Water Banks, Markets, and Prior Appropriation:

A Comparison of Water Allocation Instruments in the Eastern Snake River Plain

Sanchari Ghosh
Department of Economics
Boise State University
Phone: (208) 426-3318
Email: sancharighosh@boisestate.edu

Kelly Cobourn
Department of Economics
Boise State University
Phone: (208) 426-3302
Email: kellycobourn@boisestate.edu

Levan Elbakidze
Department of Agricultural Economics
University of Idaho
Phone: (208) 885-7382
Email: lelbakidze@uidaho.edu

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Abstract: States in the arid U.S. West, where average annual precipitation is below 20 inches, have experienced ongoing water scarcity in part due to prolonged spells of drought. Most western states rely on the doctrine of prior appropriation based on the seniority of rights to allocate water across individuals. Over the past two decades, states have established water supply banks and rental pools to facilitate the transfer of water among users on a season-to-season basis, which, in many cases constitutes a hybrid system that marks a movement towards a market-based system of allocating water but retains many of the features of current water rights institutions. The study delineates the importance of these banks in alleviating short term water scarcities when water use may be curtailed based on priority dates. It finds that under severe drought conditions, water banks may approximate the efficiency gains from a fully efficient water allocation scenario but may not prevent the large scale diversions by senior users.

1. Introduction (Background)

The Arid west or the western part of the US has been the topic of an ongoing debate for decades regarding the scarcity of water resources in the region, the various rights for appropriation of water by users, the often stringent rules for diversions and above all the severe water crisis that several states in the region have occasionally faced. In the last three decades, water transfers through creation of water markets have been encouraged in these states to maximize the potential economic gains from water being allocated from a low valued use to a high valued use according to the principle of highest economic efficiency. These markets may be referred to as economic platforms for water trading between users where the economic incentives for trade, population, income and the particular sector (agricultural or industrial) would determine the final price. Thus western states witnessed the emergence of some of the biggest water transactions carried out through popular projects like the Central Arizona Project in the Lower Colorado Basin, the Big Thompson in the Upper Colorado Basin and the Rio Grande Middle Conservancy in the Rio Grande Basin of New Mexico.

Water transfers

As is well known in any theoretical literature, transaction costs and third party external effects erode many of the efficiency gains from water trading and the same has been the case with water transfers across several western states (Chang and Griffin, 1992; Hanek, 2003). Surface water diversions to urban areas have often interfered with the performance of the agricultural sector. Thus several intra basin water transfers has been accompanied by restrictions on how much water can actually be freely allocated, given binding constraints on streamflows, adjustments due to hydrological connections between surface and ground water, and various interstate as well as transboundary agreements on water sharing..[1]

An interesting aspect of water markets in the western states is the co-existence of these markets alongside the different institutional rules governing the property rights for water in each state. In addition, most of these transfers have been restricted to surface water as the property rights and the rules for transactions for groundwater are not properly laid out in many cases, for instance,

[1] For instance, we may refer to the Rio Grande transboundary water sharing agreement between US and Mexico wherein US is obligated to transfer 60,000 acre feet of water to Mexico in absence of severe drought (Ward et al., 2006)

California. The success of the water markets have encouraged economists to devise more sophisticated water transactions through experimental markets like the real time water leasing system which incorporates physical, engineering, behavioral and an actual economic market for water transfers (Brookshire et al., 2010).

Water banks

Temporary water leasing through water banks have been common in states like California, Arizona, Colorado and Texas which have concurrently witnessed a large number of water transfers through markets in the last two decades. In contrast to water markets, these Banks have usually facilitated short term leasing at fixed prices[2] and lower transaction costs since the administrative costs are absorbed within the price set by the Bank. The presence of the permanent water banks, in addition, has reduced the transaction costs of water marketing across basins, ensured supply reliability and often led to rental-lessee arrangements for water supply. The banks have also been in dry year contingency contracts or water auctions where it played the role of a broker. The Water Strategist defines a water bank as a centralized buying, selling and/or a storage system.

In theory, water banks and the water markets are both designed to facilitate the sale or transfer or temporary leasing of water. However, the rules for establishment and guidelines for the functioning of these two water allocation mechanisms, the number of transactions carried out and the nature of transactions differ between the two. For instance, while markets try to adhere to the economic rules of efficiency, flexibility in resource allocation, low costs and the objective of welfare maximization, water banks are institutions for temporary leasing of water rights during emergencies. More often they play the role of a medium for water exchange during shortages or when users want to minimize future risks in production by entering into a lease agreement with the bank in advance.

The focus of this analysis, concerns the gains in economic efficiency that may be realized under water banking under a system of prior appropriation and how these gains compare to those

[2] Exceptions are the drought banks in California which have employed seller and buyer bidding on prices based on demand and supply in a particular growing season.

attained with a "water market" or a fully optimal water allocation scenario.[3] This is an important question because a hybrid system like water banking is a more realistic possibility in the Western U.S. than a fully optimal "water market". Further, water banking treads the middle ground between free transfer of water to its highest valued use at a market determined price and a completely institutional structure like prior appropriation where users appropriate water based on historically determined rights. It serves as a platform where heterogeneous groups of users, may exchange water temporarily to satisfy unmet demands as well as to avoid having the water forfeited to the State due to prolonged nonuse. Thus, from an economic perspective, the importance of these Banks should not be underestimated. Hence the present study attempts to investigate the economic impacts of having water allocated in the most economically efficient manner versus having water banks as an intermediary from where users may choose to rent water during shortages.

In order to address this, we compare outcomes for agricultural producers in the Eastern Snake River Plain of Idaho under three water allocation scenarios, three levels of drought intensity, and two bases for trading. Our objectives are twofold. The first is to determine the welfare implications of differing water allocation scenarios during mild, moderate, and severe drought. The water allocation scenarios include (1) the strict application of prior appropriation doctrine, in which irrigators with junior water rights face curtailment and lose their water rights for some or all of a growing season; (2) a system of prior appropriation with the potential for irrigators to exchange water through a regional water bank, where the rental rate is set by the State water agency (the current practice); and (3) a fully optimal scenario where irrigators may exchange water at an endogenously determined price with no transaction costs or property rights based constraint. A comparison of scenario (2) with the least and most economically efficient water allocation scenarios feasible (scenarios 1 and 3, respectively) allows us to determine the relative efficiency gains realized from a system that merges current water rights institutions with temporary water exchange via water banks.

Our work extends the previous literature on water marketing in the West on two fronts. One, it compares the economic efficiency gains from temporary water transfers (leases and rents)

[3] Note that in this paper we present results from a fully optimal water allocation model which is not a water market as such in the true sense of the term.

through water banks in the presence of institutional rules of prior appropriation, with the gains from allowing users to transfer water without any institutional rules in place (like seniority of rights). This issue gains significance since a hybrid system like water banking is a more realistic possibility in the Western U.S. than a fully optimal / economically efficient scenario, due to various factors including high transaction costs and hydrologic externalities, or third-party effects.

Second, unlike the large scale basin level optimization models used by Howitt et al.(2012) and Gohar and Ward (2010), this study attempts to simulate over time an individual level water trading scenario within and across growing seasons. A large number of studies on the western water markets (Colorado and Rio Grande River basins, Central Valley region) have been devoted to the long run impacts of basin scale optimization models where resource economists are primarily interested in the total benefits obtained from water transfers across all sectors with and without institutional restraints. Studies done by Murphy et al. (2000) for California and Broadbent et al. (2010) for New Mexico have recovered the impacts upon water users utilizing bidding techniques for water transactions over time. The present research attempts to simulate individual user outcomes under the three broad scenarios described previously using optimization technique. By simulating individual land and water allocation decisions and comparing the effect upon producer welfare under different water allocation scenarios, this study opens doors for policy debates about the efficiency and practical viability of hybrid systems like water banking as a substitute for a fully optimal transfer of water as has been the case in some of the popular water markets of the West.

The following section summarizes past studies on water banking and water markets in several western states and includes a brief review of the water banking structure in Idaho. Section 3 describes the methodology used while Section 4 is devoted to the study region and the data relevant for the study. Section 5 discusses the main results from the study while Section 6 concludes with policy implications and potential avenues for future research.

2. Literature on water markets and water banks

Western US has always been dominated by agricultural production as much as it has been the site for some of the worst droughts in the country. Irrigation is thus a necessity for the predominantly agricultural economies like California, Nevada and Idaho. The doctrine of prior appropriation is the governing rule for water rights in most Western states, though four states — California, Oregon, Texas and Washington— also exercise the riparian doctrine under which water use is permitted over the land area that falls within the jurisdiction of the land owner. The doctrine of prior appropriation allocates water on the basis of seniority of rights ("first in time first in right") with junior users or those having later priority dates in terms of water use having to concede their rights in the event of water shortages.

Some of the institutional rigidities within the prior appropriation doctrine related to diversion of water often hinder the allocation of water among users according to the principle of highest economic efficiency. However, the arid climate and frequent droughts, the rapid growth of population and increasing demand for water have provided the scope for intersectoral transfer of water within many of these states, with California, Nevada, Arizona, Colorado, Texas and New Mexico having witnessed large scale water transfers between agriculture and urban/municipal sectors in the last three decades (Libecap, 2010). Part of the reason why water trading proved to be a successful alternative to water use dictated by priority dates, is the beneficial use clause embedded within the prior appropriation doctrine. It states that if the water right owned by a user is not used beneficially it goes back to the water agency who administered the right and the repossessed water is not available for use by the junior water rights holders. This provides an incentive to many water users to sell their water temporarily to willing buyers and a major trend in water marketing in the western states has been both intra sectoral and intersectoral water transfers in recent years, with the latter predominating.

In a series of papers on water markets and water rights in the Western US, Libecap shows that the existence of large scale water transfer projects (like the Central Valley Project in California and the Big Thompson project implemented by the Northern Colorado Water Conservancy District) have often facilitated active water trading between different sectors within the economy. Using data for water transfers within states from 1987-08, Brewer et al. (2008) and Libecap (2010) concludes that certain trends are discernible in these water trades within the western states— a predominance of agricultural to urban water transfers, short term leases in agriculture, dominance of multiyear leases and sales of water between sectors, an increasing price trend in water transfers from agricultural to urban and industrial users than between users in the agricultural sector and a very high price differential between transfers across sectors than within sectors.. Also employing the price data for the different types of trades consummated and the USGS estimates of water applied for irrigation, Libecap (2010) calculates that the transfer of 3% of surface water from agriculture to urban use in the western US would generate about $98 million per year in net benefits.

A recent study by Howitt et al. (2012) for the San Joaquin Valley of California shows that the presence of water markets can potentially reduce farm revenue losses from drought by 30 % relative to a situation with no water transfers. The water transfers are carried out between senior rights holders in the eastern part of the Delta delivering water to the junior rights holders in the west. Newlin et al. (2002) also find that the presence of water markets could fetch benefits as high as $700 million per year in Southern California. On the other hand, Gohar and Ward (2010) show that intraregional water trading/ transfers in the Nile River Basin in Egypt would result in an increase in average annual net revenues from $7.92 to $8.42 million. Broadbent at al. (2010) employ experimental economics to determine the efficiency gains from a short term (three growing season) water leasing framework involving agricultural, municipal and environmental users in New Mexico. The experimental results demonstrate a 14-24% gain in income during the second and the third growing seasons in the Middle Rio Grande River system. Focusing on the long term benefits of water trading, Howe and Goemans (2003) note, that the presence of water markets has a positive impact on the local employment and income in the South Platte Basin in Colorado, after recovering from the initial losses in agriculture as water was being transferred from agricultural users to municipal traders.

The discussion on water markets and the efficiency gains from water trading has often been separated from a more realistic institutional set up where water transfers are facilitated by the presence of water banks. These regional banks have allowed senior users to lease or store water without the possibility of them losing the unappropriated stock. As aptly pointed out by Colby (2010), “the centralized framework (of the Bank) can act as a clearinghouse that reduces the costs of bringing a trade to fruition.” The role of these banks in facilitating the supply of water during climate change induced water shortages, for uses ranging from irrigation to instream flows, has not been understated. Yet only a handful of studies on water marketing in the West have explored in detail the economic efficiencies from having a permanent water bank (like the one established by the Idaho Water Resources Board) via-a vis the possibility of having unrestricted water transfers across various users in all seasons, subject to certain legal restrictions.

In the early 1990s, California started a trend in storing water in water banks through the introduction of the Drought Water Bank by the California Department of Water Resources. It was a mechanism through which the water scarcity in some of the driest seasons could be mitigated by allowing users to carry out temporary leases of water on the lines of a market based approach. It was followed by the futures market where water prices included a premium due to forward contracting on purchase of water in the event of a drought and the options market where the buyer had the option to purchase or not purchase the water depending upon future shortages and demand. Forward contracts and option markets incorporate the risk of water scarcity in the event of a drought (Williams (1997) and Hansen et al. (1998)). Water marketing in western US thus saw the advent of sophisticated water sharing mechanisms at predetermined prices where sellers and buyers usually entered into temporary leasing/ renting of water at these prices with the water banks.

Burke et al. (2004) evaluate the effects of a water bank on the Klamath Project irrigators and the impact on offer prices for leasing water to the bank. They compare a situation where the BOR acts as an intermediary for trading water through the bank and one in which it allocates surplus water in according to priority dates. They found that intra project trading of water led to a 10% gain in on farm revenue during scarcity compared to allocation based on priority dates.

The use of water banks to store and transfer water has grown in popularity in almost all 17 western states but more so in Arizona, California and Idaho. While Idaho has a permanent water bank from 1979, the temporary water transfers through the Drought Bank and the Dry Year Purchasing programs in California have been instrumental in supplying water to farmers as well as public agencies during years of shortages. The 2009 Drought Water Bank for instance, bought water from users' associations and irrigators upstream on the San Joaquin Delta to provide water to the local public and private water systems that were expected to face shortfalls next year. On the other hand, the Central Arizona Water Banking Program has been dedicated towards conserving water for future requirements in replenishment pools with the Water Bank projected to store around 52500 acre feet of water in 2013 at a cost of $7 million. One unique example of water banking is the Klamath Pilot Water Bank which encourages price bidding to obtain water from irrigators efficiently, as surface water is diverted through irrigation canals to the Bank for use in diverse purposes like instream flow (Colby, 2010).

According to a Washington State Dept. Report by Clifford (2004) and as noted by Colby (2010), Idaho, California and Arizona are the most active western states in terms of water banking with around $542,700.03 in rental revenue generated through transactions by the Idaho Water Bank during 2012 (IDWR Annual Report 2012). Apart from surface water transfers, groundwater banking has been prevalent in some states too, with around 20-50% of transactions in Idaho (both permanent and temporary) facilitated by the Water Supply Banks in 2008 (Contour, 2010). The institutional nature of the water banking system in Idaho has ensured a steady and reliable source of water for exchange between lessors (sellers) and renters (purchasers) over the years.

Water banking in Idaho

The water banks have been a dominant feature of temporary water exchange in Idaho in recent years. In the language of the Idaho Water Resources Board, which supervises the Water Bank, it is a water exchange market to facilitate the transfer of unused water rights so as to encourage the highest beneficial use of water and providing a source of water to those people who do not have adequate water to meet their needs. In one sense the Bank stimulates a system of consistent exchange of water rights based on user needs and in another, it safeguards the senior water rights holders from the forfeiture clause by allowing them to lease water to the Bank whenever they have excess stock. Besides, the lessors are entitled to 90% of the rental fee whenever a user rents the water from the Bank while the rest 10% goes towards administrative costs. This procedure has ensured that users likely to face severe shortages during droughts can rent water from the Bank at a fixed price. Starting from 2010, the IDWR restricted the time period for leases to the Bank to a maximum of five years.

The water bank in Idaho has been quite active since the last five years and the number of leases into the Bank has ranged from 40 to 120 in the Upper Snake and the Boise River Basins in 2012. For irrigation water use alone, there were 74 active rental agreements in 2012.

Fig 5.1 below illustrates the total amount of rental revenue earned by the lessors and the Bank in 2012. Evidently, the total Bank revenue climbed from around $200000 in 2011 to a little above

$500000 in 2012. According to the 2012 Water Bank Report published by IDWR, the rental activity increased by more than 2500% between 1998 and 2010 (*need to double check this*), while the rental revenue showed a respective increase of 18.1% and 40.1% in 2012 as compared to 2011 and 2010[4].

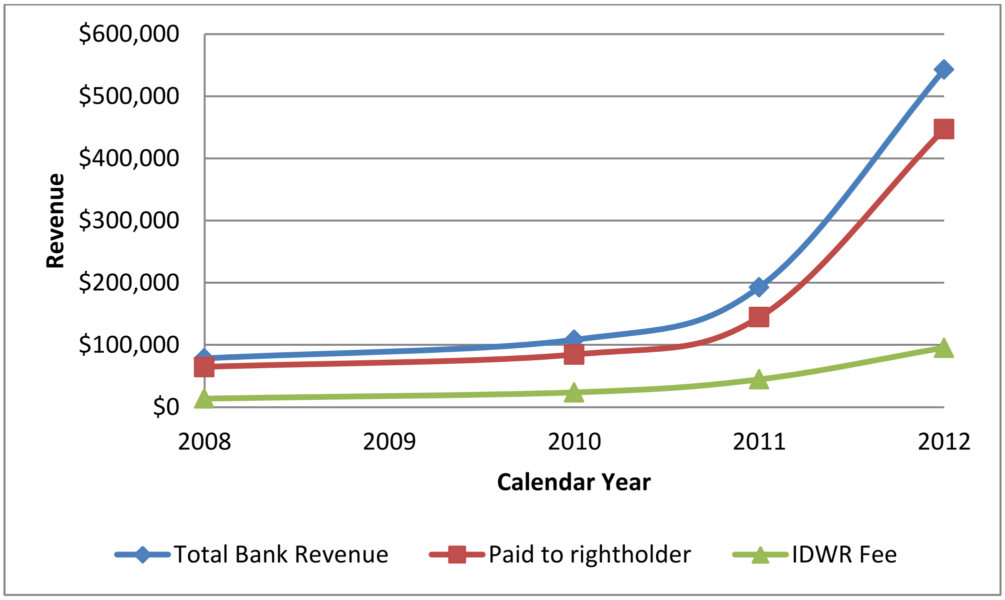

Fig 5.1 Rental revenue over the state of Idaho from water banking

Source: IDWR Water Bank Report 2012

Table 2.1 shows the average amount of water leased to and rented from the state run water banks for irrigation purposes in the past 10 years in the major administrative basins of Idaho

[4] Author's own calculations

Table 2.1: A synopsis of water banking in major basins of ESRP in recent years

Diversion rate(cfs)	Volume(acre-feet)	acres	Revenue
0.56	135.00	30	$1,485.00
0.46	112.50	25	$1,237.50
0.46	112.50	25	$157.50
0.54	135.00	27	$1,485.00
0.10	17.50	5	$245.00
0.10	17.50	5	$245.00
0.10	17.50	5	$245.00
0.10	17.50	5	$245.00
2.06	478.30	127.5	$6,696.20
2.06	478.30	127.5	$6,696.20
2.06	478.30	127.5	$6,696.20
2.06	478.30	127.5	$6,696.20
0.05	15.20	3.8	212.8
0.14	46.80	11.7	655.2
1.37	312.80	78.3	$3,440.80
1.37	312.80	78.3	3440.8
1.37	312.80	78.3	3440.8
0.66	93.50	48	$1,309.00
0.66	93.50	48	$1,309.00
0.27	88.60	25.3	$108.36
0.10	17.50	5	$192.50
0.10	17.50	5	$192.50
0.10	17.50	5	$245.00
0.06	10.10	2.9	$196.00
0.04	7.40	2.1	$103.60
0.20	35.00	10	$385.00
0.01	3.50	3.5	$245.00
0.44	67.10	20.1	$1,176.00
0.44	67.10	20.1	$1,176.00
0.20	35.00	10	$385.00
0.17	31.00	8.8	$434.00
0.30	60.00	15	$840.00
1.67	334.00	83.5	$3,674.00
1.67	2748.00	200	$30,228.00
0.64	312.00	32	$3,432.00
0.64	312.00	118.3	$3,432.00
0.17	84.40	32	$118.16
0.17	84.40	32	$118.16
4.00	1440.00	200	$15,840.00

Thus going by the above statistics, recent transfers through water banks have gone hand in hand with regular transfers by individual users through the Water resources Department in Idaho. Moreover there appears to be substantial variation in the volume of water rented across basins. Though a detailed discussion on the amount of water rented and leased into the Bank is not undertaken here, it becomes apparent that water exchange through the Bank has provided a viable alternative for users than an actual water market, to satisfy their water needs during dry seasons. In the next section we present the empirical details of our approach towards assessing the economic gains from water marketing using the presence of these banks as an intermediate case between a strict application of the prior appropriation doctrine and the more flexible water allocation that encourages transfer according to the highest economic efficiency.

3.Methods

An important question in our analysis is how to maximize producer welfare from crop production and land and water allocation decisions by each user, given the present institutional rules that dominate the water allocation structure in Idaho and other western states. To make a comparative analysis of a "full trading" optimal outcome, the economic efficiency gains are assessed based on three water allocation scenarios. These include (1) the strict application of prior appropriation doctrine, in which irrigators with junior water rights face curtailment and lose their water rights for some or all of a growing season; (2) a system of prior appropriation with the potential for irrigators to exchange water through a regional water bank, where the rental rate is exogenous and set by the State water agency (the current practice), and (3) a water market where irrigators may exchange water at zero transaction costs. A comparison of scenario (2) with the least and most economically efficient water allocation scenarios feasible (scenarios 1 and 3, respectively) allows us to determine the relative efficiency gains realized from a system that merges current water rights institutions with temporary water exchange via water banks.

The study employs the positive mathematical programming technique (Howitt, 1995) in order to calibrate the data to historical data. The PMP technique for calibrating crop production function has been applied to several agro economic studies, most recently by Ward et al. (2010, 2011) and Howitt et al (2012). The advantage of this method lies in calculating the coefficients of the crop specific yield and cost functions such that the optimized values of the yield, costs, land and water use correspond closely to the historical average values of the same for the study region.

For the base calibration, we assume that there is a fixed proportion of irrigation water used per acre of land for each crop and that the yield of the crop depends upon the land allocation decision. Specifically, following the methodology by Ward et al. (2010), the crop specific yield function for each user is given by the following production function:

$$yield = B_0 + B_1 * Land$$

where the coefficients B_0 and B_1 are determined by the first order conditions obtained from differentiating the irrigator's profit function with respect to land and water use.

The technique relies on the Ricardian theory of rent which states that yield falls off as more land is brought into production following the law of diminishing marginal productivity, with other input (water, fertilizer etc.) use held constant. $la(u,k)$ represents the land allocated for each crop by any user. A profit maximizing irrigator is assumed to take water requirement per unit of land as given and maximizes net returns by application of a total quantity of water and an associated total amount of land (Ward, 2010). The base calibration recovers the coefficients B_0 and B_1 from observed data on historical average yield per crop, input costs, crop prices and land allocation by user. The following procedure is drawn largely from Ward (2010).

Suppose total profit is expressed as:

$$\pi = (P_k * yield - C) * Land - P_w * water$$

Where, P_k is the crop price, C denotes the nonwater costs of production and P_w is the price of irrigation water.

Expressing land as a function of water if their proportion is predetermined,

$$Land = Water/B_w$$

We may rewrite the profit equation as follows:

$$\pi = \left[P_k * \left(B_0 + B_1 * \frac{Water}{B_w}\right) - C\right](Water/B_w) - P_w * water$$

Differentiating this total profit function with respect to each unit of additional water use and utilizing the relationship between land and water, we may determine the parameters B_0 and B_1 which are then used in our optimization problems.

This particular method of using a fixed proportion of water per unit of land seems appropriate for our study and has been applied for basin level modeling of water use by Ward (2010) and Ward et al. (2011). The water use per crop may be changed by altering irrigation techniques or by subsidizing the cost of the base irrigation technology, but we abstain from these in order to preserve the tractability of the model.

Each water allocation scenario is solved for a growing season to determine the optimal levels of yield per crop, the total quantity of irrigation water applied, the amount of land allocated for each crop, and the net profit earned by each user. Finally, the net gain in economic efficiency is assessed by comparing the total profits across all producers for each water allocation scenario and for various levels of drought.

The optimization models presented below characterize the producer behavior under each water allocation scenario where the producer is assumed to make choices regarding the main decision variables. In all the models that follow the index u refers to the user, k refers to the crop and s refers to the source of water.

Full curtailment

In the first case we consider a growing season where a strict application of the prior appropriation doctrine prevails across surface water and groundwater users. Water users are classified into two types—the senior rights holders (in terms of priority dates) who are allowed to divert their maximum allowable limit during times of water scarcity or moderate and severe droughts and the junior rights holders who are curtailed at the same time and may draw water after the senior users. This scenario constitutes one end of the spectrum in resource allocation where users face a situation of least economic efficiency.

The producer profit maximization problem under such a scenario is given by the following:

$$Max\ \pi = \sum_{u=1}^{U}[\sum_{k=1}^{K}\{(p_k * y_{u,k} * la_{u,k}) - \sum_{s=1}^{S}(w_{u,k} * wc_s * la_{u,k}) - (nwc_k * y_{u,k} * la_{u,k})\}] \quad (3.1)$$

Subject to

$$\sum_{s=1}^{S} w_{u,k,s} = w_{u,k} \quad (3.2)$$

$$\sum_{k=1}^{K}(w_{u,k} * la_{u,k}) \leq d_u \quad (3.3)$$

$$\sum_{k=1}^{K} la_{u,k} = maxla_u \quad (3.4)$$

π in equation (3.1) represents the total profit earned by all users in a region. The terms nwc_k and wc_s in the objective function represent the irrigation pumping costs (which differ by source) and non-irrigation costs respectively while p_k refers to the prices of the crops grown. $w_{u,k,s}$ denotes the amount of water that is applied for each crop using either groundwater or surface water and $w_{u,k}$ is the total amount of water applied per crop by each user. The term $la_{u,k}$ in equation (3.3) denotes the land acreage allocated for growing each crop by any user while d_u represents the total amount of water diverted by the user. d_u is the maximum amount of water that each user is allowed to divert in a single growing season. For simplicity we assume that groundwater users incur a finite pumping cost for water drawn from irrigation wells while the marginal cost of surface water diversion is zero.

The producer welfare is given by the net profit earned by all users within a growing season (a seasonal element may be introduced within the model to reflect profits earned across two growing seasons). The constraint set (3.2)-(3.4) consists of three components. The water demand from all sources —groundwater and surface water— comprises the total water applied by each user as shown in equation (3.2). The irrigation water demand for all crops is limited by the total amount of water that each user is allowed to divert as given by (3.3). Equation (3.4) denotes that the total land allocation for crops grown by any user should be less than the maximum amount of irrigated land that is devoted for growing those crops($maxla_u$).

It may be noted that maximization of profits for a single user is aggregated to total producer profits for an entire region subject to the above constraints. This is because with homogenous producer characteristics and risk neutral behavior, the individual profit maximizing behavior mimics the aggregate producer profit maximization.

Next we present a logical way of introducing prior appropriation in the allocation of water in this model.

Prior Appropriation

Suppose, there are a total of N water rights in a region, denoted $\widetilde{w}_t$, each of which has a unique priority date that is indexed by $t = 1, \dots, N$. They are ordered so that a priority date of $t = 1$ is senior to a priority date of $t = 2$ and so on. At the regional level, the total amount of water available for use across the region in one year is limited to $\overline{W}$. A right entitles a user to the amount of water specified by that right only if there is sufficient water available to satisfy all rights senior to it. The state water authority determines which rights to curtail by allocating the available water in order of priority until the supply has been exhausted. After that point, all rights are curtailed. A strict application of prior appropriation implies that the amount of water allocated to each right is given by:

$$wa_t = min\left\{\widetilde{w}_t, \overline{W} - \sum_{j=1}^{t-1} wa_j\right\}$$

So long as $\overline{W}$ exceeds $\widetilde{w}_1$, that right will be awarded its full legal entitlement, i.e. $wa_1 = \widetilde{w}_1$. The amount of water available to allocate to the second right is then given by the residual, $\overline{W} - \widetilde{w}_1$. So long as that exceeds $\widetilde{w}_2$, the second most senior right will be awarded its full legal entitlement, i.e. $wa_2 = \widetilde{w}_2$. This allocation process continues until the residual available to allocate to right k does not exceed $\widetilde{w}_k$. At that point, right k is awarded the quantity $wa_k = \overline{W} - \sum_{j=1}^{k-1} wa_j$ and all junior rights, for which $t > k$, receive $wa_t = 0$.

Denote the set of all water rights in the region as $\Omega = \{1, \dots, N\}$. Each irrigator in the region, indexed by $u = 1, \dots, U$, owns a subset of all water rights denoted Ω_{u}, where $S = \{\Omega_1, \Omega_2, \dots, \Omega_{\mathrm{U}}\}$ is a partition of Ω. The total amount of water available to irrigator u is given by

$\sum_{t\in\Omega_u} wa_t$. We can further partition each Ω_u into two subsets defined by whether the right is for surface (SW) or groundwater (GW), i.e. $\Omega_u = \{\Omega_{u,SW}, \Omega_{u,GW}\}$. Though prior appropriation is enforced equally across surface and groundwater rights, it is necessary to distinguish between the two because the marginal costs of extraction differ. The amount of water that irrigator u may divert from surface water sources is given by $\sum_{t\in\Omega_{u,SW}} wa_t$, and the amount available for extraction from groundwater sources is given by $\sum_{t\in\Omega_{u,GW}} wa_t$.

Water Banks and curtailment

We turn now to the more realistic possibility of renting water from the water banks with curtailment still in place for the junior rights holders during times of water shortages.[5]. It is implicitly assumed that there exists a hydrological connection between the points of diversion for the water stored in the bank and the point of use by the irrigators.

The optimization problem in this case may be expressed as:

$$Max\ \pi = \sum_{u=1}^{U}[\sum_{k=1}^{K}\{(p_k * y_{u,k} * la_{u,k}) - \sum_{s=1}^{S}(w_{u,k} * wc_s * la_{u,k}) - (nwc_k * y_{u,k} * la_{u,k})\} - (rc_u * r_u)] \tag{3.1}$$

$$\sum_{s=1}^{S} w_{u,k,s} = w_{u,k} \tag{3.2}$$

$$\sum_{s=1}^{S} r_{u,s} = r_u \tag{3.3}$$

[5] It may be noted that Idaho is one of the few states where such a bank has been established as a permanent institution catering to the needs of water users with the rental rate for water predetermined by the State water agency. The Idaho Water Resources Board sets this price depending upon the current volume of water transferred and the going rental rate.

$$\sum_{k=1}^{K}(w_{u,k} * la_{u,k}) = w_u \tag{3.4}$$

$$w_u \leq r_u + d_u \tag{3.5}$$

$$\sum_{k=1}^{K} la_{u,k} = maxla_u \tag{3.6}$$

The interpretation of the objective function and the constraints remain the same as before. However, users are now free to decide whether to rent water from the water bank or use the water available to them (diversions) in the course of the growing season. Equation (3.5) describes the user's water demand decision being influenced by the quantity of water being diverted (d_u) and the quantity that may be rented from the water bank (r_u). This brings in more flexibility to water users during times of drought. The term rc_u denotes the rental cost per care foot of water and the last term in the objective function captures the total rental cost incurred by any user who chooses to rent.

In many instances there might exist a renter lessee agreement on how much water will be rented over a season. We abstain from having this complexity in our models for scenarios (2) and (3) below without further information. Also, having a situation where the senior water right holders lease water to the junior holders when the latter face curtailment is not common according to IDWR personnel[6], and hence we assume that water is rented from the existing stock that had been previously leased to the Bank.
There are two caveats to the above assumption that are worth noting. First it implies that there is adequate water in the bank for rental purposes. Second the Board is likely to allow full renting

[6] Email communication with IDWR Water Bank specialist.

for all users who need water from the Bank during the drought season[7]. However, in order to present a situation where these assumptions do not hold, the models need to include time frames longer than a single season.

Fully optimal scenario

The next water allocation scenario assumes that there occurs free movement of water with no transaction costs which is our version of the most efficient or optimal outcome. The optimization model for this scenario basically remains the same as the previous model, except for the fact that there is no appropriation rule in the allocation of water and hence no curtailment faced by any user in the event of a drought.

Finally, we incorporate a drought scenario given each water allocation criterion. The impact of a dry season is reflected by a reduction in the net water availability for all users in the study region. For the scenario (3) or the fully efficient model, the drought is assumed to affect the total amount of water available to the users in the study region. A moderate drought is accompanied by a 10 % reduction in the total water available for use under favorable conditions while a severe drought implies a 30% reduction in the total water availability. For the curtailment scenarios (1) and (2) however, the consequences of the drought are borne heavily by the junior users or those having later priority dates in water use since they are the ones who lose rights to diversion when the call for curtailment is made. However, several water rights holder in the data had multiple priority dates to water use and hence with a moderate drought, the user having a water right with the latest priority date of 1986 lost access to that right for the season. With a severe drought almost all the groundwater users having priority dates corresponding to 1900s and later got curtailed. The users who faced curtailment during periods of severe water shortages, are able to rent water from the water banks for scenario (2). An implicit assumption in this case is that the water bank has water that had been previously leased to it and as mentioned previously, we ignore the possibility of rental lease agreement between junior and senior water rights holders. Thus for this water allocation scenario, users (both junior and senior rights holders) have the choice of renting water depending upon their demand and the probability of curtailment based on the intensity of drought. The effect of drought is more prominently felt in the water allocation

[7] This is an issue the Board faces since there have been pending requests for rentals in recent years.

scenario (1) where the users having junior water rights face curtailment and are not allowed to divert water before the senior rights holders have diverted their maximum allowable limit. It is assumed that it is not economically feasible to have water banks in the region for this scenario.

4. Study region and data

Agriculture is an important industry in Idaho, contributing nearly $5.9 billion to the State's GDP. Irrigation water used in the State irrigates about 3.32 million acres of agricultural land, over 2 million of which are located in the Eastern Snake River Plain (Frey, 2012). The study region selected spans three counties located in the Eastern Snake River Plain (ESRP) of Idaho.

Specifically, the region falls in Administrative Basin 22 in the Upper Snake River Plain covering areas within the counties of Madison, Fremont and Teton. The region is selected on the basis of the amount of water exchanged in recent years through water banks and expert comments about the economic prospects for future water transfers[8]. The water rights dataset was restricted to irrigated agricultural water users involved in farming operations. This is because the effects of increasingly variable and uncertain water supplies are likely to be borne heavily by the agricultural sector, which has important implications for rural livelihoods and economic welfare statewide.

The dataset comprises a number of irrigators including five canal companies, a large irrigation district, and numerous individual land owners. These water rights holders and the characteristics of their rights, including priority dates (seniority), source, place of use, season of use and maximum diversion rate are obtained from the Idaho Department of Water Resource's geospatial water rights dataset. Table 4.1 in the appendix summarizes the main characteristics of the water users in the study region.

Care is taken to ensure that there is a minimum of overlap of water rights between users in order to facilitate the analysis and proper interpretation of the optimization results. Though the physiography of the ESRP is such that several surface water and groundwater sources are hydraulically connected, lower chances of overlap between the water rights belonging to each

[8] The amount of water exchanged was determined by the maximum diversion rate per day and the volume of water diverted by merging the rental point of diversion and the point of use datasets available in the IDWR water rights database. (Mention the experts' correspondence and conversation).

user having spatial proximity, enables us to separate out the maximum water diverted by each user over a growing season by virtue of having a specific water right and an associated priority date on which the water right was first claimed by the user. Since all users in our study region use irrigation water, the maximum amount of water diverted for this purpose within a growing season is obtained by merging the water rights point of use dataset for irrigators with the water rights point of diversion dataset for the study region. The presence of exact priority dates of water use for each water right belonging to a user enables us to exploit the present rules of curtailment during droughts to determine the net water use and land and crop selection decisions across users.

A major issue encountered in recovering the maximum amount of water diverted by each user is the "stacked water rights"[9] problem, where any user, irrespective of the number of rights held by the user, is entitled to a maximum volume of water that is given by the "combined" acres that she irrigates. This data as well as the growing season information are obtained from the Water Rights Report for each user that comes along with the spatial water rights data. Interestingly, four of the six groundwater users in our dataset had the combined acre limit specified while none of the surface water users had such a restriction, since they had water right corresponding to just one priority date. The maximum level of diversion for these groundwater users are thus obtained by taking the minimum of diversion allowed within a growing season and the combined volume limit for diversion over all irrigated acres, to set an upper level for their water use (The surface water users also have the senior water rights with the latest priority date going back to 1986).

Technically speaking the maximum level of diversions allowed by each user may be obtained by three methods. One, is to compute the maximum level of water that each user is permitted to divert within the growing season by translating the cfs/ acre flow of water to volume of water, adjusted for the duration of the growing season for each user. However, any user who has multiple water rights corresponding to different priority dates ("stacked" rights) is allowed to use the combined volume of water over the entire land units she owns. Second, we may determine the total volume of water diverted in acre feet per year based on the head gate measurement of water flow in the particular region. Currently IDWR calculates the field head gate requirements

[9] Water rights are stacked when two or more water rights, generally of different priorities and often from different sources, are used for the same use and overlie the same place of use. (Overview of the Idaho Water Supply Bank, IDWR)

in acre feet/ year/acre for all administrative basins in each of the four planning zones or regions. For our study area this head gate requirement is 3.5 which is then multiplied by the number of acres irrigated by each user during the growing season. Finally an assessment of the volume of water drawn in recent years (2010-2011) may be made through the WMMIS/ Water Accounting database maintained by IDWR, but the data for groundwater users may not be fully available. We thus compare the water volumes from the water rights database and the headgate measurements to arrive at the maximum level of diversion by each user for whom multiple water rights are not stacked.

It may be noted here that the applicability of the methods employed to calculate the volume of water that is drawn by each user necessitates that the water rights for each user are properly laid out such that their association with the individual land holding is spatially and temporally invariant. The present rules governing water rights in Idaho ensures that there is minimal endogenous change in the water rights boundaries which is correlated with land use and user specific characteristics.

Present IDWR rules put a limit of 0.02 cfs / acre for renting water from the water bank[10]. This is converted to water availability in terms of acre feet assuming a seven months growing season[11]. The users pay a rental fee of $17/ acre foot of water rented and this adds to their total cost of pumping water depending upon the amount of water rented from the Bank.

The total number of acres irrigated by each user is obtained by overlaying the geospatial data covering our study area with the NASS Cropland Data layer (2011). The crop types and the number of acres irrigated for each crop by any user is given by extracting the cropland layer corresponding to each individual's water rights point of use area. Four main types of crops viz. alfalfa, barley, spring wheat and potatoes are considered based on the percentage of irrigated acres allocated to these crops (for all users in our study region these four crops accounted for almost 90% of the irrigated land area). The base water application rate for each crop for the PMP calibration is obtained from the Irrigation Demand Calculator developed by Contor et al. (2008) at the Idaho Water Resources Research Institute.

[10] Personal communication with IDWR personnel.
[11] Apart from one user, all had a seven months growing season corresponding to any established priority rights for water use.

The crop prices, irrigation costs (assuming center pivot irrigation system), the crop specific costs of production excluding the water withdrawal costs are obtained from the Idaho Crop Enterprise Budget Sheet (Eastern Region) for 2011 (University of Idaho Extension Center). The average irrigated and dryland yields are obtained from the NASS county specific yield data for the years 1970-2012 (availability of data varies by crop). In all cases the data is drawn from the three counties–Fremont, Madison and Teton–belonging to our study region.

The marginal cost of pumping groundwater is held fixed in the baseline scenario as well as for the alternative scenarios at $17.6/ acre foot (Idaho Crop Enterprise Budget Sheet (Eastern Region) for 2011, sprinkler irrigation). With severe drought there might be a possibility of the cost of water withdrawal being dependent upon the lift. However for a single growing season, the change in water depth due to water shortages is not likely to affect the pumping cost, but should be factored in when the model is solved for a longer time period.

The resource costs, the water use requirement per acre for each crop, historical average yields and the observed land acreage for each user are then used for the initial PMP calibration of the model as discussed in the previous section.

5. Results and Discussion

In response to differences in the severity of droughts, we expect differences in land and crop allocation decisions and most importantly in the total water use for each of the three water allocation mechanisms. For the allocation scenario where users face curtailment during moderate and severe droughts, the effect in terms of a reduction in water use is found to be relatively strong for a severe drought. In this model both water and land are assumed to be limiting factors in production, since each user does have an acreage constraint. At the extensive margin, total water use and total land allocated gets reduced at the two levels of drought intensity when we consider a full trading scenario. For the other two water allocation scenarios, the senior water rights holders seem to appropriate the available water to the highest level and the effect is prominently felt during the times of drought when senior users actually divert more water compared to a base case (no drought situation). An interesting outcome is the water rented during the growing season which is positive mostly for those water rights holders who face curtailment on the basis of their priority rights. However, with a fully efficient equilibrium, users seem to refrain from renting water at any level of drought intensity. The results are described below in terms of water use by source, land and water required for production for each crop, water rented during the season, the net change in revenues by user and finally the net returns under each water allocation scenario and for the two levels of drought intensity.

Total water used by source

Table 5.1 shows the water use by source under conditions of moderate and severe droughts. As previously mentioned, moderate drought refers to a water availability of 90% of the base supply while severe drought is characterized by a reduction of 30% of the base water supply. For the entire study region, under favorable climatic conditions, groundwater use accounts for around 16% of the total water use. For scenario (1) or when junior water rights holders(who are primarily the groundwater users) face curtailment and has no option of renting water from banks, around 17% of water used is available from groundwater at a moderate drought level while all groundwater users get curtailed during a severe drought. The presence of water banks in scenario (2) raises the proportion of groundwater used in total to 25% during a severe drought. This is because the junior water rights holders increase the amount of groundwater used by renting more water from the banks in the event of severe shortages. However, for the full trading scenario we find that the optimal level of groundwater use at the two different levels of drought intensity falls to 14% from the base use of 16%.

Land and water allocation by crops

Table 5.2 and Table 5.3 present the allocation of land and water to each crop, for the different types of water allocation scenario and for each level of drought intensity. We explain the main results by using the base or no drought condition as the reference category.

During a moderate drought, for scenario (1) or a strict curtailment of water use, there is a noticeable shift of irrigated land from barley and spring wheat while net water use for barley drops by 35 %. It may be noted that with a moderate drought in this scenario, user 12 in our dataset allocates 150 acres to potatoes but none to the other three crops. With a severe drought, total land allocated for barley and potatoes fall by 35% and 12 % respectively—irrigated land allocated to potatoes drops to around 700 acres during severe drought which translates into around 1400 acre feet devoted to production of potatoes. The result is a bit surprising since the

ESRP region ranks high in potato production[12] and may be attributed to the junior users facing curtailment and not being able to devote more irrigated water for growing potatoes.

In the presence of water banks (Scenario 2), there is a tendency for irrigators to allocate land and water for growing more of alfalfa and potatoes which incidentally earn the highest net returns per acre (on average the net returns per acre for alfalfa and potatoes are $196 / acre and $742 /acre). Interestingly, with a severe drought, resource allocation shifts from barley and spring wheat to alfalfa and potatoes. For barley, the irrigated land use falls by almost 320 acres while the same increases for alfalfa by around 215 acres; the net reduction in water use during a severe drought is around 643 acre feet for barley as water gets allocated to alfalfa and potatoes.

For scenario (3) when users are allowed to allocate resources in the most efficient manner, resource allocation towards alfalfa is found to drop by almost 23% during a severe drought. In contrast, total irrigated land devoted to potatoes falls by 135 acres and water use falls by only 5% during a severe drought in the entire study region. This pertains to the economic logic of allocating resources to the highest valued use. For the fully optimal scenario users seem to be devoting more of irrigated land to potatoes, which invariably earns the highest net returns per acre, even when there exists severe water shortages.

It may be noted that the optimal use of land and water resources seem to have moved towards alfalfa and potatoes while for the fully efficient allocation, there is a tendency for users to shift away from barley production with increases in water scarcity. For some users, this might reflect a tendency to reorient irrigated land towards crops like potatoes and probably corn which is being increasingly grown in the ESRP region. Also, since both resources are limiting, a reduction in availability of water during droughts is generally accompanied by a reduction in total land use and this is most obvious in scenario (3).

Economic efficiency gains

Next we turn to the differences in economic efficiency for each water allocation scenario under the two drought intensities. For scenario (1), while the loss is net income for a moderate drought compared to the base scenario is 5%, with the severe drought the loss in net income amounts to

[12] The ESRP region almost alone drives the potato industry in Idaho with the production valued at $500-750 million. Around 30% of the russet type potatoes in the US are grown in Idaho.

2.38 million or 37% from the base income level of $5.7 million. The average loss in total farm income is merely 1% and 2% respectively for a moderate drought in the case of the fully optimal scenario and the curtailment with water bank scenario. For a severe drought the results are similar for these two water allocation scenarios— a 7% loss in net income (as compared to the base income level of $5.7 million) for the irrigators is observed in the study region.

Table 5.4 presents the gains from a fully optimal or efficient model as compared to the two other scenarios under conditions of moderate and severe droughts. For a moderate drought ,the net gains in efficiency is around $235000 and $31400 for the fully optimal model when compared to a scenario of full curtailment and one with curtailment and the presence of water banks. However the efficiency gains falls to only $400 when a fully optimal model is compared to a scenario of curtailment with water banks. This might be attributed to the possibility of renting by six junior water rights holders who are curtailed during a severe drought. In contrast, for a fully optimal scenario, the intensity of drought seems to have forced users to adjust water and land use. With a severe drought, the total irrigated land in the study region falls from 23,215 acres to around 16000 acres for a fully optimal scenario. This is likely to affect total income across users as many would probably refrain from allocating irrigated land for production of low valued crops like barley and spring wheat in response to the droughts.

In our model both land has been held as a limiting resource, and hence with water scarcity the fully optimal model leads users to reorient resources to the highest returns and actually encourages them to economize on the scarce resources. On the other hand, for scenario (2), we find that all the junior users who face curtailment during drought rent water from the Bank and this allows them to allocate more water and land during a severe drought than would be possible without borrowing water from the bank. This raises their net income over the growing season as they base their crop selection and land use decisions on the total amount of water available. Intuitively the very insignificant gain in net efficiency for the optimal scenario over the scenario with curtailment and banks during a severe drought may be attributed to the differences in the water allocation mechanism for each. With curtailment, renting water from the Bank may seem to be an optimal strategy during severe water scarcity than when there is no probability of facing drought curtailment.

Further, we find that the senior water rights holders stand to gain the most during these severe droughts when the junior users are curtailed. The senior users tend to divert as much water as possible in the fear of losing unappropriated water. As a result they are able to raise their net revenues in the scenarios where there is a curtailment call, with a loss of merely 1.07% on average, in net revenues during a severe drought for scenario (2). In contrast, the junior users, who lose access to a number of water rights during curtailment, witness a loss of 14.64% in their average net revenues under conditions of severe drought.

Water rented

As shown in Table 5.6 there is a marked tendency by the junior users to rent water from the Bank for the severe drought case. The total amount of water rented goes up from 5310.56 acre feet during a mild drought to 160120.41 acre feet for a severe drought. An economic interpretation for the tendency to rent water during curtailment and not during a full optimal scenario may be provided here. Users who are likely to get curtailed during a drought consider the temporary transfer of water from the Bank as their sole source of water and for them the opportunity cost of rented water is below the net loss in irrigated production if they do not rent water. Here it should be noted that the additional water rented is not being leased to the Bank by the senior users in which case their water use would have declined. Lease rental negotiations and voluntary water sharing agreements between senior and junior rights holders are beyond the scope of this study without pertinent information about such transactions at the basin level.

Discussion of main results

A number of observations may be made from the results described above. First and foremost is allocation of land and water towards high valued crops like alfalfa and potatoes for all the water allocation scenarios but particularly for the cases of a fully optimal allocation and an allocation of water with curtailment during droughts and the presence of water banks. This is found to be a practice among senior water users too when curtailment is in place during moderate and severe droughts. Allocation of resources towards crops which provide the highest net returns per acre follows from economic efficiency rules and is expected for a fully efficient scenario with no appropriation constraint. However when users are being able to rent water from the bank at a price which is administratively set, they seem to be redistributing land from crops like barley towards the high valued crops. This may imply a tendency by users including those who are curtailed to maintain agricultural production instead of taking out land for non-irrigated agriculture in order to mitigate the short term effects of a drought.

This brings us to another important issue related to renting water in a fully optimal scenario. The results show that irrigators are reluctant to rent water even during a severe drought and actually reduce the allocation of land for each crop with increases in the level of drought intensity. It may be argued that users in the most efficient scenario tend to use scarce resources according to the principle of highest efficient use instead of trying to augment those resources from outside. In contrast, when there is a constraint set in the way water is being allocated during scarcity, users, particularly, those who are likely to face curtailment, prefer to rent water for the growing season since for them the problem has to do with the absence of the resource rather than its scarcity. Temporary renting of water from the bank may thus be considered a viable option for agricultural users in states like Idaho where the bank acts more as a facilitator of water exchange rather than a market for water trading where prices are determined endogenously through the demand and supply of the renters and lessors respectively.

We may refer to the irrigators' decision between renting water and switching to dryland farming as a seasonal decision and may not have any bearing on his long term profits. The results pertain to economic decisions made under different drought intensities under a single growing season and to accommodate medium to long term water allocation decisions, the model needs to be extended to a dynamic time frame.

In short, the results seem to offer the possibly of withdrawing water from banks as a remedy to alleviate the impact of short term droughts. For a state like Idaho where the system of water banking is a whole lot different than the developed water banks of California or Texas, and where priority in appropriation still is the sole method by which water rights are adjudicated, it serves the dual purpose of protecting the interests the junior water rights holders during a severe drought and also for storing surplus water from the senior users. Also evident from the study is the distribution of net revenues towards the senior users who are found to divert more water during the drought season, a result that is supported by Hoekema and Sridhar (2011) who found that in several places of the ESRP, variability in water supply is accompanied by higher levels of diversions at certain periods of the growing season. Thus for water allocation scenario (2) the senior users lose merely 1.07% in average net revenues compared to a loss of 14.64% for the junior users, all of whom face curtailment during a severe drought.

6. Conclusions

Water marketing in western US has been a widely researched topic in the economic literature but there is a dearth of studies that undertake a thorough analysis and comparison of water allocation assuming a fully efficient outcome and those through institutions as water banks which are more centralized in nature. Water transfers may take place through temporary or permanent water banks which in several occasions have been instrumental in intermediating exchange of water at a predetermined price. In this paper we attempt to quantify and compare the differences in economic efficiencies and resource allocation by agricultural water users given three alternative water allocation scenarios and conditions of moderate and severe drought.

The study region is a part of the ESRP in southeastern Idaho, where leasing to and renting water from the permanent water supply bank has picked up in the last three years. Since irrigated agriculture comprises 92% of the water requirements in ESRP, we focus on irrigated water users. The results point towards the importance of water banks as an institution that may alleviate the short term effects of drought by allowing junior water users to rent water in accordance with their needs. For a case of severe water shortage it is found that efficiency gains from having water banks are almost the same as having water allocated on the basis of the highest economic efficiency. Of course the results to some extent reflect the underlying assumptions about the irrigators' decisions being determined largely by the land allocated to each crop and the tendency to allocate less land to irrigated production during severe droughts for a fully optimal outcome. However, the results from the three different scenarios have two important implications for water management policies for drought prone regions of the western US .First when economic claims against allowing water allocation based on the market premise have been largely accepted due to its conflict with the institutional rules governing western water rights, a hybrid system of water banking with water allocation being decided on priority rights is likely to be a more feasible and realistic institution for managing water scarcity during droughts. On the other hand, the research under its present form highlights an important feature of a fully efficient water allocation model — users seem to be shifting land from irrigation as severity of droughts rises. This may have a distinct bearing on the water conservation potential inherent in such a mechanism and may support assertions by several researchers in the past that shifting land from irrigated acres by applying more water efficient measures may be a solution to cope with water scarcity in the West.

Second, the study provides empirical evidence of the tendency of senior water users to divert a large amount of water even during droughts while the junior users (who are mostly groundwater users) get curtailed and have to rent water. At a time when there is a bone of contention between conjunctive management of ground and surface water and application of prior appropriation doctrine to manage the water scarcity in the West, the results seem to point towards the necessity of an economic assessment of gains through conjunctive use of water and the distribution of the same among multiple users with different priority rights over water.

There are certain limitations of the study that need close attention. One, it is based on a small number of water users in an administrative basin within ESRP and thus the results may be applied to large scale basin level or state level studies with proper caution. However, the basic implications of the water allocation scenarios under various levels of drought will be true for any study that intends to replicate the results for another region in western US. Two, it fails to include urban and industrial users into the water allocation scenarios to investigate any changes in the economic behavior among irrigators when agriculture has to compete with other users with and without institutional constraints guiding water allocation. Finally, the research falls short of incorporating user level heterogeneity in water use based on differences in their risk taking behavior and allowing the allocations scenarios to extend over one growing season. Inclusion of an explicit expected risk and return model to investigate user behavior under levels of drought intensities is beyond the scope of this study but is an important direction for future research.

Nevertheless, at a juncture when policies to counter the impact of climate induced droughts is the overarching issue across western US, the study attempts to highlight the importance of having the water banks as an institution to alleviate the problem when a fully optimal or efficient outcome for water allocation still remains a distant possibility.

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Table 4.1: Characteristics of Water users in the study region

Ownership	Type	Priority Dates	Water use	water source	Total agricultural area irrigated
SUNNYDELL IRRIGATION DIST	Irrigation district	05/1884	Irrigation	surface water	4101.18
WILFORD CANAL CO	Canal company, irrigation and manufacturing	06/1884,04/1898, 04/1939	Irrigation	surface water	4485.47
ROXANA CANAL CO	Canal company	06/1885	Irrigation	surface water	1313.68
SALEM UNION CANAL CO LTD	Canal company	06/1888	Irrigation	surface water	5179.35
REXBURG IRRIGATION CO	Irrigation company	04/1898	Irrigation	surface water	7672.17
ISLAND WARD CANAL CO	Canal company	Jan-01	Irrigation	surface water	3695.31
THE DEAN & SHIRLENE SCHWENDIMAN FAMILY LTD PARTNERSHIP	Private ownership	12/1960,03/1969,06/1977	Irrigation	groundwater	1440.23
ALDA REMINGTON	Private user	Mar-69	Irrigation	groundwater	283.33
PARKINSON	Private user and farm ownership	4/1966, 1/1986	Irrigation	groundwater	858.44
DENNIE K ARNOLD	Private user	2/1/1969, 05/1970,01/1976, 04/1985	Irrigation	groundwater	1183.14
SETH WOOD FARMS INC	Private farm ownership	7/1/1972, 08/1985	Irrigation	groundwater	1349.93
K L B INC	Private water user ownership	09/1976, 08/1977, 04/1986	Irrigation	groundwater	2926.93

Table 5.1: Total water use by source

	Water supply					
	Base		Moderate		Severe	
Institutions	**surface water**	**groundwater**	**surface water**	**groundwater**	**surface water use**	**groundwater use**
Fully optimal	46416.07	9071.22	42755.63	7182.94	33351.78	5489.33
Banks& curtailment	46416.07	9071.22	46279.52	9207.77	41290.99	14196.30
Full Curtailment	46416.07	9071.22	41334.45	8304.92	39220.53	0.00

Table 5.2: Total land allocation by crops

		Crops			
		Alfalfa	Barley	Spring wheat	Potatoes
water supply	**Institutions**				
	Fully optimal	7838.75	6538.30	6084.38	2754.41
	Banks & curtailment	7838.75	6538.30	6084.38	2754.41
Base	**Full Curtailment**	7838.75	6538.30	6084.38	2754.41
	Fully optimal	7300.66	4931.25	5811.57	2694.33
Moderate	**Banks& curtailment**	7905.45	6459.73	6064.55	2754.74
	Full Curtailment	7756.88	4221.94	5940.70	2427.65
	Fully optimal	6062.37	1969.25	5216.79	2619.27
Severe	**Banks& curtailment**	8053.31	6217.73	6082.22	2755.51
	Full Curtailment	7358.60	2872.22	4545.60	699.98

Table 5.3: Total water allocation by crops

		Crops			
		Alfalfa	Barley	Spring wheat	Potatoes
water supply	**Institutions**				
	Fully optimal	23516.24	13076.59	13385.64	5508.81
	Banks & curtailment	23516.24	13076.59	13385.64	5508.81
Base	**Full Curtailment**	23516.24	13076.59	13385.64	5508.81
	Fully optimal	21901.97	9862.49	12785.44	5388.65
Moderate	**Banks & curtailment**	23716.34	12919.46	13342.01	5509.48
	Full Curtailment	23270.64	8443.88	13069.54	4855.31
	Fully optimal	18187.11	3938.51	11476.94	5238.55
Severe	**Banks& curtailment**	24159.93	12435.47	13380.88	5511.01
	Full Curtailment	22075.81	5744.44	10000.31	1399.96

Table 5.4 Economic gains under different institutional scenario

	water supply			
	Moderate		**Severe**	
Institutions		**Efficiency gains from optimal allocation**		**Efficiency gains from optimal allocation**
Fully optimal	5508100		5202400	
Banks & curtailment	5476700	31400	5202000	400
Full Curtailment	5262800	245300	3530500	1671900

Table 5.5: Producer profits from irrigated water use under alternative scenarios and under different levels of drought intensity

Base			Moderate			Severe		
Fully optimal	Banks& curtailment	Full Curtailment	Fully optimal	Banks& curtailment	Full Curtailment	Fully optimal	Banks& curtailment	Full Curtailment
658978.46	658978.46	658995.99	649003.09	658893.03	658996	603273.93	658351.14	658995.99
753844.58	753844.58	753863.70	746411.18	753751.42	753863.7	705664.61	753160.45	753863.70
157229.85	157229.85	157233.07	156728.98	157214.14	157233.1	148387.25	157114.52	157233.07
641501.95	641501.95	641522.18	636909.76	641403.40	641522.2	594114.76	640778.23	641522.18
854056.32	854056.32	854076.89	845883.10	853956.12	854076.9	798099.23	853320.52	854076.89
521281.85	521281.85	521295.03	517513.09	521217.62	521295	491510.15	490243.09	464845.45
115760.52	115760.52	125758.17	115387.54	115747.24	115780.5	114018.08	106078.36	0.00
412252.57	412252.57	459074.40	409247.72	403699.19	408098.1	398390.20	366687.73	0.00
247044.26	247044.26	275683.75	244019.76	246256.74	247205.9	233250.40	219462.10	0.00
404896.71	404896.71	442837.50	402043.88	404153.89	405049.2	391827.83	368179.32	0.00
312105.95	312105.95	354118.79	308462.12	311157.17	312300.7	295396.21	271422.68	0.00
489016.24	489016.24	489016.83	476533.68	405634.20	187409.3	428488.53	317219.73	0.00

Table 5.6: Water rented by users under the bank &curtailment scenario under different levels of drought intensity

users	Base	Moderate	Severe
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	1824.12
7	0	0	568.77
8	0	480.01	2659.65
9	0	0	1601.71
10	0	0	2140.26
11	0	0	2368.12
12	0	4830.55	4857.79
Total		5310.56	16020.41