Implications of Search Frictions for Tradeable Permit Markets

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Abstract

This study develops a framework of search with frictions in the context of tradeable permit markets to explain the trading behavior and search effort of the participants. The study area is the groundwater market of the Twin Platte Natural Resources District, in Nebraska. The results show that overall the market is moving towards Pareto efficiency as irrigation rights are moving from lower value users to higher value users. The results also suggest that quantity of the rights traded affects the search effort of the participants positively.

Introduction

Search frictions are major sources of efficiency loss in markets where participants engage in the process of finding one another. Examples of these markets are labor markets, marriage markets and housing markets. This study develops a framework of search with frictions in the context of tradeable permit markets to explain the trading behavior of participants in presence of search frictions. To my knowledge this study is the first to explore the implications of search frictions for environmental markets empirically.

The idea of tradable permits to reach an environmental goal goes back to Montgomery (1972). He established the theoretical grounds and proved that tradeable permits are the cost-effective way to control pollution. Since then economists through various theoretical studies promoted the use of these markets to protect environmental resources. Their efforts resulted in increasing interest of the Environmental Protection Agency (EPA) in using tradeable permit markets at national and regional levels (e.g lead trading program, acid rain program, and Regional Clean Air Incentives Market (RECLAIM) in California).

Although tradeable permit programs have been mostly successful in controlling environmental externalities at lower costs than other policies like command-and-control, their performance in practice have often came under question. One of the main critiques, specially at the regional level, is low participation rates[1]. Hoag and Hughes-Popp (1997) argue that

[1] In RECLAIM only 2% of permits were traded after 1.5 years. Also EPA projections showed a maximum

despite potential gains from trade in pollution credit trading markets, the most common feature of tradeable permit programs is low participation rates and trading volumes. One of the most notable examples is the Fox River tradeable permit program that saw only one trade taking place. Low participation rates in these markets have resulted in limited data hindering researchers' ability to analyze the performance of these markets.

One of the major factors that affect performance of tradeable permit markets are transaction costs. After the early models and applications economists mentioned that ignoring transaction costs could result in misleading results and poor design of the markets (e.g. Krupnick, Oates, and Van De Verg (1983) and Stavins (1995)). Transaction costs in this context are of two types: those of market transactions, i.e. making decision, search and bargaining; and implementation or administrative costs, i.e. establishing the market, monitoring and enforcement (Krutilla and Krause (2011)). While administrative costs are important and affect the efficiency of the market, these costs are usually born by the administration and not the participants. However, search and information costs are born by participants and are major sources of low participation and trading volumes in these markets. In a study of performance of US air pollution market, Hahn and Hester (1989b) conclude that the low number of external trades show that these markets have not reached their capacity despite substantial potential gains from trade. They argue that a major reason behind low participation in offset markets is "lack of readily identifiable offset sellers" rather than lack of demand.

Although transaction costs have been identified to be high, there has been little effort to study their implications empirically, perhaps due to lack of data. Kerr and Maré (1998) studied the efficiency of the lead phase-down market in presence of transaction costs[1]. They find that smaller companies, smaller refineries and "refineries that that do not have other

of 10% trade for SOx market (McCann (1996)).

[1] Although this market is considered one of the most successful examples of tradeable permit markets to date, 70% of transactions took place between refineries of the same companies. These internal trades could mainly be a result of better conservation practices or in the case of lead market transition towards using unleaded gasoline.

refineries to trade with within their company" are less likely to trade. The results also show that number of refineries in the company is very important in determining transaction costs. It can be understood from their results that most of the trades are carried out internally as a result of high search and information costs.

Gangadharan (2000) studied the RECLAIM in California addressing the questions regarding a firm's decision to participate in the market and the effect of transaction costs on the decision using a probit model. The study uses data from more than 2000 trades during 1995-96 from 350 facilities in NOx market. However the data used for this study is not facility specific and instead, aggregate level data is used as a measure of facility specific characteristics. The paper mentions that most facilities that trade multiple times tend to trade with the same trading partner and this could be due to high search costs. In order to estimate the effects of search costs the facilities were divided into two groups: those that traded multiple times (low search cost) and those that traded with different partners (high search costs). The results show that search and information costs can be significant and reduce probability of trade by more than 30%.

In the context of water resources, markets are being used to allocate scarce water resources, protect the streams and water bodies, and control water quality. However, most of the studies on water markets are ex-ante predictions of their performance and since they do not consider restrictions and transaction costs, they allow for more trading activity than can happen in practice (Chong and Sunding (2006))[1]. Most water markets are thin by nature: trades are bounded inside a basin or a district and the number of participants is limited (geographical thinness). As a result the data have not been adequate to study these markets in detail. There are other markets like the surface water markets in California that have experienced lager participation rates, but their data is not publicly available. Consequently, previous studies have only explored the aggregate performance of water markets[2]. However,

[1]For an example look at Vaux and Howitt (1984).

[2]In a study of two water markets in Gila and San Francisco sub-basins, in New Mexico, Colby, Crandall, and Bush (1993) show that search and information costs, and number of potential traders affect prices of the rights by comparing the general characteristics of the two markets. Howitt (1994) showed that California's

we need to better understand how water resources are being transferred among users, who buys and who sells, and also what this means in terms of efficiency of the market. These questions have not been studied in the context of water markets before.

This study develops a model of search with frictions to answer two major questions: first, how do parcel specific characteristics and market forces affect farmers' decision to trade their water rights? And whether the direction of trades follows predictions by economic theory? It also enables us to infer whether water is moving from sellers with lower value to buyers with higher value for it, i.e. whether the market is moving towards Pareto efficiency; second, what are the implications of search frictions for search effort of the participants in the market? How do these search frictions affect distances between buyers and sellers? In specific, how does trade volume and market participation rate affect distances between buyers and sellers? This study has a clear advantage over previous studies in terms of data availability and can give better information regarding the limitations of tradeable permit markets [1].

The econometric strategy is composed of two parts: the first part estimates the probability of buying and selling as a function of parcel specific characteristics by controlling for market conditions, and climate variables using a logit model. Since the ratio of trades over no-trades (ones to zeros) is very low, probabilities can be biased downwards. A rare event logit (RElogit) developed by King and Zeng (2001) is used to compare the results; the second part estimates the effects of quantity traded, on distance between trades controlling for spatial characteristics of buyers and sellers using OLS. To correct for selection bias into trading the rights a Heckman two-step model is also estimated and the results are compared.

This study contributes to the literature in two ways: first, having access to data at the

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1991 water bank created substantial overall economic gains for the state of California. Hansen, Howitt, and Williams (2007) et al look at the effects of market structure and hydrologic conditions on the style of trades, i.e. lease or sale in Western United Stated across different states and find evidence that institutions affect the style of trade.

[1] Tietenberg (2006) mentions three types of studies in assessing the performance of the tradeable permit markets: studies that focus on Pareto optimality, those that focus on cost-effectiveness, and studies on market effectiveness. Current study falls on the third category where unlike the first two it does not compare the current regulation with a baseline scenario (e.g. command-and-control) or global performance of the market and instead focuses on the performance of the market given the conditions.

farm level, it studies the actual performance of a tradeable permit market for groundwater. Second, although there are many studies acknowledging search and information costs in these markets, there has not been any study using the framework of search with frictions and their implications in practice.

The results show that overall the market has been effective in moving irrigation rights from lower value users to higher value users. This result suggests that although some previous studies on tradeable permit markets remain skeptical on performance of tradeable permit markets in local level where participants are "small, nonintegrated, and unsophisticated" Kerr and Maré (1998), this may not necessarily be the case. The results also suggest that trade volume affects the distance between buyers and sellers positively. The marginal effect is about 0.1 miles per acre for a seller and about 0.06 miles per acre for a buyer. This result suggests that there are also efficiency losses in the intensive margin of trade —something that has received less attention in the literature, i.e. those who decide to trade higher volumes search more and those who trade lower quantities search less. This is a loss in efficiency because in a well-functioning market with no search costs we do not expect to see any correlation between quantities and distance. This result suggests that providing information regarding potential traders can reduce these costs.

The paper proceeds as follows. In the next section, we introduce a general model of search with frictions in a tradeable permit market and further expand the model in more detail for a producer in a groundwater market. We then introduce the study area and the data. Following that we present the empirical approach, and finally, we present and discuss the results.

Model

In managing environmental and natural resources, tradeable permit programs are characterized by setting a limit (cap) on the aggregate amount of the resource depletion, issuing permits and allowing the participants to trade the permits. Initially, the permits could be grandfathered or auctioned off. The binding constraint on permits and profitability of using the resource creates a market where those who wish to acquire the permits buy them from those who are willing to sell their permits. Neoclassical models of competitive markets ignore the frictions of search for trading partners. They assume equilibrium price is publicly available and is a signal for buyers and sellers. As a result market clears at the equilibrium price. However, in reality, buyers and sellers in thin markets have to engage in a costly and time consuming search for a trading partner and at any time there are resources that are not reallocated in spite of demand. Search frictions have important implications for performance of markets in allocating resources between supply and demand sides (Mortensen (2011)).

This section consists of two subsections: the first one develops a general model of search with frictions in a tradeable permit market with capped homogenous input where profit of producing with the input is higher than producing without it; the next subsection studies the specific case of groundwater irrigation to explore the effects of parcel specific characteristics on profits of irrigated and dryland farming. The model provides hypotheses to be tested.

A model of Search for trading partner

This section explores the factors that affect trading activity and search intensity of buyers and sellers in presence of search frictions. The framework used is based on the ideas introduced by Mortensen (2011). Similar models have been used in understanding the performance of labor markets, housing markets, and marriage markets[1], but it has yet to be used in understanding the performance of tradeable permit markets. In this model buyers and sellers engage in a costly process of finding each other while maximizing their infinite stream of income. It is assumed that the decision is composed of two parts: maximizing the restricted profit function to get the quantity they want to trade, Q, and then looking for a trading partner maximizing their expected profits. This assumption means that the quantity traded is exogenous in search process. There are two explanations for validity of

[1] Rogerson, Shimer, and Wright (2004) surveys the studies and models in labor markets and provide several examples in housing markets and marriage markets.

this assumption: first, because this market is based on acres and farmers' decision to sell certain quantity is a result of drying certain acres, e.g. removing an endgun, or drying a land under center pivot the quantity has already been determined; second, there is an added layer of complexity from monitoring and enforcement costs to the market planner, e.g. in this specific market, in order for TPNRD to be able to monitor traded acres, they only allow certain amount of acres and shapes that can be easily monitored to be traded.

Buyers and sellers meet based on a matching function, $m(u, v)$ which is a function of number of the potential buyers, v, and the potential sellers, u. This function is increasing in both arguments, i.e. an increase in the number of either side will increase the flow of contracts. Further it is assumed that this function is homogenous of degree 1 in both arguments so that the meeting rates for buyers and sellers are only function of $(\frac{v}{u})$ which is called market tightness. The meeting rate for a seller is $\varepsilon_s = \frac{m(u,v)}{u}$ and for a buyer it is $\varepsilon_b = \frac{m(u,v)}{v}$. These meeting rates are exogenous to buyers and sellers.

For a potential seller the problem is whether to sell his permits at a price drawn from a known distribution or wait another period (to find another buyer). Assuming an infinite life for the farmer[1], if he decides to sell his water rights at price ω his payoff will be:

$$rW_s(\omega) \quad = \quad r\omega Q + \pi^0 Q \tag{1}$$

where r is the interest rate and it is assumed to be fixed over time, $W_s(\omega)$ is seller's payoff from selling the rights, Q is the quantity sold, and π^0 is per acre profit of producing without the input. Equation (1) shows that the payoff from selling the permits is equal to total amount that the seller receives plus the infinite stream of income from producing without the input. On the other hand the seller can keep his permits and wait to find another buyer:

$$rU_s \quad = \quad \pi^1 Q + \alpha_s \varepsilon_s \int_0^{\bar{\omega}} Max\{0, W_s(\omega) - U_s\} \, \mathrm{d}F(\omega) - g_s(\alpha_s) \tag{2}$$

[1]Alternatively we can assume a death rate with poison distribution, but it does not change the main results of the model.

where U_s is the payoff from not selling his rights in current period, π^1 is per unit profit of producing with the input, $\bar{\omega}$ is the upper limit of price of permits in the market, and $F(.)$ is the CDF of prices. The seller can increase the probability of finding a buyer, α_s, by increasing his effort, $g_s(\alpha_s)$, where $g_s^{'} > 0$ and $g_s^{''} > 0$. Equation (2) shows that the payoff of not selling the rights is equal to profit from producing with input plus expected gain from finding a buyer in the future and making a trade. Equations (1) and (2) form the Bellman equations for the seller.

Because $W_s(\omega)$ is strictly increasing in ω there exists a reservation price, R_s, where $W_s(R_s) = U_s$. It is the minimum price the seller is willing to accept to sell his permits. If he receives a price higher than reservation price he will sell his permits, while if the price is lower than R_s he will wait for another buyer. Solving equations (1) and (2) for R_s, we get:

$$R_s = \frac{\Delta\pi_s}{r} + \frac{\alpha_s \varepsilon_s}{r} \int_{R_s}^{\bar{\omega}} (1 - F(\omega))\, \mathrm{d}\omega - \frac{g_s(\alpha_s)}{Q} \tag{3}$$

R_s depends on the profit differential, $\Delta\pi = \pi^1 - \pi^0$, and the price per unit of permit, ω, less the per unit costs of search. Taking the first order conditions to get the optimal effort we have:

$$g_s'(\alpha_s) = \frac{\varepsilon_s Q}{r} \int_{R}^{\bar{\omega}} (1 - F(\omega))\, \mathrm{d}\omega. \tag{4}$$

Equations (3) and (4) explain the behavior of sellers in the market. It can be seen that profit differential positively affects reservation price. Besides, participation of buyers' side effects the trading activity of the sellers in two opposite ways: first, for a given reservation price, an increase in participation of buyers will increase the chance of meeting a potential buyer and thus increase seller's willingness to trade; second, an increase in the participation of buyers increases reservation price for a seller making him less likely to sell his permits. Labor market literature suggest that the former effect is stronger and thus an increase in the participation of buyers increases trading activity of sellers. However, prices in the market will increase as a result of higher reservation prices (Mortensen (2011))[1]. Notice that search effort only depends on volume of trade and participation in the market, and not on profits. The Bellman equations for a buyer are similar:

$$rW_b(\omega) = -r\omega Q + \pi^1 Q \tag{5}$$

$$rU_b = \pi^0 Q + \alpha_b \varepsilon_b \int_0^{\bar{\omega}} Max\{0, W_b(\omega) - U_b\} \,\mathrm{d}F(\omega) - g_b(\alpha_b) \tag{6}$$

The first equation shows the stream of income were he to buy Q units of permits and second equation shows the payoff from not buying the rights and continue producing without the input[2]. The reservation price for the buyer is defined as the maximum price he is willing to pay so that he is indifferent between using the input for production and not using it. solving equations (5) and (6) for R_b and α_b we have:

$$R_b = \frac{\Delta\pi_b}{r} + \frac{\alpha_b \varepsilon_b}{r} \int_0^{R_b} F(\omega) \,\mathrm{d}\omega - \frac{g_b(\alpha)}{Q} \tag{7}$$

$$g_b'(\alpha_b) = \frac{\varepsilon_b Q}{r} \int_0^{R_b} F(\omega) \,\mathrm{d}\omega. \tag{8}$$

From the reservation prices and optimal efforts for buyers and sellers we are able to produce two main hypotheses:

1. As a seller's profit differential goes up his reservation price goes up and he is less likely to sell his permits. As a buyer's profit differential goes up his reservation price goes up and he is more likely to buy permits.

2. As volume traded goes up search effort of the buyer or seller goes up[3]

Next subsection explains how parcel specific factors affect profit differential in the context of groundwater irrigation to further strengthen the first two hypotheses.

[1]In labor market literature Beveridge curve shows the relation between vacancies and employment.

[2]An advantage of this model over neoclassical model is the heterogeneity of buyers and sellers in their opportunity cost of trade. Instead of assuming that every agent can simply be a buyer or seller and obtaining demand and supply curves, here their opportunity cost depends on the type of activity they are engaged in.

[3]In the empirical analysis distance between buyers and sellers is used as a proxy for search effort

Effects of Parcel Specific Characteristics on Profit Differential

Caswell and Zilberman (1986) introduced a framework to study the effects of well depth and soil quality on irrigation technology adoption decision. They study conditions under which a profit maximizing farmer would choose to use modern irrigation technologies over traditional technologies. This part builds on their study and tries to explain how physical and spatial characteristics affect farmers' profit differential and thus their reservation price. This section assumes that water rights are defined per acre[1].

Let water use efficiency, $h_i(\mu)$, be a fraction of precipitation plus water applied to the land that is utilized by crop. let land quality, μ, be water use efficiency of the soil under no irrigation. Let $i = 0$ denote dryland and $i = 1$ be irrigated agriculture. Thus by definition $h_0(\mu) = \mu$ and $h_1(\mu) > \mu$ for $\mu \in (0, 1)$ because of land quality augmenting characteristic of irrigation. Let $h_1^{'}(\mu) > 0$ and $h_1^{''}(\mu) < 0$ so that irrigation increases land quality more for lower quality soils. At $\mu = 1$, $h_1(\mu) = \mu = 1$.

Let the per acre cost of irrigation for irrigated land be cost of pumping water and fixed costs of irrigation plus operating the land. I assume that the fixed costs are independent of the amount of water applied. Pumping cost is assumed to be a linear function of applied water. For dryland farming, costs are composed of only fixed operation costs and it is assumed that the fixed costs of irrigating are higher than fixed costs of not irrigating[2]. With this definition, costs of irrigated and dryland agriculture are:

$$C^1(.) = p_e e \gamma x(.) + K_1 \quad (9)$$

$$C^0(.) = K_0 \quad (10)$$

[1] In practice groundwater permits are defined in one of the two ways: assigning permits to the unit of volume of water extracted; or attaching them to the acres of land. In the former method pumps are metered while in the latter acres are monitored but there are no restrictions on the amount pumped from any certified acre. This study uses the latter to be consistent with the definition of permits in the study area.

[2] Based on crop budgets from University of Nebraska, Lincoln extension total per acre costs for dryland getting 125 bushels actual yield per acre of corn are \$444.87, while total per acre costs for center pivot irrigation getting 225 bushels actual yield per acre of corn is \$944.88. Total cost of pumping is estimated to be \$104.31. Thus fixed costs of irrigation (in the sense defined in this study) are much higher than those of dryland.

where p_e is the price of energy, e is the amount of energy needed to lift one unit of water one unit of depth, γ is the depth to water and $x(.)$ is the amount of water pumped (and applied) to the land. As mentioned $K_1 > K_0$. Production function is defined as a concave function and is assumed to be the same for dryland and irrigated agriculture:

$$f^1(.) = f(e_1) = f\big(Zh_0(\mu) + x(.)h_1(\mu)\big) \tag{11}$$

$$f^0(.) = f(e_0) = f\big(Zh_0(\mu)\big) \tag{12}$$

where Z is the average amount of precipitation. e_0 and e_1 are effective water, i.e. the amount of water utilized by crop in dryland and irrigated agriculture respectively. Notice that irrigation does not augment the quality of soil in utilizing precipitation. From equations (9) to (12) we can get the per acre profit functions:

$$Max\ \pi^1(.) = Pf\big(Zh_0(\mu) + x(.)h_1(\mu)\big) - p_e e\gamma x(.) - K_1 \tag{13}$$

$$Max\ \pi^0(.) = Pf\big(Zh_0(\mu)\big) - K_0. \tag{14}$$

Since the rights are defined on the acres of land being irrigated we can find the optimal per acre amount of applied water by maximizing per acre profits:

$$\underset{x(.)}{\text{Maximize}} \quad Pf\big(Zh_0(\mu) + x(.)h_1(\mu)\big) - p_e e\gamma x(.) - K_1 \tag{15}$$

The first order conditions are:

$$Ph_1(\mu)f'(Zh_0(\mu) + x(.)h_1(\mu)) - p_e e\gamma = 0 \tag{16}$$

$$\text{Or} \qquad Pf'\big(Zh_0(\mu) + x(.)h_1(\mu)\big) = \frac{p_e e\gamma}{h_1(\mu)} \tag{17}$$

Equation (16) shows that there is a specific level of applied water per acre $x^*(P, p_e, \mu, \gamma, Z, e)$ that maximizes per acre profits of irrigation and equation (17) shows that the value marginal product (VMP) of effective water is equal to price of effective water. An increase in price of effective water would result in a decrease in amount of water applied, $x(.)$. Since irrigation increases both revenues and costs, the question is under what conditions profit of irrigation is bigger than dryland farming. The comparative statics are derived to explain the effect of parcel specific characteristics (well depth and land quality), market forces (prices of diesel and output), and climatic conditions (precipitation) on profit differential.

Well depth only affects profit of irrigated agriculture. Taking the derivative of π^1 with respect to γ we have:

$$\frac{\partial \pi^1(.)}{\partial \gamma} = \left[Pf'h_1(\mu) - p_e e \gamma\right] \tfrac{\partial x(.)}{\partial \gamma} - p_e e x(.) = -p_e e x(.) \tag{18}$$

where the term in brackets is zero from the envelop theorem. Equation (18) shows that as well depth increases, irrigation cost increases and profit of irrigation decreases. When well depth is zero, $\gamma = 0$, profits of irrigated agriculture is greater than profits of dryland agriculture, $\Delta\pi > 0$, but as depth of well increases costs of irrigation go up, decreasing the profit differential between irrigated and dryland agriculture until at one specific well depth profits are equal. After this point irrigation does not make economic sense and the farmer sells the irrigation rights. Since at lower depths profit differential is higher we expect the farmers with lower depths to be less likely to sell and more likely to buy the rights.

Land quality increases profits of both irrigated and dryland agriculture. Since irrigation increases water use efficiency at a decreasing rate we expect that at a specific land quality profit differential is maximum. Taking the derivative of $\Delta\pi$ with respect to μ we have:

$$\frac{\partial \Delta\pi(.)}{\partial \mu} = P.\left\{ f'\big(Z\mu + h_1 x(.)\big)\left[Z + x(.)h_1'\right] - f'(Z\mu)Z \right\}. \tag{19}$$

For low land qualities, $h_1(\mu)$ is low and $h_1'(\mu)$ is high. Since price of effective water is high for low land qualities, their marginal value product is high and thus $\frac{\partial \Delta\Pi}{\partial \mu} > 0$ i.e. profit differential decreases as soil quality decreases. For high land qualities, $h_1(\mu)$ is high (it is equal to 1 at the maximum point) and $h_1'(\mu)$ is low (it is equal to zero when $h_1(\mu) = 1$). This means price of effective water is low and thus VMP of irrigation is low. For very high soil qualities $\frac{\partial \Delta \Pi}{\partial \mu} < 0$, i.e. as soil quality increases profit differential decreases. There is a soil quality, μ^*, between highest and lowest soil qualities that has the maximum profit differential. Farmers with low and high quality soils are most likely to sell while farmers with medium quality soils are least likely to sell. On the other hand, buyers with medium soil quality are most likely to buy and those with high and low soil qualities are least likely to buy.

Since price of output only affects the revenues and because the output of irrigated agriculture is always higher than dryland agriculture we would expect a higher price of output to increase the profit differential. On the other hand an increase in price of fuel only increases costs of irrigation and reduces the profit differential:

$$\frac{\partial \Delta \pi(.)}{\partial P} = f\big(Z\mu + h_1 x(.)\big) - f(Z\mu) \tag{20}$$

$$\frac{\partial \Delta \pi(.)}{\partial p_e} = -e\gamma x(.). \tag{21}$$

For any positive amount of applied water $\frac{\partial \Delta \pi}{\partial P}$ is positive and $\frac{\partial \Delta \pi}{\partial p_e}$ is negative, i.e. as price of output goes up or price of energy goes down the profit differential for every soil quality of sellers and buyers goes up. Finally to see the effects of changes in average precipitation, Z, on the profit differential the partial derivative with respect to Z is taken:

$$\frac{\partial \Delta \pi(.)}{\partial Z} = \big[Pf'\big(Z\mu + h_1 x(.)\big) - Pf'(Z\mu)\big]\mu. \tag{22}$$

The optimal amount of effective water for irrigated agriculture does not depend on precipitation. Thus for a given soil quality two cases can happen: if the amount of precipitation is low, VMP of irrigation is higher than VMP of dryland and an increase in precipitation increases profit differential; if the amount of precipitation is high then VMP of irrigation is lower than VMP of dryland and as precipitation increases profit differential decreases.

Prices and precipitation have a direct and an indirect effect on participation: they directly affect reservation prices through profit differential and indirectly affect reservation prices by affecting the reservation price of the other side of the market. As argued earlier mathematically the effect is ambiguous but labor market literature suggest that the effect of other side's participation is significant on one's trading activity.

Study Area

Twin Platte Natural Resources District

In 1969, 24 Natural Resources Districts (NRDs) were established based on L.B. #1357 in accordance with natural basins in Nebraska[1] (Figure 1). NRDs were originally designed for water development projects but their responsibility toward other land and water management, development and protection programs in the districts has increased over time. Twin Platte Natural Resources District (TPNRD) is responsible for management of land and water in Arthur and Keith Counties, the northern two-thirds of Lincoln County, and the western two-thirds of McPherson County in western Nebraska (Figure 2). To protect the stream level[2] , in 2004 Nebraska's Department of Natural Resources (DNR) designated TPNRD as fully appropriated which meant that no new acres could be irrigated in the district and only transfers of acres under irrigation was possible.

Major crop produced in TPNRD is corn. Acres under corn production is about 6 times larger than soybeans and almost 6 times that of wheat, the second and third crops produced in Nebraska. Most of the land under corn production is irrigated (acres under irrigation is about 2 times that of dryland). Based on reports from University of Nebraska extension, irrigated corn yields are on average more than 3 times that of dryland corn[3] and the gap is widening. This has created a high demand for irrigated corn in the state.

[1] A merger in 1989 reduced that number to 23 Natural Resources Districts.

[2] The purpose for protecting the stream was to protect the habitat for migration of whooping cranes (Grus americana).

[3] In 2012 the average irrigated yield was 190 bushels/acre, while average dryland yield was 59 bushels per acre

Market Structure

TPNRD is responsible for management of water resources within the district and have designed rules and regulations for water transfers. Trades can only take place inside the district. TPNRD has to approve the trades and is responsible for monitoring and enforcement of the trades and regulations.

Groundwater rights in TPNRD are based on the area of land under irrigation and there is no limits on the amount that can be pumped on those acres. Only permanent trades are allowed to take place by TPNRD and no leases or temporary transfers are allowed. In order to reduce the monitoring costs TPNRD only approves trades of either the whole parcel or certain portions of the parcel that can easily be monitored.

Transfers of water rights are based on a trading ratio called stream depletion factor (SDF) assigned to each parcel. SDF is an estimate of the amount of water depleted from the Platte River due to groundwater pumping. It is calculated mainly based on hydraulic conductivity, saturated thickness, storage coefficient, distance to the surface water feature and distance to the aquifer boundary. To ensure that withdrawal from the river does not increase with transfers, trades in the district are unidirectional, i.e. if the SDF of the new acres is less than that of old acres, number of acres transferred can remain the same, while if the SDF of new acres is higher than SDF of old acres, numbers of acres transferred should decrease proportional to the increase in SDF. TPNRD is expecting that by imposing this rule depletion from river will decrease over time.

Sources of Transaction Costs

There are two types of transaction costs in tradeable permit markets, costs of implementation and costs of transactions. The first group are those of designing the institutions, implementing the market, monitoring and enforcement. These costs are usually born by the governing body of the market[1]. In the case of TPNRD groundwater market monitoring costs are shared between the district and traders. Although TPNRD is responsible for monitoring, imposing limitations on acres traded passes some of the the costs to the traders.

On the other hand transaction costs for participants are those of gaining information about the market, making decision, search costs and bargaining costs. Search costs in this market, like most thin environmental markets, are significant. An evidence for high search costs is the dominance of internal trades and that most of the external trades take place between neighboring buyers and sellers[2]. TPNRD groundwater market is an informal market[3] and there were no brokers present in the market during the period of this study. Buyers and sellers had to search for potential traders which can be very costly. Since gains from trade increase when there are more heterogeneity between a buyer and a seller, and since there are spatial correlations in physical characteristics of parcels, close distances between traders could mean that traders forgo benefits of trading with more heterogenous partners due to high costs of finding a better trade.

Data

This study uses the data on 93 trades that occurred during 2005 and 2013. The data is a confidential dataset from TPNRD and contains the number of acres traded in each transaction and information about buyers and sellers including their geographic location. One of the advantages of the data over previous studies is that parcel specific characteristics[4]

[1] Sometimes traders bear the costs, e.g. in air pollution market participants were responsible for monitoring and reporting the amount of pollution.

[2] More than half of the trades happen within a distance of 5 miles(figure3).

[3] There are different definitions of informal water markets that depend on focus of the authors on different aspects of these markets. In a more general definition Carey, Sunding, and Zilberman (2002) consider it as an immature market where prices are not publicly known, in a study of Australian water markets Bjornlund (2004) consider it as a temporary transfer of rights rather than a permanent trade and Easter, Rosegrant, and Dinar (1999) define it by the difference in enforceability of the trades compared to formal markets. In this study I use a definition closer to Carey, Sunding, and Zilberman (2002), specifically, by informal market I mean the situation where trades are "coffee shop trades", i.e. search process usually consists of buyers or sellers looking for each other by asking around if there are others willing to trade.

[4] There are no parcel specific data available for dryland acres that do not trade. This is because they do not deplete the Platte River and are not of interest to TPNRD.

are available. A disadvantage of the data, though, is that it does not contain prices of trades.

Field level data include soil type, pump rate and depth to water. The data for well characteristics are collected from the Nebraska Department of Natural Resources (DNR) well database which is publicly available. The data on soil qualities are gathered from U.S General Soil Map (STATSGO) from Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture (USDA). Futures prices of corn and diesel are retrieved from Quandl futures database. Precipitation data for Noth Platte Airport station has been retrieved from National Climatic Data Center (NCDC) of National Oceanic and Atmospheric Administration (NOAA).

Table 1 shows mean values for field level characteristics of the parcels. First column shows certified irrigated acres that did not sell their rights during the period the market was active, while second column shows those that did sell their water rights. Column 3 shows dryland acres that remained dryland by the end of 2013, and the last column shows those that did buy water rights in this period and started irrigated agriculture. Since no parcel specific data are available for non-irrigating acres, I assume all the sections that are not fully irrigated, or are not in the lakes, towns or river, and do not have slopes above 10%[1] can be irrigated. Pump rates are in gallons per minute (gpm), and well depth is a measure of depth to water. Soil qualities are divided into 3 categories: low quality soils are sandy soils that are coarse and have low water holding capacity, high quality soils are loamy soils which have very high water holding capacity, and medium quality soils (silty soils) have water holding capacity between sandy and loamy soils.

From the first two columns of Table 1 it can be seen that pump rate and depth to water of irrigating acres that sell their water rights are lower than those that do not sell their water rights. Most of the decertified acres come from low quality soils. We also see that those that sell their rights have higher SDFs. From the last two columns it can be seen that those that buy water rights have higher pump rates and higher well depths[2]. Most buyers have medium

[1] TPNRD does not allow irrigation on acres with slopes higher than 10%.

[2] Although dryland acres do not irrigate they probably have some information regarding the wells and

quality soils and their SDF is higher than that of non-buyers. From the table it can also be seen that stream depletion factor is decreasing as a result of trades in the market (64.55 for sellers and 49.88 for sellers).

Table 2 shows the time trend of trades in the Twin Platte NRD[1]. Trades in this study only refer to external trades and internal trades are not included since there are no search costs for these trades. We can see from the table that during the first few years market activity was very low. Over time, the market has developed: number and volume of trades, and distance between buyers and sellers have all increased.

Although in a well-functioning market we would expect higher value trades take place earlier during the period when market is active, in our sample this is not the case. Higher value trades happen during later years of market activity. This can be because of lack of information about the market during the early stages of market activity and that information costs are high in the market.

Figure 3 shows the distribution of distances between new and old acres. As can be seen from this figure most of the trades have taken place within a 5 miles radius, i.e. between neighboring sections[2]. This can be an evidence of high search costs in the market.

Econometric Strategy

The empirical part of the study comes in two parts. The first one, explains the trading decision based on hypotheses derived from reservation prices of buyers and sellers (hypothesis 1), and the second part estimates the effect of volume traded on the distances between buyers and sellers (hypothesis 2).

quality of water on their section.

[1]Values are means at the respective year. No trade took place in 2006.

[2]Each section is approximately 2 miles by 2 miles.

Effects of Profit Differential and Market Participation on Probability of Trade

This section is related to hypothesis 1, and explains the empirical strategy to estimate the effects of parcel level characteristic on probability of trade. Based on the theoretical model the trading decision is a function of profit differential and the probability of finding a trading partner which depends on participation rate on the other side of the market, $R_i(\Delta\pi_i, \varepsilon_i)$. The covariates of profit differential are well depth, pump rate, soil type, SDF, prices of corn and diesel, and 1-year lagged precipitation[1]. Lagged precipitation is used because it is expected that the amount of precipitation during the past growing season affects farmers' expectation about the current season. Pump rate and SDF are not modeled in the theoretical model but it is expected that higher pump rates have a positive effect on profit differential, and parcels with higher SDF are expected to be more likely to sell (and less likely to buy) while parcels with lower SDF are expected to be less likely to sell (and more likely to buy) because of the unidirectional nature of trades. The participation on the other side depends on market forces, i.e. prices of output and input and climatic conditions, i.e. precipitation. The sellers will sell their water rights if $\omega > R_s$ and as R_s goes up a seller is less likely to sell. Buyers will buy if $\omega < R_b$ and a buyer is more likely to buy when R_b is higher.

Since the major crop in the district is corn it is assumed that corn is the only crop produced. Further it is assumed that all the irrigating parcels are using diesel as fuel. The unit of observation is a parcel of land at each year and the farmer owning an irrigated parcel makes the decision to sell the rights of irrigation to the parcel, and a farmer owning a dryland parcel decides wether to buy water rights to irrigate the parcel. In order to explain the effects of parcel specific characteristics on the probability of trading the rights two logit regressions for buyers and sellers are used. The data for sellers' regression comes from the subsample of irrigated parcels while the data for buyers' regression comes from the subsample of dryland

[1]For the sake of simplicity I use precipitation instead of 1-year lagged precipitation.

acres.

$$
\begin{aligned}
Prob(sell = 1|X) &= \tfrac{exp(\beta_0+\beta_1 X_1+\beta_2 X_2)}{1+exp(\beta_0+\beta_1 X_1+\beta_2 X_2)} && (23)\\
Prob(buy = 1|X) &= \tfrac{exp(\beta_0+\beta_1 X_1+\beta_2 X_2)}{1+exp(\beta_0+\beta_1 X_1+\beta_2 X_2)} && (24)
\end{aligned}
$$

where X_1 is a vector of parcel specific characteristics and X_2 is the price of diesel, price of corn, and precipitation. Since the number of events is much smaller than nonevents, King and Zeng (2001) argue that the intercept of the logistic regression might be biased downward which will underestimate the probability of events. They introduced a model called Rare Event logit (RElogit) that corrects for this bias in a manner similar to penalized likelihood models. I compare the results of logit and RElogit regression to see how the rareness of the data affect the probabilities.

Effect of Volume of Trade and Market Participation on Distance Between Buyers and Sellers

This section is related to hypothesis 2 and explains the identification strategy to estimate the effects of quantity traded and market forces on distance between buyer and seller. In this section, distance between buyer and seller is used as a proxy for search effort. This idea is based on the model of costly search in labor markets introduced by Howitt and McAfee (1987). They assume that workers are born at random location and look for firms taking a random direction. In their model search effort is defined to be the speed of search that the worker travels at through space to find a firm with vacancy. In the context of the market under study it is expected that closer distances between buyers and sellers could result in stronger ties between them and thus lower search costs. The following OLS regression estimates the effect of volume of trade on the distance between buyers and sellers:

$$E(distance_i|V) = \tau_{0_i} + \tau_{1_i} Q + \tau_{2_i} V \qquad (25)$$

where $i = \{seller, buyer\}$, Q is the quantity traded and V is a vector of price of diesel, price of corn, precipitation, SDF, and the ratio of irrigated acres over non-irrigated acres in a 2-mile radius. The idea behind using ratio of irrigated over non-irrigated land is to capture whether sellers who have higher densities of irrigated land around them are more likely to look longer distances for a buyer, and buyers with higher densities of irrigated land are less likely to look further to find a seller. We have also controlled for the difference between SDF of the seller and buyer. Since the main factor in SDF is the distance from the river, trades that happen with different distances from the river will have different SDF.

One important assumption in identifying the effect of quantity traded on distance is that quantity traded and distance are not simultaneously determined. As mentioned in the theory section the reason to believe this is the case is that the rights are defined based on acres and TPNRD does not allow the transfer of quantities of acres that are difficult to monitor, thus the decision to buy or sell the rights should be made before looking for a trading partner[1].

One issue that might arise is whether spatial autocorrelation can affect the interpretation of distance. Since the goal is to study the effect of quantity traded on distance, as long as the quantity traded is not correlated with the error term there is no problem. Our data suggests that quantities traded are distributed normally over different characteristics. Figure 5 shows a map of TPNRD with traded acres, where the shades of the sections show the propensity score for having agricultural practices on that section as a function of physical characteristics of the sections.

Another concern that might arise in the OLS model is selection bias. This bias comes from the possibility that those who decide to trade their water rights are different from those who do not trade on the unobservable characteristics. In order to control for this selection a Heckman two step regression is estimated. However this regression assumes that those who did not trade, did not participate in the market. This is a limitation of this study, because the data for those who participated in the market but did not trade is not available, instead,

[1]There is also anecdotal evidence that farmers decide the quantity they want to buy or sell and do not change that quantity over time

only data for the whole sample and those who traded is observed.

Results and Discussion

Moving Towards Pareto Efficiency

Results of logit and RElogit models for trading activity of sellers and buyers are shown in Table 3. Marginal effects at mean values are shown in Table 4. The constant term in RElogit models are bigger, since the logit model underestimates constant terms, but the difference is small. Probability of selling at mean values is 0.42% in logit model, while it is 0.45% in RElogit. Probability of buying at mean values is 0.20% and 0.21% in logit and RElogit models respectively.

The results show that overall the market is moving the resources from lower value users to higher value users. Pump rates follow our predictions. Higher pump rates increase buyers' probability of participation in trades and decrease the sellers' probability of participation in trades. As expected sellers with medium soil quality are least likely to sell their water rights, however buyers with high and medium soil qualities are more likely to buy. This can either be because the expected profit differential for farmers with high quality soils is high, or maximum profit differential for buyers is at a higher quality soil type than silty soil. This results also suggests that the relationship between soil quality and probability of participating in trade is non-monotonic.

The results also show that sellers with higher SDF are more likely to sell and buyers with higher SDF are more likely to buy. While the sign follows our expectation for the seller, for the buyer the sign is opposite of what we expected. This is an interesting result: although the SDF is decreasing over time (Table 2), which means the amount of water depleted from the river is decreasing, buyers with higher SDF are more likely to buy than those with lower SDF. One possible explanation is that the market has not reached its full potential. This could be because search costs are very high for lower SDF buyers. In fact, in the next subsection we will see that they look longer distances for trading partners.

Higher prices of corn and lower prices of fuel increase the probability of trade for both buyers and sellers. A possible explanation is that higher price of corn and lower price of fuel increase buyers' participation in the market and this will encourage more sellers to sell their rights. This confirms the results of theory section about the effect of two sides of the market on each other. Interestingly, as lagged precipitation increases, probability of trade for both buyers and sellers also increases. This could either be because higher precipitation in the previous year increases the supply of permits and as a result encourages buyers to participate in trades, or because the amount of precipitation in the region is low and as the precipitation increases, the profit differential increases, the demand goes up and trading activity in the market goes up as a result. In either case, the effect of precipitation on probabilities are much smaller than prices which could mean that the demand side is the major driver of this market.

Effect of Trade Volume and Market Participation on Distance

The results of distance regressions on volumes of trade and market participation for buyers and sellers are shown in Table 5. The first column shows the results of the OLS regression and the second column shows the results of the Heckman model's outcome regression for the seller. Columns 3 and 4 show the results of OLS and Heckman's second step for the buyer respectively.

The results show that volume of trade has a positive and significant effect on distances between buyers and sellers. The marginal effect is 0.073 miles per acre for a seller and 0.054 miles per acre for a buyer. Interpreting distance as a proxy for search costs, one possible explanation is that those with larger quantities to trade expect higher gains from trade and invest more in searching for a trading partner. However, high search costs for those who want to trade very large quantities can possibly result in under-investment in search effort, e.g. in our sample, some of the sellers who decided to sell the rights of irrigation to their entire parcel end up selling their rights in multiple trades. This could be because finding a buyer who is willing to buy the rights to the entire parcel is very time consuming and thus costly[1]. This can result in quantities traded that are less than optimal and reduce market efficiency. A similar explanation can be made for those who want to trade smaller quantities: Since the gains from trade are smaller they invest less on search effort. However, since trading with more heterogeneous partners creates higher gains from trade, and because there are spatial correlations in physical characteristics of parcels, there could be higher gains from trade when a buyer and a seller at longer distance trade with each other.

The results also show that as participation in the market increases distance between buyers and sellers decreases. As we saw earlier, higher prices of corn, lower prices of fuel and higher precipitation would increase participation of both buyers and sellers and this results in less search effort and thus shorter distances between buyers and sellers.

Furthermore, the results show that those with higher SDFs, search significantly shorter distances for trading partners. Combined with the results of trading decision, the result shows that lower SDFs are less likely to participate in the market and have higher search costs. Notice that 1) I have controlled for ratio of irrigated acres over non-irrigated acres in a 2-mile radius and it does not have any significant effect on the distance of trade[2], 2) there is no specific clustering of irrigated acres on higher SDFs (Figure 4) and 3) I have controlled for the difference between SDF of seller and buyer.

Comparing the results of OLS with the Heckman 2-step model, the results show that selection is not significant for sellers and coefficients are very close. However, the standrad errors and significance levels suggest that the inverse Mills ratio is correlated with prices, precipitation and seller's SDF[3]. The seller's SDF is not significant suggesting that we might not observe lower distances for higher SDFs for the population. For the buyers, the selection into trade is significant and is correlated with the price of corn.

[1] The same is true for buyers.

[2] I have also tried dummy variables for different ratios of irrigated over non-irrigated acres and the result was never significant.

[3] This Multicollinearity is one of the limitations of the Heckman model when the first and second steps have elements in common, e.g. look at Bockstael et al. (1990).

Overall the results show that the market is moving the resources towards higher value users although there is some loss of efficiency due to high search costs: 1) those who are in sections with lower SDFs have higher search costs which can be a possible explanation for their lower participation rates; 2) Those who want to trade larger quantities invest more in their search effort.

Policy Implications

In recent years tradeable permit markets have been increasingly considered as a solution to environmental and natural resources problems. However, our experience with them have been very mixed. While markets like fishing quota markets (e.g. Newell, Sanchirico, and Kerr (2005)) and RECALIM (Fowlie, Holland, and Mansur (2012)) have been successful, others like water quality trading markets have been very unsuccessful in achieving their goals (e.g. Hahn and Hester (1989a)). Thus it is very important to understand the reasons behind the success or failure of these markets. Current study provides us with a somehow successful market that can provide us with several policy relevant conclusions.

First, the results show that the relationship between soil quality and probability of trade is non-monotonic. This result can suggest that the relationship between crop production function and soil type is more complicated than a linear relationship where lower quality soils have higher profit differential between irrigated and dryland agriculture and are less likely to sell their rights. Although there might be other sources of heterogeneity among producers in the market, this study suggests that non-monotonicity of the effect of soil type on probability of trade should be taken into account when studying direction of trade in water markets where soil type is the main source of heterogeneity.

Second, most previous studies on tradeable permit markets remain skeptical on the performance of tradeable permit markets in local level where participants are "small, non-integrated, and unsophisticated" (Kerr and Maré (1998)). This study suggests that This is not always the case. The TPNRD groundwater market provides us with an example where water moves from lower value users to higher value users. One possible reason for the success of the market can be the heterogeneity among participants in the market. Another reason might be that the demand for water is high and the cap is binding and enforced. As we saw earlier the demand side was very important for the development of the market.

Finally, despite the relative success of TPNRD groundwater market in reallocating water, the results suggest that quantity of trades affects search effort of participants positively. This result suggests that there are also efficiency losses in the intensive margin of trade —something that has received less attention in the literature, i.e. those who decide to trade higher volumes search more and those who trade lower quantities search less. This is a loss in efficiency because in a well-functioning market with no search costs we do not expect to see any correlation between quantities and distance. This result suggests that providing information regarding potential traders can reduce these costs. Also, from the normative point of view, this result can suggest that when studying these markets ex-ante, the effect of quantities traded on search costs of agents should be considered. This can provide us with predictions that are more relevant to the outcomes in the real world.

Future work could study groundwater markets in more detail. Having access to prices of trades, future research can better explain the trading activity of individuals. Specifically, prices of trades can enable us estimate the bargaining power of buyers and sellers in the market. Also access to parcel specific crops produced and irrigation technology can help us understand how water markets affect choice of crops, irrigation technology and in general conservation practices among producers. Future research could also incorporate pump rates and SDF into the model to further strengthen the theoretical framework. In addition, studying these markets under the framework of dynamic search with frictions might provide us with helpful results in steady states.

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Figures and Tables

Figure 1: Map of Natural Resources Districts in Nebraska

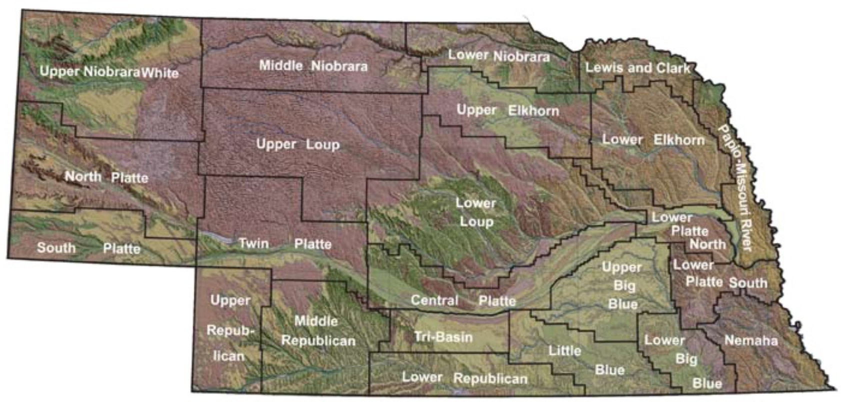

Figure 2: Map of Twin Platte Natural Resources District

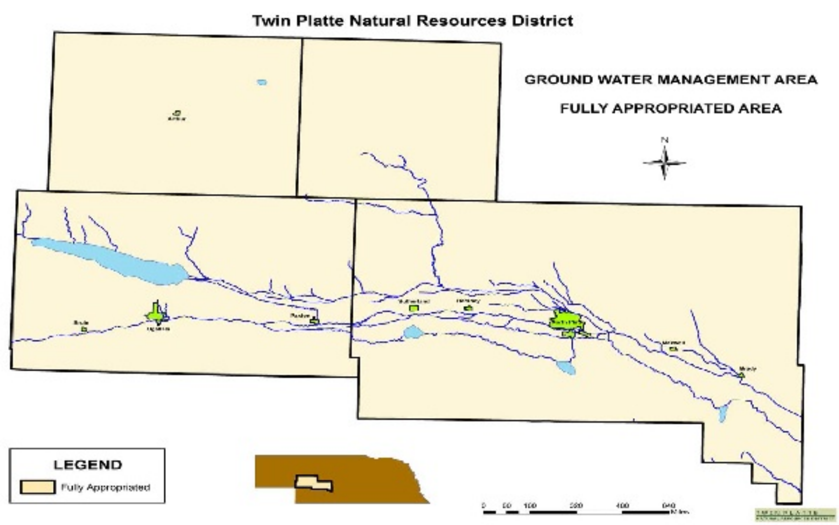

Figure 3: Distribution of Distance Between Buyers and Sellers in Trades

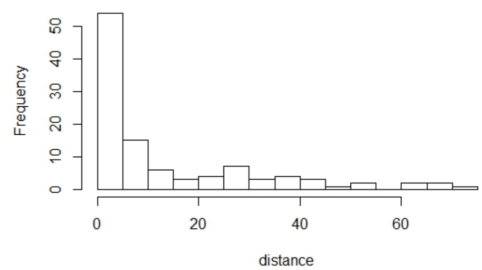

Figure 4: Distribution of Stream Depletion Factors of Irrigated Acres

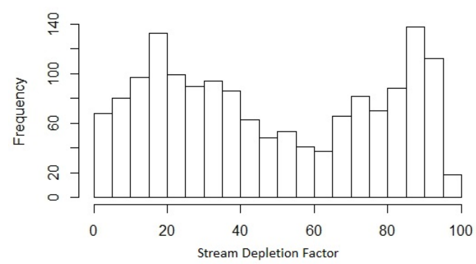

Figure 5: Distribution of Sold (Red), Bought (Blue) and Irrigated (Grey) Acres Over Sections With Propensity of Having Agriculture

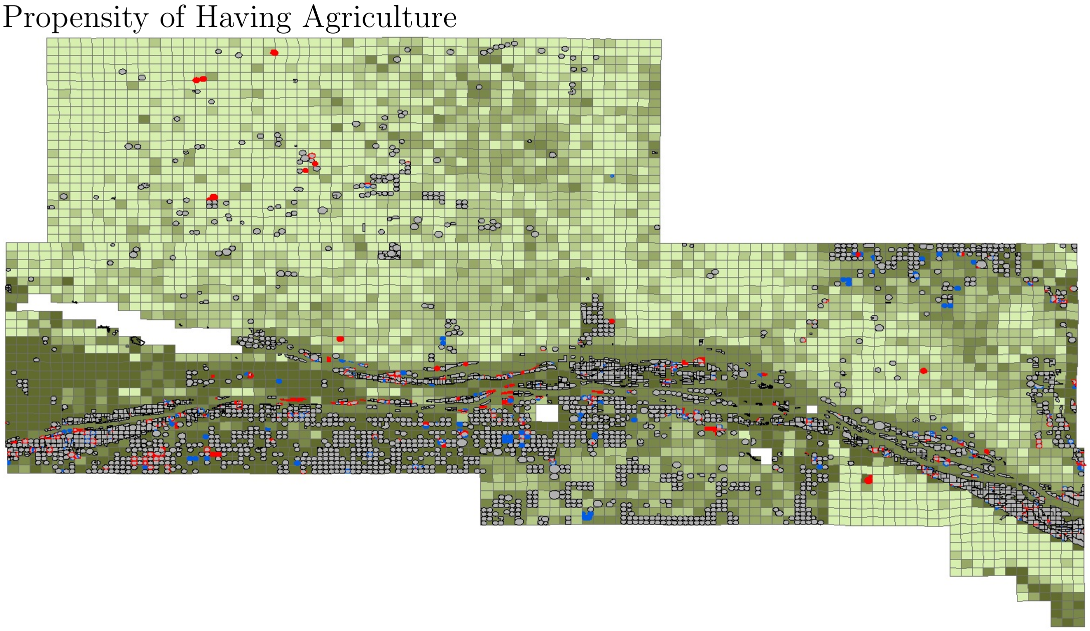

Figure 6: Distribution of Sold (Red), Bought (Blue) and Irrigated (Grey) Acres Over Sections With Stream Depletion Factors: High (Dark) to Low (Light)

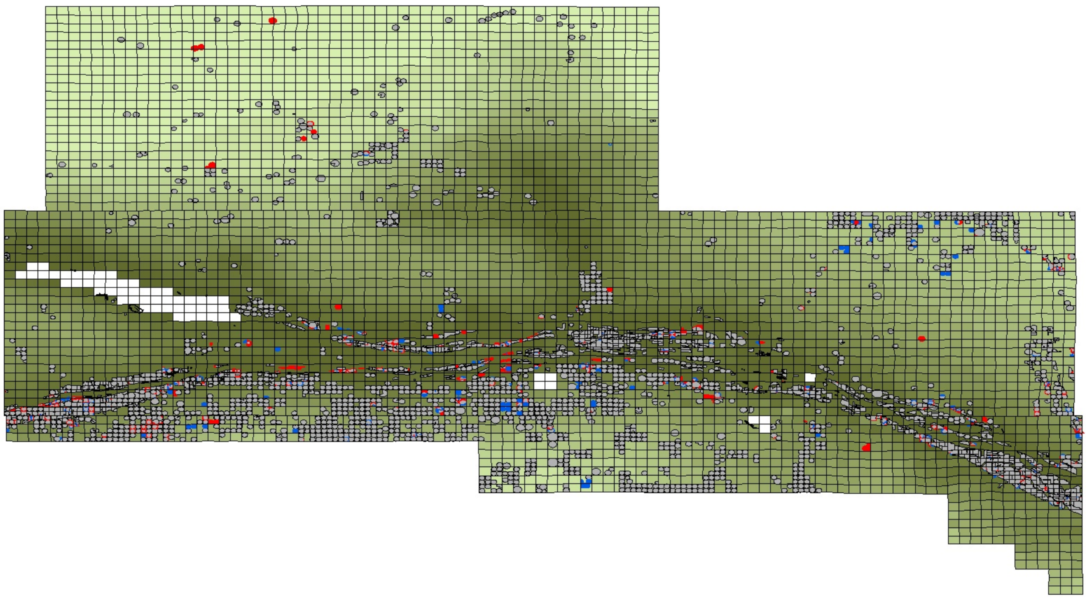

Table 1: Parcel Specific Characteristics of Irrigated and Dryland Acres

	Irrigated Acres		Dryland Acres	
	did not sell	sold	did not buy	bought
Pump Rate (gpm)	1145.91	977.14	524.34	986.63
Well Depth (feet)	297.11	221.12	219.16	282.87
High Quality Soil (Loamy)	0.14	0.25	0.05	0.14
Medium Quality Soil (Silty)	0.38	0.22	0.16	0.51
Low Quality Soil (Sandy)	0.48	0.53	0.79	0.35
Stream Depletion Factor	47.23	64.55	38.78	49.88
n	1471	92	2794	91

Table 2: Time Trend of Trades in Twin Platte Natural Resources District

	Corn	Fuel	Lagged	Distance between	Decertified Acres			New Acres		
year	futures	Price	Precipitation	buyer and seller	n	Average	total	n	Average	total
2005	5.97	6.63	1494.82	1.30	3	26.49	79.47	3	24.09	72.28
2007	7.88	5.52	853.17	2.83	2	64.19	128.38	2	64.19	128.38
2008	19.84	15.36	2489.33	4.62	4	88.86	355.43	4	82.27	329.09
2009	49.14	28.84	7799.17	3.49	15	69.73	1045.90	14	68.76	962.63
2010	40.32	34.56	5907.00	20.40	12	33.29	399.43	12	33.20	398.36
2011	73.32	46.08	6329.00	10.91	12	58.70	704.43	12	57.13	685.55
2012	170.64	108.27	14242.50	11.22	27	56.19	1517.17	27	54.53	1472.22
2013	121.38	67.66	2735.58	19.19	17	66.74	1134.63	17	59.38	1009.40

Table 3: Results of logit and RElogit Regressions for Seller and Buyer

	Dependent variable:			
	sell	sell	buy	buy
	logistic	*rare events logistic*	*logistic*	*rare events logistic*
	(1)	(2)	(3)	(4)
Price of diesel	-1.250^{***}	-1.239^{***}	-0.872^{**}	-0.872^{**}
	(0.339)	(0.338)	(0.375)	(0.374)
Price of corn	1.165^{***}	1.152^{***}	0.734^{***}	0.727^{***}
	(0.209)	(0.209)	(0.208)	(0.208)
precipitation	0.005^{***}	0.005^{***}	0.002^{*}	0.002^{*}
	(0.001)	(0.001)	(0.001)	(0.001)
Pump rate	-0.001^{***}	-0.001^{**}	0.0005^{***}	0.0005^{***}
	(0.0002)	(0.0002)	(0.0001)	(0.0001)
Depth to water	-0.002	-0.002	0.002^{**}	0.002^{***}
	(0.001)	(0.001)	(0.001)	(0.001)
SDF seller	0.013^{**}	0.013^{**}		
	(0.005)	(0.005)		
SDF buyer			0.008^{*}	0.008^{*}
			(0.004)	(0.004)
High quality soil	-0.044	-0.037	1.464^{***}	1.460^{***}
	(0.269)	(0.269)	(0.357)	(0.357)
Medium quality soil	-0.685^{**}	-0.676^{**}	1.585^{***}	1.548^{***}
	(0.270)	(0.269)	(0.247)	(0.247)
Constant	-8.250^{***}	-8.139^{***}	-9.000^{***}	-8.951^{***}
	(0.939)	(0.938)	(0.800)	(0.799)
Observations	11,860	11,860	22,443	22,443
Log Likelihood	-486.816	-486.816	-529.159	-529.159
Akaike Inf. Crit.	991.632	991.632	1,076.318	1,076.318
Note:				*p<0.1; **p<0.05; ***p<0.01
Note:				SDF is stream depletion factor.

Table 4: Marginal Effects of Logit and RElogit Regressions for Seller and Buyer

	Dependent variable:			
	sell	sell	buy	buy
	logistic	*rare events logistic*	*logistic*	*rare events logistic*
	(1)	(2)	(3)	(4)
Price of diesel	-5.274957e-03	-5.551478e-03	-1.765308e-03	-1.854421e-03
Price of corn	4.917126e-03	5.161119e-03	1.485108e-03	1.545716e-03
precipitation	2.045198e-05	2.143715e-05	3.601422e-06	3.687804e-06
Pump rate	-2.227245e-06	-2.316848e-06	9.757147e-07	1.021423e-06
Depth to water	-6.944229e-06	-7.465511e-06	4.007818e-06	4.587675e-06
SDF seller	5.508658e-05	5.760989e-05		
SDF buyer			1.577003e-05	1.770903e-05
High quality soil	-1.856367e-04	-1.660527e-04	2.962984e-03	3.105475e-03
Medium quality soil	-2.890405e-03	-3.027133e-03	3.208186e-03	3.290918e-03

Note: SDF is stream depletion factor.

Table 5: Results of OLS and Heckman 2-Step Regressions of Distance for Seller and Buyer

	Seller		*Buyer*	
	OLS	*Heckman selection*	*OLS*	*Heckman selection*
	(1)	(2)	(3)	(4)
Acres sold	0.073**	0.073***		
	(0.028)	(0.027)		
Acres bought			0.054*	0.057**
			(0.029)	(0.028)
Price of corn	−6.425**	−7.859*	−4.531*	−3.115
	(2.463)	(4.091)	(2.595)	(2.667)
Price of diesel	12.442***	14.048**	9.847**	8.502*
	(4.554)	(5.749)	(4.905)	(4.863)
Lagged precipitation	−0.040***	−0.047***	−0.036***	−0.032***
	(0.011)	(0.018)	(0.012)	(0.012)
Seller's stream depletion factor	−0.215***	−0.242***		
	(0.055)	(0.082)		
Buyer's stream depletion factor			−0.255***	−0.236***
			(0.065)	(0.063)
Stream depletion factor difference	0.273***	0.276***	0.082	0.109
	(0.080)	(0.077)	(0.077)	(0.074)
ratio of certified acres	−4.938	−3.853	−2.506	6.940
	(8.420)	(8.422)	(8.564)	(9.390)
Constant	27.971***	43.837	27.832**	−14.668
	(9.791)	(38.128)	(10.560)	(24.591)
Observations	92	11,860	91	22,443
R^2	0.423	0.425	0.394	0.419
Adjusted R^2	0.375	0.369	0.343	0.362
ρ		-0.303		0.722
Inverse Mills Ratio		-3.767 (8.771)		11.928* (6.289)
Residual Std. Error	12.478 (df = 84)		12.825 (df = 83)	
F Statistic	8.811*** (df = 7; 84)		7.725*** (df = 7; 83)	

Note: *p<0.1; **p<0.05; ***p<0.01