} + D + r \frac{\partial D}{\partial r} - \frac{\partial t^c}{\partial r} = 0.$$

Simplifying the above expression we get

$$D^B + r^A \frac{\partial D^B}{\partial r^A} = \frac{\partial D^B}{\partial r^A} \left[p^A \frac{\partial q^A}{\partial w^A} - \frac{\partial c_w^A}{\partial w^A} \right] + \frac{\partial t^A}{\partial r^A}. \quad (14)$$

The above first order condition suggests that state A will charge a water transfer price such that the marginal revenue of water transfer $\left[D^B + r^A \frac{\partial D^B}{\partial r^A} \right]$ equals the marginal benefit forgone in domestic consumption $\left[\frac{\partial D^B}{\partial r^A} \left(p^A \frac{\partial q^A}{\partial w^A} - \frac{\partial c_w^A}{\partial w^A} \right) \right]$ and the marginal cost of water transfer $\left[\frac{\partial t^A}{\partial r^A} \right]$.

Knowing the water demand of state B and C , state A sets a price r^{A*} , while state B , observing the price and knowing the demand of state C , will buy D^{B*} amount of water from the water abundant state A and sets a price r^{B*} . Similarly observing the price of water transfer, states C would buy D^{C*} amount of water.

State A is the monopoly seller of water to the state B , and has exclusive control over the price of water, and so for the amount of water transferred D^{B*} to state B at a price r^{B*} , state A will charge a higher monopoly price. State B is the only buyer of water from state A and has the exclusive control over the amount of excess water to be bought. Observing a higher price, state B will buy a lesser amount of water and charge a even higher price to state C for transfer of water.

Figure 3 illustrates the isoprofit curves of the states A and B , and the inverse demand for water. In Figure 3 we measure D^B , the amount of water transfer on the horizontal axis and the price of water transfer, r^A , on the vertical axis. Lower isoprofit curves represent higher profit for state B as holding D^B constant, the state does better when r is lower $d\pi^B \Big|_{dD^B=0} = -D^B dr^A < 0$.

[Inset Figure 3]

In Figure 3 isoprofit curve $(IC)_2^B$ represent a higher profit than the isoprofit curve, $(IC)_1^B$. In contrast, holding D^B fixed, state A does better when r^A is higher as $d\pi^A \Big|_{dD^B=0} = D^B dr^A > 0$, so higher isoprofit curve $(IC)_2^A$ represent higher profit for state A . The result of the model suggests that state A would charge a higher price, r^{A*} , and state B buys a lower amount of water, D^{B*} . The outcome is depicted in Figure 3 at point F . The outcome $(r^*, D(r^*))$ at point F is not efficient, because there are other bargains in which both states can be better off (see Figure 3). At the tangency of state A 's isoprofit curve to the demand for water constraint (point F), state A 's isoprofit curve has a negative slope (see Figure 3). State B 's isoprofit curve has zero slope as it crosses the

demand for water line. Hence the outcome, depicted in figure at point F , is not a Pareto efficient situation because state A 's trade-off between r and D does not equal state B 's tradeoff between the same (see Figure 3). Monopoly price of water charged by state A is at top of this Pareto improvement region (point F) and it is too high (see Figure 3). State B faces high price of water and prefers to buy a lower amount of water. Amount of water purchase is at the left of this Pareto improvement region (the shaded region in Figure 3) hence it is too low, so the outcome is inefficient. Both the states profits will be increased if r and D were in the shaded region (say point E).

According to proposition 1, state B would charge an even higher price to state C for water transfer than state A would have charged to B , it would create further inefficiency as state C would buy even lesser amount of water.

We have seen that the uncooperative equilibrium produces an inefficient outcome. There are other bargains where all the states can be made better off. If the game is repeated, the loss from non cooperation will accumulate and there will be strong incentives for both the states to reach an agreement better than the uncooperative equilibrium. Each year, states face scarcity of water and can re-negotiate the amount of water transfer and the price for it. Clearly, one could argue that choosing a cooperative solution is a much better outcome, so the states could implicitly create a mechanism that deters deviation from a cooperative outcome to reach a stable Pareto superior outcome.

The question remains whether it is better than the outcomes without market transfer? The answer to the question depends on how a market transfer will affect the water allocation of water scarce state C relative to the socially optimal allocation, and is demonstrated using Figure 4. Let S_I is the supply curve of water, which measures the

marginal cost of water transfer of state B (see Figure 4). The water demand that measures the marginal benefit of water consumption with no transaction cost is D_I .

[Inset Figure 4]

According to the Coase theorem, the social planner will choose a water allocation on the Pareto efficient frontier that is equivalent to maximizing the joint benefits of the states from the water transfer (Coase 1960). The joint benefits of the state B and C from the water transfer can be represented as

$$V = \pi^B + \pi^C . \quad (15)$$

The efficient allocation of water between the states is determined by maximizing the above function subject to $W_Y + W_Z + D^B(r^A) = w^C + w^B$.

As indicated in Figure 4, the optimal water allocation by a social planner, state C 's water demand D_I is equal to S_I at w_1^C . According to this efficient market based water allocation, state C receives an additional amount of water w_1^C at a price r_1^B . If state B charges the monopoly price for the excess water transferred to state C , then the optimal allocation of water, w_2^C , to the latter state will be determined where $MR_I = MC$ (see Figure 4). State C will buy less and the outcome will be inefficient but still better than the outcome without any market based water transfer. The deadweight loss will be of the magnitude of the area of a triangle DEF . If state A charges a monopoly price for the water transfer to state B , then the latter state's marginal cost of transferring water will be higher for every unit of water transfer. State B will purchase less water and sell water at a higher price to state C . It will induce state C to buy even less water. The deadweight loss will increase further to GHF . The deadweight loss that arises from the states using monopoly

power in setting up the price, gets larger as more and more states are involved in such market based water transfer.

4. Water Allocation through Cooperation

In a democratic set up of a country, even though there is limited scope for cooperation to resolve such water conflicts in a social planner's way, we know many states do care about each other and settle water conflict among them.

We hypothesize that if two states are ruled by members belonging to same political party, then an upstream water surplus state might recognize the welfare of downstream water scarce states and enforce their water claims. In such case water allocation decision between two states will be similar to that of a planner, who is responsible for integrated management of the river basins.

Considering such situation, we make an attempt to determine the allocation of transferred water between different states from river linking. We assume that relatively water abundant state incorporates some proportion of water deficient state's benefit function in its net benefit function where the weights are the altruistic concerns. The net benefit function of donor state A can be expressed as

$$NB^A = \pi^A + m_B^A \pi^B + m_C^A \pi^C \quad (16)$$

where m_B^A and m_C^A are the parameters reflecting state A 's altruism towards states B and C . The value of altruism factor lies between 0 and 1. If $m_B^A = m_C^A = 1$, state A would play the role of a social planner; whereas if $m_B^A = m_C^A = 0$ then state A would not care about the other states and engage in maximizing its own welfare only.

Similarly, we can define altruism of state B towards state C in terms of net benefit function of state B , which can be expressed as $NB^B = \pi^B + m_C^B \pi^C$. (17)

In the setting of river basin linkage as explained in section 3, state B solves the water allocation problem by solving (17), subject to the water availability constraint given in equation (1).

Given the net benefit function (17), state B would choose the optimal share of water diversion, α_B to state C . The first order condition is expressed as follows

$$\frac{\partial \pi^B}{\partial w^B} = m_C^B \frac{\partial \pi^B}{\partial w^C}. \quad (18)$$

The first order condition of the maximization problem could be similar to that of the social planner's maximization problem, but the marginal benefits of state C from water consumption would be weighted by state B 's altruism toward state C .

Solving the first order conditions produces the optimal share of water diversion by state B as a function of the share of water diverted by state A and altruistic concerns amongst the three states $\alpha_B = \alpha(\alpha_A, m_C^A, m_C^B)$. Also if $m_C^B = 0$ then state B would unilaterally divert water without caring about the loss of state C 's welfare.

Proposition 2: If the head state (state A) shares less water with the middle state (state B), then the latter state will share more water with the tail state (state C). However, if the middle state is less altruistic then the rate of increase in the diversion of water for tail state will be less.

We derive the impact on the change in the state B 's share of diversion from change in state A ' share of water diversion using implicit function theorem. It is

$$\text{expressed as } \frac{\partial \alpha_B}{\partial \alpha_A} = - \frac{\frac{\partial^2 NB^B}{\partial \alpha_B \partial \alpha_A}}{\frac{\partial^2 NB^B}{\partial \alpha_B^2}} = - \frac{\left[-(1 - \alpha_B) \frac{\partial^2 \pi^B}{\partial w^{B^2}} + \alpha_B m_C^B \frac{\partial^2 \pi^C}{\partial w^{C^2}} \right] (W_X W_Y + \alpha_A W^2_X)}{\frac{\partial^2 NB^B}{\partial \alpha_B^2}} \quad (19)$$

Assuming the benefit curve of state C to be more concave than that of state B, we

get $\left[-(1 - \alpha_B) \frac{\partial^2 \pi^B}{\partial w^{B^2}} + \alpha_B m_C^B \frac{\partial^2 \pi^C}{\partial w^{C^2}} \right] < 0$. Again considering the second order condition to

be negative $\frac{\partial^2 NB^B}{\partial \alpha_B^2}$, we get $\frac{\partial \alpha_B}{\partial \alpha_A} < 0$ from expression 19. It implies that if state A

diverts less water to state B, then latter state will divert more water to state C. However,

the rate of increase in α_B for a decrease in α_A will increase for higher level of m_C^B . If

$m_C^B \rightarrow 0$ then $\frac{\partial \alpha_B}{\partial \alpha_A} > 0$; and under such conditions state B (middle state)will divert

less share of water to state C (the tail state) as state A (head state) diverts lesser share of water to the middle state.

Knowing such reaction function of state B, state A maximizes the net benefit function with respect to the share of water diverted to state B, α_A subject to the water constraint (1) and state B reaction function $\alpha_B = \alpha(\alpha_A, m_B^A)$. The first order condition of the above problem is

$$\frac{\partial \pi^A}{\partial w^A} = m_B^A \frac{\partial \pi^B}{\partial w^B} \left[(1 - \alpha_B) - \left(\frac{W_Y}{W_X} + \alpha_A \right) \frac{\partial \alpha_B}{\partial \alpha_A} \right] + m_C^A \frac{\partial \pi^C}{\partial w^C} \left[1 + \left(\frac{W_Y}{W_X} + \alpha_A \right) \frac{\partial \alpha_B}{\partial \alpha_A} \right]. \quad (20)$$

The above first order condition suggests that state A will share a proportion of water with states B and C such that its own marginal benefit from such water transfer is equal to the weighted marginal benefit of states B and C. The weights include the altruistic concerns and reaction of state B to state A change in water diversion. State B's marginal consumption of water from a change in share of water diverted by state A can be decomposed into two effects. One is the direct effect from an increase in the share of

water diverted by state A , $[(1 - \alpha_A)W_X]$ while the other is indirect effect $\left[(W_Y + \alpha_A W_X) \frac{\partial \alpha_B}{\partial \alpha_A} \right]$

which arises from an increase in state B 's share as the latter state diverts less water to the state C . Similarly, an increase in share of water diversion of state A has two effects on the welfare of state C . First, an increase in the share of water diverted by state A would directly increase the water consumption of state C by $\alpha_A W_X$. Second, as more water is diverted to state B , following proposition 2, the latter state would also decrease the share of water diversion to state C . Water consumption of state C would decrease by

$$(W_Y + \alpha_A W_X) \frac{\partial \alpha_B}{\partial \alpha_A}.$$

Given the reaction function of state B and first order condition given in equation 20, we can derive the optimal shares of water diversion $\alpha_A^*(m_B^A, m_C^B, m_C^A)$, $\alpha_B^*(m_C^B, m_B^A, m_C^A)$ by state A and B respectively.

In the above model, political relations are crucial elements influencing the altruistic behavior of the states and thereby the water allocation. The paper demands the determination of political relationship between the states to predict the outcome of a water sharing allocation from water transfer.

We consider that there are two national political parties M and N . These political parties or their regional ally parties dominate political governance in each federal state with different perspectives on domestic policies. The political parties campaign for votes in an election and consider that there is equal chance that one of the two parties can rule the government in a state. We also assume that the chance of winning an election is exogenously determined and independent of water allocation issues.

For analytical simplicity we consider that there is no political relationship between the two different parties, and thus if two different political parties rule two different states then the political relationship between the states $m_j^k = 0$ where $j \neq k$. On the other hand if there members of a political party govern two different states, then $m_j^k = 1$. Table 1 shows the different possible combinations of political party led governments in each state in a given year.

[Insert Table 1]

Without loss of generality, there are four possible situations of political relationship. In case 1, same party is ruling each state and $m_B^A = m_C^B = m_C^A = 1$. In this case, the optimal water share allocation between the states would be as that of a benevolent social planner. In cases 2 and 4, a different political party is ruling either at the head or the tail state. In case 2, $m_B^A = 1$ and $m_C^B = 0$, while in case 4 $m_B^A = 0$ and $m_C^B = 1$. Here in both the cases the state government with a different political party will divert water unilaterally. However, in case 4, there is a different political party in the head state and has opportunity to care about itself, and thus it can affect the welfare of both states B and C . On the contrary, in case 2 only state C would be worse off from having a different political party in power. In such case both the states A and B would divert a share of water so that state C is worse off and this case is the worst case from a social planner's perspective for state C . In case 3 where $m_B^A = m_C^B = 0$, both state A and B will divert water unilaterally and maximizing their own welfare. In this case, as there are same political party in the states A and C , state A can influence the welfare of state C by diverting more water to state B . As the endowment of water increases in state B , the marginal cost of water consumption will increase. As a consequence state B would divert the excess water

to state C . In such case state A would have to divert more than the optimal water consumption of state B .

In future, changes in political relationship between the two states can worsen the degree of altruism that could affect the share of water allocation. If there is hostile relationship between two states in future, the donor state could choose to unilaterally divert water, and make the recipient state worse off in terms of its net benefit. In the model, the probability that same political party would rule both the donor and recipient state is $\frac{1}{2}$ under the condition that there is an equal chance for both the political parties to win an election of a state. It means that $P(m_B^A = 1) = P(m_B^A = 0) = P(m_C^B = 1) = P(m_C^B = 0) = 1/2$. In the four cases as mentioned, the optimal share of water transfer diverted by state A would be different and is based on the degree of political altruism with states B and C . Suppose α_A^l and α_B^l ($l = 1, 2, 3, 4$) are the respective shares of water diversion by states A and B in cases 1-4.

Hence the expected payoffs of state A and B would be as follows

$$\begin{aligned} ENB^A = & P(m_B^A = m_C^A = 1) \left[\pi^A(\alpha_A^1) + \pi^B(\alpha_A^1) \right] + P(m_B^A = 1 \& m_C^A = 0) \left[\pi^A(\alpha_A^2) + \pi^B(\alpha_A^2) \right] \\ & + P(m_B^A = 0 \& m_C^A = 1) \left[\pi^A(\alpha_A^3) + \pi^C(\alpha_A^3) \right] + P(m_B^A = 0 \& m_C^A = 0) \left[\pi^A(\alpha_A^4) \right] \end{aligned} \quad (21)$$

$$\begin{aligned} ENB^B = & P(m_B^A = m_C^B = 1) \left[\pi^B(\alpha_B^1, \alpha_A^1) + \pi^C(\alpha_B^1, \alpha_A^1) \right] + P(m_B^A = 0 \& m_C^B = 1) \left[\pi^B(\alpha_B^4, \alpha_A^4) + \pi^C(\alpha_B^4, \alpha_A^4) \right] \\ & + P(m_B^A = 1 \& m_C^B = 0) \left[\pi^B(\alpha_B^2, \alpha_A^2) \right] + P(m_B^A = 0 \& m_C^B = 0) \left[\pi^B(\alpha_B^3, \alpha_A^3) \right] \end{aligned} \quad (22)$$

In case of hostile political relationship between the states, donor state could unilaterally divert water and result in an inefficient of water allocation. Richard *et. al*

indicates that the central government can intervene to create a “threat point” in water allocation decisions of the states. However, the central government ruled by one of the national parties can be biased towards the state, ruled by members of the same party, in arbitration of water disputes. Instead, a central autonomous authority could act as a benevolent social planner giving equal weights to the benefit of each state. The social planner’s water allocation (α_A^1, α_B^1) would approximate the water allocation shares where there is a same political party ruling the three states. The states have the incentive to deviate from such water allocation plan once there is a change in the political power ruling the state. To prevent such situation from occurring, there is a need to develop a strong institution that could prevent the states to deviate in the case of hostile political situation. It could make the agreement of sharing of water sustaining in the long run.

Strategies modelling punishment mechanism deterring deviance and forcing compliance with the social planner’s solution is modelled here. Suppose there exists a central autonomous authority that has power to impose punishment in case of deviation from social planner’s solution.. Consider the punishment be a and b shares of net benefits of state A and B respectively of deviation. In the case 1 where state A and B diverts water according to the social planner plan, there is no punishment.

Given the punishment scheme and $P(m_B^A = 1) = P(m_B^A = 0) = P(m_C^B = 1) = P(m_C^B = 0) = 1/2$, the present discounted value of expected net benefits of state A and B would be

$$ENB^A = \frac{1}{1-\delta} \left[\pi^A(\alpha_A^1) + \frac{1}{2} \pi^B(\alpha_A^1, \alpha_B^1) + \frac{1}{2} \pi^C(\alpha_A^1, \alpha_B^1) \right] \quad (23)$$

$$\text{and } ENB^B = \frac{1}{1-\delta} \left[\pi^B(\alpha_A^1, \alpha_B^1) + \frac{1}{2} \pi^C(\alpha_A^1, \alpha_B^1) \right] . \quad (24)$$

In the case, state A deviates from the social planner's water allocation plan, the social planner imposes the punishment and the expected payoff of state A would be

$$\begin{aligned}
 ENB_d^A = & \frac{1}{4} \left[\begin{aligned} & [\pi^A(\alpha_A^1) + \pi^B(\alpha_A^1, \alpha_B) + \pi^C(\alpha_A^1, \alpha_B)] \\ & + [\pi^A(\alpha_A^2) + \pi^B(\alpha_A^2, \alpha_B)] \\ & + [\pi^A(\alpha_A^3) + \pi^C(\alpha_A^3, \alpha_B)] \\ & + \pi^A(\alpha_A^4) \end{aligned} \right] \\
 & + \frac{\delta}{1-\delta} \frac{1}{4} \left[\begin{aligned} & [\pi^A(\alpha_A^1) + \pi^B(\alpha_A^1, \alpha_B^1) + \pi^C(\alpha_A^1, \alpha_B^1)] \\ & + (1-a)[\pi^A(\alpha_A^2) + \pi^B(\alpha_A^2, \alpha_B)] \\ & + (1-a)[\pi^A(\alpha_A^3) \\ & + \pi^C(\alpha_A^3, \alpha_B)] + ((1-a)\pi^A(\alpha_A^4) \end{aligned} \right] \quad (25)
 \end{aligned}$$

State A would not deviate if $ENB^A \geq ENB_d^A$. Simplifying the above expression, we get

that state A would not deviate if

$$a \geq \frac{\left[\sum_{i=2}^4 \pi^A(\alpha_A^i, \alpha_B) - 3\pi^A(\alpha_A^1) \right] + \pi^B(\alpha_A^2, \alpha_B) - \pi^B(\alpha_A^1, \alpha_B) + \pi^C(\alpha_A^3, \alpha_B) - \pi^C(\alpha_A^1, \alpha_B)}{\left[\sum_{i=2}^4 \pi^A(\alpha_A^i, \alpha_B) + \pi^B(\alpha_A^2, \alpha_B) + \pi^C(\alpha_A^3, \alpha_B) \right] \delta} \quad (26)$$

Similarly to deter deviance the punishment for state B can be designed as

$$b \geq \frac{\left[\sum_{i=2}^4 \pi^B(\alpha_B^i, \alpha_A) - 3\pi^B(\alpha_B^1) \right] + \pi^C(\alpha_A^2, \alpha_B) - \pi^C(\alpha_A^1, \alpha_B)}{\left[\sum_{i=2}^4 \pi^B(\alpha_B^i, \alpha_A) + \pi^C(\alpha_B^2, \alpha_A) \right] \delta} \quad (27)$$

Expression 26 and 27 implies that donor state may not deviate if the share of the punishment is greater than the proportional difference in each state's payoff between the cases with and without political hostility. The share of punishment will increase if state is more impatient with a lower discount factor.

Thus a central autonomous authority, in the form a National Water Commission independent of political pressure, could play a crucial role. It can help in enforcing efficient water allocation when the states are ruled by political parties of conflicting interest. If the punishment threat could be made credible considering the proportional difference in payoff with and without political hostility, then it will deter the states from deviating from an efficient outcome. The central autonomous authority will help to decouple water conflict issues from other conflicting issues of the states. This could be one of the policy to reduce conflict between states if not eliminate them.

5.1 Simulation results:

In this section, we evaluate the case of water allocation between head, middle and tail states – Orissa, Andhra Pradesh and Tamil Nadu respectively under some of the prominent river links. In the framework of the theoretical model we discuss –what could happen if there is no cooperation among states compared to a situation when water is allocated as planned by a social planner.

The Table 2 shows the downstream water allocation from river basins, the corresponding states, and the enroute irrigated command area and capital costs. Much of the river basin wise data has been gathered from Amarasinghe and Srinivasulu (2009).

Table 3 shows the states (head, middle, tail) wise water availability and net gain from transfers as planned. It suggests that in the head state , Orissa per capita water availability is much higher compared to Andhra Pradesh and Tamil Nadu. The relative water scarcity justifies the notion of river linking to transfer the surplus water to the deficit river basins. *[Insert Table2 & 3]*

The head state, Orissa, is planned to transfer 21 % of the total water availability to the downstream states. The middle state, Andhra Pradesh will transfer within state around 30 % of water from surplus river basin, Godavari, to the deficit basins, Krishna and Pennar; while only 7 % of the total water resource available in three river basins of the state was transferred downstream to tail end state, Tamil Nadu.

The net value of crop output per 1000 cubic meter is shown in table 3. It shows that marginal gain in the value of crop output from water in the middle and tail states are 2.5 and 7 times higher respectively than in the head state. After taking into consideration the capital costs , we find the net benefit of water transfer is even more lower in the head state compared to other downstream states.

The relevant policy question emerges- despite low individual economic return why the head state will agree to forgo water for the downstream states. In this section, we attempt to determine the optimal water share of water diversion by the recipient state under different political scenario as explained in the earlier sections. The net benefit function used in the simulation was constructed using the real data as provided by Amarasinghe and Srinivasulu (2009).

In the simulation, we also calculate the penalty amount that the states would pay to the central autonomous authority in the case of deviation from the water allocation plan of the later. The optimal water allocation has been computed by simulation using excel. The results are shown in Table 4.

[Insert Table 4]

The results indicate that head state, Orissa would divert 8.41% less water to Andhra Pradesh than planned if the political party ruling Orissa is not having any alliance with political parties of the other two states. However, in such situation (case 4) the tail state Tamil Nadu will be compensated by the middle state Andhra Pradesh for having political alliance. In case 3, even though the middle state, Andhra Pradesh is having political opposition with members of the political party ruling the other two states, Orissa will compensate the middle state so that tail end state, Tamil Nadu is better off. However, in such case the opportunity cost of transferring water is much higher for Orissa than in case 1, where water is allocated by a social planner or members of single national party ruling all the three states. As the present water consumption level is much below the optimal water consumption level in Andhra Pradesh, Orissa would have to divert much higher proportion of water to Andhra Pradesh to make Tamil Nadu meeting its water demand. Table 4 also lists different penalties imposed on the states as a percentage of the gain in net benefit. It shows that the head state, Orissa will incur heavy penalty if it shares hostile political relationship with the other two states. For middle state, Andhra Pradesh the penalty is maximum in case 2, where the political party in power of the tail state is different from the other two states. In such case, the combined penalty of the donor states Orissa and Andhra Pradesh is also high compared to other cases.

5. Summary and Conclusion

In India, one of the world's largest democracies, interstate rivers have been both a focal point of creative institution building and a source of great contention. The costs of these conflicts and the costs of failure to focus on the entire river basin are rising rapidly as water scarcity increases (e.g. Booker 1995, Young 1995, Howe 2005). In India, an unambiguous institutional mechanism for settling interstate water does not exist (Iyer 1994; Richards and Singh 2002). Thus, under the Government of India Act of 1935, extensive power over water development and management was given to the states, while the River Board Act of 1956 created river boards to develop and regulate interstate rivers. In this scheme, state governments have limited incentives to develop co-operative projects (Gundimeda and Howe 2008).

The paper focus on India's River Linking project, and how such project could further multiply the intensity of conflicts between states. We attempt to do an ex ante analysis of the sharing of the transferred water between the donor and the recipient states. We have developed two water transfer frameworks to analyze the allocation of water between states and river basins in India as a result of the proposed National River Linking project. The transfer of water from one state to another can be achieved either through a contractual agreement by which the state that receives water pays the donor state or through mutual consent arising from good political relationship between the states.

Even though no formal markets exist for trading surface water in India, one might argue that water market might have the potential to achieve voluntary, economically efficient transfers of water that can overcome rigidities of allocation system (Gundimeda and Howe 2008).

However we find that a market-based water transfer could lead to an inefficient outcome in the case where the number of buyer and seller of water are limited. The donor states could charge a much higher price and the buyer would buy less amount of water. The result is a large deadweight loss. The loss could increase further if there are many states located in the middle between the initial donor of the water (the head state) and the final recipient state (the tail state). In such cases, the middle states will charge much and the tail end states will buy much lesser amount of water.

We also consider cases where water transfer may take place through cooperation between the states. In the context of river linking we find that with better relationship, the middle state could divert higher proportion of water even if the head state shares less water with the middle state.

Political relations can also influence the altruistic concerns of the states and thus can determine water allocation. We recognize the risk in benefit loss of water recipient states could stem from hostile political relationship between the donor and the recipient state. We find that, if a different political party is ruling the tail state, then it will be worse off as the head and middle state will jointly divert a much greater share of water. This is also the worst case scenario from a social planner's perspective. In such a case of political hostility, the initial donor (or head) state has the opportunity to divert water

unilaterally and the cost of water transfer could outweigh the benefits. To prevent such an outcome from occurring, a central autonomous authority could play a crucial role.

The central authority could facilitate an efficient allocation of water through credible threat of imposition monetary fines which depends on the gain in deviation. Unlike in the present scheme where there is little incentive for states to co-operate, central autonomous authority can promote cooperation among states through making the action of unilateral diversion of water from non cooperation more costly. Singh (2008) argued that inter state water disputes have to be disentangled from the general interstate conflict and from other political pressure. Mitra (2007) also noted that given the influence of politics on the efficacy of the existing statutory mechanism, a new paradigm for dispute resolution is required. An autonomous central authority will help to decouple water conflicts issues from other conflicting issues of the states. It can lead to conflict resolution and efficient allocation of water that could be sustaining in the long run.

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Fig 1. India River Linking as Planned

Figure 2. A schematic diagram showing the interstate water transfer

Figure 3: Isoprofit curves of states *A* and *B* and efficient bargaining

Figure 4: Market based water transfer and resource allocation

Table 1: Possible combinations of ruling political parties in three states involved in water transfer

States	Political Parties Ruling the Government			
	Case 1	Case 2	Case 3	Case 4
<i>Orissa</i> (Head)	<i>M</i>	<i>M</i>	<i>M</i>	<i>N</i>
<i>Andhra Pradesh</i> (Middle)	<i>M</i>	<i>M</i>	<i>N</i>	<i>M</i>
<i>Tamil Nadu</i> (Tail)	<i>M</i>	<i>N</i>	<i>M</i>	<i>M</i>

Table 2: Details of the River Linking in the Peninsular Basin

Peninsular Links¹	States under each link	Total water Transfers from the canals (million cubic meter)	Downstream diversion from the canals (million cubic meter)	En route Irrigated Area (hectares)	Capital cost in million USD(2003-04 constant prices)
Mahanadi (Manibhadra)-Godavari (Dowlaiswaram)	Orissa, Andhra Pradesh	12,165	6500	Orrisa-256770 Andhra Pradesh-88578	1370
Godavari (Inchampalli)-Krishna (Nag sagar)	Andhra Pradesh	16426	14200	Andhra Pradesh - 255264	599
Godavari (Inchampalli)-Krishna (Pulichintala)	Andhra Pradesh	4370	--	Andhra Pradesh-467589	1097
Godavari (Polavaram)-Krishna (Vijayawada)	Andhra Pradesh	5325	3501	Andhra Pradesh-139740	473
Krishna (Nagarjunsagar)-Pennar (Somasila)	Andhra Pradesh	12146	8426	Andhra Pradesh-581017	203
Pennar (Somasila)-Cauvery (Grandanicut)	Andhra Pradesh, Tamil Nadu	8565	3855	Andhra Pradesh-283553 Tamil Nadu-315447	1472
Cauvery (Kattalai)-Vaigai Gunder	Tamil Nadu	2252	---	Tamil Nadu-452000	581
Pamba-AchankvoilVaipar	Tamil Nadu	635	---	Tamil Nadu-56233	457

Note:¹ In the bracket we have mentioned the location of the place where the river will be linked.

The above table was adapted from Amarasinghe and Srinivasulu (2009)

Table 3: Satewise water availability and gains from river linking

States	River Basins	Water available (billion cubic meter)	Per capita water availability (cubic meter per person)	Water Available After Transfers (billion cubic meters)	Net value of crop output (\$) per 1000 cubic meter	Net gains (\$ per ha per year)	Net Benefit function ¹
Orissa	Mahanadi	30.10	2458.824	23.60	26.89	91.79	$B^A = 170(w^j)^{1/2}$
Andhra Pradesh	Godavari, Krishna, Pennar	54.68	1245.908	57.33	67.16	280.52	$B^B = 470(w^j)^{1/2}$
Tamil Nadu	Cauvery	6.62	549.0798	10.47	183.08	865.39	$B^C = 2541(w^j)^{1/2}$

Note:¹The parameter of the benefit functions has been calculated using the data of marginal gain from water .The data was gathered from Amarasinghe and Srinivasulu (2009)

Table 4: Simulations results

	Case 1	Case 2	Case 3	Case 4
Share of water diverted by State Orissa in percentage - α_A	21.35	17.83	19.12	12.94
Share of water diverted by State Andhra Pradesh in percentage – α_B	7.01	3.45	2.88	8.5
Penalty imposed on Orissa as a percentage of total benefit	0	4.23	3.75	8.16
Penalty imposed on Andhra Pradesh as a percentage of total benefit	0	6.01	2.60	0

Appendix Table 1: Developing Countries and Regions with Relatively Scarce Water Supplies

Region/Country	Total Water Withdrawal (km ³)			Total Withdrawal as a Percentage of Renewable Water Supply (%)		
	1995	2010	2025	1995	2010	2025
Huaihe	77.9	93.7	108.3	83	100	115
Haihe	59.2	62.1	62.9	140	147	149
Huanghe	64.0	71.1	79.5	89	99	111
Changjian	212.6	238.5	259.1	23	26	29
Songliao	51.5	59.2	67.6	26	30	34
Inland	89.5	98.9	111.2	299	330	371
Southwest	8.3	9.7	12.3	1	1	2
ZhuJiang	77.1	84.9	96.9	19	21	24
Southeast	38.8	41.4	47.7	27	29	33
China total	678.8	4,356	845.5	26	29	33
Sahyadri Gats	14.9	18.7	20.8	14	17	19
Eastern Gats	10.5	13.7	11.6	67	87	74
Cauvery	11.8	12.8	13.1	82	89	91
Godavari	30.2	33.3	38.8	27	30	35
Krishna	46.2	51.4	57.5	51	57	63
Indian-Coastal-Drain	34.8	46.9	43.6	108	145	135
Chotanagpur	7.2	10.9	14.3	17	26	34
Brahmari	25.5	27.2	31.0	24	22	26
Luni River Basin	41.9	43.1	50.8	148	140	166
Mahi-Tapti-Narmada	31.4	34.3	36.3	36	39	42
Brahmaputra	5.5	7.2	9.2	1	1	1
Indus	159.1	178.7	198.6	72	81	90
Ganges	255.3	271.9	289.3	50	54	57
India total	674.4	750.0	814.8	30	33	35
Pakistan	267.3	291.2	309.3	90	98	105
Philippines	47.0	58.2	70.0	24	29	35
South Korea	25.8	34.9	35.9	56	75	78
Mexico	78.6	86.2	94.2	24	26	29
Egypt	54.3	60.4	65.6	89	99	108
Other West Asia/North Africa^{a/}	143.2	156.0	171.5	116	125	139

Notes: a/ Excluding Turkey.

Source: Barbier (2005, Table 1.6); adapted from Rosegrant *et al.* (2002), Table B.3.