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THE IMPACT OF IRRIGATION RESTRICTIONS ON CROPLAND VALUES IN NEBRASKA

Abstract

Irrigation restrictions play an important role in allocating water in Nebraska, but the costs of these water management institutions are difficult to measure. This study takes advantage of temporal and spatial variation in water management policies across Nebraska, as well as plot level data that incorporates information on cropland values, irrigation status, and physical characteristics to measure the impact of irrigation restrictions on cropland values. Using a hedonic model with field-level fixed effects, we find that irrigation moratoria decreased the value of affected cropland in recent years when higher commodity prices increased the relative profitability of irrigation relative to dryland.

Keywords: Hedonic valuation; Irrigation; June Agricultural Survey; Water resource management

1 Introduction

Irrigation water is a key input for many farming systems, and the effects of different water management strategies on agricultural water users have important policy implications. Conflicts over agricultural water use have been an issue in the western United States since widespread development of irrigation began in the latter half of the nineteenth century. Globally, access to agricultural water is an increasing source of conflict. The increase in extreme temperature and adverse weather events predicted by many global climate models could exacerbate such conflicts. Improving the efficiency of irrigation water allocation will be a key element in addressing widespread water shortages and related conflicts. Various water management institutions can serve to ration water resources where its current use is not socially optimal, but often impose costs on current or potential water users. These costs can be difficult to measure, as water or water-use rights are often not tradable. When pumping rights are transferable, transactions costs to trading are often quite high (Palazzo and Brozović, 2014).

Estimates of the costs of irrigation restrictions on current users can inform debate and policy development, as well as explain the ongoing resistance to irrigation restrictions. This study measures the cost of irrigation restrictions in Nebraska. We take advantage of temporal and spatial variation in groundwater management institutions in Nebraska over the past two decades, as well as unique plot-level data on cropland values, irrigation status, and physical characteristics. We first review irrigation management institutions in Nebraska and the literature on the estimated value of groundwater irrigation, and then estimate the costs that irrigation restrictions have imposed upon cropland values in Nebraska.

2 Background and Literature Review

Nebraska overlies parts of six river basins: Niobara, Upper Platte, Lower Platte, Blues, Republican, and Missouri. Most of the state is underlain by the High Plains, or Ogallala, aquifer. Groundwater is managed by local conservation districts in Nebraska. Since 1972, groundwater in Nebraska has been managed by Natural Resource Districts (NRDs), which are responsible for managing a wide range of natural resources (Stephenson, 1996). Among the responsibilities of NRDs are the protection of aquifers from overuse and pollution. Boundaries of the NRDs follow the natural boundaries of sub-watersheds within the river basins; there are 23 NRDs in the state. In the NRDs overlying the Republic River Basin (RRB) and the Platte River Basins, the resources must also be managed to comply with interstate water use compacts.

Allocations of water within interstate river basins have been a source of long-term conflict between Nebraska and its neighbors. The North Platte River, for example, flows though Colorado, Wyoming, and Nebraska. Major irrigation development of the North Platte began in the 1880s, and conflicts arose among competing water users shortly thereafter. In 2001, the North Platte Decree between the United States, Nebraska, Wyoming, and Colorado ended litigation that began in the 1930s. Concern over habitat degradation for endangered species is driving the ongoing Platte River Recovery Implementation Program in Nebraska.

Water withdrawals in the Republican River Basin (RRB) of Colorado, Nebraska, and Kansas is another source of active conflict. A particularly contentious issue has been the extent to which ongoing pumping of water from the Ogallala Aquifer leads to reduced flows in streams and rivers close to pumping sites. When surface water flows were allocated between the states in the 1940s, irrigation technology suitable to the sandy soils and rolling hills of the area did not exist. However, as center pivot irrigation technology has developed over the last fifty years, pumped groundwater has become an extremely important input supporting agricultural production in the region.

Following decades of litigation, in 2002 the Supreme Court decided that groundwater pumping by Nebraska farmers in the RRB reduced the availability of surfacewater to downstream users in Kansas. As a result groundwater management districts in Nebraska were required to introduce agricultural water use restrictions to reduce their impacts on stream flow. A moratorium on new wells was imposed; this effectively removed the future option to irrigate land that was currently in dryland production. Annual volumetric restrictions were placed on all existing wells, based on certification of historical irrigated area, and well metering was completed in the Nebraska portion of the RRB. Trading of water rights is now allowed in some portions of the basin, but institutional barriers have so far resulted in economically insignificant water sales or leases.

The institutional history of management varies by NRD. The Upper Republican NRD has the longest history of regulation in the state: well metering took place from 1978–1982 and volumetric restrictions on pumping were implemented once metering was complete. In the Lower and Middle Republican NRDs and the Tri-Basin NRD, metering began in 1998 and volumetric restrictions were not in place until 2004. In the portions of the state that overlie the North Platte and Platte River Basins, metering and volumetric restrictions began in over-appropriated sub-basins as early as 2002 and well drilling moratoria were implemented as early as 2001. In areas of the state that have not faced interstate litigation over water, groundwater irrigation wells are not metered and farmers may drill new wells, though all active wells must be registered with the local NRD. The NE Department of Natural Resources (DNR) uses the information from NRDs to maintain an active wells database for the state. All wells must be registered with the local NRD at the time drilling commences. The information required for registration includes the locational coordinates of the well, owner and contractor information, and groundwater pumping characteristics including acres irrigated, pumping water level, and yield of water well. Data on pumping water levels and well yields are not updated, so these data represent conditions at the time the well was registered. The DNR compiles information from each NRD to maintain an active wells directory for the state.

In part to comply with the Republican Settlement, the Nebraska legislature passed LB 962 in 2004, which required NRDs that were over- or fully-appropriated in their water use to develop and implement integrated water management plans. Note that any NRD may implement an integrated management plan. The purposes of integrated water management are to understand how water moves through the regional hydrologic regimes and manage water supplies at the basin scale (Schellpeper, 2012). In over- or fully-appropriated basins, an NRD may implement regulations to reduce water withdrawals such as those in place in the RRB, including well metering and volumetric restrictions, well-drilling moratoria, and certifying irrigated acres. By certifying irrigated acres, the right to irrigate is limited to a particular field. Additionally, the remaining basins not declared fully- or over-appropriated are reviewed prior to January 1 of each year to ensure an adequate water supply.

Over 565,000 acres in Nebraska are irrigated with surface water diverted from streams and rivers. The state has public and privately-managed surface irrigation districts that work independently of NRDs. The U.S. Bureau of Reclamation manages some of the surface irrigation districts. The first moratorium on new surface water appropriations in Nebraska was implemented on the Niobara River from the Nebraska-Wyomining state line downstream to the headgate of the Mirage Flats Canal on November 30, 1990. On July 14, 2004 moratoria on new surface water appropriations were implemented in the RRB, the North Platte River Basin, the South Platte River Basin, the Platte River Basin above the mouth of the Loup River, the White River Basin, and the Hat Creek Basin. In 2006 LB 1226 was passed to clarify implementation of LB 962. Among the provisions, it granted authority to NRDs to request the DNR to stop issuing surface water rights where a NRD has imposed a groundwater development moratorium.

Studies of surface water rights consistently find that the presence of irrigation rights significantly increase agricultural land values. Xu et al. (1993) found that surface-water supplied irrigation in Washington State had a positive effect on the sale price of agricultural land while Faux and Perry (1999) found similar positive results in Oregon. Studies of groundwater and land values however have been mixed. No significant value was found in New Mexico (Sunderland et al., 1987) or Colorado (Hartman and Taylor, 1989), but Torell et al. (1990) found the value of irrigation to be significant and positive for the entire Ogallala Aquifer. One reason for this difference is that the larger study offered more variation in terms of production value and institutional management. One complicating issue for groundwater is that its use for irrigation remains largely unrestricted. In areas where water use is unrestricted, the option to irrigate in the future is also reflected in land values. Petrie and Taylor (2007) lend support to this idea of option values. In areas where the relative future profitability of irrigation are uncertain, the value of possibility of converting from dryland to irrigated production may be substantial. They study the effects of a moratorium on surface water use permits in Dooly County, Georgia and find that permits added value to agricultural land only after the restriction was implemented. Similar results are found for Chase County, Nebraska, which lies in the Upper Republican NRD (Islam and Brozović, 2010).

Differences in methodology may lead to differences in estimates of the value of irrigation rights. Specifically, cross sectional hedonic models may underestimate the value of water rights. Buck et al. (2014) found a substantial increase in the contribution of water rights to farmland values once plot-level fixed effects were accounted for in their model. This bias may be due to unobservable field, soil or operator characteristics that are correlated with both land values and irrigation rights. For example, it may be more politically expedient to restrict irrigation rights in areas that are already less suitable for irrigation. The unique data used in this study will allow for comparison with studies that have used both cross sectional and panel models to estimate the value of irrigation rights.

3 Data and Methodology

We implement a hedonic price model to estimate the value of irrigation restrictions on Nebraska cropland, which is a standard approach in the irrigation valuation literature. The hedonic model recognizes that the value of an agricultural parcel reflects the expected present value of future rents from the parcel (Palmquist, 1989). Farmland is treated as a differentiated factor of production, with n characteristics, $\{z_1, \ldots, z_n\}$, affecting the productivity and thus the land value, R, or $R = R(z_1, \ldots, z_n)$. The value of the characteristic can be implicitly estimated using hedonic analysis even though we do not observe a market for that characteristic (Freeman III et al., 2014). The standard estimating equation for hedonic farmland value models is in the form $R = \beta Z + \epsilon$, where R is the observed or estimated per acre land value, Z is a vector of observable farmland characteristics $(z_1, \ldots, z_n)$, β is a vector $(b_1, \ldots, b_n)$ of the (implicit) present value of observable farmland characteristics $(z_1, \ldots, z_n)$, and ϵ is an error term that encapsulates unobserved factors that can influence farmland values. Our estimating equation, which follows the standard hedonic model, is

$$R_{it} = \beta_1 Z_i + \beta_2 X_i + \beta_3 IRR_{it} + \beta_4 NRD_i + \beta_5 M_{it} + \beta_6 d_t + \epsilon_{it} \tag{1}$$

where R_{it} is per acre value of cropland, Z_i is a vector of field-level characteristics, X_{it} is a vector of operation characteristics, IRR_{it} is the share of cropland irrigated, NRD_i are NRD indicator variables, M_{it} indicate whether a moratorium or other irrigation restrictions are in place, and d_t are time dummies. This approach will allow us to compare our results with a wide range of studies that estimate the value of irrigation rights.

This study employs confidential, nationally representative, and geo-coded panel data on field (plot) level cropland values from the NASS-USDA June Area Survey (JAS). The JAS is conducted annually in early June and collects land value data that underpin the official USDA farmland values published annually in August. The survey uses an areaframe sampling methodology in which approximately one square mile segments are randomly sampled. Once sampled, a segment remains in the sample for five years, and is then replaced. The operators of all plots of land or tracts within each segment are interviewed, and detailed data on land use and value are collected. JAS also indicates plot size and how many acres within a plot are irrigated. Various land characteristics were matched with each segment using segment centroids (latitude and longitude). Plot- or operator- level cropland values, irrigation status, plot size, sales volume, and operator age variables are aggregated to the segment level using survey weights for our analysis. The survey weights allow for data to be representative at the state level. Aggregating to the segment level also controls for changes in ownership during the study period, which would cause the field to be assigned a different identification number. The variables used in our analysis are summarized in table 1.

While hedonic models of farmland values typically use farmland transaction values, several studies on the determinants of farmland values have used survey data from the JAS (i.e. (Borchers et al., 2014), (Towe and Tra, 2012), and (Schlenker, Hanemann, and Fisher, Schlenker et al.)). JAS data is used to inform official USDA farmland values, which have been shown to be highly correlated to transactions values (Zakrzewicz et al., 2012). While observed market values of farmland may still be considered ideal, use of JAS data has some advantages. The JAS is a representative sample, while transactions values might not be representative if certain types of parcels are more likely to go up for sale in a given year. A methodological advantage for our study is that JAS parcels are sampled for 5 years, while it would be unlikely for the same parcel to be sold more than once during our study period. Another issue with transactions data is that farmland markets are thin, or the volume of farmland transacted in any given year is low. One study estimated that only one percent of farmland in Illinois is transacted per year (Sherrick, 2012). This implies that farmland transactions values may be less reliable than if farmland were traded in a higher volume market. Borchers et al. (2014) estimate a national-level hedonic model of farmland values with JAS data and found that the current determinants of farmland were consistent with previous research that largely used transactions values.

Groundwater use in Nebraska is governed by Natural Resource Districts (NRDs). Moratoria may be district-wide or specific to a sub-watershed. Segments whose boundaries overlapped NRDs or areas with different irrigation restrictions were not considered in this analysis. Less than one percent of the data were discarded. Irrigation wells must be registered with the Nebraska Department of Natural Resources (DNR). The data on pumping water levels and well yields are taken from the DNR active wells database. These data reflect measurements reported at the time of well installation. In order to approximate groundwater characteristics and pumping costs for parcels that do not use groundwater in production, well data on pumping water levels and well yields are interpolated to segment centroids.

While we can interpret $\beta_5 M_{it}$ broadly as irrigation restrictions due to the simultaneity in the implementation of various regulations, in practice restrictions on well development or irrigation moratoria have been the primary restriction. However, other regulations such as volumetric restrictions have also been implemented. These regulations are both highly correlated with the moratoria and generally not binding in practice. According to estimates in Palazzo and Brozović (2014), less than one percent of wells in any NRD were constrained by the limits. Variables to account for volumetric limits were tested and results were consistent with Palazzo and Brozović (2014). The high collinearity between moratoria and volumetric limits presented severe multicollinearity problems when both were included because volumetric limits generally follow after or are simultaneously implemented with development restrictions. For the rest of this article, we will refer to the impact of $\beta_5 M_{it}$ on cropland values the either the as impact of moratoria and irrigation restrictions, given their general interchangeability.

One issue for identification of the impact of irrigation restrictions is the broad definition of a moratoria used in this study. Our definition of a moratorium includes both permanent development moratoria and stays, which may be temporary. This definition is based on how information on irrigation stays are compiled by the DNR, which does not always distinguish between preliminary and permanent restrictions on irrigation development. Many of the moratoria currently in place started out as preliminary stays and were likely expected by farmers to be permanent. The laws in place are designed to limit further over-appropriation of a sub-basin in advance of final determination of the status of available water resources. The precision and the bias of our estimate of the impact of moratoria is affected by whether producers anticipate a given moratorium or not. If some moratoria are anticipated and others are not, then our estimate of irrigation restrictions will be less precise. If dryland producers anticipate a moratorium and invest in wells prior to its implementation, then this biases our estimates downward.

One way to interpret the variable, *Moratorium*, is that it represents the condition that no new irrigation development is currently permitted. Farmers may have different expectations about how long a stay on development will be in place, which could add noise to results. The determination of fully- and over-appropriated is a contentious issue within Nebraska, with the preliminary determination in the Lower Niobara going to the Nebraska Supreme Court in 2011. Indicator variables for NRDs should control for some of these issues, but fully understanding farmers' expectations about irrigation development regulations on cropland values in this context comes with caveats. We expect our broad definition of a moratorium to decrease the precision of our coefficient estimates on *Moratorium*, but it may also bias the estimates. Since stays may not become permanent, the bias is likely to be downward. Many of the temporary stays were overturned by the DNR were in place only from 2006–2009, so *Moratorium*Year* interactions should limit much of the bias to those years.

To estimate our model, we use Ordinary Least Squares (OLS). The reported standard errors are robust to correlation at the NRD level, and survey weights are applied to our estimates. Use of survey weights allows for our analysis to be representative at the state

(Nebraksa) level. While our initial pooled cross section analysis does not control for all factors that might be correlated with the irrigation status of cropland, we do control from many key factors. Biophysical traits such as slope, pumping capacity, and total acres irrigated are commonly missing from hedonic studies (Shultz, 2010). We control many of these variables in our current study, including various indicators of land quality (Z_i). Multicollinearity was an issue for many of the available land and soil quality variables available through SSURGO. Land Capability Classifications were highly collinear with the water holding capacity of the topsoil, which we deemed a more useful variable for our analysis. We also control for many of the factors associated with the irrigation adoption decision by including key plot and operator characteristics. One addition to this model is to include multiple interactions between irrigation status and other factors.

Changing market conditions and irrigation practices and status over time might affect our results. This is a common issue in the hedonic literature, and it has been recognized that the underlying hedonic price function may change over time. Further, the impacts of the moratoria may vary based on current irrigation practices or may change over time due to changing market conditions. Changing market conditions are especially relevant over our study period, as corn prices increased substantially from 2007 through 2012 and farm income was on upward trend throughout the entire period. Hence we include various interaction terms to our model, including irrigation*year ($\gamma_1 IRR_{it} * d_t$), irrigation* moratoria ($\gamma_2 IRR_{it} * M_{it}$), and moratoria*year ($\gamma_3 M_{it} * d_t$). These interaction terms are also in line with the recommendations of Kuminoff et al. (2010), that a generalized differences in differences approach may address potential endogeneity between land values and presence of a moratorium.

Another important extension to the standard hedonic model is to control for observation-level characteristics. Buck et al. (2014) showed that unobserved heterogeneity present in cross sectional models can lead to substantial downward bias in estimates of water rights.

We follow their approach and implement the following segment-level fixed effects model,

$$R_{it} = \beta_2 S_{it} + \beta_3 IRR_{it} + \beta_5 M_{it} + \beta_6 d_t + i_t + \gamma_1 IRR_{it} * d_t + \gamma_2 IRR_{it} * M_{it} + \gamma_3 M_{it} * d_t + \epsilon_{it} \quad (2)$$

While the segment-level fixed effects absorb most operator characteristics and segment biophysical characteristics, we also control for share of land irrigated (IRR_{it}) and sales class (S_{it}), both of which can change annually. Further, we include the different interaction terms which control for changes in market conditions as well as unobservable time-variant factors that may be correlated with land values, implementation of moratoria and irrigation practices.

Cropper et al. (1988) found that simpler linear or log-linear functional forms perform best when unobserved heterogeneity or endogeneity are an issue. However, in this paper we are able to use segment-level fixed effects and control various sources of endogeneity. Kuminoff et al. (2010) suggest that more flexible function forms may have superior performance under this type of specification. We show our results using a linear model, a log-log model with all continuous variables transformed, and the quadratic box cox, which performed best in a comprehensive evaluation of different functional forms (Kuminoff et al., 2010).

4 Results

In tables 2 and 3, we summarize the results of two statistical models: pooled cross section and fixed effects panel, under two different functional forms, linear and log-log (all continuous variables are transformed using the natural logarithm). The results of the fixed effect model using a Box-Cox functional form are presented in table 4. We limit this analysis to the fixed effects model, in line with the finding of (Kuminoff et al., 2010) that this functional form performs best when various potential endogeniety issues are being addressed. Results from the transformed models were largely consistent with those from the linear models, but often implied a much different magnitude of effects. The quadratic Box-Cox transformation with segment fixed effects and interaction terms is the preferred model based on the hedonic literature (Kuminoff et al., 2010). The use of different functional forms allows us to compare with previous studies that used different approaches.

Table 2 reports the coefficient estimates for the pooled cross section models. The coefficient estimates for *Share irrigated* (IRR_{it}) are positive and significant for each of the linear and logarithmic specifications. Based on the insignificance of *Moratorium* (M_{it}) across all specifications, it would seem that moratoria on new wells in Nebraska has not had a significant effect on land values. However, when one considers the effect of moratoria over time, we see statistically significant negative effects from 2007–2012 in the linear model (table 2 column 2) and statistically significant negative effects in 2009 and 2012 in the logarithmic model (table 2 column 4). The magnitudes of the estimates for *Share irrigated* and *Moratorium* will be discussed in detail when the marginal effects of the variable are considered.

The control variables generally had their expected signs, though their significance was sensitive to specification. The variable *Sales class* (S_{it}) is positive and significant across specifications. The estimated signs for *Slope* and *Well depth* were positive for the linear models and negative for the logarithmic models, though none were significant. We would expect both variables to have negative effects on land values.

The results of the fixed effects regression found in table 3 are in many ways consistent with the pooled cross section model. Both irrigation and farm size have a positive and statistically significant impact on cropland value across specifications, while the moratorium does not have a statistically significant impact except in 2011 and 2012 (for the linear specification in column 2 only). The results of the quadratic Box-Cox fixed effect model in table 4 are also largely consistent. *Sales class* and *Irrigation share* have the same direction of impact and a similar level of statistical significance. *Moratorium* has a statistically significant and impact in 2008, 2009, and 2012, although the effects in 2008 and 2009 have a weaker level of statistical significance.

In order to compare the effects of *Share irrigated* and of *Moratorium* on land values across models, average marginal effects are given in table 5. The effects of the variables on land values are given in dollars. For irrigation, the average difference in value between fully-irrigated and dryland cropland values were calculated. For *Moratorium*, the average difference in value between cropland with a moratorium in place from 2000–2012 and cropland with no moratorium in all years was calculated. The estimate of the impact of a moratorium must be interpreted carefully relative to the impact of irrigation on cropland values. Our measure of irrigation covers only current irrigation practices, and does not fully take into account expectations for longer term irrigation water supply or demand. Our measure of the moratoria, however, encompasses a potentially permanent restriction on irrigation, and is likely to take into account long term expectations.

Overall the impact of irrigation is much more consistent than the effect of moratoria, which range from \$480 to \$964 per acre. The estimates from the pooled cross section model are generally larger than estimates from the fixed effects models. The fixed effects models control for time-invariant unobserved farmland characteristics that affect productivity and hence value. This may be due to irrigation being correlated with these time-invariant unobserved farmland characteristics that are also associated with an increase in value. The range across the fixed effects and quadratic Box-Cox models is smaller, \$480-\$744 per acre. The linear specifications from both the pooled cross section and fixed effects panel models are larger than the log-log specification. This may be due to extreme land values having a large influence in the linear specification. The values from the quadratic Box-Cox specification are similar with and without interactions, around \$572-\$579, while other models are more sensitive to the inclusion of interactions. Given the superior performance of Box-Cox models in Kuminoff et al. (2010) and the relative flexibility of the transformation, we assume our estimates of around \$575 are the true value.

Overall our estimates of the value of irrigation are consistent with other hedonic studies conducted in the same area and over similar time periods. Islam and Brozović (2010) found groundwater values of \$839 per acre in Chase County from 2000–2008. Shultz (2010) estimated the value of irrigation to be around \$827 per acre in the Niobara River Basin during the same period. Shultz and Schmitz (2010) found values ranging from \$460 in the Central Platte River Basin to \$795 in the Upper Republican, from 2000–2007. Torell et al. (1990) found groundwater to be valued at \$545 from 1979–1986 in Nebraska, which in real dollars is similar to our estimates. The methods used in these studies are most comparable to those used in our pooled cross section model which yield estimates between \$659 to \$964.

Irrigation moratoria appear to have only affected cropland values during the later years in our study period, and are thus more sensitive to both model specification and functional form. The marginal effects of the impact of a moratoria vary widely across models and specification, from nearly zero to more than \$4,000 per acre. Across all specifications, the addition of various interactions to the model, including the moratoria-year interactions, dramatically increase the impact of the moratoria. These results highlight the importance of functional form choice for hedonic studies that seek to measure the value of irrigation water and water management institutions. However, the more dramatic methodological implication is the difference between models with and without interaction terms. Our approach of adding multiple interactions allows for a more flexible modeling of the value of the moratoria over the study period and offer insight into how the impact of moratoria changed with changing water demand and market conditions.

During this period, there were profound structural changes to commodity markets, with rapid expansion of ethanol production and strong growth of demand from developing countries. This led to increased commodity prices and commodity price volatility in the later part of our study period. Kuminoff et al. (2010) make the point that the hedonic price function may change over time, and our results demonstrate how this is an important consideration in modeling water management institutions. The irrigation moratoria may not have not been effectively binding when they were first implemented, or in other words producers would have made the same irrigation decisions with and without a moratorium in place. The runup in corn prices that began in 2007 increased the profitability of irrigated corn relative to dryland crops. This change in prices may have led producers that were previously not using irrigation to consider irrigation, if allowed under current water management regulations. Hence our results imply that well moratoria and other irrigation restrictions may have played a role in moderating use of irrigation water in Nebraska in recent years.

Another possible explanation for the larger impact of moratoria in later years is related to the coverage of the moratoria. From 2006–2008, the Lower Loup, Lower Platte, and Lower Niobara NRDs were preliminarily determined by their respective NRD authorities to be fully-appropriated and stays on new irrigation development were issued. In 2009 these determinations were overturned by the DNR. Farmers in these temporarily limited NRDs may have held different expectations about the effects of the moratoria or did not consider limits on irrigation expansion as costly as those in NRDs where the moratoria could be assumed to be more permanent.

Using the preferred quadratic Box-Cox model, the average impact of irrigation development moratoria on cropland values in the study was $1100 per acre. On dryland, a moratorium eliminates the option to irrigate in response to changes in markets, production technologies, or growing conditions. In NRDs where irrigated acres are certified, groundwater pumping rights from a well are tied to a particular field. In these NRDs a moratorium also removes an irrigator's option to expand irrigation to additional acres. A moratorium may also signal to farmers that more regulations such as binding volumetric restrictions might be in the offing. For dryland, a moratorium represents the loss of the option to irrigate. For irrigated cropland, a moratorium represents the potential, or even presence, of more stringent regulations of water use. Note that the impact was also measured over just irrigators and just dryland producers and the results were similar. This might reflect the inherent profitability of dryland on dryland farms and the profitability of irrigation on irrigated farms. We'd expect the impact to be greatest on dry farms that were not able to irrigate but would have liked to after corn prices increased.

To the best of our knowledge, this study is the first to directly estimate the impact of irrigation development moratoria on cropland values. These results are consistent with, if slightly different from, the finding by Petrie and Taylor (2007) that the value of irrigation rights were significant and positive in Dooly County, GA once a moratorium on new rights was imposed. Their result is due to the loss of the option for dryland producers to irrigate in the future. The results of this paper indicate that while the value of irrigation is positive in the presence of a moratorium, the groundwater irrigation moratoria in Nebraska impose negative costs on all affected cropland.

Hendricks and Peterson (2012) estimated the average cost to cease irrigating in Kansas to be $64 per acre per year. In western portions of Kansas, the High Plains aquifer is being mined to the point that it may no longer support irrigated production. This is in contrast to Nebraska, where the supply of groundwater in the High Plains aquifer is greater and enjoys higher recharge. As the saturated thickness of an aquifer shrinks with the depletion of the supply, pumping costs will rise as well yields decrease and pumping water levels increase. It is expected that the value of ceasing irrigation in one year would be much less than the value of permanently giving up the right to irrigate, especially if the supply of groundwater is greater and the costs of pumping are less.

5 Discussion

Our results have methodological implications for future studies on the impact of irrigation water management institutions as well as policy implications. As noted in other studies, not accounting for unobservable plot-level characteristics may lead to bias in estimates of the value or irrigation or various types water use rights. Further, the hedonic price function associated with water use rights may change over time, and hedonic models should account for these potential changes. The generalized differences-in-differences approach used in this study demonstrates the importance of such modeling considerations. Finally, our results were rather sensitive to our choice of functional form, although the general direction of the relationship between key variables was consistent.

Our results clearly indicate the the impact of irrigation restrictions changed over time. While there are several explanations for this, some key narratives related to market conditions are consistent with this finding. If the moratoria were not binding in the earlier years of our study, this situation may have changed as corn prices increased dramatically from 2007. The moratoria may have been easier to implement if instituted during a period of lower prices or when current production economics did not support new irrigation development. Despite the small initial impact of these moratoria, our results show that they can still be significant if market conditions change. While the moratoria may be effective at preventing overexploitation of water resources in such situations, the economic cost to producers and landowners can be substantial during periods of high crop prices.

Future studies should examine other regions to determine whether the results of this paper hold more broadly in other regions. Nebraska has a unique institutional framework that includes a well-developed system of regulations. Nebraska also enjoys high-quality, relatively cheap-to-pump groundwater for irrigation. Kansas also has management institutions in place, but the quality of the aquifer for large-scale irrigation is lower than in Nebraska.

Many regions of the United States have few if any regulations or restrictions on the pumping of groundwater for irrigation. In much of the United States, restrictions are driven not by local groundwater depletion but by interstate agreements over surface water flows. Building local support for these restrictions, in the absence of a local water scarcity, is a challenge shared by many policymakers seeking to address environmental externalities.

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Table 1: Summary statistics

Variable	Description	Mean	Std. Dev.	Min	Max
Land value	Operator-reported cropland value, per acre	2,142.34	1,653.45		
Share irrigated	Irrigated cropland acres/Total cropland acres	0.55	0.37		
Sales class	Farm-level index	8.64	1.36	2.00	13.00
Mean slope	Mean slope for all tracts within the segment	2.06	1.35	0.00	13.55
Std. dev. slope	Standard deviation of the slope for all tracts within the segment	0.87	0.55	0.00	8.26
Topsoil quality	Water-holding capacity of the topsoil	175.92	36.26	45.00	233.10
Well yield	Gallons per minute	897.45	266.06	158.29	2,231.16
Well depth	Pumping water level, feet below surface	112.96	61.06	15.22	332.76
Population-interaction index	County-level index of urban-related population effects	5,347.64	5,760.52	295.38	56,925.32
Distance to urban area	Distance to nearest town with population of at least 250,000	198.31	85.26	0.00	576.17
Moratorium	Dummy variable equal to one if a stay or moratorium on new irrigation rights is implemented; zero otherwise	0.29	0.45	0.00	1.00

Table 2: OLS Hedonic Regression Results

	(1) Land value	(2) Land value	(3) ln(Land value)	(4) ln(Land value)
Share irrigated	996.0***	1030.4***	0.0353***	0.0363***
	(125.2)	(201.8)	(0.00668)	(0.00656)
Moratorium	-192.4	456.6	-0.0367	0.0958
	(151.0)	(281.5)	(0.0399)	(0.0866)
Farm size	84.36***	74.82***	0.515***	0.505***
	(16.09)	(16.60)	(0.0681)	(0.0680)
Slope	128.4	134.6	-0.0213	-0.0329
	(196.5)	(198.0)	(0.0353)	(0.0314)
Std. dev. slope	-254.5	-284.3	-0.0612	-0.0598
	(288.5)	(283.8)	(0.0353)	(0.0316)
Topsoil quality	3.428***	2.993***	0.124	0.127
	(0.741)	(0.695)	(0.0714)	(0.0662)
Well yield	0.137	0.179	0.211***	0.200***
	(0.100)	(0.102)	(0.0406)	(0.0460)
Well depth	0.482	0.0113	-0.0252	-0.0273
	(0.534)	(0.484)	(0.0275)	(0.0258)
Population-interaction index	0.0855*	0.0865*	0.153***	0.158***
	(0.0315)	(0.0311)	(0.0343)	(0.0316)
Distance to urban area	-0.467	-0.651	-0.152***	-0.150***

	(0.885)	(0.864)	(0.00802)	(0.00813)
Moratorium*2000		-49.66		0.00288
		(40.88)		(0.0457)
Moratorium*2001		29.22		0.0478
		(75.30)		(0.0912)
Moratorium*2002		-18.26		0.0322
		(78.79)		(0.0704)
Moratorium*2003		-27.83		0.00814
		(82.09)		(0.0774)
Moratorium*2004		-88.71		0.0228
		(97.43)		(0.0816)
Moratorium*2005		-197.8		-0.0357
		(112.0)		(0.0777)
Moratorium*2006		-309.5		-0.111
		(154.6)		(0.0752)
Moratorium*2007		-611.8**		-0.120
		(215.3)		(0.0807)
Moratorium*2008		-895.8***		-0.144
		(204.8)		(0.0730)
Moratorium*2009		-616.9*		-0.165*
		(254.2)		(0.0750)
Moratorium*2010		-822.3**		-0.128

		(232.9)		(0.0729)
Moratorium*2011		-1267.2***		-0.132
		(302.0)		(0.0899)
Moratorium*2012		-2281.6***		-0.223*
		(465.1)		(0.0903)
Share irrigated*year; Share irrigated*Moratorium		X		X
R^2	0.693	0.722	0.843	0.850
Observations	801181	801181	801181	801181

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3: Fixed Effects Regression Results

	(1) Land Value	(2) Land Value	(3) ln(Land value)	(4) ln(Land value)
Share irrigated	678.9***	647.5***	0.0273***	0.0256***
	(68.95)	(152.3)	(0.00434)	(0.00461)
Moratorium	-9.159	502.6	-0.0518	0.0138
	(123.7)	(287.3)	(0.0359)	(0.0594)
Sales class	67.09**	61.20**	0.290***	0.300***
	(20.84)	(19.31)	(0.0533)	(0.0529)
Moratorium*2000		-30.13		0.0213
		(27.95)		(0.0391)
Moratorium*2001		79.07		0.102
		(52.12)		(0.0645)
Moratorium*2002		9.872		0.0565
		(44.72)		(0.0441)
Moratorium*2003		23.89		0.0266
		(58.26)		(0.0495)
Moratorium*2004		-52.73		0.0152
		(48.66)		(0.0351)
Moratorium*2005		-26.23		-0.000722
		(122.5)		(0.0363)
Moratorium*2006		-187.4		-0.0794

		(97.04)		(0.0510)
Moratorium*2007		-248.3		-0.0888
		(129.0)		(0.0543)
Moratorium*2008		-459.8*		-0.0872
		(173.2)		(0.0522)
Moratorium*2009		-336.9		-0.0792
		(235.8)		(0.0451)
Moratorium*2010		-313.1		-0.0278
		(256.8)		(0.0605)
Moratorium*2011		-905.5*		-0.0709
		(358.7)		(0.0665)
Moratorium*2012		-1863.1**		-0.199*
		(561.8)		(0.0828)
Share irrigated*year; Share irrigated*Moratorium		X		X
R^2	0.488	0.527	0.499	0.511
Observations	800359	800359	800359	800359

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4: Quadratic Box Cox Fixed Effects Regression Results

	(1) trans(Land value)	(2) trans(Land value)
Moratorium	-0.168	-0.154
	(0.115)	(0.226)
Share irrigated	0.204***	0.217***
	(0.0280)	(0.0350)
Sales class	0.622***	0.673***
	(0.112)	(0.118)
Moratorium*2000		0.0247
		(0.112)
Moratorium*2001		0.296
		(0.196)
Moratorium*2002		0.151
		(0.131)
Moratorium*2003		0.0731
		(0.153)
Moratorium*2004		0.00417
		(0.108)
Moratorium*2005		-0.0594
		(0.130)

Moratorium*2006		-0.321
		(0.181)
Moratorium*2007		-0.375
		(0.196)
Moratorium*2008		-0.437*
		(0.202)
Moratorium*2009		-0.407*
		(0.155)
Moratorium*2010		-0.240
		(0.243)
Moratorium*2011		-0.531
		(0.265)
Moratorium*2012		-1.115**
		(0.363)
Share irrigated*year; Share irrigated*Moratorium		X
R^2	0.537	0.552
Observations	800359	800359

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5: Average marginal effects for moratorium and share irrigated

	Irrigation	Moratorium
Cross-section[c]linear model 1, No interactions	678.9*** (68.95)	-9.159 (123.7)
Cross-section linear model 2, Interactions	964.1** (382.5)	-6803.8*** (70.59)
Cross-section logarithmic model 1, No interactions	765.8 (556.5)	-75.60 (53.30)
Cross-section logarithmic model 2, Interactions	659.1 (421.4)	-1194.64 (962.32)
FE[d]linear model 1, No interactions	678.9*** (0.0000863)	-9.159*** (0.0000945)
FE linear model 2, Interactions	743.6 (391.7)	-4029.5*** (153.3)
FE logarithmic model 1, No interactions	544.1* (256.6)	-95.98* (47.10)
FE logarithmic model 2, Interactions	480.2** (195.7)	-658.9* (325.4)
FE QBC model[e]1, No interactions	572.4** (225.5)	-94.06** (38.21)
FE QBC model 2, Interactions	578.6** (229.1)	-1095.1* (492.0)

Standard deviations in parentheses;

[a] The effect of moratorium is estimated as the difference in no moratorium and a moratorium in all years;

[b] The effect of irrigation is estimated as the difference in no irrigation and fully irrigated;

[c] Pooled cross-section OLS model;

[d] Fixed effects model;

[e] Quadratic box cox model

Table 6: Coefficient Estimates for Control Variables in Cross-Section Regressions in Table 2

	(1) Land value	(2) Land value	(3) ln(Land value)	(4) ln(Land value)
Lower Big Blue	-699.9***	-695.8***	-0.208***	-0.216***
	(164.6)	(140.2)	(0.0260)	(0.0262)
Upper Elkhorn NRD	-155.1	-209.4	-0.0349	-0.0237
	(104.4)	(106.6)	(0.0546)	(0.0506)
Lower Elkhorn NRD	202.3	207.3	0.217***	0.168**
	(118.5)	(124.3)	(0.0499)	(0.0500)
Little Blue NRD	-352.9***	-326.7***	-0.0819**	-0.0898**
	(42.88)	(37.59)	(0.0242)	(0.0245)
Upper Loup NRD	-1061.0***	-992.3***	-0.558***	-0.536***
	(213.2)	(226.6)	(0.0676)	(0.0631)
Lower Loup NRD	-685.9***	-628.5***	-0.169**	-0.164**
	(92.51)	(76.84)	(0.0502)	(0.0485)
Lewis & Clark NRD	-362.2	-318.0	0.0353	-0.0135
	(184.8)	(210.2)	(0.0566)	(0.0559)
Papio-Missouri River NRD	-191.7	-259.8	-0.177**	-0.207**
	(592.1)	(567.8)	(0.0583)	(0.0559)
Nemaha NRD	-279.6	-417.7	0.0312	0.0206
	(218.5)	(253.5)	(0.0650)	(0.0764)

Upper Niobara-White NRD	-1284.2***	-1201.4***	-0.873***	-0.877***
	(196.9)	(212.6)	(0.0741)	(0.0760)
Middle Niobara NRD	-873.0***	-778.6***	-0.171	-0.156
	(153.0)	(130.8)	(0.0899)	(0.0844)
Lower Niobara NRD	-383.6*	-249.7	-0.0297	-0.0129
	(167.4)	(136.8)	(0.0801)	(0.0735)
North Platte NRD	-1090.3***	-1000.6***	-0.513***	-0.522***
	(149.4)	(181.8)	(0.0581)	(0.0644)
South Platte NRD	-903.8***	-852.1***	-0.746***	-0.730***
	(104.1)	(78.50)	(0.0719)	(0.0723)
Twin Platte NRD	-922.0***	-786.0***	-0.523***	-0.518***
	(122.4)	(136.7)	(0.0508)	(0.0525)
Central Platte NRD	-455.0***	-498.2***	-0.103***	-0.106***
	(57.94)	(69.51)	(0.0242)	(0.0219)
Lower Platte North NRD	-96.04	-85.13	0.115***	0.112***
	(253.8)	(260.7)	(0.0219)	(0.0217)
Lower Platte South NRD	-1055.7	-1079.0	0.0369	-0.0179
	(637.1)	(598.1)	(0.0657)	(0.0646)
Upper Republican NRD	-857.8***	-928.5***	-0.513***	-0.502***
	(127.9)	(138.9)	(0.0882)	(0.0860)
Middle Republican NRD	-903.4**	-1019.8**	-0.473***	-0.443***
	(279.9)	(356.2)	(0.0894)	(0.0945)

Lower Republican NRD	-749.8***	-800.7***	-0.280***	-0.302***
	(159.6)	(197.6)	(0.0648)	(0.0720)
Tri-Basin NRD	-524.7***	-371.5***	-0.156***	-0.162***
	(93.94)	(96.88)	(0.0317)	(0.0346)
2000	70.24*	138.0	0.0459	0.0433*
	(29.29)	(67.00)	(0.0237)	(0.0204)
2001	49.95	137.8	0.0467	0.000863
	(44.39)	(89.34)	(0.0362)	(0.0391)
2002	94.35	217.9**	0.0844*	0.0417
	(55.23)	(76.15)	(0.0362)	(0.0439)
2003	160.7***	214.9**	0.130***	0.0956*
	(41.93)	(74.33)	(0.0318)	(0.0381)
2004	292.6***	312.4**	0.221***	0.164***
	(45.13)	(107.7)	(0.0333)	(0.0399)
2005	415.3***	460.7**	0.308***	0.278***
	(62.76)	(135.1)	(0.0363)	(0.0435)
2006	554.1***	767.5**	0.362***	0.351***
	(83.34)	(237.7)	(0.0447)	(0.0594)
2007	811.1***	994.8**	0.485***	0.477***
	(97.10)	(285.1)	(0.0441)	(0.0539)
2008	1242.8***	1376.8***	0.679***	0.666***
	(139.2)	(229.7)	(0.0498)	(0.0388)

2009	1307.7***	1533.6***	0.684***	0.673***
	(151.5)	(253.0)	(0.0480)	(0.0425)
2010	1509.3***	1649.8***	0.777***	0.755***
	(159.5)	(307.4)	(0.0492)	(0.0398)
2011	2229.4***	2390.0***	1.004***	0.979***
	(243.6)	(389.0)	(0.0566)	(0.0440)
2012	3941.1***	3703.7***	1.348***	1.360***
	(358.5)	(523.6)	(0.0538)	(0.0482)
Share irrigated*2000		-148.4		0.000413
		(97.86)		(0.00540)
Share irrigated*2001		-207.0		-0.00900*
		(117.4)		(0.00422)
Share irrigated*2002		-292.6**		-0.00682
		(98.89)		(0.00600)
Share irrigated*2003		-181.3		-0.00412
		(104.9)		(0.00582)
Share irrigated*2004		-145.5		-0.00930
		(146.8)		(0.00530)
Share irrigated*2005		-99.54		-0.00751
		(168.3)		(0.00549)
Share irrigated*2006		-356.4		-0.00960
		(303.3)		(0.00727)

Share irrigated*2007		-103.0		-0.0112
		(307.1)		(0.00663)
Share irrigated*2008		262.1		-0.0174*
		(254.3)		(0.00694)
Share irrigated*2009		-203.1		-0.0157*
		(382.2)		(0.00752)
Share irrigated*2010		64.55		-0.0150
		(313.5)		(0.00724)
Share irrigated*2011		259.1		-0.0143*
		(428.0)		(0.00631)
Share irrigated*2012		1314.6		-0.0102
		(879.8)		(0.00869)
Moratorium*Share irrigated		-187.9		0.0219*
		(263.6)		(0.00960)
Constant	-662.7	-563.5	3.747***	3.807***
	(428.6)	(457.7)	(0.505)	(0.510)
R^2	0.693	0.722	0.843	0.850
Observations	801181	801181	801181	801181

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 7: Coefficient Estimates for Control Variables in Fixed-Effects Regressions in Tables 3 & 4

	(5) Land value	(6) Land value	(7) ln(Land value)	(8) ln(Land value)	(9) trans(Land value)	(10) trans(Land value)
2000	32.39	25.16	0.0332*	0.0524**	0.105*	-0.000720
	(0.0204)	(16.59)	(30.17)	(0.0141)	(0.0166)	(0.0390)
2001	63.48**	52.86	0.0756**	0.0659*	0.221**	0.104
	(21.30)	(28.26)	(0.0218)	(0.0256)	(0.0637)	(0.102)
2002	98.96**	124.7*	0.0996***	0.0857**	0.302***	0.311*
	(29.61)	(45.35)	(0.0259)	(0.0297)	(0.0768)	(0.145)
2003	151.2***	119.6*	0.148***	0.147***	0.446***	0.390*
	(26.31)	(43.88)	(0.0254)	(0.0292)	(0.0738)	(0.153)
2004	271.8***	263.4***	0.237***	0.213***	0.727***	0.882***
	(35.73)	(53.71)	(0.0274)	(0.0336)	(0.0814)	(0.160)
2005	358.9***	228.0	0.302***	0.296***	0.938***	0.999***
	(72.11)	(204.0)	(0.0270)	(0.0338)	(0.0880)	(0.158)

2006	530.3***	604.8***	0.366***	0.371***	1.161***	1.536***
	(68.08)	(108.5)	(0.0372)	(0.0386)	(0.117)	(0.251)
2007	789.9***	800.1***	0.483***	0.484***	1.558***	2.074***
	(92.69)	(145.9)	(0.0408)	(0.0451)	(0.134)	(0.254)
2008	1228.6***	1078.9***	0.670***	0.686***	2.199***	2.588***
	(136.9)	(155.4)	(0.0395)	(0.0264)	(0.138)	(0.253)
2009	1308.8***	1331.8***	0.685***	0.678***	2.252***	2.767***
	(129.6)	(208.4)	(0.0396)	(0.0402)	(0.129)	(0.251)
2010	1522.9***	1393.5***	0.776***	0.772***	2.571***	2.896***
	(151.9)	(236.0)	(0.0421)	(0.0487)	(0.147)	(0.309)
2011	2402.1***	2297.3***	1.030***	1.028***	3.491***	3.992***
	(255.8)	(352.7)	(0.0461)	(0.0494)	(0.175)	(0.301)
2012	4039.6***	3755.8***	1.350***	1.385***	4.738***	5.357***
	(384.8)	(453.3)	(0.0523)	(0.0487)	(0.211)	(0.307)
Share irrigated*2000		26.53		0.00601		0.0344
		(36.94)		(0.00355)		(0.0224)

Share irrigated*2001	5.631	0.00364	0.0212
	(38.98)	(0.00352)	(0.0244)
Share irrigated*2002	-56.30	0.000167	-0.0083
	(42.82)	(0.00400)	(0.0279)
Share irrigated*2003	35.79	0.00284	0.0169
	(61.03)	(0.00440)	(0.0293)
Share irrigated*2004	6.361	-0.00455	-0.0367
	(65.65)	(0.00508)	(0.0361)
Share irrigated*2005	219.1	-0.000539	0.0017
	(204.6)	(0.00370)	(0.0272)
Share irrigated*2006	-54.56	-0.00669	-0.0540
	(120.0)	(0.00655)	(0.0484)
Share irrigated*2007	96.91	-0.0120	-0.0728
	(141.6)	(0.00615)	(0.0477)
Share irrigated*2008	551.3**	-0.00630	-0.0150
	(155.0)	(0.00565)	(0.0441)

Share irrigated*2009		112.3		-0.0103		-0.0609
		(282.5)		(0.00662)		(0.0513)
Share irrigated*2010		418.4*		-0.00532		-0.0102
		(194.9)		(0.00604)		(0.0501)
Share irrigated*2011		652.3*		-0.00731		-0.0162
		(250.4)		(0.00444)		(0.0389)
Share irrigated*2012		1321.8*		-0.00573		0.0214
		(550.6)		(0.00483)		(0.0496)
Moratorium*Share irrigated		-408.0		0.00970		0.0548
		(285.0)		(0.00584)		(0.0395)
Constant	360.5	354.5	6.494***	6.460***	11.82***	11.61***
	(234.1)	(279.3)	(0.119)	(0.123)	(0.306)	(1.953)
R^2	0.488	0.527	0.499	0.511	0.537	0.552
Observations	800359	800359	800359	800359	800359	800359

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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