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The Impact of Irrigation Restrictions on Cropland Values in Nebraska

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Given the expansive water consumption of the agricultural sector in the western United States, irrigation practices have increasingly been restricted as a way to combat water scarcity. Using segment-level panel data on land values and irrigation status, we measure the extent to which irrigation restrictions are capitalized into irrigated and nonirrigated cropland values in Nebraska. On average, irrigation restrictions did not have a measurable impact on farmland values across 1999–2012. However, our results show that the effects of the restrictions vary considerably over time and that basins that were more dependent on irrigation were disproportionately impacted by the restrictions.

Key words: June Area Survey, water resource management

Irrigation water is a critical input for many farming systems. The effects of different water-conservation approaches on agricultural water users have important policy implications. Many policies designed to curtail water withdrawals are likely to have a large effect on the viability of existing farming systems. In the western United States, where roughly two-thirds of cropland is irrigated, agricultural irrigation accounts for 80%–90% of consumptive water use. Given the drought-like conditions that have affected the region, calls for a tightening of allowable irrigation water withdrawals have grown over the past decade, though little empirical evidence exists on the economic impacts of such restrictions. As continued population growth and climate change are expected to increase the likelihood of future water shortages (e.g., Vörösmarty et al., 2000), the efficacy of policies geared toward rationing irrigation water use will become increasingly important.

In this study, we measure the impacts of irrigation restrictions in Nebraska, which has a mix of irrigated and dryland agriculture. Irrigation water use in the state, which has increased recently in response to technological improvements, relies heavily on the Ogallala Aquifer (Peterson, Marsh, and Williams, 2003). In the early 2000s, a number of localized policies were introduced to curtail the development of new wells in order to limit impacts on streamflows. To measure the effects of these restrictions, we estimate a series of land-value models using a unique panel dataset assembled from the U.S. Department of Agriculture's (USDA) June Area Survey for 1999–2012. By including segment fixed effects to mitigate potential omitted-variable bias, we exploit fine-scale panel variation to estimate the effects of irrigation restrictions on cropland values. Our panel dataset allows us to consider the complex interactions between groundwater irrigation intensity, drought resilience, and commodity markets by analyzing how the impacts of the restrictions have varied over time and across different cross sections of Nebraska farms.

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While not always considered first-best, restrictions on irrigation, such as volumetric withdrawal limits or moratoria on new wells, are much more common than market-based approaches to regulating agricultural water consumption. Increasing the cost of water to end users can curb use, but pricing water at "socially optimal" levels may not be politically feasible and generally requires private information that is costly for policy makers to obtain. Water markets, in theory, allow for socially optimal use of water in times of scarcity, and they have been successful in some locations (e.g., Brooks and Harris, 2008; Calatrava and Garrido, 2005; Hanak, 2015; Regnacq, Dinar, and Hanak, 2016). However, vested interests in longstanding water-allocation institutions, such as the prior appropriation doctrine in the western United States, often inhibit the establishment of fully functioning water markets. Markets for groundwater, historically subject to less regulation than surface water, are particularly difficult to implement given the difficulties of establishing pumping rights and the high transaction costs associated with trading (Palazzo and Brozović, 2014).

Given these challenges, restricting irrigation water use through regulations is often the default approach for addressing scarcity. While water use restrictions can serve to ration water consumption toward socially optimal levels, like other policies, they can impose costs on current or potential water users. These costs can be difficult to measure as a result of data limitations, uniform timing of the implementation of restrictions, and the presence of other confounding trends. As an example, irrigation restrictions may have differential impacts on irrigated and dryland agriculture, which are not readily distinguishable in many data sources.

In the case of a moratorium on new well development, the basis of a major suite of policies implemented in Nebraska, the effect on cropland values is ambiguous. On one hand, a restriction on new well development may increase land values if the policy has a positive effect on expectations regarding future groundwater availability, but the opposite may hold if the policy constrains farmers' ability to adapt irrigation practices to changing market and environmental conditions. For existing dryland farmers, the *ex ante* effects of new well restrictions are also difficult to judge. The moratoria may shut off a source of option value for farmers who value the ability to irrigate in the future, but dryland farming may become relatively more profitable if the policies have a binding effect on the ability of irrigation-dependent farmers to adapt. Particularly, the enhanced drought resilience of dryland farm operations may increase their value relative to irrigated operations (Hornbeck and Keskin, 2014). In general, estimates of the costs of irrigation restrictions can inform policy debates by quantifying how different groups of users (or potential users) are affected by the policies. While the impacts of restrictions on land values have implications for the political feasibility of different approaches to manage water scarcity, they also inform discussions on the efficiency or optimality of different institutions for managing water scarcity.

Although irrigation plays a large role in the U.S. farm sector, the effects of groundwater irrigation on farmland values are mixed. No significant effect was found in New Mexico (Sunderland, Libbin, and Torell, 1987) or Colorado (Hartman and Taylor, 1989), but Torell, Libbin, and Miller (1990) found the marginal value of irrigation water 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 arrangements. A complicating factor for studying groundwater is that its use in irrigation remains largely unrestricted. In areas where water use is unrestricted, the option to irrigate in the future is also reflected in land values. For areas where the relative future profitability of irrigation is uncertain, the value of possibility of converting from dryland to irrigated production may be substantial. Petrie and Taylor (2007) lent support to this idea of option values. They studied the effects of a moratorium on surface water use permits in Dooly County, Georgia, and found that permits added value to agricultural land only after the restriction was implemented. Islam and Brozović (2010) found similar results for Chase County, Nebraska, which lies in the Upper Republican Natural Resource District (NRD).

Differences in methodology may lead to different estimates of the value of irrigation rights. Specifically, cross-sectional models may underestimate the value of water rights. Buck, Auffhammer, and Sunding (2014) found that irrigation water deliveries increase farmland values substantially, after accounting for unobserved heterogeneity with segment-level fixed effects. The ability to control for unobservable factors that are correlated with both land values and irrigation rights can be critical for studying how irrigation restrictions impact land values. For example, it may be politically expedient to restrict irrigation rights in areas that are already less suitable for irrigation. Importantly, the novel panel data used in this study allow us to control for unobservable plot-level characteristics that would otherwise bias our estimates.

Our paper contributes to the existing literature on the costs of irrigation restriction policies in three ways. First, by using an extensive panel dataset covering multiple years of regulations, we are able to identify the effects of irrigation restrictions within a generalized difference-in-differences framework. Previous studies, such as Petrie and Taylor (2007) and Islam and Brozović (2010), relied exclusively on cross-sectional variation to estimate the impacts of irrigation policies on land values. Second, we are able to shed light on several important sources of heterogeneity in the irrigation restriction treatment effects, which have important implications concerning the distributional impacts of the policies. Since Nebraska contains a mixture of irrigated and dryland agriculture, we are able to assess which types of production systems are most affected by irrigation restrictions. Additionally, the 14-year period covered by our data enables us to explore how the costs of irrigation restrictions may depend on market conditions, which exhibited substantial variation during our study period. Third, by estimating the effects for different cross sections of Nebraska farms in our dataset, we are able to determine whether the impacts of the policies differed measurably between areas that are more or less dependent on irrigation for crop production. We find that, on average across 1999–2012, irrigation restrictions did not have a measurable impact on cropland values for all of Nebraska. However, our results show that the effects of the restrictions vary considerably over time. Irrigation restrictions had a negative impact on irrigated cropland values from 2006–2008, when both restrictions and crop prices were increasing. We find a similar negative impact at the end of the study period as well, when crop prices were also high. For the Platte and Republican Basins in southwest Nebraska, we find an average decline of almost 14% in irrigated cropland with restrictions over the entire study period. These regions are relatively more irrigation-dependent and have been affected by interstate conflict and litigation over water rights.

Irrigation Development and Policies in Nebraska

Nebraska overlies parts of 6 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. 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 (Figure 1). In the NRDs overlying the Republican 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 drives the ongoing Platte River Recovery Implementation Program in Nebraska.

Water withdrawals in the RRB of Colorado, Nebraska, and Kansas are 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

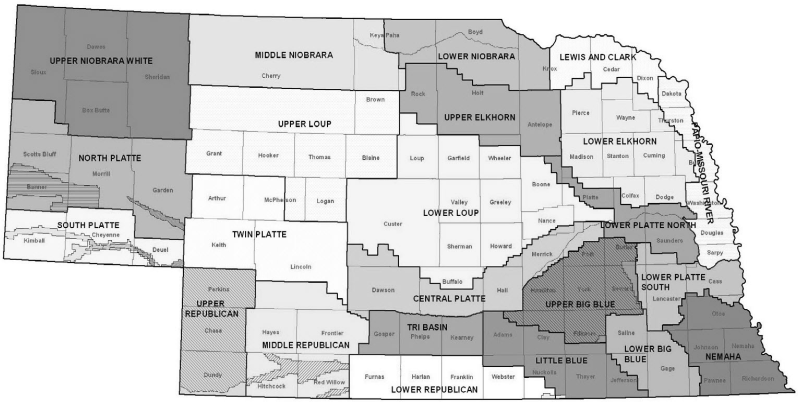

Figure 1. Nebraska's Natural Resource Districts

Source: http://water.unl.edu/crops/nitrogen.

to the sandy soils and rolling hills of the area did not exist. However, as center-pivot irrigation technology has developed over the last 50 years, pumped groundwater has become a key input to agricultural production in the region.

Following decades of litigation, in 2002 the Supreme Court ruled that groundwater pumping by Nebraska farmers in the RRB reduced the availability of surface water to downstream users in Kansas, in violation of an interstate agreement. 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, which effectively removed the future option to irrigate land that was currently in dryland production. Annual volumetric restrictions based on historic irrigated area were placed on all existing wells and well metering was completed in the Nebraska portion of the RRB. Water rights are now allowable 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 in 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 implemented in 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 Nebraska 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.[1] The purpose of integrated water management plans is 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

[1] Any NRD may implement an integrated management plan.

Table 1. Summary Statistics

Variable	Definition	Obs. (weighted)	Mean	Std. Dev.	Between Std. Dev.	Within Std. Dev
Cropland Value	Operator-reported cropland value, $ per acre	1,172,766	2,326	1,756	1,905	941
Irrigation restrictions	Share with development or use restriction	1,172,766	0.30	0.46	0.51	0.21
Share irrigated	Irrigated cropland acres/total cropland acres	1,172,766	0.55	0.35	0.41	0.09
Sales class	Farm-level index	1,172,766	8.51	1.22	1.35	0.61
Mean slope		1,172,766	2.07	1.37		
Std. dev. slope	Standard deviation of slope	1,172,681	0.88	0.57		
Topsoil quality	Water-holding capacity of the topsoil	1,172,766	176	37		
Well yield	Gallons per minute	1,172,766	891	260		
Well depth	Pumping water level, feet below surface	1,172,766	112	62		
Population-interaction index	County-level index of urban population effects	1,172,766	5,307	5,906		
Distance to urban area	Population greater than 250,000	1,172,766	200	85		

Notes: Observations and all statistics use survey weights. The unweighted number of observations is 3,166 segment–years.

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 over- or fully appropriated are reviewed prior to January 1 of each year to ensure an adequate water supply.

The restrictions include both permanent regulations and temporary stays. For example, many of the moratoria currently in place started out as preliminary stays before becoming permanent, but this is not always the case. 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. Most restrictions in place were well established as being permanent by 2012. However, the determination of fully appropriated and over-appropriated is a contentious issue in Nebraska, with the preliminary determination in the Lower Niobara going to the Nebraska Supreme Court in 2011. A majority of the temporary stays were in place from 2006–2009 and were subsequently overturned by the DNR.

Data

This study employs confidential, representative, and geocoded panel data on plot-level cropland values from the USDA National Agricultural Statistics Service's June Area Survey (JAS) from 1999–2012. The JAS is conducted annually in early June and collects the land-value data that underpin the official USDA farmland values report, published annually in August. The survey uses an area-frame sampling methodology in which approximately 1-square-mile "segments" are randomly sampled. Once sampled, a segment remains in the sample for 5 years, at which point it is 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. While the term "(land) parcel" is more commonly used than "segment," we use the latter term to align with JAS terminology.

JAS responses also indicate plot size and how many acres within a plot are irrigated. Through special permission from NASS, we obtained the centroid of each segment, enabling us to link the JAS data to external spatial data sources.[2] The variables used in our analysis are summarized in Table 1. Due to the confidentiality of individual segment information, the sampling design of JAS ensures that segments are distributed across all agricultural areas of the state. Survey weights can be applied to generate representative estimates at the state and national levels. We chose to apply survey weights to all of our analyses to prevent over-weighting of smaller segments or segments from less agriculturally important areas.[3] Smaller segments and farms are both more numerous relative to their share of agricultural land use. This is a serious concern, given i) the large number of small farms in general, which would likely not irrigate or irrigate substantially and ii) the sampling design of JAS may lead to over-weighting of small plots if survey weights are not used, since all plots in a segment are included in the survey despite their size. Solon, Haider, and Wooldridge (2015) strongly advised calculating robust standard errors when using survey weights, so all of our models feature standard errors that are robust to correlation at the NRD level. Since the irrigation restrictions were implemented at the NRD level, clustering standard errors by NRD is a natural way to guard against spatial autocorrelation affecting the precision of our results.

JAS data are used to produce the official USDA farmland value estimates, which have been shown to be highly correlated with transactions values (Zakrzewicz, Brorsen, and Briggeman, 2012). Borchers, Ifft, and Kuethe (2014) confirmed that JAS data reflect agricultural as well as nonagricultural use values of farmland, similar to studies using transactions values. Further, several recent studies on the determinants of farmland values have used survey data from the JAS (e.g., Ifft, Kuethe, and Morehart, 2015; Towe and Tra, 2012; Schlenker, Hanemann, and Fisher, 2007). However, most farmland valuation studies use farmland transaction values. Although a robust sample of repeated observed market transactions of farmland would be ideal for estimating the impacts of irrigation restrictions, the JAS data enjoy several advantages over more widely available data sources. The JAS is, by design, a representative sample, which may not be the case for transaction prices if certain types of segments are more likely to be sold in a given year. Sherrick (2012) estimated that only 1% of farmland in Illinois is transacted per year, which implies that models estimated using farmland transaction prices may be subject to sample-selection issues. Further, research by Bigelow, Ifft, and Kuethe (2017) has found that average farmland values between acre-weighted farmland sales data and weighted JAS farmland value data are virtually indistinguishable at the New York state level. Last, the panel structure of the JAS allows us to include field-level fixed effects, which mitigate the potential for time-invariant unobservable factors to bias estimation results.

To track irrigation restrictions over the study period, we compiled narrative and spatially referenced data sources from the Nebraska DNR, individual NRDs, and other water management units in the state. Moratoria and other development restrictions were either district-wide or specific to a sub-watershed. These restrictions were mapped by identifying their coverage areas using geographic information systems. The JAS segment was considered to be all land with a half-mile radius of the segment centroid. Using this approach, the JAS segments were matched to the data on irrigation restrictions. Segments that overlapped NRD boundaries or separate areas with different irrigation restrictions were not considered in this analysis. Less than 1% of the data were discarded.

Avoiding multicollinearity was a key consideration for determining how irrigation restrictions would by measured for the empirical model. Well development or new irrigation rights moratoria have been the most common restrictions in the state. Other regulations, such as volumetric

[2] Because our study concerns irrigation restrictions as well as other spatial characteristics, we aggregate all plot-level data to the segment level, as unique physical or spatial characteristics of individual plots cannot be identified. Further, aggregating to the segment level also controls for changes in ownership during the study period, which would cause the plot to be assigned a different identification number.

[3] We report an unweighted version of our estimation results in the Online Supplement.

Table 2. Summary Statistics: Mean by Year

Year	Cropland Value	Irrigation Restrictions	Share Irrigated	Sales Class	Mean Slope	Std. Dev. Slope	Topsoil Quality	Well Yield	Well Depth	Population Index	Distance to Urban Area
1999	1,537	0.15	0.48	7.86	2.10	0.88	175	875	105	5,752	194
2000	1,580	0.19	0.51	7.99	2.06	0.87	174	897	107	5,747	195
2001	1,646	0.18	0.53	8.20	2.06	0.88	175	897	111	5,618	198
2002	1,596	0.23	0.54	8.24	2.01	0.86	176	902	112	5,010	203
2003	1,662	0.25	0.55	8.21	1.99	0.85	175	932	114	4,909	208
2004	1,756	0.32	0.54	8.21	2.10	0.90	178	919	118	4,889	209
2005	1,939	0.31	0.57	8.43	2.10	0.91	176	905	119	5,019	208
2006	2,063	0.43	0.57	8.40	2.05	0.87	175	896	117	5,303	206
2007	2,326	0.47	0.58	8.60	2.09	0.87	176	889	114	5,433	202
2008	2,627	0.55	0.56	8.79	2.06	0.86	174	874	110	5,720	194
2009	2,790	0.32	0.54	8.93	2.14	0.88	179	868	110	5,474	197
2010	2,854	0.30	0.56	8.94	2.05	0.85	176	864	110	5,168	201
2011	3,319	0.29	0.55	9.09	2.11	0.90	177	870	110	5,028	199
2012	5,097	0.26	0.57	9.31	2.04	0.89	176	883	105	5,195	191
Average	2,326	0.30	0.55	8.51	2.07	0.88	176	891	112	5,307	200

Notes: Land values are adjusted to 2012 dollars using the Consumer Price Index.

restrictions, have also been widely implemented in western Nebraska. 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 1% of wells in the RRB were constrained by the limits. Variables to account for volumetric limits were tested and results were consistent with Palazzo and Brozović (2014). The high correlation 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.

With few exceptions, restrictions on both surface water and groundwater tended to be imposed either simultaneously or in close succession. Similarly, the suite of possible restrictions on a given irrigation source tended to be imposed simultaneously. Both of these patterns limit the ability of the model to differentiate the impacts of these policies. In developing the model described below, we chose a single indicator equal to 1 if any development restrictions were imposed on either surface water or groundwater irrigation and 0 otherwise. New development moratoria or development stays were generally the first restriction in an area and represent the most common restrictions found throughout the sample.

Tables 1 and 2 contain descriptive statistics for the variables used in our analysis. The average cropland value across all segments and years in our study is $2,326. As shown by the between and within standard deviations, cropland values exhibit substantial variation across our study area and over the time period we consider. 30% of the segment–year observations were subject to an irrigation restriction, which exhibited some temporal variation in how they affected individual plots. Table 2 illustrates trends in the mean values of our study variables over time. In line with national trends, average cropland values increased by a factor of more than 4 during our study time frame, rising from $1,537/acre in 1999 to $5,097/acre in 2012. Additionally, Nebraska farms exhibited growth over this time period, as the average sales increased from $100,000–$249,999 (sales class 8) to $250,000–$499,999 (sales class 9). Similarly, the share of land irrigated within each segment also exhibited a general increase between 1999 and 2012, consistent with the observed trend of increased irrigation in Nebraska during this period.

Empirical Model

We estimate a generalized difference-in-differences (DID) model with segment-level fixed effects to measure the effects of irrigation restrictions on cropland values in Nebraska. This modeling strategy has seen increased use in the irrigation valuation literature as more granular panel data become available (e.g., Buck, Auffhammer, and Sunding, 2014; Hendricks and Peterson, 2012; Schoengold, Sunding, and Moreno, 2006). Using repeat sales transactions for individual parcels, Buck, Auffhammer, and Sunding (2014) showed that unobserved heterogeneity present in cross-sectional models can lead to substantial downward bias in the marginal implicit price of surface water deliveries. Repeat sales data are rarely available, however, since the small number of arms-length transactions over time for a given parcel means that, in most settings, researchers will not be able to find a sufficiently large and representative sample of repeat sales transactions. The unbalanced-panel nature of the JAS data provides a viable alternative which allows us to estimate a segment-level fixed effects model similar to that of Buck, Auffhammer, and Sunding (2014).

Since the JAS elicits information directly from farm operators, one interpretation of our empirical approach is that we are estimating a willingness-to-accept function that reflects farmers' reservation price or their expected net present value of the returns associated with the surveyed segments. However, as discussed, JAS data have been shown by other studies to be a reliable, high-quality source of farmland values in a variety of contexts. Ultimately, we cannot prove whether the underlying economic model is best interpreted as a willingness-to-accept function or as a reasonable approximation of a first-stage hedonic model based on market transactions. Our empirical approach centers on exploiting the panel structure of the JAS data in a reduced-form estimation framework to measure the extent to which the irrigation restrictions are capitalized into operators' land value assessments.[4]

Following the approach of Buck, Auffhammer, and Sunding (2014), a baseline version of the model we estimate is given by

$$L_{it} = \beta_1 S_{it} + \beta_2 R_{it} + f_i + d_t + \varepsilon_{it}, \quad (1)$$

where L_{it} is per acre value of cropland in segment i in year t, S_{it} is farm operator's sales class, R_{it} indicates whether any irrigation restrictions are in place, f_i denotes parcel or segment fixed effects, d_t denotes year fixed effects, and ε_{it} represents variation in land values not explained by our model. While the segment fixed effects absorb most operator characteristics and segment biophysical characteristics (e.g., soil quality), we also control for the farm operator's sales class (S_{it}), which is the primary time-varying operator characteristic in the JAS. Sales class is a general farm typology measure of gross farm sales and ranges from less than \$1,000 to greater than \$5 million. Sales class ranges from 1 to 13, with 1 smallest and 13 largest. We include this variable to control for potential farmland investments made by different types of operators in response to irrigation policies.

Since our goal is to estimate the effect of irrigation restrictions on land values, a natural question to ask is whether the restrictions have differential effects on irrigated and nonirrigated land. One option would be to include IRR_{it}, the share of cropland irrigated in the segment, in the specification and interact it with R_{it}. However, IRR_{it} is an endogenous, dynamic-choice variable that is almost certainly correlated with ε_{it}, the unobserved idiosyncratic annual shocks to cropland values. To avoid having to instrument for IRR_{it}, we estimate our preferred specification separately with irrigated and dryland cropland segments. We also report our results with aggregate cropland values for our baseline specification.

We define "irrigated parcels" as those with *any* irrigation reported during *any* observed year, with all other parcels being defined as dryland. For irrigated parcels, the left-side variable in 1 is the weighted average of irrigated and nonirrigated cropland values observed for the tracts in each segment. The "dryland parcels" sample is made up of segments that have only nonirrigated land values reported throughout the study period. We interpret dryland parcels as cropland unlikely to have recent irrigation potential or history, given the ubiquity of irrigation adoption throughout Nebraska and the open-access manner in which groundwater has historically been managed.[5]

One of the main contributions of this study concerns our ability to exploit the within-segment variation in the JAS dataset to identify the impact of irrigation restrictions. However, the model given by equation (1) does not account for the fact that the effect of irrigation restrictions may vary over time and implicitly assumes that no unobserved time-varying factors are correlated with the irrigation restrictions. Temporal changes in irrigation technology and commodity market conditions could influence how irrigation restrictions are capitalized into farmland values. Kuminoff, Pameter, and Pope (2010) suggest that a generalized DID estimation strategy may mitigate the potential endogeneity of policy variables in land value panel regression models. We account for this in our model by introducing a restriction–year interaction term, $\gamma_1 R_{it} d_t$, to equation (1):

$$L_{it} = \beta_1 R_{it} + \beta_2 S_{it} + \gamma 1 R_{it} d_t + f_i + d_t + \varepsilon_{it}. \quad (2)$$

[4] In the Online Supplement, we estimate a cross-sectional model of cropland values and find that the estimate for a variable representing the share of land irrigated is consistent with results from prior studies in Nebraska using transaction values. Given the high quality of JAS data, in conjunction with this data-validation exercise, we are confident in referring to our estimates as impacts on farmland values.

[5] To gauge the robustness of these decisions regarding the composition of the irrigated and dryland samples, as well as the construction of the dependent variables, we report out main model—estimated with different definitions of irrigation status—in the Online Supplement, which produces largely consistent results. We also estimate our main specification using only the nonirrigated value component of the irrigated parcels' combined land value to examine how the irrigation restrictions affected option values for irrigation.

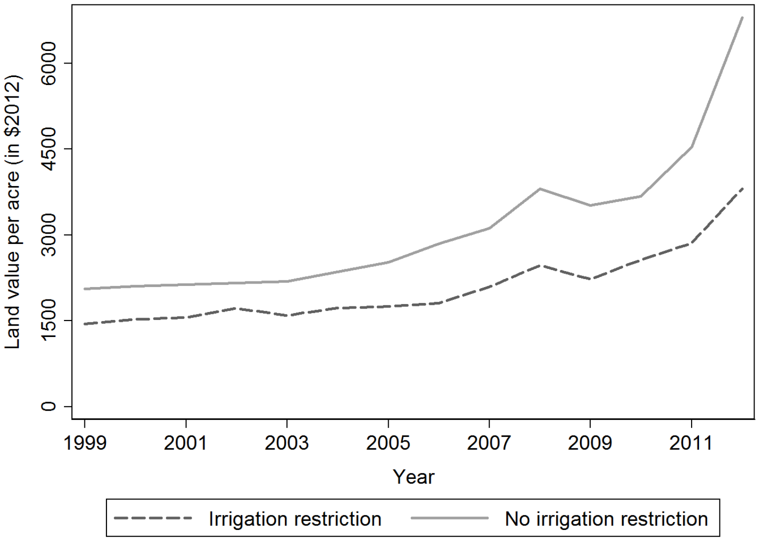

Figure 2. Mean Irrigated Land Values by Restriction Status

Source: June Area Survey.

We motivate the inclusion of the interaction term by discussing three relevant trends that coincide with our study area and time frame: i) commodity market conditions, ii) changes in irrigation technology, and iii) changing expectations of the permanence of irrigation restrictions.[6]

Changing market conditions could influence our results, since the desire for new irrigation development may vary with shifts in the supply and demand of agricultural commodities. It has been widely recognized in the literature that the hedonic price function is unstable and may change over time (e.g., Zabel, 2015; Zhang and Nickerson, 2015). Changing market conditions are especially relevant for our study, as corn prices were high in 2007–2012 and farm income, more broadly, was on an upward trend throughout the entire 1999–2012 study period. The per acre price differential between official USDA irrigated and nonirrigated cropland values stayed between $690 and $710 until 2007, increased to $900 in 2008, and reached $2,340 by 2012. Changes in the irrigated–nonirrigated price differential are likely driven by the high corn prices sustained over this period rather than by yield trends. Although both average irrigated and nonirrigated corn and soybean yields increased during the study period, USDA-NASS county-level yield estimates suggest that irrigated yields did not increase at a greater rate than nonirrigated yields. These trends jointly suggest that irrigation water became substantially more valuable under higher commodity prices. The irrigated–dryland value differential is reflected in our JAS cropland-values data in Figures 2 and 3. For both irrigated and nonirrigated cropland, the differential between average restricted and unrestricted cropland values is much larger in the second half of our study period, suggesting that the effect of irrigation restrictions may vary over time.

Prices for corn and soybean prices—which make up the vast majority of cropland acres in Nebraska—are highly correlated. According to USDA data, Nebraska had about 10 million total planted acres of corn and 5 million of soybeans, compared to about 1 million acres of wheat, out of total 21.6 million acres of cropland in 2012. Wheat acreage, for which irrigation is not common, experienced a gradual decline during the study period, while corn and soybeans acreage experienced sustained gradual increases. Based on USDA-NASS county estimates, some western and southern counties experienced a decline in irrigated corn acreage, while some northern and eastern counties

[6] We confirm that including the annual interaction effects, $\gamma_1 R_{it} d_t$, improves model fit (relative to equation ((1)) or a model with a grouped interaction for 2007–2012) with a set of likelihood-ratio tests. The results for all of the likelihood-ratio tests produce p values less than 0.001, rejecting the more parsimonious specifications in favor of equation ((2)).

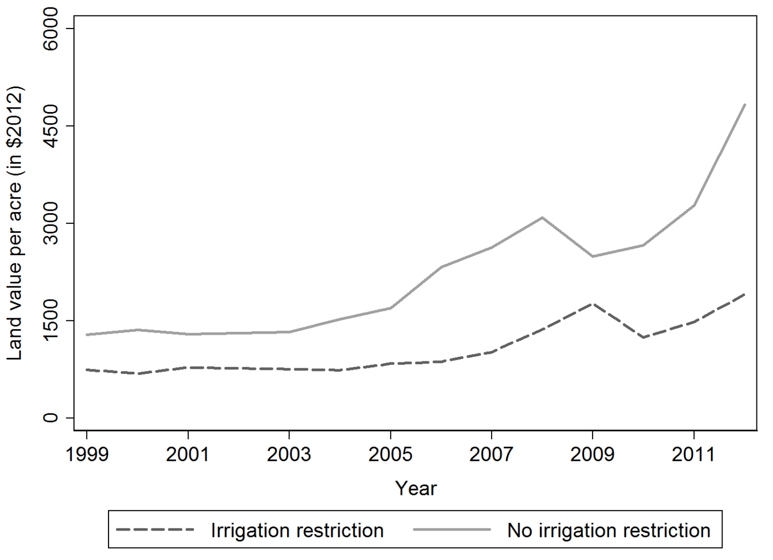

Figure 3. Mean Nonirrigated Land Values by Restriction Status

Source: June Area Survey.

experienced an increase. Trends for irrigated soybeans were similar. These crop acreage trends further support the notion that changing market conditions may have altered the effects of irrigation restrictions over time.

Changes in irrigation technology also occurred during our study period. Total irrigated acres in Nebraska expanded by 12% over 2002–2007, with most of this expansion occurring in areas that already had high levels of irrigation.[7] By 2008, 80% of irrigated acres in Nebraska used sprinkler systems (of which center-pivot sprinkler systems made up 98%), which are more efficient than gravity/flood systems. This was a moderate increase, about 5 percentage points, from 2003 (Johnson et al., 2011). Areas using gravity systems would likely have fewer restrictions on water use or lower returns to irrigation. Although the majority of irrigated acres included in our study were using center-pivot technology, the persistent, albeit slight, trend toward more efficient irrigation technology provides a third motivation for allowing the effects of the restrictions to vary over time.

One additional issue for identifying the impact of irrigation restrictions is, as noted above, the inclusion of both permanent development moratoria and temporary stays in our dataset, which we are unable to distinguish between. Information on irrigation stays is compiled by the DNR, which does not always differentiate between preliminary and permanent restrictions on irrigation development. Our estimates are affected by whether producers anticipate a new restriction as well as by their beliefs about its permanence and impact. For example, if dryland producers anticipate a moratorium and invest in wells prior to its implementation, this biases our estimates toward 0. In this sense, one way to interpret the marginal effect of R_{it} is that it represents the imposed condition that no new irrigation development is currently permitted, lending further support to the inclusion of the restriction–year interaction term. Since many of the temporary restrictions were put in place around 2006–2009, a period that also coincided with the onset of high corn prices, we would expect those years to be most affected by the implementation of temporary restrictions that were subsequently overturned.

In addition to allowing the effects of the restrictions to vary over time, we also analyze the extent to which various cross sections of Nebraska farms were differentially affected. To this

[7] Irrigated acreage declined by 2% over 2007–2012, an effect that is largely attributable to the severe drought that affected the Midwest and Plains regions in 2011–2012.

end, we estimate a series of models with alternative subsamples of the data aimed at measuring heterogeneity in the underlying baseline estimates. First, to explore explicitly how groundwater irrigation reliance affects the results, we also estimate the models using only observations that had above-median certified groundwater irrigable acreage.[8] Second, to explore the importance of the positive temporal trend in irrigation found through most of our study period, we estimate our models after excluding observations from the 7 counties that had the largest increase in irrigated acreage. Third, we restrict our model to NRDs in the Republican and Platte River Basins. These western basins have significant agriculture, and the normal crop water requirements across Nebraska exhibit a steep gradient increasing from east to west. In addition, these basins were subject to substantial growth in irrigation restrictions during our study period.

The appropriate specification of empirical property-value models has attracted considerable attention in the hedonic literature. Cropper, Deck, and McConnell (1988) found that simpler linear functional forms perform best when unobserved heterogeneity or endogeneity are an issue. In this paper we are able to use segment-level fixed effects and control for some sources of omitted variable bias, specifically segment-level characteristics that affect both irrigation choice and land values, such as soil type and irrigation suitability. We report our results using a log-linear model, which, based on a Box–Cox test, is preferred over a linear model.[9]

Results

The coefficient estimates of our main specification are reported in Table 3 and are broken into separate sets of estimates for all segments, irrigated parcels, and dryland parcels. The dependent variable in all models is the logged per acre land value, adjusted to 2012 dollars using the Consumer Price Index (CPI-U). Standard errors in all models are clustered by NRD to mitigate the potential for biased precision from spatial autocorrelation. While the direction and statistical significance of the estimated parameters have implications for evaluating the irrigation restrictions and modeling approach, the annual marginal effects of the irrigation restrictions (taking into account the baseline and interaction effects) are more meaningful. We therefore only briefly discuss the regression results before moving on to a discussion of marginal effects.

The year effects illustrate strong annual growth in farmland values, particularly for irrigated land, over our study time frame. Sales class has a positive and statistically significant effect on land values when estimating the model with all three subsamples, indicating that, intuitively, farms with a larger volume of sales are associated with more valuable land. Although the baseline effect of the irrigation restrictions is insignificant using all three samples, the restriction–year interaction coefficients provide some evidence that the effect of irrigation restrictions is not static between 1999 and 2012.

The average and year-specific marginal effects of the irrigation restrictions are given in Table 4 in percentage terms.[10] On average for the entire period (and prior to 2006), irrigation restrictions

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[8] We only estimate a model for the irrigated parcel component of this subsample. There are only 38 dryland parcels in this subsample, which may reflect a deliberate decision to not irrigate on the part of farmers but is more plausibly because of the manner in which the certified groundwater rights were matched to the JAS segments.

[9] The Box–Cox test produced a λ test statistic of 0.26 ($p<0.001$), which supports a log-linear specification. Kuminoff, Pameter, and Pope (2010) suggest that more flexible functional forms may have superior performance for well-identified specifications. We also estimated our main specification with the quadratic Box–Cox model recommended by Kuminoff, Pameter, and Pope (2010), who found that it performed best in a comprehensive evaluation of different functional forms when fixed effects were included in the model. However, given the Box–Cox test results and the fact that the quadratic Box–Cox estimates are qualitatively similar to those from the log-linear specification, we use the log-linear model as our preferred baseline specification.

[10] Following Kennedy (1981), due to the log transformation of our dependent variable we convert the marginal effects into percentage terms using the following formula: $100 * (e^{\hat{b}-\frac{1}{2}*\hat{v}} - 1)$, where $\hat{b}$ denotes the marginal effect and $\hat{v}$ denotes its associated variance.

Table 3. Coefficient Estimates

	Log Cropland Value		
	All Parcels	**Irrigated Parcels**	**Dryland Parcels**
Irrigation restriction (IR)	0.028	−0.026	0.238
	(0.070)	(0.079)	(0.150)
2000	0.015	0.030	0.004
	(0.030)	(0.034)	(0.034)
2001	0.070	0.099	−0.030
	(0.036)*	(0.043)**	(0.027)
2002	0.029	0.038	0.035
	(0.046)	(0.057)	(0.028)
2003	0.100	0.121	0.032
	(0.044)**	(0.051)**	(0.059)
2004	0.154	0.169	0.135
	(0.045)***	(0.052)***	(0.041)***
2005	0.188	0.227	−0.007
	(0.045)***	(0.060)***	(0.079)
2006	0.276	0.267	0.361
	(0.057)***	(0.050)***	(0.123)***
2007	0.387	0.384	0.493
	(0.068)***	(0.070)***	(0.098)***
2008	0.471	0.476	0.496
	(0.067)***	(0.072)***	(0.151)***
2009	0.480	0.474	0.590
	(0.061)***	(0.060)***	(0.151)***
2010	0.545	0.559	0.560
	(0.079)***	(0.081)***	(0.197)**
2011	0.757	0.766	0.784
	(0.061)***	(0.069)***	(0.192)***
2012	1.117	1.144	1.078
	(0.075)***	(0.088)***	(0.200)***
2000×IR	−0.094	−0.073	−0.049
	(0.057)	(0.084)	(0.036)
2001×IR	0.056	0.070	0.038
	(0.102)	(0.127)	(0.075)
2002×IR	0.020	0.087	−0.150
	(0.068)	(0.090)	(0.065)**
2003×IR	−0.005	0.037	−0.086
	(0.068)	(0.057)	(0.113)
2004×IR	−0.029	0.028	−0.223
	(0.046)	(0.067)	(0.126)*
2005×IR	−0.019	0.012	−0.006
	(0.063)	(0.074)	(0.127)
2006×IR	−0.212	−0.139	−0.417
	(0.096)**	(0.090)	(0.158)**
2007×IR	−0.221	−0.154	−0.456
	(0.085)**	(0.097)	(0.140)***
2008×IR	−0.158	−0.093	−0.345
	(0.093)	(0.109)	(0.147)**

Continued on next page...

Table 3. – continued from previous page

	Log Cropland Value		
	All Parcels	Irrigated Parcels	Dryland Parcels
2009×IR	−0.111	−0.024	−0.464
	(0.087)	(0.084)	(0.179)**
2010×IR	−0.096	−0.060	−0.163
	(0.094)	(0.117)	(0.188)
2011×IR	−0.190	−0.145	−0.317
	(0.104)*	(0.125)	(0.173)*
2012×IR	−0.296	−0.260	−0.378
	(0.125)**	(0.144)*	(0.190)*
Farm Size	0.033	0.030	0.054
	(0.013)**	(0.015)*	(0.015)***
Constant	7.083	7.107	5.939
	(0.107)***	(0.124)***	(0.218)***
R^2	0.865	0.831	0.946
Segments	881	696	185
Segment–years	3,166	2,573	593
Weighted observations	1,172,766	965,280	199,492

Notes: Standard errors clustered by Natural Resource District are reported in parentheses. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level. Irrigated parcels had irrigated cropland values reported in some years (and also include any reported nonirrigated cropland values); dryland parcels never had irrigated cropland values reported.

did not have a statistically significant impact on cropland values in the full sample (column 1 of Table 4). From 2006–2008, however, irrigation restrictions were associated with a 12%–18% decline in land values. This is likely attributable to the uptick in temporary moratoria implemented in 2006–2009 and also reflects the larger number of irrigation restrictions from 2006–2008 (see Table 2). We also see evidence of a 15%–24% decline in 2011–2012.

Separating the results by irrigation status reveals that irrigation restrictions had no measurable impact on dryland farms (Table 4, columns 2 and 3). This not surprising, given our definition of a dryland parcel. However, the impact on irrigated parcels is similar to that of the entire sample. Before 2005, irrigation restrictions had no measurable impact on irrigated parcel values. For irrigated land, we find that the irrigation restrictions had a negative effect of a 15%–17% in 2006–2007 and a larger, negative effect of 17%–27% in 2011–2012.

Overall, these results suggest that the effects of the restrictions were confined to a handful of years during our study time frame, with the most robust effects for irrigated parcels taking place in 2006–2008, when the volume of restrictions in place was at its peak. The general lack of an effect during the early half of our study period is not surprising, as this was a period of relatively low commodity prices, which would weaken the advantage of having higher yields through irrigation. Between 2006 and 2008, commodity prices were relatively high, which, coupled with the increase in restrictions, suggests that the relative returns associated with expanding irrigation would have been higher. According to the U.S. Drought Monitor, 2006 was an especially bad drought year for much of Nebraska, lending further support to the idea that the restrictions would have been binding around that time. In addition, we find that the irrigation restrictions may have had a serious impact, amounting to roughly a quarter of the value of land, during the later years of our time frame, a period characterized by even higher commodity prices and the onset of another large drought.

Subsample Analysis and Robustness Checks

We estimate our baseline models with several subsamples of the data to consider whether the pooled results presented in the previous section obscure any meaningful sources of cross-sectional

Table 4. Marginal Effects of Irrigation Restrictions

	All Parcels	Irrigated Parcels	Dryland Parcels
Average×IR	−6.51	−7.85	6.54
	(5.13)	(5.17)	(13.86)
1999×IR	2.53	−2.88	25.39
	(7.23)	(7.72)	(18.87)
2000×IR	−6.55	−10.23	20.52
	(10.53)	(10.80)	(18.15)
2001×IR	7.77	3.48	28.96
	(15.15)	(16.32)	(18.58)
2002×IR	4.34	5.72	11.30
	(8.57)	(9.59)	(15.93)
2003×IR	1.85	0.72	16.59
	(7.36)	(8.37)	(14.88)
2004×IR	−0.40	−0.25	4.74
	(6.63)	(7.89)	(12.27)
2005×IR	0.43	−1.91	23.98
	(5.45)	(6.06)	(17.42)
2006×IR	−16.91	−16.21	−9.50
	(4.35)***	(4.78)***	(11.88)
2007×IR	−17.57	−17.52	−11.85
	(5.04)***	(5.23)***	(12.58)
2008×IR	−12.41	−12.29	−4.57
	(5.44)**	(6.42)*	(12.03)
2009×IR	−8.35	−5.56	−12.72
	(6.00)	(6.57)	(16.09)
2010×IR	−7.05	−9.38	8.91
	(7.20)	(8.00)	(13.95)
2011×IR	−15.18	−17.04	−2.89
	(7.68)**	(9.16)*	(14.92)
2012×IR	−23.64	−26.60	−7.31
	(9.78)**	(12.44)**	(17.44)
Segments	881	696	185
Segment–years	3,166	2,573	593
Weighted observations	1,172,766	965,280	199,492

Notes: For ease of interpretation, the marginal effects shown in this Table have been converted to percentages using the method suggested by Kennedy (1981). Standard errors clustered by Natural Resource District are reported in parentheses. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level. Irrigated parcels had irrigated cropland values reported in some years (and also include any reported nonirrigated cropland values); dryland parcels never had irrigated cropland values reported.

heterogeneity in the impact of the restrictions. We present results of the yearly marginal effects for these models in Table 5. Graphical representations are available in the Online Supplement (www.jareonline.org).

We first exclude all segments with below-median certified groundwater-irrigable acres from our estimation to measure whether segments with a relatively greater reliance on, and access to, groundwater are more or less sensitive to the restrictions (column 1 of Table 5). The results for irrigated parcels in this subsample are similar to the results from our main irrigated parcel sample. We find evidence of a (marginally significant) 14%–15% decline in 2006–2007, which is in line with results from the full irrigated sample. In addition, the restriction effect for 2011 (26%) is quite large.

Table 5. Marginal Effects for Different Cross Sections of Nebraska Farms

	Above Median Groundwater Acres	Low Irrigated Acreage Expansion		Platte/Republican River Basin	
	Irrigated	Irrigated	Dryland	Irrigated	Dryland
Average×IR	−4.23	−7.48	6.04	−13.61	15.83
	(10.31)	(5.11)	(14.32)	(6.81)**	(11.66)
1999×IR	11.61	−2.99	23.75	−14.14	−1.71
	(15.96)	(8.49)	(19.28)	(8.63)	(10.93)
2000×IR	9.71	−9.39	20.48	−21.96	−2.63
	(17.99)	(8.62)	(18.38)	(13.19)*	(8.57)
2001×IR	−0.58	0.39	28.42	1.73	8.82
	(17.04)	(13.79)	(19.21)	(18.68)	(12.85)
2002×IR	13.28	3.27	11.81	5.84	−4.55
	(12.73)	(8.43)	(16.13)	(13.04)	(6.27)
2003×IR	12.67	0.00	18.27	1.43	0.82
	(12.40)	(8.44)	(14.86)	(8.93)	(7.83)
2004×IR	9.30	−2.59	4.51	−2.07	−16.38
	(13.53)	(7.36)	(12.44)	(12.43)	(7.52)**
2005×IR	1.22	−4.08	25.05	−2.47	8.67
	(10.28)	(6.99)	(17.61)	(11.71)	(12.70)
2006×IR	−14.15	−12.76	−12.16	−25.24	−14.33
	(8.12)*	(5.75)**	(12.21)	(8.42)***	(15.33)
2007×IR	−15.79	−15.38	−14.36	−19.44	−7.11
	(9.19)*	(6.42)**	(13.34)	(6.51)***	(18.06)
2008×IR	−10.80	−10.65	−7.24	−16.57	12.35
	(10.58)	(6.74)	(12.52)	(12.83)	(19.33)
2009×IR	−10.53	−2.64	−14.41	−15.61	−11.80
	(10.55)	(6.58)	(16.65)	(14.99)	(16.15)
2010×IR	−13.43	−8.22	8.66	−21.26	52.72
	(10.93)	(7.32)	(14.48)	(7.37)***	(27.24)*
2011×IR	−26.01	−13.50	−3.06	−28.01	131.53
	(12.81)**	(9.05)	(15.55)	(10.61)***	(42.73)***
2012×IR	−25.75	−26.22	−5.19	−32.74	65.28
	(16.57)	(11.92)**	(17.54)	(15.93)**	(33.00)**
Segments	380	580	170	292	82
Segment–years	1,403	2,145	549	1,076	265
Weighted observations	548,833	808,757	189,143	400,102	72,307

Notes: For ease of interpretation, the marginal effects shown in this table have been converted to percentages using the method suggested by Kennedy (1981). Standard errors clustered by Natural Resource District are reported in parentheses. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level. Irrigated parcels had irrigated cropland values reported in some years (and also include any reported nonirrigated cropland values); dryland parcels never had irrigated cropland values reported.

Next, we estimate our preferred specification after excluding the 7 counties with the largest increase in irrigated acres during our study period (columns 2 and 3 of Table 5). Any time-varying trends related to irrigation potential and technological change are *less* likely to be present in these counties. Compared to the baseline results, we see a similar impact of irrigation restrictions on irrigated and dryland parcels in these counties. This provides evidence that changes in irrigation technology and expansion are not driving our main results.

Last, we consider an additional source of heterogeneity by restricting the estimation of our main specification to all in NRDs in the Platte and Republican River Basins (columns 4 and 5 of Table 5). This is a near-ideal part of Nebraska in which to consider the impact of irrigation restrictions. In this agriculture- and irrigation-intensive area, the irrigation restrictions had statistically significant average effect of nearly 14% on irrigated parcels throughout the study period, driven by negative impacts on land values in 2000, 2006–2007, and 2010–2012. While the impact in 2000 was only marginally significant, the region experienced land-value declines of 19%–32% in 2006–2007 and 2010–2012. These declines are larger than that for our baseline irrigated sample and provide evidence that restrictions were costly for this region when commodity prices were high. However, the results for dryland parcels in this region are in stark contrast to those of the main specification. Irrigation restrictions are associated with a large and statistically significant increase in dryland parcel values over 2010–2012. This fits in with the story of dryland drought resilience found in prior studies (Hornbeck and Keskin, 2014), as well as improvements and investments in dryland agriculture practices and technology in an area where irrigation restrictions have been reported to be "binding."

To gauge the sensitivity of our results to the JAS survey design, we also estimate our models using the unweighted versions of the irrigated and dryland samples (Online Supplement Table S2). The results of these robustness checks are broadly similar to those from the baseline specification, though with a more noisy signal, which provides additional evidence that the restrictions had some time-varying effects on land values in our study area. Additionally, in Online Supplement Table S3 we report estimates from the baseline models using three alternative groupings for the dependent variable: i) the irrigated value component of the irrigated parcel sample, ii) the nonirrigated value component of the irrigated parcel sample, and iii) all nonirrigated values from both the irrigated and dryland samples. For the first grouping, the effects are generally smaller and not statistically significant for the individual study years, with the exception of effects of -15% in 1999 and -6% in 2006. The results of the second and third groupings, however, show a bit more variation, with significant positive effects in several years for the early part of the study period (prior to 2005). These findings suggest that our findings for irrigated parcels may be driven by loss of option value. Another interpretation is that that positive values for some years for nonirrigated cropland suggest switching of land with irrigation potential between irrigated and nonirrigated status and hence support our preferred classifications.

Discussion and Conclusion

In this paper, we have shown that restrictions on irrigation development are not consistently capitalized into the value of Nebraska farmland. This may be surprising to researchers, given the generally enhanced production capability of irrigated over nonirrigated land. However, we do see large negative impacts in southwestern Nebraska, a region particularly dependent on irrigation and affected by interstate conflict and litigation over water rights. Our results clearly indicate the impact of irrigation restrictions changes over time. The findings also reflect the heterogeneous impacts of irrigation restrictions, supporting some key narratives related to market conditions and policy changes. Given the large role that irrigation restrictions play in water management institutions in western states, disentangling the varied impacts of irrigation restrictions that may be obscured when looking at more aggregated impacts is a noteworthy contribution to research on this topic.

Commodity markets play a key role in framing our results. Low prices in the early part of our study period, which conceivably could have weakened demand for new irrigation infrastructure, may have led to a null effect of irrigation restrictions on irrigated lands. Corn prices increased dramatically after 2007; around this time, we begin to see a negative relationship between cropland values and irrigation restrictions in some years. Irrigation restrictions may have played a role in moderating use of irrigation water in Nebraska in recent droughts. While the moratoria may have been effective at preventing overexploitation of water resources between 2006 to 2012, we found some evidence that the economic cost to producers and landowners can be significant during periods of high crop prices. Going forward, droughts during commodity price booms may impose costs on farmers whose irrigation practices are restricted by volumetric withdrawal limits or constraints on new well development. However, these costs could be outweighed by the long-term costs of unrestricted water access on the environment and future farm production.

During the later part of our study period, when commodity prices were high, farms may also have had more experience with irrigation restrictions as well as confidence in their permanence, which have contributed to the results for 2010 onward. These expectations are not observed but may be influencing our results. From 2006–2009, temporary restrictions that were eventually overturned may have driven a consistent negative decline on irrigated cropland parcels with an irrigation restriction. A challenge for researchers is that irrigation restrictions may not be immediately binding and it may take some time for market participants to internalize the impacts of restrictions. If the moratoria were not binding in the earlier years of our study, this situation appears to have changed in the later half, when both temporary and permanent restrictions appear to have influenced land values in some years.

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 of irrigation or various types of water use rights. Further, the hedonic price function associated with water use rights may change over time, and hedonic applications should account for these potential changes. The generalized difference-in-differences approach used in this study demonstrates the importance of such modeling considerations. Additionally, we have shown the JAS to be a source of quality information on plot-level land values, which, when coupled with its panel-based survey design, should continue to prove useful in future policy evaluations.

Nebraska has a unique institutional framework that includes a well-developed system of regulations to provide farmers with access to 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. While we have shown, in a reduced-form framework, that irrigation restrictions show temporal variation in their effect on land values, a natural next question to ask is how the restrictions actually affected pumping behavior and the rate of aquifer drawdown. As policies aimed at promoting long-term sustainable groundwater management have both costs and benefits, the distribution of net social benefits of interest to local policy makers is a function of both biophysical and financial impacts.

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Online Supplement

To compare our estimates to those commonly found in the literature based on transactions data, we estimate a pooled cross-sectional model similar to those used in farmland-value studies using Nebraska transactions data. This allows us to compare irrigation water valuation between operator estimates of cropland values and market values. For this data-validation exercise, our estimating equation is

$$L_{it} = \beta_1 Z_i t + \beta_2 S_i t + \beta_3 IRR_{it} + \beta_4 NRD_i + \beta_5 R_{it} + \beta_6 d_t + \varepsilon_{it}, \quad \text{(S1)}$$

where Z_i is a vector of parcel-level characteristics, IRR_{it} is the share of cropland irrigated, and NRD_i are NRD indicator variables, in addition to previously defined variables. This approach will allow us to compare our results to those of Torell, Libbin, and Miller (1990), Islam and Brozović (2010), Shultz (2010), Shultz and Schmitz (2010), all of whom estimate irrigation water contribution to farmland values in various locations in Nebraska.

While our pooled cross-section analysis does not control for all factors that might be correlated with the irrigation status of cropland, we do include many key factors in Z_i. Biophysical traits such as slope, pumping capacity, and acres irrigated are commonly missing from hedonic studies (Shultz, 2010). We also control for many of the factors associated with the irrigation adoption decision by including the key parcel and operator characteristics: sales class, slope, water-holding capacity, 2010 population interaction index, and distance from a city with population greater than 250,000.

Multicollinearity was an issue for many of the land- and soil-quality variables available through SSURGOAc. In particular, Land Capability Classifications were highly collinear with the water-holding capacity of the topsoil, which we deemed a more useful variable for our analysis (Topsoil Quality). We include slope and mean slope as additional indicators of soil productivity. The data on pumping water levels and well yields were taken from the DNR active wells database. These data reflect measurements reported at the time of well installation. 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. We additionally include two measures of urban influence: the 2010 population interaction index and distance to cities with a population greater than 250,000. The construction of these two development pressure–related variables is described in detail in Borchers, Ifft, and Kuethe (2014).

Table S1 reports the coefficient estimates for the pooled cross-section models. We interpret the regression results for the purpose of evaluating the comparability of JAS data to transactions values. The coefficient estimate for *Share irrigated* (IRR_{it}) is positive and statistically significant at the 1% test level and indicates that land value increases 68% if irrigation goes from 0 to 100%. This coefficient implies a marginal effect of going from 0 to 100% irrigation of \$2,898/acre in 2012 dollars and \$830/acre in 2002 dollars.

Many other variables have an impact on cropland values that is largely consistent with the literature or as implied by economic theory. Measures of slope are not associated with higher land values, but topsoil quality is. Further, an additional gallon per minute of well yield is associated with a statistically significant 0.01% increase in cropland value. Given the importance of irrigation in Nebraska, perhaps this effect reflects overall irrigation potential or quality. Moving up an additional sales class is associated with a 5% increase in cropland values. Both coefficients measuring development pressure or urban amenities are statistically significant with the expected signs. Interaction with urban populations is associated with higher cropland values, while increasing distance away from cities is associated with lower cropland values.

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/acre in Chase County in 2000–2008. Shultz (2010) estimated the value of irrigation to be around \$827/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

Table S1. Cross-Sectional Estimation Results

	Log Cropland Value
Share irrigated	0.681
	(0.120)***
Irrigation restrictions	−0.143
	(0.039)***
Sales class	0.047
	(0.010)***
Slope	0.007
	(0.029)
Std. dev. slope	−0.050
	(0.049)
Topsoil quality	0.002
	(< 0.001)***
Well yield	< 0.001
	(< 0.001)***
Well depth	> −0.001
	(< 0.001)
Population-interaction index	< 0.001
	(< 0.001)***
Distance to urban area	−0.001
	(< 0.001)***
Constant	6.411
	(0.178)***
R^2	0.704
Segments	881
Segment–years	3,166
Weighted observations	1,172,681

Notes: Year and NRD fixed effects included in estimation. Standard errors clustered by Natural Resource District are reported in parentheses. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level. A table entry of <0.001 indicates a positive estimate in the (0, 0.001) interval, while an entry of > −0.001 represents a negative estimate in the (−0.001, 0) interval.

the Upper Republican over 2000–2007. Torell, Libbin, and Miller (1990) found groundwater to be valued at $545 over 1979–1986 in Nebraska, which is similar in real dollars to our estimates. The methods used in these studies are most comparable to those used in our pooled cross-section model, which yields a marginal effect of irrigation of $830/acre in 2002 dollars. This result suggests JAS operator-reported cropland values can provide comparable research results to studies using transactions values.

Table S2. Unweighted Estimation Results

	Irrigated (unweighted)	Dryland (unweighted)
Average×IR	−3.97	9.64
	(7.14)	(16.68)
1999×IR	−0.38	29.3
	(10.18)	(23.11)
2000×IR	−6.12	29.64
	(13.55)	(21.12)
2001×IR	13.77	35.95
	(20.81)	(21.40)*
2002×IR	9.29	14.08
	(12.90)	(17.99)
2003×IR	4.72	18.35
	(12.03)	(17.46)
2004×IR	2.14	6.55
	(9.25)	(14.83)
2005×IR	−2.27	29.27
	(8.28)	(23.68)
2006×IR	−14.94	−4.22
	(5.54)***	(14.15)
2007×IR	−11.78	−8.69
	(6.44)*	(14.78)
2008×IR	−9.62	−0.21
	(8.58)	(14.91)
2009×IR	−1.3	−11.05
	(8.07)	(18.86)
2010×IR	−8.02	6.53
	(10.73)	(17.89)
2011×IR	−6.6	0.04
	(11.93)	(18.57)
2012×IR	−24.4	−10.62
	(13.91)*	(23.11)
Segments	696	185
Segment–years	2,573	593
Weighted observations	n/a	n/a

Notes: For ease of interpretation, the marginal effects shown in this table have been converted to percentages using the method suggested by Kennedy (1981). Standard errors clustered by Natural Resource District are reported in parentheses. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level. Irrigated parcels had irrigated cropland values reported in some years (and also include any reported nonirrigated cropland values); dryland parcels never had irrigated cropland values reported.

Table S3. Robustness Checks: Alternative Definitions of Baseline Groupings

	Irrigated Parcels (irrigated values only)	Irrigated Parcels (nonirrigated values only)	All Nonirrigated Values
Average×IR	−3.48	4.44	4.59
	(3.80)	(6.93)	(7.94)
1999×IR	−15.37	16.26	20.28
	(6.76)**	(11.06)	(12.21)*
2000×IR	−8.79	12.65	15.14
	(7.92)	(9.94)	(10.81)
2001×IR	1.27	24.54	26.03
	(7.34)	(13.61)*	(14.16)*
2002×IR	5.21	11.54	10.72
	(4.50)	(8.24)	(9.41)
2003×IR	0.56	15.91	15.36
	(6.38)	(7.50)**	(8.16)*
2004×IR	1.13	13.14	8.56
	(6.06)	(7.12)*	(7.62)
2005×IR	0.74	7.96	12.12
	(5.71)	(7.37)	(8.57)
2006×IR	−6.42	1.43	−4.4
	(2.98)**	(5.43)	(5.75)
2007×IR	−4.67	−5.82	−9.12
	(5.03)	(5.72)	(6.65)
2008×IR	−5.75	−9.23	−7.29
	(5.36)	(6.44)	(6.84)
2009×IR	−8.99	0.05	−5.64
	(6.55)	(8.46)	(8.72)
2010×IR	7.53	−6.7	−0.99
	(8.02)	(8.55)	(8.60)
2011×IR	−5.03	−5.5	−4.81
	(7.99)	(12.43)	(10.30)
2012×IR	−10.19	−14.09	−11.73
	(15.39)	(10.64)	(10.61)
Segments	696	563	748
Segment–years	2,333	1,799	2,392
Weighted observations	604,515	299,012	498,504

Notes: For ease of interpretation, the marginal effects shown in this table have been converted to percentages using the method suggest by Kennedy (1981). Standard errors clustered by Natural Resource District are reported in parentheses. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level. Irrigated parcels had irrigated cropland values reported in some years (and also include any reported nonirrigated cropland values); dryland parcels never had irrigated cropland values reported.

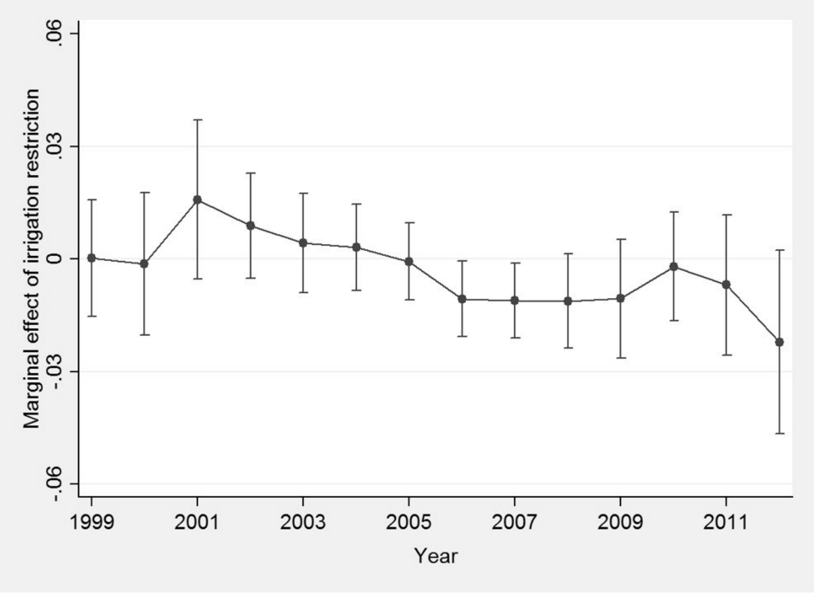

Figure S1. Impact of Irrigation Restrictions on Cropland Values, 1999–2012

Notes: Marginal effects by year based on the estimation of equation (2) under a log-linear functional form with 95% confidence intervals. Includes all irrigated and nonirrigated cropland values. This graph was created using the STATA *marginsplot* command.

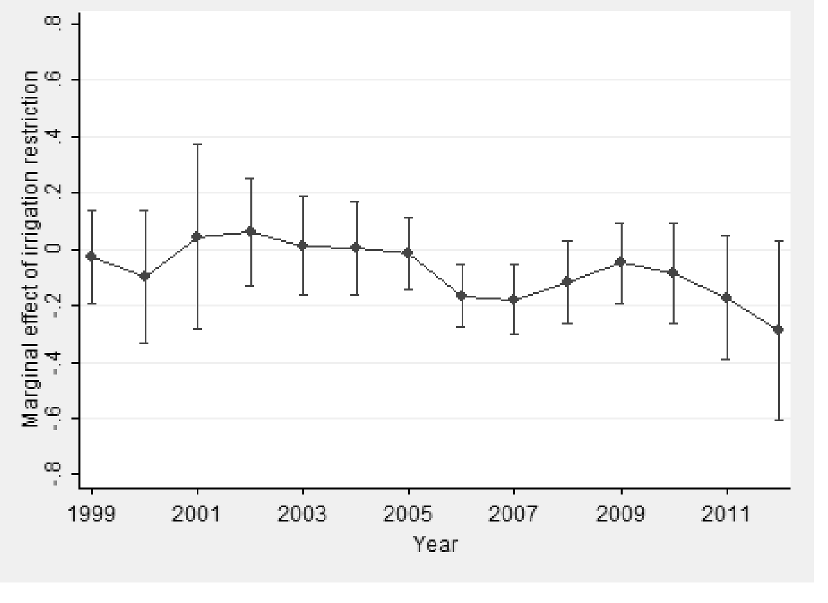

Figure S2. Impact of Irrigation Restrictions on Irrigated Parcel Cropland Values, 1999–2012

Notes: Marginal effects by year based on the estimation of equation (2) under a log-linear functional form with 95% confidence intervals. This graph was created using the STATA *marginsplot* command.

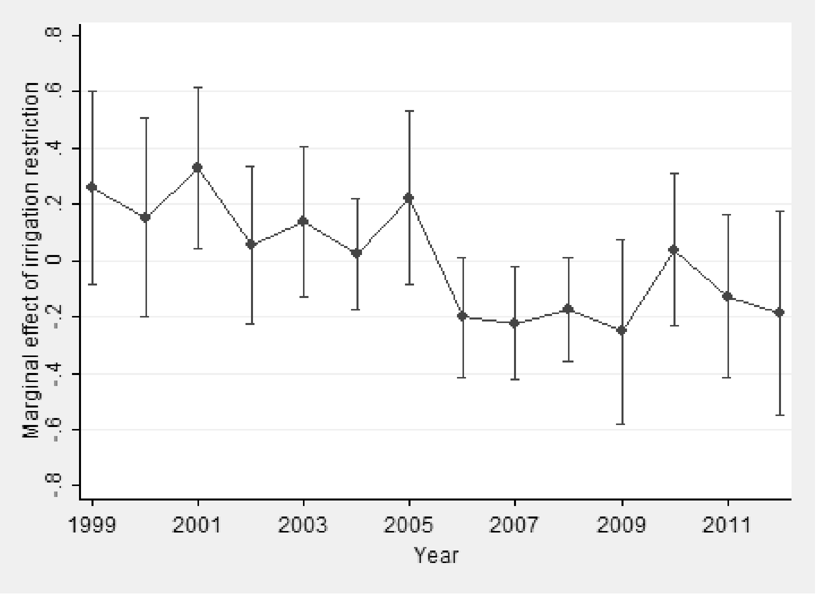

Figure S3. Impact of Irrigation Restrictions on Nebraska Dryland Cropland Values, 1999–2012

Notes: Marginal effects by year based on the estimation of equation (2) under a log-linear functional form with 95% confidence intervals. This graph was created using the STATA *marginsplot* command.

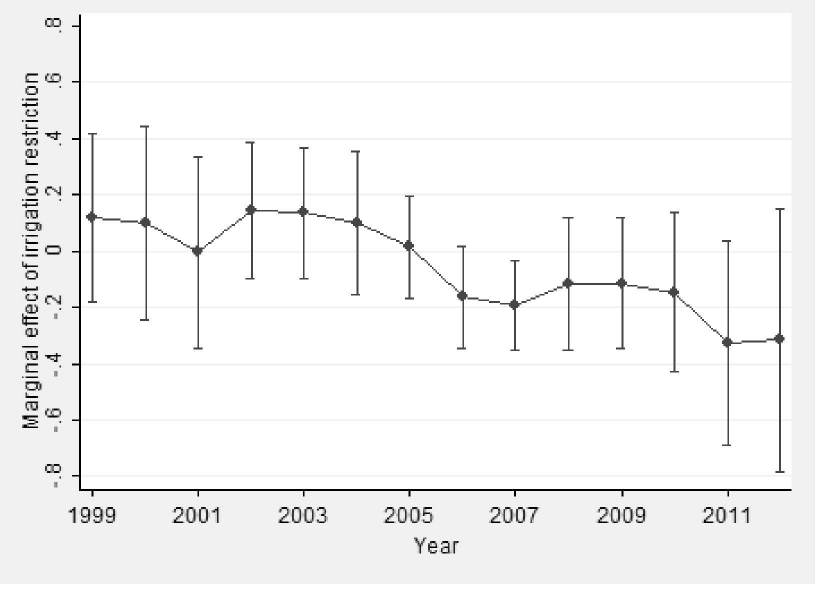

Figure S4. Impact of Irrigation Restrictions on Nebraska Irrigated Parcel Cropland Values: Above Median Groundwater Acres

Notes: Marginal effects by year from 1999–2012 based on the estimation of equation (2) under a long-linear functional form with 95% confidence intervals, excluding all segments with below-median certified groundwater acres. This graph was created using the STATA *marginsplot* command.

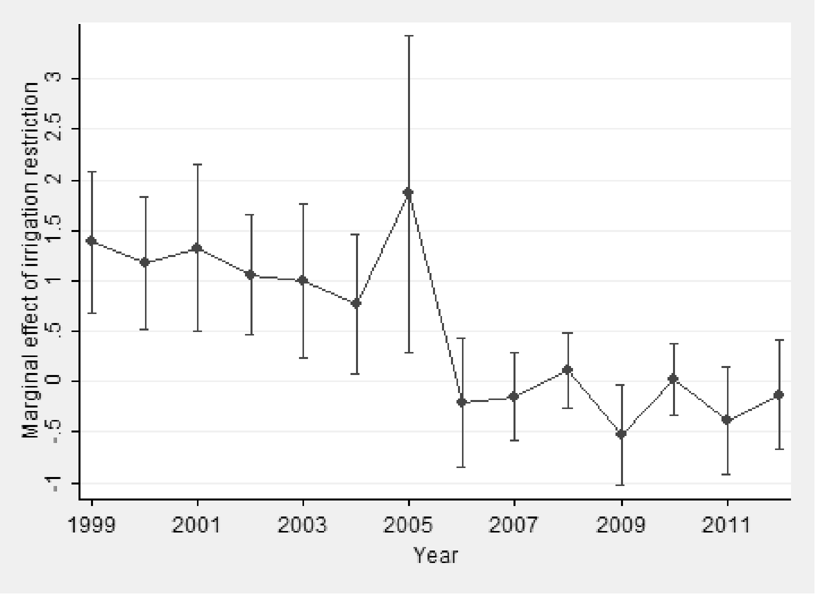

Figure S5. Impact of Irrigation Restrictions on Nebraska Dryland Cropland Values: Above Median Groundwater Acres

Notes: Marginal effects by year from 1999–2012 based on the estimation of equation (2) under a log-linear functional form with 95% confidence intervals, excluding all segments with below-median certified groundwater acres. This graph was created using the STATA *marginsplot* command.

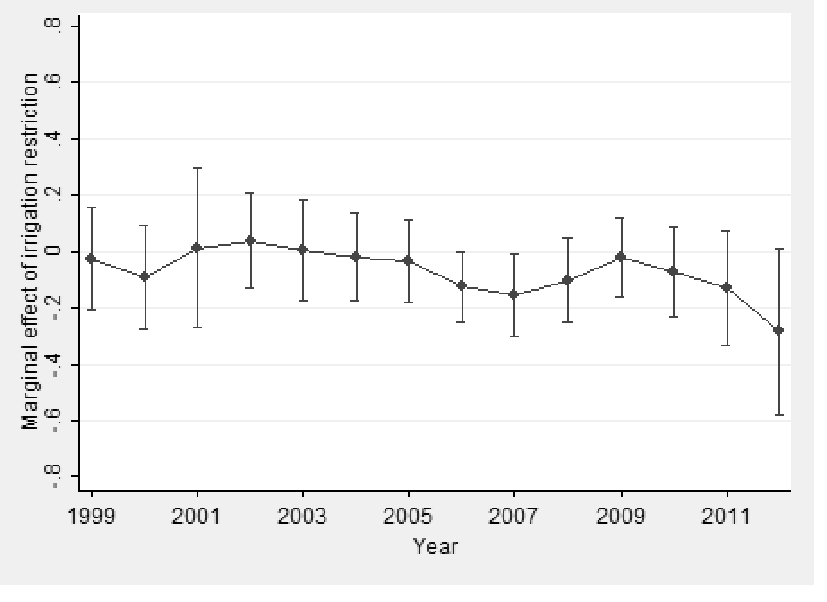

Figure S6. Impact of Irrigation Restrictions on Nebraska Irrigated Parcel Cropland Values: Excludes High Irrigation Expansion Counties

Notes: Marginal effects by year from 1999–2012 based on the estimation of equation (2) under a log-linear functional form with 95% confidence intervals, excluding the 7 counties (Antelope, Buffalo, Custer, Dawson, Holt, Lincoln, Platte) that made up the majority of irrigation acreage expansion from 2002–2007 (Johnson et al., 2011). This graph was created using the STATA *marginsplot* command.

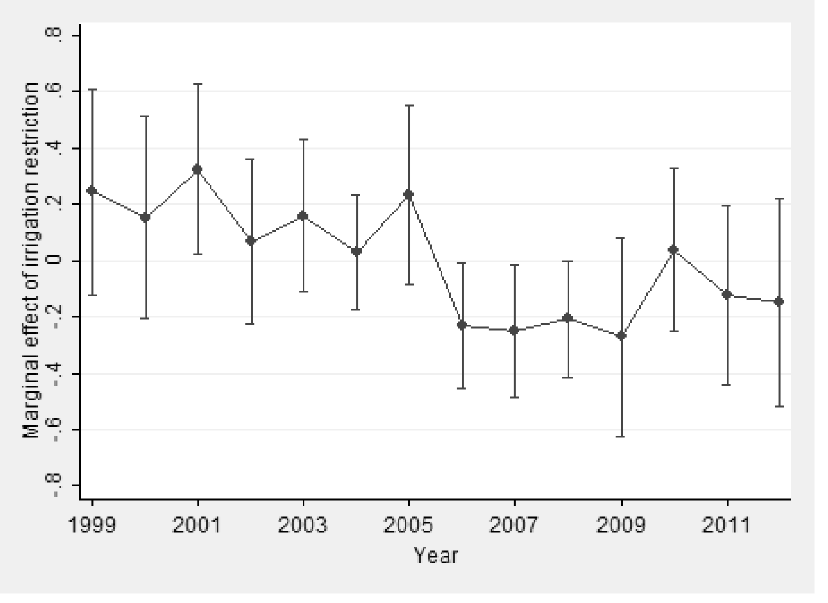

Figure S7. Impact of Irrigation Restrictions on Nebraska Dryland Cropland Values: Excludes High Irrigation Expansion Counties

Notes: Marginal effects by year from 1999–2012 based on the estimation of equation (2) under a log-linear cox functional form with 95% confidence intervals, excluding the 7 counties (Antelope, Buffalo, Custer, Dawson, Holt, Lincoln, Platte) that made up the majority of irrigation acreage expansion from 2002–2007 (Johnson et al., 2011). This graph was created using the STATA *marginsplot* command.

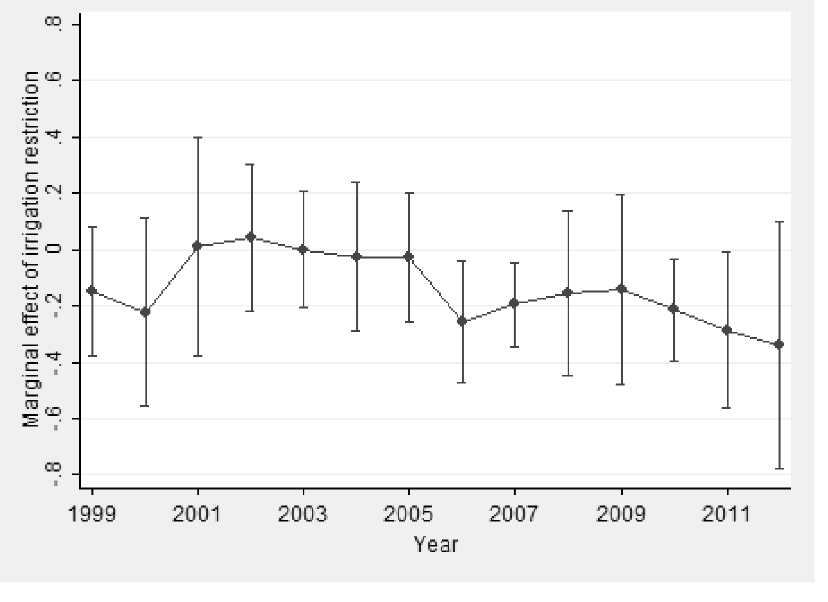

Figure S8. Impact of Irrigation Restrictions on Platte and Republican NRD Irrigated Parcel Cropland Values

Notes: Marginal effects by year from 1999–2012 based on the estimation of equation (2) under a log-linear functional form with 95% confidence intervals for Central; North; South; Twin Platte; and Lower, Middle, and Upper Republican Natural Resource Districts. This graph was created using the STATA *marginsplot* command.

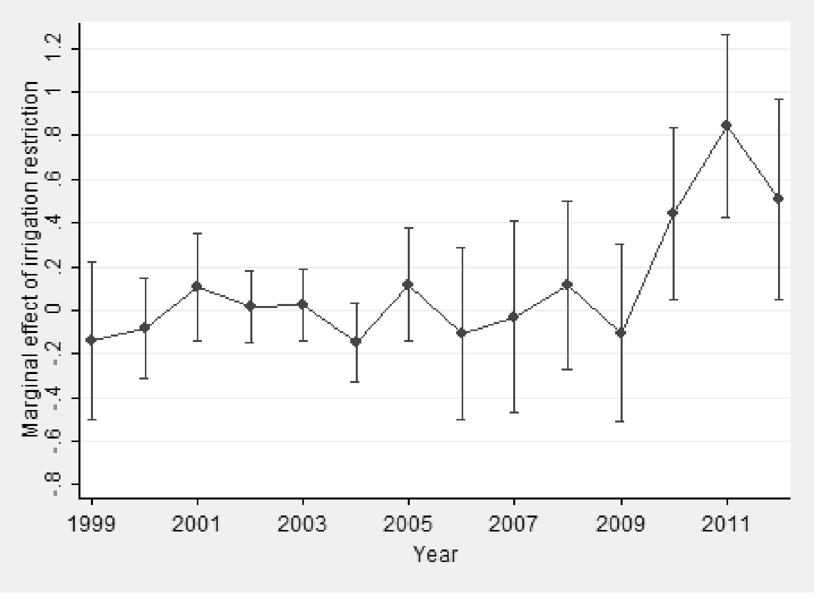

Figure S9. Impact of Irrigation Restrictions on on Platte and Republican NRD Dryland Cropland Values

Notes: Marginal effects by year from 1999–2012 based on the estimation of equation (2) under a log-linear functional form with 95% confidence intervals for Central; North; South; Twin Platte; and Lower, Middle, and Upper Republican Natural Resource Districts. This graph was created using the STATA *marginsplot* command.

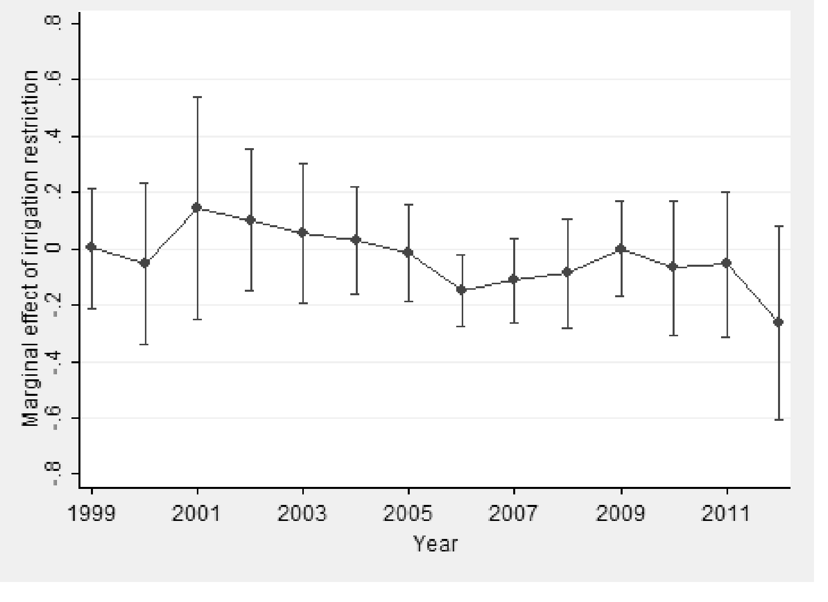

Figure S10. Impact of Irrigation Restrictions on Nebraska Irrigated Parcel Cropland Value: No Survey Weights

Notes: Marginal effects by year from 1999–2012 based on the estimation of equation (2) under a log-linear functional form with 95% confidence intervals, without survey weights. This graph was created using the STATA *marginsplot* command.

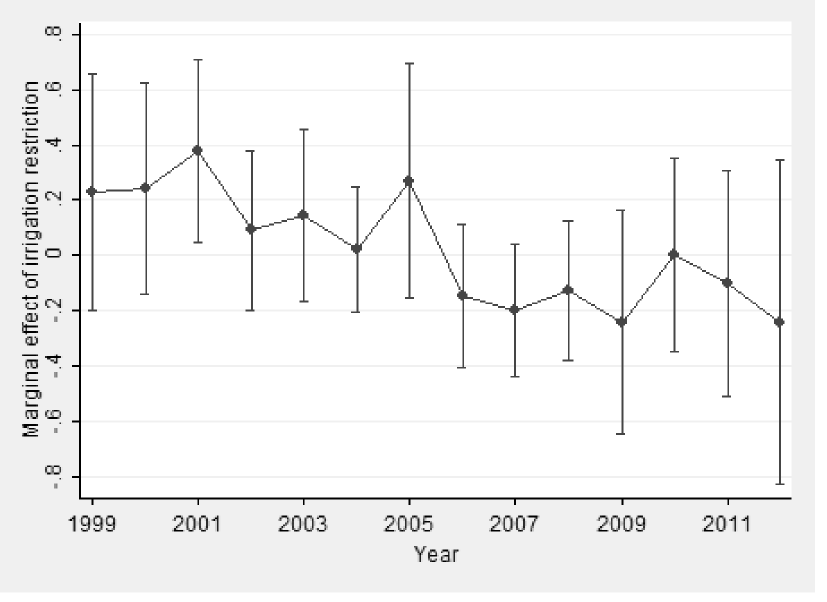

Figure S11. Impact of Irrigation Restrictions on Nebraska Dryland Cropland Values: No Survey Weights

Notes: Marginal effects by year from 1999–2012 based on the estimation of equation (2) under a log-linear functional form with 95% confidence intervals, without use of survey weights. This graph was created using the STATA *marginsplot* command.

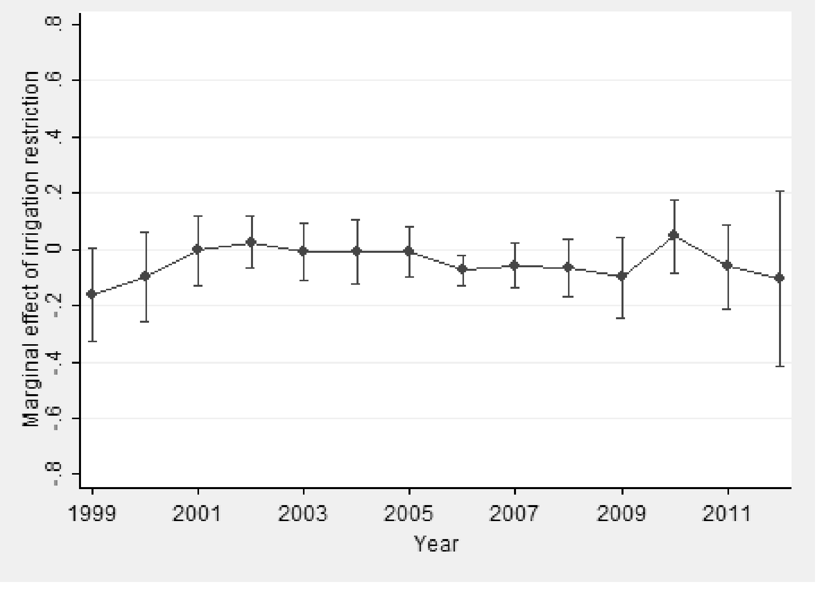

Figure S12. Impact of Irrigation Restrictions on Nebraska Irrigated Parcel Cropland Values-Irrigated Tracts Only, 1999–2012

Notes: Marginal effects by year based on the estimation of equation (2) under a log-linear functional form with 95% confidence intervals. This graph was created using the STATA *marginsplot* command.

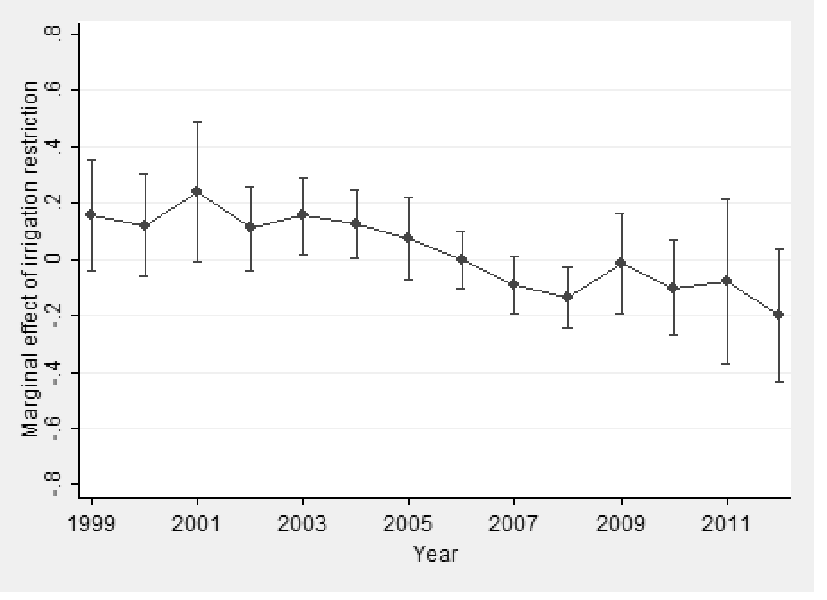

Figure S13. Impact of Irrigation Restrictions on Nebraska Irrigated Parcel Cropland Values-Nonirrigated Tracts Only, 1999–2012

Notes: Marginal effects by year based on the estimation of equation (2) under a log-linear functional form with 95% confidence intervals. This graph was created using the STATA *marginsplot* command.

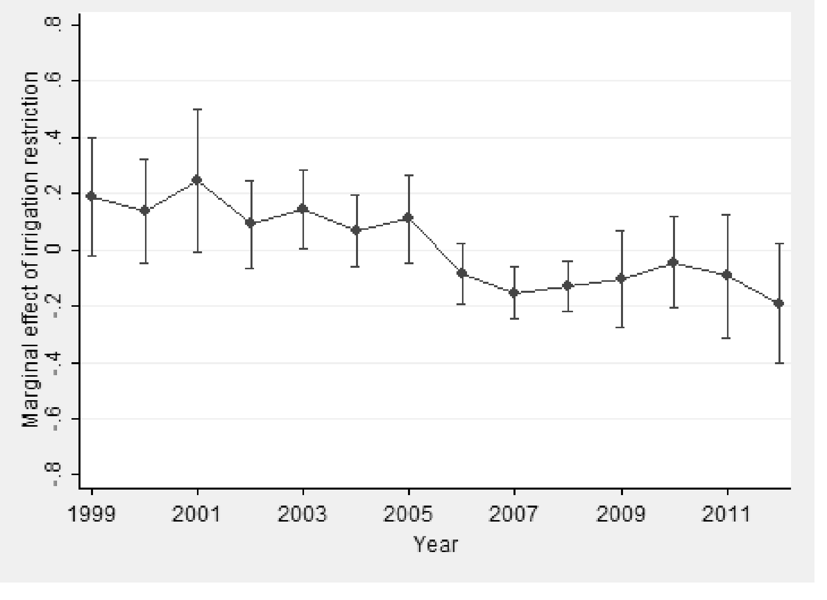

Figure S14. Impact of Irrigation Restrictions on Nebraska Nonirrigated Tract Cropland Values, 1999–2012

Notes: Marginal effects by year based on the estimation of equation (2) under a log-linear functional form with 95% confidence intervals. Includes nonirrigated tracts from both irrigated and dryland parcels. This graph was created using the STATA *marginsplot* command.