THE GRAVITY OF WATER:
Water Trade Frictions in California

Charles REGNACQ
Université de Pau et des Pays de l'Adour

Ariel DINAR
University of California, Riverside

Ellen HANAK
Public Policy Institute of California

Abstract

It is relatively well accepted that costs associated with transfers weigh upon water markets and deter some exchanges. But few studies explicitly address such costs and their impacts on trading behavior. In this paper we fill this gap, using a tool from the international trade literature—the gravity equation. We first develop a theoretical model to assess the micro-foundation of this approach in a water market context. The model distinguishes between variable and fixed costs of trade, which allows disentangling of the decision to enter into the water market (extensive margin) and the decision on the quantity of water to be transferred (intensive margin). Then we test the theoretical predictions using water transfer data among California water districts over a 17-year period. We approximate transfer costs by distance and institutional factors. Results validate the theoretical predictions and show the importance of distance and institutional impediments in the decision to trade. (150 words)

Key Words: Water Markets; Gravity Equation; Transaction Costs

JEL Codes: Q5, Q25

THE GRAVITY OF WATER:
Water Trade Frictions in California

INTRODUCTION

As water scarcity increases in many regions, decentralized management of this resource using market-based institutions (Msangi and Howitt, 2006) has been of growing interest among policy makers (Easter, Rosegrant and Dinar, 1998, Easter and Huang, 2014). For more than three decades, water markets have been developed in many water-scarce regions, such as Chile, Australia and states within the western USA, each within different institutional settings (Bjornlund and McKay, 2002). In line with traditional trade theory, the transfer of property rights to water among users is seen as an efficient reallocation mechanism for this resource, enabling it to move from lower to higher value uses (Brown, 2006). In California, where most water rights were allocated decades ago, trading enables flexible reallocation that can benefit the overall economy (Hanak, 2015).

Interest in the market as a reallocation tool in California grew in the late 1970s, in the wake of an acute drought that created significant water scarcity in both the urban and agricultural sectors. Two official reports (Governor's Commission to Review California's Water Law (1978) and Phelps, Moore and Graubard. (1978)) strongly endorsed water trading to support the growth of the Californian economy. Legislation was enacted in the early 1980s to facilitate trading, but the market did not take off until the next severe drought (1987-1992) – particularly as of 1991, when the state established a drought water bank (Hanak 2015).

But as a general observation neither in California nor in other states in the western USA have water markets emerged as a major reallocation mechanism (Hanak, 2015; Brown, 2006 and Hansen Howitt and Williams, 2015). For example, while water trading in California has grown significantly since the early 1990s, trading volumes by the late 2000s were only roughly 3 to 5 percent of total water use in the urban and agricultural sector (Hanak 2015). As a point of comparison, water trading in Australia's Murray-Darling Basin has accounted for a third or more of total water availability (AITHER, 2014, 2015; Howitt, 2014) Water seems to be less "liquid" than expected (Hollinshead, 2008) and the reality of water markets falls short of their potential.

Inflexibility in water markets is particularly problematic during extreme events such as droughts. In such situations, water markets can lessen the costs of scarcity by enabling the reallocation of water to higher value activities. As an example, at the height of Australia's Millennium Drought, water deliveries to agriculture were slashed by about half, but agricultural output was only cut by about a quarter, thanks to active trading (AITHER, 2014, 2015) During California's 2015 drought,

Howitt, Medellin-Azuara and MacEwan (2014) estimate that water scarcity resulted in agricultural sector losses by roughly $1.7 billion in 2014 (roughly 3-4% of annual revenues), along with 7,500 lost farm jobs (3%) from land fallowing. Trading cannot eliminate scarcity, but it can help mitigate the impact of such extreme events by reallocating water to higher value crops.

It is relatively well accepted that costs associated with transfers deter some trading. But few studies explicitly assess the effects of such costs on trading (Archibald and Renwick, 1999; Hanak, 2005; Lefebvre, Gangadharan and Thoyer, 2012). Griffin (2006:356) stated that "Too much is omitted to associate results with potential market results. The behaviors of individual agents (true market agents) are not represented, and the frictional transaction costs of market activity are neglected too".

This paper complements the existing literature on water markets with a focus on "transfer costs" – including both institutional factors traditionally considered as transaction costs, as well as the costs of conveyance. Using the framework of New Economic Geography (NEG), we develop a model of water trade, including transfer costs. We then test empirically the theoretical predictions using water market data from California with the gravity equation tool (Tinbergen, 1962). We validate the use of the gravity equation to study water markets and show that transfer costs (approximated by distance and institutional impediments to trade) are an important factor in water trade.

The paper is developed as follows. The first section describes the relevance of using the NEG tools to explain the impact of transfer costs. Then, we develop a simple theoretical model of water trade between water districts by applying international trade framework in which a combination of a variable and a fixed transfer cost creates a bias toward proximity. This provides an explicit formalization of different friction costs and the foundation for the empirical test. In a third section, we provide empirical evidence of such effect in bilateral water trades between water districts in California.

TRANSFER COSTS AND GEOGRAPHY

"Why are there so few transactions among water users?" This question raised by Young almost 30 years ago (Young, 1986) is still relevant today. One of the major impediments suggested by the literature is the highly complex institutional setting in which transfers occur. Indeed, due to the intrinsic characteristics of water, a set of restrictive laws and regulations have been promulgated to limit the risk of market failure and as a consequence curbed the incentive to trade. Thus, prior to any water transfer, both transacting parts have to engage in a costly process to ensure the completeness of the transfer contract: what we call in this paper, the transaction cost. As pointed by Culp, Glennon and Libecap (2014), the intrinsic characteristics of

water lead any decision toward this resource to be highly politicized with an important risk aversion: "*water rights holders are theoretically free to transfer their rights to upstream or downstream water users. But the reality is more nuanced, with transfers complicated by a series of procedural and regulatory requirements that characterize Western water rights, making it very difficult to transfer water rights*" (Culp, Glennon and Libecap, 2014:13). In other words, the transfer of water is costly in terms of time and money. By limiting transfers, such costs induce a post-trade allocation very close to the initial endowment, preventing a move toward more efficient outcomes in the Californian water economy (Griffin, 1991).

It is worth noting that a transfer cost is not always synonymous with inefficiency. Indeed, as pointed out by Colby (1990), such costs can be viewed as a tax to factor in various forms of externalities induced by a water transfer. For instance, by changing the time and place of use of a water right, a transfer might adversely affect the volume of water available to downstream water right-holders or to the environment. The legitimacy of each component of transfer costs is beyond the scope of this paper. Whether they legitimately adjust for such externalities or not, transfer costs are not neutral in the trading process, and should be considered in water markets analysis.

The nature of transfer cost

In this paper we refer to the cost of water transfer between locations using the broad term of transfer cost, in order to capture terminology of both the transaction cost as well as the conveyance cost. The transaction cost includes any cost induced by the search and negotiation with all relevant parties in the trade, such as the buyers, the sellers and also any other agents affected by the transfer (Libecap, 2005). Previous empirical work on this matter found that an important share of the water price is due to this component of transfer cost. For example, Colby (1990) estimated a mean supplemental cost in New Mexico at 6% of the agreed price.

From the taxonomy of Archibald and Renwick (1999), the transaction cost can be distinguished into two categories. The first is the "Administratively Induced Cost" (AIC) and is generally common to any property type transfer. It includes the search for a reliable partner and the negotiation process over price, quantity and time of delivery and is borne by the seller as well as the buyer. While such a cost is difficult to suppress, it can be reduced by improving the information dissemination. For example, Bjornlund (2003) shows how the use of an internet platform in the Australian water markets made information much more easily accessible and decreased the ex-ante cost of search for a good match. In the Californian water markets, water exchanges are often driven by bureaucratic processes and become abstruse (Libecap, 2011) deterring small agents from entry (Carey, Sunding and Zilberman, 2002).

The second type of cost, more specific to water markets is the "Policy Induced Cost" (PIC). It is designed to adjust for potential incompleteness of water contracts.

Indeed, due to the complex and sometimes non-observable features of water, defining a complete set of property rights for this resource may be difficult (if not impossible). Any water transfer is thus subject to a set of policy rules to prevent agents not directly involved in the contract but possibly affected by the exchange to be harmed. Such so-called "no-injury" rules, combined with the "wet water" policy (designed to ensure that water is physically available for a trade at the specified time and place) define more precisely the quantity of water available for trade, the source of water (surface water or groundwater), and the approval process with which a seller has to comply. The seller generally bears the cost of demonstrating that a water export will not affect other users, which requires a closer look at the hydrological and legal aspects of the trade (Easter and McCann, 2010). For any transfer of water, a public notice and approval by at least one of the competent authorities is required (depending on the type of water right traded, federal and/or state environmental agencies), implying a non-negligible investment in time and money.

Furthermore, the concern from the area of origin over potential environmental, economic or pecuniary externalities has led some local authorities to implement groundwater ordinances (Hanak, 2003). Such rules are generally designed to restrict groundwater extraction for the purpose of exporting water outside of county boundaries. These ordinances do not prohibit such trades, but they require potential sellers to undertake costly studies to document the potential effects of groundwater exports (Hanak, 2003). Using panel data on trading, Hanak (2005) finds that the widespread adoption of ordinances reduced exports from 1996 to 2001 by 20%, increased within-county trades by 65%, and lowered the overall volume traded by 11%. As of 2014, 22 of California's 58 counties had implemented such ordinances (Hanak, 2015). Such transaction costs are generally seen as a major impediment to water transfers because the required up-front investment can discourage market entry (McCann and Easter, 2004; Carey, Sunding and Zilberman, 2002).
Even in the absence of local ordinances, objections by source-region residents can also exert pressure on potential sellers to limit out-of-county trades. Holland (2012) reported the case of a potential transfer between Modesto Irrigation District (MID) and the San Francisco Public Utility Commission (SFPUC) where the City of Modesto and several local groups tried to block the contract even though the SFPUC offered a price 70 times higher than the local price. (MID ultimately chose not to finalize the transfer agreement.) As another example, a transfer from the Glenn-Colusa Irrigation District (GCID) to the Metropolitan Water District of Southern California (MWDSC) during the drought in 2009 was challenged several times by local groups, slowing down the approval process and finally preventing the transfer from occurring (Howitt, 2014 in Easter and Huang, 2014:90).

Ghimir and Griffin (2014) looked at such issues in Texas, focusing on the impact of differences in water districts' institutional setting to explain the relative low participation in trade among the irrigation districts (ID). The main idea is that IDs

are facing larger problems of coordination due to their decision rules. The authors show that such institutions lead to an internal over-use and external under-use of water. In this case, it is not a formal policy-induced cost (as with California's export ordinances) but rather a more diffused cost of lobbying activities and negotiating with different conflicting parties within the district or the county (Colby et al. 1989).

Finally, the conveyance cost encompasses all cost related to physically moving water from the seller to the buyer, and is thus principally related to infrastructure constraints. The cost of conveying water as well as the difficulties in accessing the network of canals and storage facilities for purposes of trading can discourage districts from water market entry (Israel and Lund, 1995). For California, a century of water supply-enhancing policy and investment endowed the state with a relatively well-developed conveyance infrastructure. But, nowadays this network is constrained (Hanak, 2015). In particular, the Sacramento-San Joaquin Delta, the crossroad for many north-south and east-west trades presents obstacles. Due to environmental concern, pumping from the Delta is restricted and limits the water availability for markets. In addition, a "wheeling charge" is usually required for using conveyance facilities for transfers. Chong and Sunding (2006) report the example of the water transfer between San Diego Water Authority and Imperial Irrigation District, which occurred in 1998. In this case, the facilities owned by the Metropolitan Water District of Southern California (MWDSC) were required to convey the water transferred but the MWDSC charged a wheeling price of 262 dollars/AF, which doubled the initial price that the San Diego Water Authority had to pay for this water.

The impact of distance on transfer costs

Figure 1 depicts the geographic scale of water transfers in short-term lease for a 17 years period. We divided the state into three geographic categories: the *county* if the seller and buyer are located in the same county, the *region* if the buyer is located in a contiguous county to the buyer, and finally *statewide* if the export of water goes beyond the contiguous county. Such depiction bolsters the statement in previous studies that water markets are predominantly local (Hanak, 2015). Indeed, together, county and regional transfers account for the lion's share (roughly 4/5) of water contracts, and they also dominate the volumes traded. In short, Figure 1 shows a strong bias toward proximity

Figure 1

The geographic pattern of water trade depicted in Figures 1 is in agreement with the transfer cost hypothesis described above. Indeed many such costs depend on the geographic scale of water transfers. For example, the groundwater ordinances make water export outside of the county boundaries particularly arduous and thus tend to bias trading to occur within-county. Similarly, pumping restrictions in the Sacramento-San Joaquin Delta hinder trades across longer distances (mainly north

to south of the Delta), even though northern counties tend to have more abundant water supplies available for trading.

Distance is also an important factor in conveyance costs, as the transferors have to bear the charge of carrying water through the California network plus the loss of water by evaporation or possible percolation into the ground. As assumed in the work of Chakravorty, Horman and Zilberman (1995), the longer the distance between the seller and the buyer, the higher is this conveyance cost. Finally, due to the geographic dimension of the Policy-Induced Cost, distance can raise the costs of search for potential partners. Because it is costly to ascertain the possibility to trade water over a long distance (with a higher risk of denial) and to learn about water conditions elsewhere, potential sellers might prefer to minimize search costs by seeking local buyers rather than by conducting a statewide search. Such propensity for proximity makes the market thinner and mostly regional. For Texas, Ghimir and Griffin (2014) present some evidences that the proximity between an irrigation district and an urban center increases significantly the propensity to trade water.

The fact that distance and other related costs are potentially important factors in water trade make the well-known gravity equation tool particularly attractive to study water markets in more depth. Indeed, this empirical method enables the analysis to account for any type of friction in an elegant manner. First introduced by Tinbergen (1962) to study the flows in international trade, the gravity equation is now widely used to explain many impediments that can enter in a bilateral interaction. In its naïve form, the trade (where i is the exporter and j the importer) is positively correlated with the economic size of both partners and negatively correlated with the friction's variable (such as distance), with σ being the elasticity parameter and G, a constant term[1].

$$Trade_{ij} \propto G \frac{Size_i \; Size_j}{\left(Frictions_{ij}\right)^{\sigma}}$$

The resemblance with the Newtonian equation gave the name to this economic tool, and it is particularly useful for analysis the frictions in many types of transfers. Furthermore, the multiplicative form make it easy to handle for theoretical modeling and empirical estimation, and it has been introduced in other fields of economics research such as migration (Anderson, 2011) and foreign direct investment (Head and Ries, 2008), and it can be applied in wide range of bilateral interactions (Head and Mayer, 2014). It is thus an interesting framework to study impediments in water markets and, with needed adaptations it can be applied to the context of this paper. The major difference between the gravity equation above and

[1] We do not provide here the theory behind the gravity equation and its multiple forms in the international trade context because it is not the purpose of this paper. While many improvements (in term of theoretical foundation and empirical strategy) have been added since its first use, the logic behind stays as explained in the text.

the original model in Tinbergen (1962) is that here transfer costs include both variable and fixed components, whereas Tinbergen's model included just variable costs.

Fixed and variable components of the transfer cost

The mean transfer cost of 6% of the transaction price found in Colby (1990) does not reflect the important variation in transfer cost. Brown et al. (1992) estimated a transfer cost ranging from 2 dollars per acre-feet (AF) to 1,384 dollar/AF, and in other studies, transfer costs range from 3% to 70% of the total cost of water acquisition (MacCann and Garrick, 2014 in Easter and Huang, 2014 p12). The authors partly explain such a variation by a large fixed cost with a mean value of 474 dollars/AF if the transfer is below 5 AF, which falls to approximately 4 dollars/AF if the exchange is above 150AF (with a progressive increase from 5 to 150 AF). Carey, Sunding and Zilberman (2002) define such fixed costs as the cost for searching a potential trading partner. They demonstrate how this transfer cost can bias trade, within the same district, toward intra-network (identical canals) rather than inter-network (between different canals but still connected in the same district). Indeed, as developed in the previous section, the risk of denial increases with distance and the necessary sunk cost to enter into a water market spurs sellers to favor closer importer districts over farther districts. Again, some recent work in the field of international trade introduced a fixed component to the estimation of the gravity equation (Helpman, Melitz and Rubinstein, 2008; Chaney, 2008; Arkolakis, 2010 and Allen, 2014). Such specification is particularly attractive to explain the zeros in bilateral trade (the multiplicative form of the gravity equation implies that trade is never zero, which is obviously false in reality). Thus adding to the variable transfer cost, a fixed component for each participation in water markets allows us explain and predict the decision to enter into the water market and to explain the zeros in trade.

We identify several types of variable and fixed transfer costs (Table 1).

Table 1

Both variable and fixed transfer costs have an impact on the decision to trade (the so-called extensive margin of trade) but only the variable cost affects the quantity of trade (the intensive margin of trade). It is thus particularly important to disentangle these two types of costs in order to properly analyze their effects and understand the potential impacts of reforms that could reduce these costs.

THEORETICAL MODEL

In this section we develop a simple theoretical model to highlight impediments in the water trading process. We identify the variables representing the fixed cost of water trade and provide a foundation for the gravity equation estimated in the

empirical section. This model is relatively similar to that developed by Archibald and Renwick (1999), but we relax some of their assumptions to facilitate analysis of different types of transfer costs and to improve the tractability. This enables us to derive an analytical solution to the model.

The setup

Consider a discrete set of $n \in N$ water districts distributed over a continuum but finite space S. We divide the set N of districts into two separate groups: I and J where districts $i \in I \subset N$ are potential exporters and districts $j \in J \subset N$ are potential importers of water. Each district supplies water to a total number of $A_n > 0$ agents at a price $p_n > 0$ per AF and similar for all agents (i.e., district boards do not discriminate among members through heterogeneous rate setting). The cost per AF of water extracted by the district for its members is $c_n \leq p_n$. Each agent in each district only possesses one acre of land to produce a homogenous good considered as the numéraire. The total demand of water is thus $\overline{W}_n = \gamma_n A_n$ where $\gamma_n > 0$ is the consumption of water per acre, which is identical for all agents in the district n but different for each district (such that $\gamma_i \neq \gamma_j \; \forall \, i \in I$ and $\forall \, j \in J$). Finally, the total revenue without any trading activity for district n is $Y_n = p_n W_n$ and its profit, net of extraction cost is

$$\pi_n = \gamma_n A_n \left(\frac{p_n}{c_n} - 1 \right) \tag{1}$$

Under normal conditions, the water entitled to the district equates to total demand, such that no export or import is feasible unless a variation of structural parameters (such as demand of agents) occurs. It is worth noting that in reality there can be intra-district water trade among members, but in this study, we consider the district as the smallest entity. This implies that we need make the following assumption:

Assumption 1: *Within any district n,*
(i) The only source of water for agents is the water district supply and only the district can engage in water market activity.
(ii) There is no asymmetry of power between agents within the district.
(iii) Profit from the district's activity is redistributed to its members in equal shares.

This choice has been made for practicality, since relevant data are not available at the level of individual water users. This choice closely mirrors reality for urban districts, since inhabitants are not allowed to enter into the water market; only the district (granted with the water right) can. In agricultural districts, farmers sometimes have more autonomy, but they generally have to act through the district for water trades, implying the need for a coordination and agreement with other farmers in the district. Thus, it is rarely the case that individuals can export or import; it is more common that districts make such decisions. The second part of assumption 1 implies that we do not explicitly account for possible strategic behavior

of agents within the water district. However we do implicitly implement local pressure (in a simplistic form) through the fixed cost of transfer.

The first part of assumption 1 implies that the members of a district cannot have access to water except the quantity supplied by the district. The reality is more nuanced. While this holds true for urban districts where inhabitant rarely get their own water supplies, it might be oversimplified for the agricultural districts where farmers can dig their own wells to extract groundwater without any control on the part of the water district. However, in the theoretical model, this fact does not change the results, as we have assumed that all members are identical within the district.[2]

The second and third parts of assumption 1 imply no inequalities among members within the district. From equation (1), the income earned by each member is $\pi_n/A_n = \gamma_n(p_n/c_n - 1)$. Considering individuals or districts is thus exactly identical and will not change the qualitative results of the model. This assumption implies that the district will maximize its profit to redistribute the maximum income to its members, considering that a district is only a surrogate for individual members' behavior. A more sophisticated model (see for example McCann and Zilberman, 2000) could be developed taking into account specific power in the decision making process and inequalities of endowment, financial constraints, or income within each district. Without accurate and complete data on such factors, however, it becomes impossible to test this, and so is not relevant in this study.

Inter-district water markets

During a drought, the demand of a subset J of districts could exceed the current supply. This makes water exchange between districts economically possible, leading to an inter-district water market. A share z_{ij} of agents in a potential importer district $j \in J$ would need a certain quantity of water from the exporter district $i \in I$. District i has thus the possibility to sell a share $x_{ij} \in [0; 1]$ of its water endowment to district j at a price $p_{ij} > 0$. This price is negotiated before the transfer takes place and depends on the negotiated price and the extraction cost from water sources inside the importer district.

A seller/exporter has to incur the transfer cost (combination of transaction and conveyance cost), which is defined as the sum of the resources necessary for the transfer to occur (similar to Carey, Sunding and Zilberman, 2002). As explained in the section on transfer costs above, we differentiate between a variable and a fixed transfer cost but both are dependent on the distance D_{ij} between i and j.

[2] This will be a source of concern for the empirical application, which we solve by using an approximation of water consumption per district rather than water supplies.

Assumption 2: *Within the space S, every district $i \in N$ is located at a non-zero distance from a district $j \in N$ and $i \neq j$ such that $D_{ij} \in]0; S]$.*

Assumption 2 is obvious as it implies that districts have clear, non-overlapping boundaries. This makes it relevant to use distance as a metric and ensures that a solution exists to the model. Based on assumption 2, we can define the two following assumptions on transfer costs:

Assumption 3: *Within the space S,*
(i) The variable cost is dependent upon the quantity of water transferred x_{ij}, the distance D_{ij} from the potential buyer and infrastructure limitation through the Sacramento-San Joaquin Delta T_{ij}^{delta}.
(ii) Every unit of water transferred from i to j is subject to an increasing marginal cost of $x_{ij}\tau(D_{ij}; T_{ij}^{delta})$ with $\tau(D_{ij}; T_{ij}^{delta}) > 1$.
(iii) The transfer cost is increasing with distance and infrastructure limitation such that: $\frac{\partial \tau(D_{ij};T_{ij}^{delta})}{\partial D_{ij}} > 0$ and $\frac{\partial \tau(D_{ij};T_{ij}^{delta})}{\partial T_{ij}^{delta}} > 0$

With assumption 3, we define the variable transfer cost as a marginal loss of water value equals to $1 - \tau_{ij}x_{ij}$. Thus for each AF of water with a unit value of p_{ij}, a share $\tau_{ij}x_{ij}$ is lost during conveyance from i to j such that the real revenue per agent is $p_{ij}x_{ij}(1 - \tau_{ij}x_{ij})$. It implies that there exists a threshold equals to $1/(2\tau_{ij})$ where:

$$\frac{\partial p_{ij}x_{ij}(1 - \tau_{ij}x_{ij})}{\partial x_{ij}} > 0 \quad for \quad x_{ij} < \frac{1}{2\tau_{ij}}$$

$$\frac{\partial p_{ij}x_{ij}(1 - \tau_{ij}x_{ij})}{\partial x_{ij}} < 0 \quad for \quad x_{ij} > \frac{1}{2\tau_{ij}}$$

And it is straightforward to see that $x_{ij}(1 - \tau_{ij}x_{ij}) < x_{ij} \ \forall \ x_{ij} > 0$. The limit of unity imposed for the variable transfer cost ensures that the share of water allocated to transfer is less than one (however, this condition could be easily relaxed with some cautions on the value of parameters).

The reason for this functional form can be better understood if we consider the situation where x_{ij} correspond to the share of water entitlement planned for export and $x_{ij}(1 - \tau_{ij}x_{ij})$, the actual share of the water entitlement that can be exported. For value of x_{ij} close to one the difference between the planned and the actual export is low but as long as x_{ij} increases, the supplemental quantity of water that can be conveyed is diminishing until it reaches the threshold $1/(2\tau_{ij})$, which correspond to

the potential amount of water that can be exported[3]. Beyond that value, any intention to export $x_{ij} > 1/(2\tau_{ij})$ implies an actual ~~real~~ export of less than $1/(4\tau_{ij})$.

It is worth noting that the variable transfer cost is dependent not only on distance but also on other variables. We define two districts as being close to each other in terms of the variable transfer cost and in terms of geographic distance. Thus for three district i, j and k (all within N), we say that i is closer to j than k if $\tau_{ij} < \tau_{ik}$.

Assumption 4: *Within the space S,*
(i) The fixed cost is independent of the quantity of water transferred but dependent on the distance D_{ij} from the potential buyer and from the Policy Induced Cost and other infrastructure limitation T_{ij}^{c}.
(ii) Each seller willing to engage in water trade has to pay a fixed transaction cost $F(D_{ij}; T_{ij}^{c}) > 0$.

Following assumptions 1, 3 and 4, we can define the profit function of a district i when engaging in water trading activity with a district j:

$$\pi_{ij} = \gamma_i A_i\left[z_{ij}x_{ij}p_{ij}(1 - \tau_{ij}x_{ij}) + p_i(1 - z_{ij}x_{ij})\right] - F_{ij} \qquad (2)$$

The maximum value of x_{ij} is $1/\tau_{ij}$ because the revenue from trading activity (first term in the bracket) is then negative and thus induces a loss compared with the profit when $x_{ij} = 0$. In this formalization, the cost of water supply c_i is included as part of the fixed cost as we assume that water entitlement is fixed for any district.

Figure 2 depicts the profit function expressed in equation (2) with two different values of τ_{ij} (assuming that $\gamma_i A_i = z_{ij} = 1$). The linear function $y_i = p_i x_{ij}$ is the value of the share x_{ij} of water within the district. It represents the opportunity cost of exporting the share x_{ij} of water instead of serving members inside district i. The inverted U shape function $y_{ij} = z_{ij}x_{ij}p_{ij}(1 - \tau_{ij}x_{ij})$ is the revenue from water trading activity and represents the gains from engaging in water trading after having settled the fixed cost F_{ij}.

When the variable transfer cost increases, the profit and the optimal quantity of water for export fall (moving from continuous lines to dashed lines).

Water availability
The total amount of water that can be extracted by the district for both activities (distribution to its members and exports outside of the district's boundaries) is

[3] Inserting the threshold into the actual water export $1/(2\tau_{ij})$ yields the potential amount of water exported as $1/(4\tau_{ij})$

limited by the district's water entitlement. But as we have formalized in the previous section, the quantity of water exported is reduced by the quantity of water served to its members. Thus when an exporter district exports water to multiple importer districts in the same water year, the quantity of available water is decreasing in a discrete manner each time a water transfer is contracted. The quantity of water available for possible export from i to j depends on the share of water previously traded μ_{ij}, which can be expressed as follows.

$$\mu_{ij} = \left(1 - \sum\nolimits_{k \neq j} z_{ik} x_{ik} \mu_{ik}\right) \tag{3}$$

and

$$W_{ij} = \mu_{ij} \gamma_i A_i = \gamma_i A_i \left(1 - \sum\nolimits_{k \neq j} z_{ik} x_{ik} \mu_{ik}\right) \tag{3.1}$$

where k stands for districts that have been served by district i prior to the transfer to j. For the first contract in the water year, $W_{ij} \equiv \bar{W}_i = \gamma_i A_i$, but any subsequent transfers are subject to the water constraint of equation (3). We impose as a condition that $W_{ij} \geq 0$, which comes naturally as $x_{ik} < 1$ and by the definition $z_{ik} < 1$. Thus, the quantity of water available for trade is always positive but diminishes to zero as exports increase. This condition also implies that if the value of W_{ij} gets too low, the district will cease search activity, as the probability of finding an importer district offering a sufficiently high price for a low quantity of water is decreasing.

The intensive and extensive margins of water trade

So far, we have set the different assumptions needed in this model and presented the situation of each district with respect to water markets. In this section we determine analytically the extensive and intensive margins of trade. The former corresponds to the decision to trade or not and the latter refers to the quantity of water (in acre-feet) that a district i will transfer to a district j when a contract has already been agreed upon. For each district willing to enter into the water market, the extensive margin question has to be answered before the intensive margin question, however here, we first calculate the intensive margin because it is the determining factor in the decision to finalize a water contract.

The intensive margin of water trade

Using equation (2) and plugging the constraint of equation (3) into it, we get the profit function

$$\pi_{ij} = W_{ij}\left[z_{ij} x_{ij} p_{ij}\left(1 - \tau_{ij} x_{ij}\right) + p_i(1 - z_{ij} x_{ij})\right] - F_{ij} \tag{4}$$

Solving the derivative of (4) with respect to x_{ij} gives the optimal share of water that can be traded by district i with district j.

$$x_{ij}^{*} = \frac{p_{ij} - p_i}{2\tau_{ij}p_{ij}} < 1 \quad \forall\, p_{ij} > p_i \;\text{ and }\; \tau_{ij} > 1 \tag{5}$$

It is straightforward to see and quite intuitive to understand that the quantity of water traded by i is decreasing with the variable transfer cost (τ_{ij}), and the price of water inside district i, (p_i), is increasing with the price of water in the inter-district water market (p_{ij}). With assumption 3 and as $p_{ij} \geq p_i$, the optimal share of water x_{ij}^{*} exported never exceeds the unity.

In this setting, the exporter district will not decide to simultaneously sell water to multiple importer districts. We assume a sequential choice during the water year where district i perceives multiple potential importer districts and moves from one to another until the water availability for its own activity reaches a specific threshold. We can express such availability by

$$W_{ij} = \gamma_i A_i \left(1 - \frac{1}{2}\sum\nolimits_k z_{ik}\mu_{ik}\frac{p_{ik} - p_i}{\tau_{ik}p_{ik}}\right) \tag{6}$$

Thus the total quantity of water traded between i and j in AF is given by $X_{ij} = z_{ij}x_{ij}^{*}W_{ij}$. Substituting by (5) and (6) yields

$$X_{ij} = z_{ij}\gamma_i A_i \left(1 - \frac{1}{2}\sum\nolimits_k z_{ik}\mu_{ik}\frac{p_{ik} - p_i}{\tau_{ik}p_{ik}}\right)\frac{p_{ij} - p_i}{2\tau_{ij}p_{ij}} \tag{7}$$

The extensive margin of water trade

Equation (7) is a depiction of the quantity of water exported. However this sole equation is not sufficient to explain the low occurrence of water trade observed in reality. While we can explain some zero trades with water availability W_{ij}, it is the hypothesis that most of the bilateral zero trade values are due to a fixed cost which prevents some districts from entering into the water market. Indeed, it is unlikely that the decision not to trade is only due to a lack of water available for trade. We thus implement a fixed cost F_{ij} defined in assumption 4.

Plugging (5) into (4), we can calculate the profit from an optimal export of water:

$$\pi_{ij} = W_{ij}\left(p_i + z_{ij}\frac{\left(p_{ij} - p_i\right)^2}{4\tau_{ij}p_{ij}}\right) - F_{ij} \tag{8}$$

It is straightforward to see that a water district will enter into the water market if and only if profit from exporting a share of its water endowment exceeds the profit from using its total water endowment for the district's members. Thus $\pi_{ij} \geq p_i W_{ij}$ and by using (8) with some rearrangement we define the function ψ_{ijt} and get the condition for trade to occur

$$\psi_{ijt} = z_{ij} W_{ij} \frac{\left(p_{ij} - p_i\right)^2}{4\tau_{ij} F_{ij} p_{ij}} - 1 \geq 0 \qquad (9)$$

We define the indicator variable I_{ij} such that

$$I_{ij} = \begin{cases} 1 & \text{if } \psi_{ijt} \geq 0 \\ 0 & \text{if } \psi_{ijt} < 0 \end{cases}$$

This indicator variable is the extensive margin of water trade and equals one if equation (9) holds and zero otherwise.

The water trading system

From the previous section and using equation (7) and (9), we can define the system of equations that explain water transfers. As we will empirically analyze the water market in a panel over a 17-year period, we introduce here a time subscript t (where t is an integer value from 1 to 17). All variables are time-dependent except the number of agents within a district A_i, which is assumed to be identical over time. We set $\omega_{ijt} \equiv \left(p_{ij} - p_i\right)/\left(2p_{ij}\right)$

$$X_{ijt} = I_{ijt} A_i \frac{z_{ijt} \gamma_{it} \omega_{ijt}}{\tau_{ijt}} \left(1 - \sum\nolimits_k \frac{z_{ikt} \mu_{ikt} \omega_{ikt}}{\tau_{ikt}}\right) \qquad (10)$$

$$I_{ijt} = 1 \iff \psi_{ijt} = p_{ijt} A_i \frac{z_{ijt} \gamma_{it} \omega_{ijt}^2}{\tau_{ijt} F_{ijt}} \left(1 - \sum\nolimits_k \frac{z_{ikt} \mu_{ikt} \omega_{ikt}}{\tau_{ikt}}\right) - 1 \geq 0 \qquad (11)$$

And the total number of importer partners that a district i has, is simply computed as follows

$$K_{it} = \sum\nolimits_j I_{ijt}$$

Equation (10) corresponds to the intensive margin of water trade and equation (11) to the extensive margin. It is worth noting that while the intensive margin of water trade (the quantity) is dependent solely on the variable transfer costs, and the extensive margin (the decision to trade) is dependent on both types of costs (variable and fixed) in a multiplicative relation. By using the system of equations above, it is now possible to derive some results from the theoretical model.

Proposition 1: *Everything else equal for a district $i \in N$, an increase of*
(i) The variable transfer cost τ_{ikt} in trading with district k and with district $j \neq k$, while keeping τ_{ijt} constant, increases the water trade quantity with district j.
(ii) The variable and/or fixed transfer cost in trading with district k while keeping the variable and/or fixed transfer cost with district $j \neq k$ constant implies a higher probability of trade occurrence with district j.

(iii) The water market price p_{ij}, with p_{ikt} constant, implies a higher probability of trade occurrence with district j.

Proof: We can easily prove proposition 1 by taking the derivative of equation (10) and condition (11) with respect to τ_{ikt}.

$$\frac{\partial X_{ijt}}{\partial \tau_{ikt}} = I_{ijt} A_i \frac{z_{ijt}\gamma_{it}\omega_{ijt}}{\tau_{ijt}} \left(\frac{z_{ikt}\mu_{ikt}\omega_{ikt}}{\tau_{ikt}^2} \right) > 0$$

$$\frac{\partial \psi_{ijt}}{\partial \tau_{ikt}} = p_{ijt} A_i \frac{z_{ijt}\gamma_{it}\omega_{ijt}^2}{\tau_{ijt} F_{ijt}} \left(\frac{z_{ikt}\mu_{ikt}\omega_{ikt}}{\tau_{ikt}^2} \right) > 0$$

We thus can show that both functions are increasing with transfer costs to other districts. Similarly, we can prove (iii) of proposition 1 (recall that $\omega_{ijt} = (p_{ijt} - p_{it})/(2p_{ijt})$):

$$\frac{\partial \psi_{ijt}}{\partial p_{ijt}} = \frac{p_{ijt}^2 - p_{it}^2}{4p_{ijt}^2} \frac{z_{ijt}\gamma_{it}A_i}{\tau_{ijt}F_{ijt}} \left(1 - \sum\nolimits_k \frac{z_{ikt}\mu_{ikt}\omega_{ikt}}{\tau_{ikt}} \right) > 0 \qquad \blacksquare$$

From proposition 1 *(i),* the quantity of water traded with a district j depends on other potential partners $k \in N$ and more particularly on the ratio ω_{ikt}/τ_{ikt}. This ratio is always less than unity and can be interpreted as the increase in relative revenue from trade, net of variable transfer costs. The two other parts of proposition 1 ((ii) and (iii)) suggest that the decision to trade with a partner j depends on the ratio ω_{ikt}/τ_{ikt} but also on the total cost of transfers $\tau_{ijt}F_{ijt}$.

EMPIRICAL EVIDENCE

The framework presented in the theoretical model is associated with estimation challenges due to the highly non-linear nature of the equations. Furthermore, the limited coverage and reliability of data available at the district level is of particular concern for developing a structural estimation. Thus, in this section we provide empirical evidence by estimating a reduced form of the system of equations (10) and (11). Appendix A.1 describes the variables employed.

We use water trade data from California, which was collected at the water district level, and we construct a table of bilateral relations for 237 water districts distributed among 45 counties (of a total of 464 districts in 54 counties) over a period of 17 years. The selection of the sample followed elimination of districts for which we had insufficient or not reliable data. We eliminated also primarily small districts that are off the grid of conveyance facility or that they lack capacity to physically trade water (no link between them and the other districts). Finally, we didn't account for the Imperial Irrigation District as it has passed only one long-term

agreement with the MWDSC, which might bias the estimate (the long-term water transfer has been important in quantity and highly controversial among farmers).

Data Sources and Variables

The water trade (X_{ij})

The water trade $X_{ij}$is our endogenous variable and is collected at the water district level, appropriate to the bilateral estimation. This point can be considered as the main impediment on such empirical studies, because it is generally difficult to find sufficient data on water trade. Several previous studies attempted to use water trade data from the Water Strategist dataset. This source provides trading information for the Western United States, and it is particularly interesting because it gives also the prices for many transactions. Unfortunately, this database generally presents importers and exporters as a group of districts, which makes it impossible to use in a bilateral study. Such aggregation makes the analysis of transfer costs particularly difficult because it becomes impossible to differentiate between districts engaging in water markets and those who do not. We thus use the data set collected by Hanak and Stryjewski (2012) for water transfers in California from 1977 to 2011. This dataset accounts for most of the trade that occurred between districts, and it identifies each district. For more details on this dataset, see Hanak (2003) and Hanak and Stryjewski (2012).

While this dataset presents transfers during 1977 to 2011, the low occurrence of trade in early years and the lack of accurate data on districts' characteristics before the 1990's, led us to focus our analysis on the most recent 17-year period (1995-2011). Such a choice removed approximately one-fifth of the observations but allowed us to estimate a more robust model. We also decided to focus our estimation only on short-term water leases. Indeed, three types of water transfer are reported in the database: short-term (one-year) leases, long-term (multi-year) leases, and sales. (Sales are permanent transfers of water rights; multi-year leases vary from 2 to 75 years.)

As we focus on the extensive margin of trade, the low occurrence of long-term leases makes the estimates particularly difficult and unsuitable in our analytical context. Indeed, transfers costs associated with such long-term leases are generally very high for the first year (when the contract is enacted) and lower for the subsequent years. The transfer cost of water transfer decision in a long-term lease cannot be compared with the transfer cost associated with short-term lease. Furthermore, the geographic pattern of water transfers stays relatively similar with or without long-term leases. We thus drop this type of trade and analyze only short-term leases.

Trade frictions ($\tau(D_{ij})$ and F_{ij})

We need to estimate the impact of frictions that could exist between districts, but this information is not directly available. A classical assumption from the bilateral

trade studies is to approximate such variable by the distance between the exporter and the importer, which holds also in the context of water market. Indeed, as discussed in the section on transfer costs, the physical limitation on water conveyance and wheeling costs, which reach, in some circumstances a very high level, curb the incentive to transfer or even to search for potential trade partner outside of the region. We thus construct our variable of conveyance cost (expressed by the variable τ_{ij} in the theoretical model) by using the distance between the two districts and a binary variable that captures whether the districts are separated by the Sacramento-San Joaquin Delta.

In order to calculate the distance between districts, we use the GPS coordinates of each district's centroid of their area provided by Cal-Atlas database and approximate the distance using a "flying bird" approach represented by Vincenty's (1975) equation. The database does not report all districts; for those lacking a GPS coordinate we approximate with the coordinates of the district's office.

While it is expected that distance has a negative and significant coefficient, it is not the sole impediment to water transfers. The Sacramento-San Joaquin Delta is also a matter of concern for any northern transferor willing to trade water with a district located south of the delta. To account for this limitation, we use a binary variable T_{ij}^{delta} taking the value 1 if the potential transfer requires crossing the Delta and 0 otherwise. We consider that any districts located in San Joaquin County or further south must incur the supplemental cost of moving water through the Delta to receive water from any district located north of San Joaquin County. We use a factor variable that multiplies the income of the importer district with the dummy T_{ij}^{delta} in order to account for the effect of the expected price on the decision to cross or not the delta.

We assume that distance is also playing a role in the fixed costs of transfers, since geographic proximity is generally known to induce more exchanges. It is hypothesized that districts close to each other have more contact and hence greater ease of trading. We also account for other types of fixed costs with several other binary variables. County groundwater ordinances are included as T_{ijt}^{ord}, which takes the value 1 if the county is subject to a groundwater ordinance and 0 otherwise. This variable takes the value 0 when two districts are located in the same county because such regulation typically applies for transfers outside of a county's boundaries. It is time-dependent, as some counties have passed such restriction after 1995. We implement a factor variable which is intended to account for the capability of exporter district to overcome the fixed cost that are implied by ordinances. In order to do so, we multiply the dummy variable T_{ijt}^{ord} by the income of district i (Y_{it}).

We also include a binary variable that accounts for institutional networks within which trading is more likely because the approval process is easier – specifically

when districts are served by the same water supply project. (Technically, this often means the districts have contracts for deliveries of shares within the same overall water rights, which are held by the project operator). We consider the State Water Project (SWP), the Central Valley Project (CVP) and within the latter project, we differentiate between various types of projects (e.g., the Friant-Kern, the Madera, the Delta Mendota, the Tehama-Colusa, the San-Luis and Cross Valley Canal and deliveries from Sacramento and San-Joaquin river)[4]. Here we define the transfer cost $T_{ijt}^{pro} = 1$ if the districts are not located in the same project and 0 otherwise.

Finally we include a binary variable that captures the "learning" effect of participating in inter-district water market. We expect that when a district enters into the water market for the first time, frictions and thus fixed costs are higher, but repeated market participation confers experience and decreases transfer costs. Thus we define the variables $T_{it,trade}$ and $T_{jt,trade}$ equals to 0 if the district i or the district j has participated to water market before the year t.

The equation for the variable and the fixed transfer cost is:

$$\hat{\tau}_{ijt} = D_{ij}^{\delta_\tau} \prod\nolimits_c \exp(\beta_{\tau c} T_{ijt}^c) \qquad \hat{f}_{ijt} = D_{ij}^{\delta_f} \prod\nolimits_c \exp(\beta_{fc} T_{ijt}^c) \qquad (12)$$

Where δ_τ, δ_f and $\beta_{\tau,c}$ and $\beta_{f,c}$ are the estimated coefficient for the distance and the set of binary variables. We expect that all variable defined here will have a negative association with the bilateral trade expect for the factor variable which is expected to be positive.

District-specific data (Y_{nt}, W_{nt} and z_{jt})

Our theoretical model suggests that two district-specific variables should be included in the empirical model: the quantity of water used (W_{nt}) and the potential demand of water by each importer district (z_{jt}). The theoretical model would also need water price data but such information is not available. We approximate the variable ω_{ijt} by calculating an index as follow:

$$\widehat{\omega}_{ijt} = \frac{Y_{jt}}{Y_{it} + Y_{jt}}$$

Where $Y_{it}$and Y_{jt} are respectively the total income (net of treatment cost) of district i and j at time t. We extracted data for the first variable from the California State Controller's Office, which publishes annual financial reports for many special districts in California (including water districts). These reports provide district-level annual revenues and costs. To account for differences in water treatment cost between urban and agricultural districts (since the latter supply untreated water),

[4] Data of water deliveries from each canal can be found at: http://www.usbr.gov/mp/cvo/deliv.html

we subtracted treatment costs from the total operating and non-operating revenues. Due to some irregularities in this dataset, we needed to apply some transformations. We first corrected and completed this database by collecting financial reports provided on several districts' websites and calculated the moving average over a three-year period to reduce the effects of some extreme values; we also replaced missing values with an log-OLS estimation (independent variables are the mean income over the 17 years period and the year). Given the low share of missing values and the relatively low year-to-year variation in revenues, this method provides a relatively good approximation of the true value.

The second variable (W_{nt}) is the quantity of water used by each district. As we need to consider both urban and agricultural water use, we used two types of data sources for this variable. First, we approximated the quantity of water used by the district with the population served within the boundaries. For urban districts, we used water data as reported in Urban Water Management Plans, and include this quantity for each year in the 17-year analysis period. For agricultural districts, we use the service area multiplied by the evapotranspiration net of rainfall. For two-thirds of these districts, the surface area is taken from the database of Cal-Atlas. Information for the remaining third is extracted from official documents from the districts. All surface area values are expressed in acres. The evapotranspiration value is given by Land and Water use estimates (at county level) from DWR[5], which estimates the need for applied water depending on the agricultural production in each county. However the measures begins in 1998 and in order to fill in the missing value for 1995-1997 we use the California Irrigation Management Information System (CIMIS) database. This program collects climatic data from around 200 stations distributed throughout California. Because the CIMIS stations do not always correspond to the location of the districts, we calculated the weighted mean of ET_0 from CIMIS data to approximate the district location. The methodology is as follow.

In order to have a relatively close value of the weather condition in district $n \in N$, we calculate the distance as a "flying bird" between each station s in the entire State and district n. Then we calculate the weighted mean for evapotranspiration and rainfall:

$$ET_{nt}^{0} = \frac{\sum_s \left(\frac{d_{sn}^{max} - d_{sn}}{d_{sn}^{max} - d_{sn}^{min}} ET_{st}^{0} \right)}{\sum_s \left(\frac{d_{sn}^{max} - d_{sn}}{d_{sn}^{max} - d_{sn}^{min}} \right)} \quad \text{and} \quad R_{nt} = \frac{\sum_s \left(\frac{d_{sn}^{max} - d_{sn}}{d_{sn}^{max} - d_{sn}^{min}} R_{st-1} \right)}{\sum_s \left(\frac{d_{sn}^{max} - d_{sn}}{d_{sn}^{max} - d_{sn}^{min}} \right)}$$

Where d_{sn}, d_{sn}^{max}, and d_{sn}^{min} are respectively the distance, maximum and minimal distance between the station s and the center of district n. We then regress through

[5] Data accessible at : http://www.water.ca.gov/landwateruse/anaglwu.cfm#

OLS the calculated data from CIMIS and the data from DWR for the years 1998-2010 and predict values for 1995-1997 and 2011.

Finally, we constructed the potential demand for water by district j from district i (z_{ijt}) by simply using the total quantity of water W_{nt} as defined in the previous paragraph.

All the variables described in this section are assumed to have a positive impact on the bilateral water trade.

Summary statistics for regression variables

The following table provides the summary statistics of the continuous and binary variables included in our empirical model.

Table 2

The summary statistics suggest a large difference in the average distance between the whole dataset (upper panel) and the dyads with trade (lower panel). This shows a large bias toward proximity in the decision to engage in short-term trades.

Strategy and Estimation Issues

The gravity equation tool has been applied in numerous previous studies within the international trade literature, and many improvements in empirical methods have been introduced since Tinbergen (1962). More specifically, the recent contribution of Santos and Tenreyro (2006) addressed the problem of choosing the right econometric model. The classical way to estimate the gravity equation is to perform a log-linear OLS, with k explanatory variables Y_{ijk}

$$\ln(X_{ij}) = \alpha_0 + \beta_k \ln(Y_{ijk}) + \varepsilon_{ij}$$

However Flowerdew and Aitken (1982) showed that with this method the estimated coefficients are severely biased when the errors ε_{ij} are heteroskedastic (which is generally the case in bilateral trade models). The main reason is that trade data exhibit more variation for smaller volumes of trade, which implies an increase in the variance of ε_{ij}. Another, more technical, problem arises when the dependent variable has some zero values because the logarithm of zero is not defined. Several solutions have been proposed to deal with this issue. The simplest is to throw away the zeros from the database and perform the regression only on the non-zero observations (as in Brada and Mendez, 1985 and Bikker, 1987). This method is certainly not suitable in our case as we intend also to estimate the factors associated with no water trading (the extensive margin of trade). Simply suppressing the zeros would thus lead to an important selection bias and would allow us to only estimate half of the model (the intensive margin of trade expressed by equation (10)). Other methods imply the use of a Tobit model (Eaton and Tamura, 1994) or to keep the log-linear OLS and add for each dyad the term $\ln(X_{ij} + 1)$ as dependent variable instead of

$\ln(X_{ij})$ (as in Eichengreen and Irwin, 1995). As pointed by Santos and Tenreyro (2006), these two approaches will generally produce inconsistent estimators of coefficients, particularly when the proportion of zeros is high. In our estimation the non-zero trade data only represent approximately 0.14% of the total number of dyads of water districts. It is thus particularly important to have a model that can handle an estimation with such a large share of zeros.

The problem of the traditional method to estimate the gravity equations led some researchers to prefer other types of econometric models such as the Poisson family (Santos and Tenreyro; 2006). In this case the assumption is that the volume of trade is drawn by a Poisson distribution with a conditional mean as a function of the explanatory variables. Such a model is originally designed to estimate (non-negative) count data, but by imposing the assumption of integer value on trade volumes, we can use this distribution to estimate water trade. Thus, the equation to be estimated becomes:

$$X_{ij} = \exp(\alpha_0 + \beta_k \ln(Y_{ijk}))\varepsilon_{ij}$$

The first striking point is that, due to the multiplicative form implied by the Poisson distribution, the dependent variable is not log-transformed, which eliminates the issue of logs of zeros previously mentioned. Secondly, King (1988) showed that coefficients estimated by Poisson are consistent and generally efficient even in the presence of heteroskedastic errors. The reduced form that we will intend to estimate is as follows:

$$\hat{X}_{ij} = \alpha_0 \frac{\hat{\omega}_{ijt}^{\eta} W_{it}^{\theta_i} W_{jt}^{\theta_j}}{D_{ij}^{\delta_\tau} \left(\prod_c \exp(\beta_{\tau c} T_{ijt}^c\right)} \tag{12}$$

where γ, δ, η, β_c, θ_i and θ_j are the coefficients to be estimated. One problem with using Poisson is that it is no longer possible to disentangle the extensive margin from the intensive margin. We thus run a Probit regression with the similar right hand side variables using the probability of trade as the dependent variable.

$$P(\hat{X}_{ij} > 0) = \Phi \left\{ \frac{\hat{\omega}_{ijt}^{\eta} W_{it}^{\theta_i} W_{jt}^{\theta_j}}{D_{ij}^{(\delta_f + \delta_\tau)} \left(\prod_c \exp((\beta_{\tau c} + \beta_{fc}) T_{ijt}^c)\right)} \right\} + \eta_{ijt} \tag{13}$$

where Φ is the standard normal cumulative distribution function. To control for year heterogeneity, we introduce year fixed effects in both the Poisson and the Probit regressions.

Results

We first present the results for the Probit model (to determine the extensive margin of water trade), and then the results for the Poisson estimation (for the intensive

margin of water trade). As the model is in multiplicative form, we transform all variables into logs. The estimated coefficients are thus elasticities.

The extensive margin of trade

We start by estimating whether a given district decides to engage in trading. We test different forms for equation (13) to show the importance of the different transfer costs variables. For all models, we provide the pseudo R2, the AIC and BIC criterion and the measure of the Receiver Operating Characteristic (ROC). This last indicator can be viewed as the goodness of fit of the model. Column (I) tests the simplest model with almost no transfer cost variables. Column (II) includes the same variables as in column (I) but with the binary transaction cost variables. Finally, column (III) shows the results for all transfer cost variables.

The models presented in column (IV) and (V) correspond to the estimation for dyads between exporter districts and importer counties. In these cases, all variables for districts i are the same as in the three first columns, but j's variables are aggregated at the county level. We take the sum of W_{jt}, $\widehat{\omega}_{ijt}$ and the average for all bilateral transfer costs variables (D_{ij}; T_{ijt}^{pro}, T_{ijt}^{delta}). Results are shown in Table 3.

Table 3

In each model, we have introduced year fixed effects to control for climatic variability and unobserved heterogeneity over time. Most of the coefficient are significant at 1% percent level and show the expected sign.

Adding distance improves the robustness in both cases (districts-districts and districts-counties) as all criteria show better fitness. Furthermore, the distance variable exhibits a negative coefficient, which is in line with the theoretical model and indicates that districts would prefer to trade water with partners at closer distances. Similarly, inexperience in water market of i (T_{it}^{trade}) is negative and significant in all models, which implies that districts may be reluctant to participate in water exchanges.

County groundwater ordinances have also a strong negative impact on the decision to trade, and our results are in line with findings in Hanak (2005).

The factor variables are positive and significant at 1% implying that the income of the district affects trade decisions.

The extensive and intensive margin of water trade

We now turn to estimate both the extensive and the intensive margin of water trade (the quantity of water that was actually traded) using a Poisson regression. The

different columns represent the same data procedure as in the Probit estimate in Table 3: columns (I), (II) and (II) depict trade for districts-districts dyads, while column (IV) and (V) are for districts-counties dyads. Similarly to the Probit estimation, we use year fixed effect to control for heterogeneity across years.

Table 4

In this model, the Goodness of Fit (GOF) criterion, measured by Adjusted R-square, is obtained by regressing, using OLS, the predicted trade volumes against the observed values. It is not surprising to have a small GOF as the number of non-zero trades is relatively small in comparison with the total number of dyads. As depicted in Table 4, a relatively similar result as in the Probit estimates (Table 3) emerges. The inclusion of distance and trade experience allows significant increases of all goodness of fit criteria adjusted R^2 between prediction and observation and at the aggregate level, the predicted values with included distance variables double the explained variance. This suggests a particularly important and significant impact of the distance on participation in the water market.

Table 5 presents OLS regression results for correlation between aggregate observations and aggregate predictions. We sum the observed amount of water transfer for each exporter district (row 1) and for each exporter county (row 2) and regress it with the predicted coefficient of the three first models of the Poisson regression. We find a significant improvement of the adjusted R^2 between the simple model of column (I) and the complete model of column (III).

Table 5

It seems thus particularly important to include bilateral variables, including variables that capture transfer costs, in analysis of water market behavior.

POLICY IMPLICATIONS

The empirical evidence suggests that short-term water markets in California lack flexibility. Short-term leasing of water is a crucial type of trading because it allows a rapid and potentially easy adaptation to weather shocks as well as a learning process for participants on how water markets work (Culp, Glennon and Libecap, 2014). Given its non-definitive character (in contrast to permanent sales and even long-term leases) exporters and importers can adjust and experience water trade without experiencing a high risk from potential "mistakes". Long-term leases are not definitive, but as Hansen, Howitt and Williams (2012) show, a substantial number of long-term leases are for more than 20 years – far less flexible than short-term (one-year) leases. Thus smaller districts might be excluded from water markets as the up-

front cost for short-term lease and long-term leases are generally prohibitively high. Thus short-term lease appears to be more suitable to cope with unpredictable and extreme events such the drought that California is currently experiencing more specifically for smaller districts as they have not always the possibility to pay the sunk cost for long-term leases.

The major impediment to short-term trades seems to be search for a trading partner (extensive margin of water trade) due to the uncertainty and fixed transfer cost. Several improvements can be made to promote water markets.

A first and necessary intervention is to develop more comprehensive management of groundwater instead of imposing export ordinances. While some regions need to protect their water resources (and more particularly groundwater) from the risk of depletion, the ordinances discriminate against exports instead of regulating groundwater use more generally within the basin, thereby preventing transfers that might be welfare-enhancing (Hanak, 2005). The State of California recently took this path by adopting legislation that will require local agencies to manage groundwater basins sustainably. This may help districts determine whether they can export groundwater (or use it in substitution of surface water exports) under some circumstances. Other types of legal restrictions could also be clarified and implemented in a more comprehensive and flexible institutional setting, such as facilitating inter-project trade. Facilitating the search for trading partners is also important to enhance market participation. As pointed out by Culp, Glennon and Libecap (2014), an online platform – such as those operated in Australia's Murray-Darling Basin – could lower the fixed transfer cost of search.

Finally, encouraging better collection and management of information at the State level could facilitate the water market entry rate. The example of the State of Colorado is interesting in this regard, where most water trade is under the supervision of one water district: the Colorado Big-Thompson (Libecap, 2011). Such a system could provide a healthy balance between the necessary protection for third parties and lowering transfer cost to improve market flexibility.

CONCLUSION

In this paper we have developed a simple theoretical model and tested it to highlight the impacts of transfer costs on California water markets. While some of these costs are a legitimate means to protect a natural resource, rationalizing the trading process might allow traders to lower transfer costs without increasing risks of unintended externalities. The main result of this paper is that transfer costs impede transfers, likely limiting water users from benefitting from the advantages of water markets. Streamlining the institutional framework and developing more transparent administrative mechanisms seem to be necessary for increased trade.

This paper also contributes to the literature by presenting water trading within a micro-based trade theoretical framework, including the gravity equation, which allows studying the frictions in bilateral interactions. We show empirically that this approach provides insights into analyzing water trading. We believe that the theoretical model and the empirical inference developed in this paper could be applied and enhanced in future research to improve understanding of water markets.

However, further research should focus on improving the accuracy of the data collected and finding a good approximation of prices of water traded, which would make it possible to improve estimates of the impact of transfer costs. Limited information in our dataset on the seniority of water rights, which affects availability during droughts, may have affected our results. Such information is becoming available with the advent of new reporting requirement in the state.

REFERENCES

AITHER. 2014. The AITHER Water Markets Report 2013–14 review and 2014–15 outlook, Melbourne, Australia. Accessed on October 13, 2015 at http://www.aither.com.au/wp-content/uploads/2014/11/Aither-WaterMarketsReport-Oct2014.pdf.

AITHER. 2015. The AITHER Water Markets Report 2014–15 review and 2015–16 outlook, Melbourne, Australia. Accessed on October 13, 2015 at http://www.aither.com.au/wp-content/uploads/2015/08/Aither_WaterMarketsReport2015-FINAL-07Aug.pdf.

Albert, R., and A.L. Barabási. 2002. "Statistical mechanics of complex networks". *Reviews of Modern Physics* 74(1): 47–97.

Allen T. 2014. "Information Frictions in Trade", *Econometrica* 82: 2041–2083

Anderson, J.E. 2011. "The Gravity Model," *Annual Review of Economics*, Annual Reviews 3(1): p133-160

Archibald, S.O., and M.E. Renwick. 1998. "Expected Transaction Costs and Incentives for Water Market Development". In Easter K. W. and Rosegrant M. W. and Dinar A. Springer US, pp 95-117

Arkolakis, C. 2010 "Market Penetration Costs and the New Consumers Margin in International Trade", *Journal of Political Economy*, 118 (6): 1151-1199

Bikker, J. 1987. "An international trade flow model with substitution: an extension to the gravity model". *Kyklos* 40: 315–337.

Bjornlund, H., and J. McKay. 2002. "Aspects of Water Markets for Developing Countries – Experiences from Australia, Chile and the US". *Journal of Environment and Development Economics* 7(4): 767–793

Brada, J., and J. Mendez. 1985. “Economic integration among developed, developing and centrally planned economics: a comparative analysis”. *Review of economics and statistics* 67(4): 549–556.

Brander, J.A., and M.S. Taylor.1998. "Open access renewable resources: Trade and trade policy in a two-country model," *Journal of International Economics* 44(2): 181–209.

Brewer, J., R. Glennon, A. Ker, and G.D. Libecap. 2008. “Water Markets in the West: Prices, Trading, and Contractual Forms.” *Economic Inquiry* 46(2):91–112.

Brookshire, D.S., M.E. Colby, and P.T. Ganderton. 2004. “Market Prices for Water in the Semiarid West of the United States”. *Water Resources Research* 40:1-14

Brown, T.C. 2006. “Trends in Water Market Activity and Price in the Western United States.” *Water Resources Research* 42:1-14.

Brown, F. L., C. DuMars, M. Minnis, S.A. Smasal, D. Kennedy, and J. A. Urban. 1992. “Transfers of water use in New Mexicom”, Rep. 267, N. M. Water Resour. Res. Inst., Las Cruces.

Carey, J. M., and D.L. Sunding. 2001. “Emerging markets in water: a comparative analysis of the Central Valley and Colorado Big Thompson Projects”. *Natural Resources Journal* 41: 283-328.

Carey, J. M., D.L. Sunding, and D. Zilberman. 2002. "Transaction costs and trading behavior in an immature water market," *Environment and Development Economics*, Cambridge University Press, 7(04): 733-750

Chakravorty, U., E. Hochman, and D. Zilberman 1995. "A Spatial Model of Optimal Water Conveyance," *Journal of Environmental Economics and Management* 29(1), p 25-41

Chaney, T. 2008. “Distorted Gravity: The Intensive and Extensive Margins of International Trade”. *American Economic Review* 98 (4): 1707–1721.

Chaney, T., 2014. “The Network Structure of International Trade”. *American Economic Review*, 104(11): 3600–3634

Chichilnisky, G. 1993. “Global environament and North-South trade”. Standford Institute for Theoretical Economics, technical report No. 31

Chong, H., and D. Sunding. 2006. “Water markets and trading”. *Annual Review of Environment and Resources*, 31, p239-264

Colby, B.G. 1990. "Transaction Costs and Efficiency in Western Water Allocation," *American Journal of Agricultural Economics*, 72(5): 1184-1192.

Colby, B.G., A.M. McGinnis, K.A. Rait, and R.W. Wahl. 1989. “Transferring Water Rights in the Western States – A Comparison of Policies and Procedures” Natural Res. Law Ctr., Univ. of Colo. Sch. of Law 1989

Culp, P.W., and R. Glennon, and G. Libecap. 2014. “Shopping for Water: How the Market Can Mitigate Water Shortages in the American West”. Discussion paper, *Stanford Woods Institute for the Environment*, October 2014.

Dixon, L.S., N.Y. Moore, and S.W. Schechter. 1993. "California’s 1991 Drought Water Bank: Economic Impacts in the Selling Regions", RAND, MR-301-CDWR/RC, Santa Monica, California.

Easter, K.W., and L.M.J. McCann. 2010. “Nested institutions and the need to improve international water institutions”, *Water Policy*, 12(4): 500–516

Easter, K.W., M.W. Rosegrant, and A. Dinar. 1998. "The future of water markets: a realistic perspective." K.W. Easter, M.W. Rosegrant and A. Dinar. Boston, MA: Kluwer Academic Publishers, pp. 277-283.

Easter, K.W., and Huang Qiuqiong (Eds.) 2014. “Water Markets for the 21st Century: What Have We Learned?” Springer Netherlands.

Eaton, J., and S. Kortum. 2002. "Technology, Geography, and Trade," *Econometrica* 70(5): 1741-1779

Eaton, J., and A. Tamura. 1994. “Bilateralism and Regionalism in Japanese and U.S. Trade and Direct Foreign Investment Patterns”. *Journal of the Japanese and International Economies* 8 (4): 478 – 510.

Eichengreen, B., and D.A. Irwin. 1995. “Trade blocs, currency blocs and the reorientation of world trade in the 1930s”. *Journal of international economics* 38: p1-24

Flowerdew, R., and M. Aitkin. 1982. “A method of fitting the gravity model based on poisson distribution”. *Journal of regional Science* 22: p191-202

Ghimire, N., and R.C. Griffin. 2014. "The Water Transfer Effects of Alternative Irrigation Institutions” *American Journal of Agricultural Economics* 96(4): pp. 970-990

Governor’s Commission to Review California’s Water Rights Law, 1978. Final Report, Sacramento, California.

Griffin R.C. 1991. “The Welfare Analytics of Transaction Costs, Externalities, and Institutional Choice”. *American Journal of Agricultural Economics* 73(3) p. 601-614.

Griffin R.C. 2006. “Water Resource Economics: The Analysis of Scarcity, Policies, and Projects”. Cambridge, MA: MIT Press.

Haddad, B.M. 2000. "Rivers of Gold: Designing Markets to Allocate Water in California", Washington, DC: Island Press.

Hanak, E. 2003. "Who Should Be Allowed to Sell Water in California? Third-Party Issues and the Water Market". San Francisco, CA: Public Policy Institute of California.

Hanak, E. 2005. “Stopping the Drain: Third-party Responses to California's Water Market," Contemporary Economic Policy, Western Economic Association International, vol. 23(1), pages 59-77, 01.

Hanak, E. & Stryjewski E. , 2012. "California's Water Market, By the Numbers, Update 2012". San Francisco, CA: Public Policy Institute of California.

Hanak, E. 2015. "A Californian postcard: lessons for a maturing water market" in *Routledge Handbook of Water Economics and Institutions*. K. Burnett, R. Howitt, J.A. Roumasset and C.A. Wada. p.253

Hansen, K., R. Howitt, and J. Williams. 2015. "An Econometric Test of Water Market Structure in the Western United States". *Natural Resource Journal* 55:p 127

Head, K., and T. Mayer. 2014, "Gravity Equations: Workhorse,Toolkit, and Cookbook", chapter 3 in Gopinath, G, E. Helpman and K. Rogoff (eds), vol. 4 of the *Handbook of International Economics*, Elsevier: 131–-195.

Head, K., and T. Mayer. 2013. "What separates us? Sources of resistance to globalization," *Canadian Journal of Economics*, Canadian Economics Association, 46(4): pp.1196-1231

Helpman, E., M. Melitz, and Y. Rubinstein. 2008. “Estimating Trade Flows: Trading Partners and Trading Volumes”. *Quarterly Journal of Economics* 123 (2): pp 441–487.

Hollinshead, S.P. 2008. “Water is Not Liquid: Securitization, Transaction Costs, and California's Water Market”. *Columbia Journal of Environmental Law* 33 (2): p323

Howitt, R.E. 1994, “Effects of Water Marketing on the Farm Economy,” in H. O. Carter, H. J. Vaux, Jr., and A. F. Scheuring (eds.), Sharing Scarcity: Gainers and Losers in Water Marketing, Agricultural Issues Center, University of California, Davis, June.

Howitt, R.E., J. Medellin-Azuara, D. MacEwan, J.R. Lund, and D.A. Sumner. 2014. “Economic Analysis of the 2014 Drought for California Agriculture. Center for Watershed Sciences”, University of California, Davis, California. Available at http://watershed.ucdavis.edu.

Holland, J. 2012. “Modesto Irrigation District Kills Proposed Water Sale.” Modesto Bee. September 18.

Illingworth, W. 2002. “Analysis of Economic Impacts of Proposed Land Retirement in Westlands Water District,” draft prepared for Westlands Water District, September.

Israel, M., and J.R. Lund. 1995. “Recent California Water Transfers: Implications for Water Management” *Natural Resource Journal* 35 pp1-32

Jaeger, W.K. 2004. "Conflicts over Water in the Upper Klamath Basin and the Potential Role for Market-Based Allocations" *Journal of Agricultural and Resource Economics* 29 (2): pp.167-184

King, G. 1988 "Statistical models for political science event counts: bias in conventional procedures and evidence for the exponential Poison regression model." *American Journal of Political Sciences* 32:pp. 839-863

Lee, H., D. Sumner, and R. Howitt. 1999. "Economic Impacts of Irrigation Water Cuts in the Sacramento Valley", *Agricultural Issues Center*, University of California, Davis.

Lefebvre, M., L. Gangadharan, and S. Thoyer. 2012, "Do security-differentiated water rights improve the performance of water markets?" *American Journal of Agricultural Economics* 94 (5): 1113-1135

Libecap, G.D., 2005. "Chinatown: Transaction Costs in Water Rights Exchanges. The Owens Valley Transfer to Los Angeles," ICER Working Papers 16-2005, ICER - International Centre for Economic Research.

Libecap, G.D. 2010. "Institutional Path Dependence in Climate Adaptation: Coman's "Some Unsettled Problems of Irrigation"." *American Economic Review*, 101(1): 64-80

Libecap, G.D. 2011. "The Economic Institutions of Water", National Bureau of Economic Research Reporter, 2011

McCallum, J., 1995. "National borders matter: Canada-US regional trade patterns". *American Economic Review* 85 (3), 615–623.

McCann, R.J., and D. Zilberman, 2000. "Governance Rules and Managment Decisions in California 's Agricultural Water Districts". In Dinar, A. (Ede.), The Political Economy of Water Pricing Reforms, New York: Oxford, pp. 79-103.

McCann, L., and K. W. Easter. 2004. "A framework for estimating the transaction costs of alternative mechanisms for water exchange and allocation", *Water Resources Research* 40 (9)

Msangi, S. and R.E. Howitt. 2007. "Income distributional effects of using market-based instruments for managing common property resources," *Agricultural Economics* 37(s1): 249-259

Phelps, C.E., N.Y. Moore, and M.H. Graubard. 1978. "Efficient Water Use in California: Water Rights, Water Districts, and Water Transfers", RAND, R-2386-CSA/RF, Santa Monica, California,

Rauch, J. E. 1999. "Networks versus markets in international trade," *Journal of International Economics* 48(1): 7-35

Samarawickrema, A. & Kulshreshtha, S., 2009. "Marginal Value of Irrigation Water Use in the South Saskatchewan River Basin, Canada" Great Plains Research: A Journal of Natural and Social Sciences. Paper 999.

Santos Silva, J.M.C., and S. Tenreyro. 2006. “The log of gravity”, *The review of economics and statistics* 88 (4): 641-658.

Tinbergen, J. 1962. "Shaping the World Economy: Suggestions for an International Economic Policy". Twentieth Century Fund, New-York.

Trefler, D. 1995. "The case of the missing trade and other mysteries". *American Economic Review* 85 (5): 1029–1046.

Vincenty, T. 1975 “Direct and inverse solutions of geodesics on the ellipsoid with application of nested equations” *Survey Review* 22(176): 88-93. Available from: http://www.ngs.noaa.gov/PUBS_LIB/inverse.pdf

William, E. K., and L.MJ. McCann. 2010. "Nested institutions and the need to improve international water institutions." *Water Policy* 12: 500-516

Young, R.A. 1986. "Why are there so few transactions among water users?", *American Journal of Agricultural Economics*, 68: 1143–1151.

Table 1: Decomposition of transfer costs between variable and fixed components

Variable Transfer Cost	- Water loss through evaporation and percolation - Wheeling cost for using conveyance facilities (storage, canals and pumping) - Physical network limitation (Sacramento-San Joaquin Delta)
Fixed Transfer cost	- County groundwater ordinances - Inter-project transfers - Search for potential trading partners - Negotiation over prices, quantity and quality

Table 2: Summary statistics

Variables	Mean	Standard Deviation	Min	Max
The whole Sample (950,844 observations)				
share perenial crop	0.22	0.15	0.00	0.64
expected water price	0.50	0.35	0.00	1.00
water use (exporter)	9.39E+04	2.83E+05	1.50E+02	4.03E+06
water use (importer)	9.31E+04	2.81E+05	1.50E+02	4.03E+06
distance	352.89	232.64	0.01	1170.97
ordinance	0.41	0.49	0.00	1.00
different project	0.96	0.20	0.00	1.00
cross delta	0.39	0.49	0.00	1.00
income x ordinance	4.63E+06	2.06E+07	0.00E+00	4.27E+08
income x cross delta	4.41E+06	2.55E+07	0.00E+00	1.12E+09
trade experience (exporter)	0.63	0.48	0.00	1.00
trade experience (importer)	0.63	0.48	0.00	1.00
only trade (1374 observations)				
share perenial crop	0.33	0.12	0.01	0.64
expected water price	0.59	0.32	0.00	1.00
water use (exporter)	1.36E+05	2.29E+05	4.71E+02	3.94E+06
water use (importer)	3.36E+05	5.05E+05	1.21E+03	3.78E+06
distance	69.52	77.31	0.04	833.68
ordinance	0.23	0.42	0.00	1.00
different project	0.33	0.47	0.00	1.00
cross delta	0.02	0.13	0.00	1.00
income x ordinance	1.90E+06	8.27E+06	0.00E+00	1.39E+08
income x cross delta	3.08E+06	3.63E+07	0.00E+00	6.42E+08
trade experience (exporter)	0.04	0.19	0.00	1.00
trade experience (importer)	0.10	0.30	0.00	1.00

Table 3: Probit estimation

Variables	(I)		(II)		(III)		(IV)		(V)	
share perenial crop	**1.85**		**1.07**		**0.25**		**1.74**		**-1.21**	
	0.07	***	0.09	***	0.09	***	0.10	***	0.17	***
expected water price	**0.08**		**0.07**		**0.04**		**0.26**		**0.43**	
	0.01	***	0.01	***	0.01	***	0.03	***	0.05	***
water use	**0.13**		**0.09**		**0.06**		**0.23**		**0.22**	
(exporter)	0.01	***	0.01	***	0.01	***	0.02	***	0.02	***
water use	**0.14**		**0.15**		**0.14**		**0.21**		**0.17**	
(importer)	0.01	***	0.01	***	0.01	***	0.03	***	0.04	***
log(Distance)			**-0.37**		**-0.28**				**-0.55**	
			0.01	***	0.01	***			0.02	***
ordinance					**-0.41**				**-1.08**	
					0.15	***			0.24	***
different project					**-0.55**				**-0.75**	
					0.03	***			0.05	***
cross delta					**-3.38**				**-6.13**	
					1.05	***			1.07	***
log(income x ordinance)					**0.02**				**0.06**	
					0.01	*			0.02	***
log(income x cross delta)					**0.18**				**0.33**	
					0.06	***			0.06	***
trade experience			**-1.06**		**-1.00**				**-1.29**	
(exporter)			0.05	***	0.05	***			0.07	***
trade experience			**-0.59**		**-0.55**				**-1.24**	
(importer)			0.03	***	0.03	***			0.08	***
constant	**-6.26**		**-3.28**		**-2.75**		**-8.47**		**-2.52**	
	0.10	***	0.13	***	0.13	***	0.28	***	0.33	***
McFadden adjusted R^2	0.11		0.36		0.39		0.22		0.52	
AIC	18453.30		13355.45		12650.05		10124.94		6208.55	
BIC	-2032.30		-7094.85		-7741.43		-2730.84		-6566.37	
ROC	0.83		0.97		0.98		0.91		0.98	

Table 4: Poisson regression

Variables	(I)		(II)		(III)		(IV)		(V)	
share perenial crop	**5.35**		**3.38**		**1.94**					
	0.33	***	0.36	***	0.43	***				
expected water price	**0.51**		**0.45**		**0.47**		**0.22**		**0.37**	
	0.05	***	0.07	***	0.09	***	0.04	***	0.08	***
water use	**0.73**		**0.56**		**0.49**		**0.67**		**0.54**	
(exporter)	0.04	***	0.05	***	0.05	***	0.03	***	0.05	***
water use	**0.92**		**0.86**		**0.76**		**1.29**		**1.07**	
(importer)	0.04	***	0.04	***	0.04	***	0.05	***	0.09	***
log(Distance)			**-0.65**		**-0.51**				**-0.85**	
			0.02	***	0.02	***			0.08	***
ordinance					**-2.54**				**-2.55**	
					1.10	**			1.16	**
different project					**-1.15**				**-0.68**	
					0.16	***			0.14	***
cross delta					**-13.53**				**-15.52**	
					2.64	***			3.94	***
log(income x ordinance)					**0.15**				**0.14**	
					0.08	**			0.08	*
log(income x cross delta)					**0.73**				**0.82**	
					0.14	***			0.21	***
trade experience			**-3.16**		**-3.01**				**-3.00**	
(exporter)			0.30	***	0.30	***			0.30	***
trade experience			**-1.29**		**-1.22**				**-2.21**	
(importer)			0.17	***	0.18	***			0.32	***
constant	**-17.88**		**-10.13**		**-7.49**		**-21.66**		**-9.94**	
	0.86	***	0.88	***	0.89	***	0.89	***	1.43	***
McFadden adjusted R^2	0.27		0.437		0.468		0.322		0.576	
AIC	6.00E+07		4.63E+07		4.37E+07		4.45E+07		2.78E+07	
BIC	-2.22E+07		-3.60E+07		-3.85E+07		-2.11E+07		-3.78E+07	
GOF	0.0115		0.0262		0.0251		0.0147		0.0985	

Table 5: Goodness of Fit

	(I)	(II)	(III)
$\sum_j X_{ijt}^{k_i}$	0.0867	0.2309	0.2678
$\sum_{k_i}\sum_j X_{ijt}^{k_i}$	0.6471	0.7113	0.769

Figure 1: Short-term lease contracts numbers (Fig 1a) and volume (Fig 1b) of water transferred (1995 to 2011)

Figure (1a)

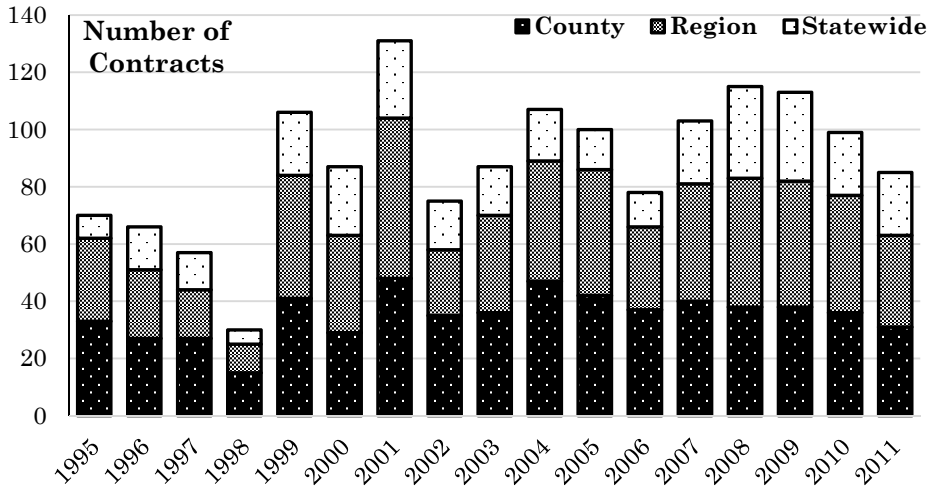
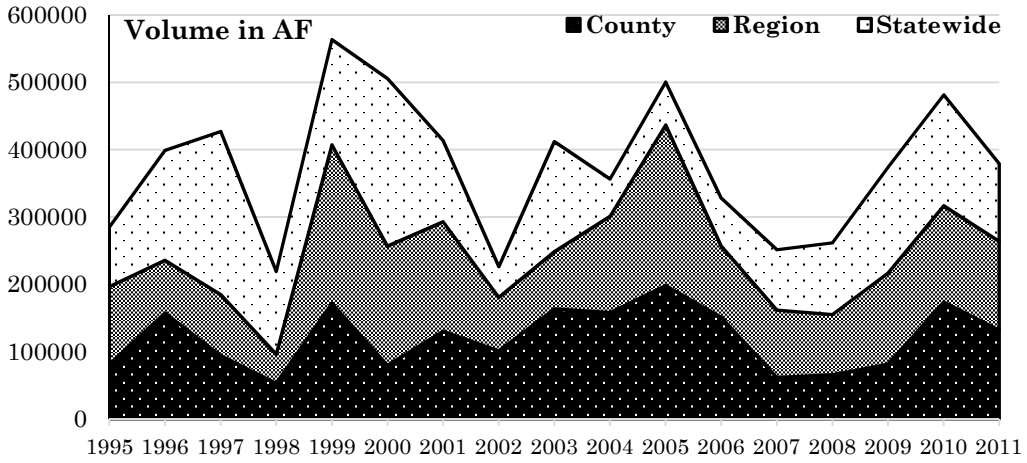


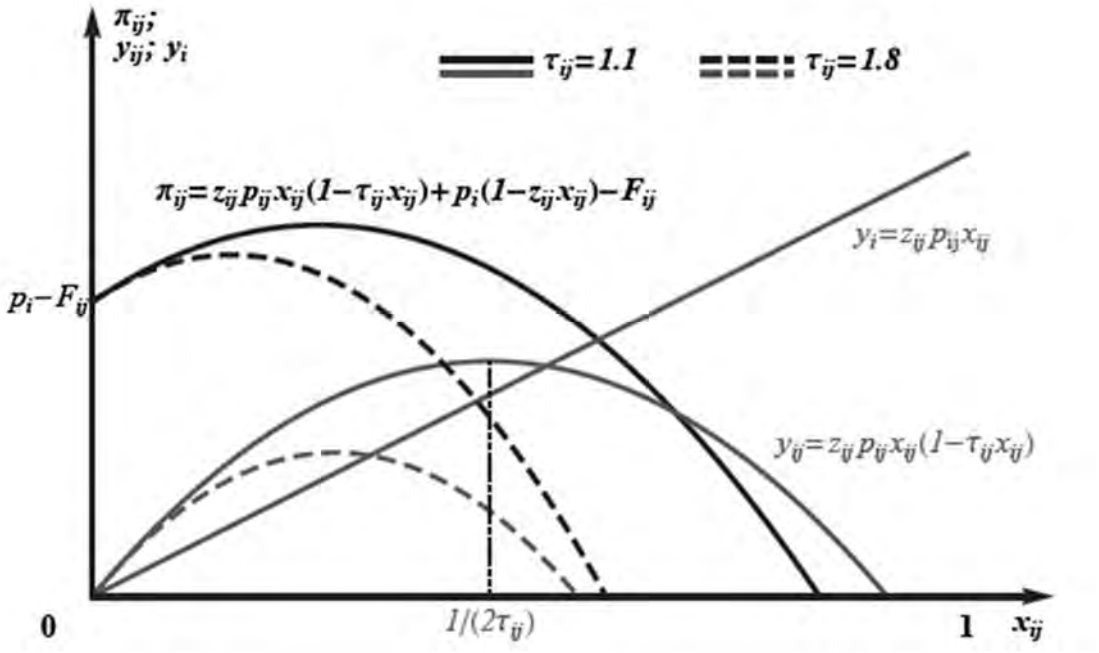
Figure (1b)



Source: See empirical section and Hanak and Stryjewski (2012) for more explanation on the data.

Note: In our analysis, we only consider short-term leases across water districts. This excludes a significant share of total water traded through long-term leases. However, long-term leases have a broadly similar geographic pattern.

Figure 2: The profit function

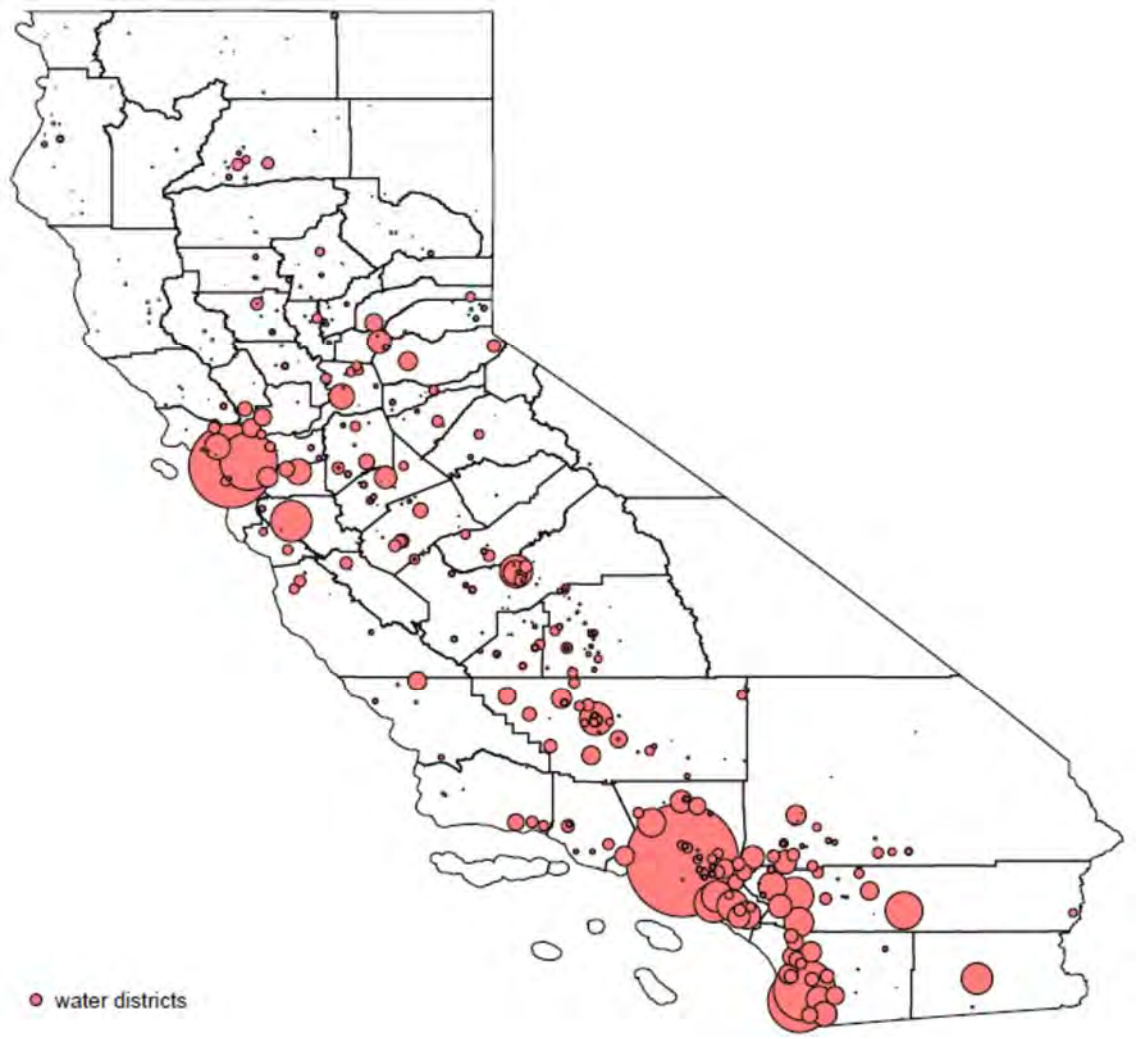


Values: $z_{ij} = 1$; : $\gamma_i A_i = 1$; $p_{ij} = 3.5$; $p_i = 1.5$; $F_{ij} = 0.5$ and $\tau_{ij} = 1.1$ (solid lines); $\tau_{ij} = 1.8$ (dashed lines).

Appendix A: Variables' definitions

variables		Definition	unit
share perenial crop	γ_{it}	Share of perenial crop for each county	Percentage
district's income	Y_{nt}	Adjusted income (net of water treatement cost) of the district	Dolars
district's water use	W_{nt}	water use in the district	Acre-feet
distance	D_{ij}	Distance between the exporter and importer districts	Kilometers
ordinance	$T_{ijt,ord}$	If the exporter county is subject to groundwater ordinance	Dummy
different project	$T_{ijt,pro}$	If exporter and importer district are not located into the same project	Dummy
cross delta	$T_{ijt,del}$	If exporter and importer district are on either side of the San Joaquin Delta	Dummy
trade experience	$T_{ijt,trade}$	If the district had never experienced the water market at the year t	Dummy

Appendix B: Sample district distribution within the State of California



Source: Map created by the authors.
Note: Each water district in our sample is depicted by a red circle with the size of the circle being proportional to its average revenue from water sales (in dollars) during the period 1995-2011.