Economic Impact of Groundwater Regulation in Nebraska: A Hedonic Price Analysis

Aakanksha Melkani* Taro Mieno† Aaron Hrozencik‡ Renata Rimšaitė§
Shunkei Kakimoto¶ Nicholas Brozovic‖

Introduction

Groundwater is vital to agriculture in USA as a primary source of irrigation and/or an important supplement to surface water irrigation during times of water scarcity. Its regulation has increasingly become more common and important due to growing aquifer depletion concerns (Scanlon et al. 2012; Konikow 2015; Babbitt et al. 2018). However, despite the importance of groundwater resources for the agricultural economy and the increasing regulations on its use, a lack of consensus exists within the economic literature regarding whether the benefits of regulation outweigh the costs. We examine this issue in this paper via a hedonic price analysis of farmland values in Nebraska.

Groundwater is the primary source of irrigation in the USA with 60% of irrigated land being partially or wholly irrigated by groundwater in 2017 (U.S. Census Bureau 2017). Since groundwater is more commonly developed for irrigation privately, it has historically been less regulated than surface water which was developed with substantial public intervention. However, in recent years new groundwater regulations have rapidly emerged across different parts of the western USA due to increasing aquifer depletion concerns (Scanlon et al. 2012; Haacker, Kendall, and Hyndman 2016). A well-known example is the adoption of the Sustainable Groundwater Management Act by the state of California in 2014 to manage its groundwater resources. Groundwater depletion has itself been a growing concern due to the unprecedented development of irrigation in parts of USA

*University of Nebraska
†University of Nebraska-Lincoln
‡Economic Research Service, USDA
§University of Nebraska
¶University of Minnesota
‖University of Nebraska

to grow high value crops in the latter part of the 20th century (Hornbeck and Keskin 2014) and the frequent and recurring droughts faced in last few decades (Wehner et al. 2017).

There is a rich theoretical literature that discusses the benefits and costs of groundwater regulations for agriculture using hydro-economic models. In their seminal work assessing the economic implications of groundwater management, Gisser and Sanchez (1980), argued that the benefits of groundwater management are too small for justifying its management. This position has been contested and researchers have since argued that benefits of groundwater regulations can be large under certain contexts. These include cases when the marginal value from consumptive use of groundwater use is low (Koundouri 2004) and when the value from non-consumptive use is high (Tomini 2014). Groundwater management may be also be beneficial when there are high and non-linear cost of pumping groundwater as aquifer levels fall and when hydrological connections between water bodies may lead to severe negative externalities from groundwater extraction (Koundouri 2004). An example of such a case was demonstrated by Brozović, Sunding, and Zilberman (2010) in case of large and unconfined aquifers with wells concentrated close to each other. More recent work in this area maintains that groundwater management strategies that have been recently implemented in certain parts of the USA can raise aquifer levels but at some loss of short-term profits to farmers (Hrozencik et al. 2017; Manning et al. 2020). These costs, however, vary across different management strategies and across space (Hrozencik et al. 2017). Overall, we find a lack of consensus in the theoretical literature on the benefits and costs of groundwater management policies.

The econometric literature exploring the benefits and costs of groundwater regulations is relatively thin, perhaps due to the lack of adequate data suitable for such an analysis. For example, Edwards (2016) and Ifft, Bigelow, and Savage (2018) both examine how groundwater use regulations are capitalized into farmland values. While Edwards (2016) finds a positive impact of groundwater management in Kansas for hydrologically connected areas, Ifft, Bigelow, and Savage (2018) find that irrigated land value fell in response to groundwater rules in Nebraska. Using the case of Southern California, Ayres, Meng, and Plantinga (2021) demonstrate water markets as a form of groundwater management that can bring overall net benefits to farmers while also enabling the efficient use of water via trading of water rights. More extensive research has been conducted in understanding the behavioral responses of farmers to groundwater regulations and institutions in form of changing water use, adopting new technology, and cropping patterns [Pfeiffer and Lin (2014); Mieno et al. (2022); Cobourn et al. (2022); Drysdale and Hendricks (2018); Golden and Leibsch (2018)]. However, the overall effect of regulations on farmers' welfare remains thin and the evidence mixed. In particular, the differential effect of different groundwater management strategies have not been examined via rigorous econometric analysis. Further, existing studies have utilized either survey-based or assessed land value data for analysis. Both of these may suffer from some biases. Survey based land value data may embody hypothetical bias of the respondent since the land values are not based on actual sale value of the land. Assessed land values on the other hand are based on tax assessments of agricultural lands, which vary by state law and are often a lower bound of the true value of the land (Anderson 2012).[1] Conceptually, as dynamic welfare maximizers, farmers may perceive groundwater regulations to be beneficial if they believe that the current rate of groundwater depletion imposes negative externalities on their current or future economic returns. On the other hand, if farmers do not believe the current rate of groundwater extraction to be unsustainable or to negatively affect their economic returns, they may perceive regulations to lower their current and future returns. Thus, theoretically, regulations may be capitalized either positively or negatively into farmland values, making a case for an empirical exploration of this question.

We address these knowledge gaps by assessing the changes in farmland values in the state of Nebraska in response to two types of groundwater regulations: well drilling moratoria (restrictions on future development of land for irrigation) and water allocations (limits on quantity of water that can be pumped for irrigation from existing irrigation structures). We leverage data on observed agricultural land market transactions data between 2005-2021 and information on spatially and temporally heterogeneous groundwater use regulations to assess the costs and benefits of differing groundwater management policies. To the best of our knowledge, this is the first study to examine the economic effect of groundwater regulation through a hedonic price analysis of actual

[1] Actual land transactions, as used by us, are also likely to suffer from bias due to sample selection, i.e., only the sample of farmers that sold in a particular year were observed (Bigelow, Ifft, and Kuethe (2020)). This may lead to biased estimates if the selection into selling land was correlated with some unobservables that influences land values. Spatially differentiated market imperfections maybe one cause of concern because they may lead to land values being systematically higher (or lower) depending upon the ease with which land can be transacted. Through our conversations with several land owners in Nebraska, we gathered no evidence of any such market imperfection.

market transaction data. It is also the first study that differentiates between the different types of groundwater regulations thus disentangling their unique impacts.

Background and Context

Nebraska is reliant on groundwater for supporting its vast agricultural sector. It has the most irrigated acres in the USA.; close to 90% of which comes from groundwater (Dieter 2018). Groundwater has been managed in Nebraska historically since the 1970s through 23 locally elected Natural Resources Districts (NRDs). Apart from advisory and educational roles, the NRDs have considerable power to create and enforce regulatory tools (Bleed and Babbitt 2015; Babbitt et al. 2018; Schoengold and Brozovic 2018). One of the unique feature of groundwater management in Nebraska (and few other states overlying the High Plains aquifer) is that they have been developed, adopted, and managed by local authorities. The earliest groundwater regulation in Nebraska came about in 1979 in the Upper Republican NRD. Several new regulations emerged since the early 2000s, starting from South-west Nebraska, and moving to the North and East (Figures 1 and 2). These evolving regulations in the past two decades provide the context of our study.

The NRDs have adopted several different methods for groundwater management. These include strategies to restrict water use such as placing a well moratorium and imposing water allocations. A variety of auxiliary measures have also been adopted to complement and effectively implement these management strategies. These include mandatory establishment of flowmeters on high-capacity wells, restricting the number of acres that can be irrigated, and imposing minimum spacing between adjoining wells. Incentive-based groundwater regulations include cost-share programs that subsidize farmers to adopt water-saving technologies (Zoubek 2015). A tax on irrigated acres has also been imposed in certain parts of Nebraska as a management tool. Although the cost imposed by the tax is deemed insufficient to incentivize farmers to reduce water use, the capital raised through taxation has been used to develop a large scale streamflow management programs that have been instrumental in resolving water related conflicts in the state (Schoengold and Brozovic 2018). Voluntary Integrated Water Management (IWM) plans have also been developed by several NRDs. These are contingent plans that lay down groundwater management policies that the NRDs will adopt if groundwater levels fall below certain pre-determined levels.

In this paper we focus on two types of management techniques – the well moratorium and water allocations. Well moratorium refers to a prohibition on construction of new high-capacity irrigation wells that can extract large amounts of water from an aquifer. Water allocations refer to placing an upper limit on the volume of water that can be pumped per acre per year from a well. In practice, well allocations are made for a period of 3-5 years such the aggregate water use within those years does not exceed the lump-sum allocation limit. We chose to focus on these two regulations as they have direct implication on current and potential future water use and crop revenues of all producers within NRDs that have implemented them. Secondly, there is some evidence that these regulations can reduce water use (Mieno et al, 2022) and increase the saturated thickness of aquifer (Hrozencik et al. 2017). Thus, they are atleast partially effective in achieving the goals of groundwater management. These regulations are also quite widespread across the state with 15 (8) NRDs having implemented moratoriums (allocations) at some point of time.

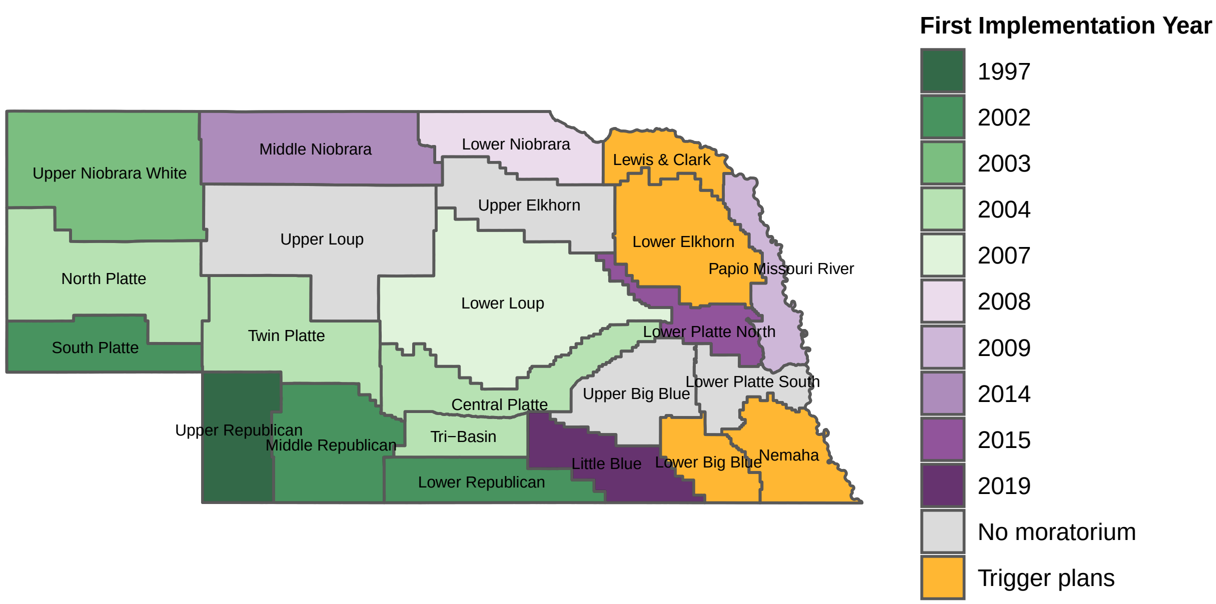

Figure 1: Well moratorium by NRD and year in Nebraska

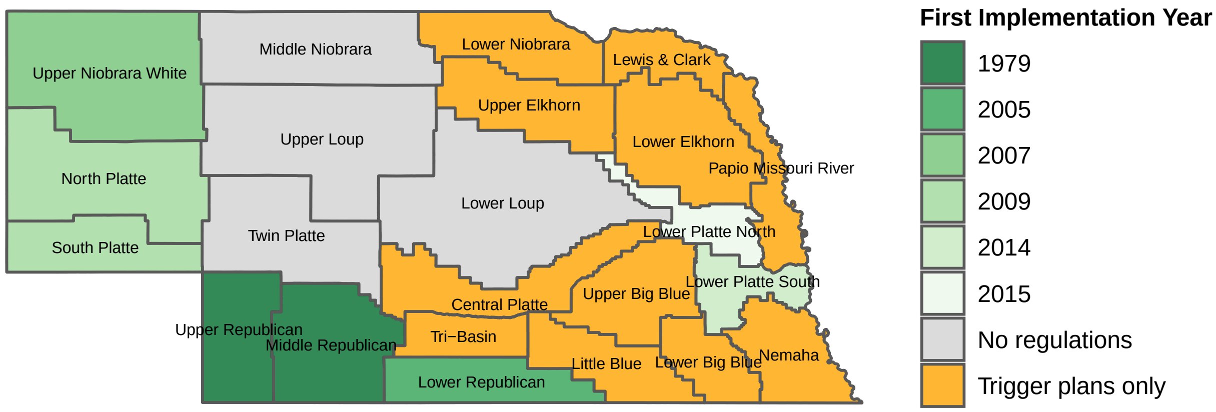

Figure 2: Water allocations by NRD and year in Nebraska

Economic framework and testable hypotheses

We motivate our research question by assigning an economic value to each parcel of land as follows:

$$V = Y(\mathbf{X}, w; z) + \sum \delta[Y(\mathbf{X}, w; z)]$$

where, V is the net present value of land. V comprises of the current land revenue $(Y(.))$ and the stream of future discounted land revenues (with discount factor being δ). The land revenue is a function of the vector of agricultural inputs ($\mathbf{X}$), irrigation (w), and quasi-fixed factors such as weather and soil characteristics (z). Price of crop output has been normalized to one for easier notation. A farmer's optimal water use for parcel *i* (w_i^*) is a function of the saturated thickness of the aquifer (h) and the water used by other neighboring farmers (w_j^*) (Peterson and Saak, 2013, Edwards (2016)).

$$w_i^* = f(h, w_j^*) \text{ such that } \frac{\partial w_i^*}{\partial h} > 0 \text{ and } \frac{\partial w_i^*}{\partial w_j^*} < 0$$

The negative relationship between w_i^* and w_j^* represents the negative externality of one farmer's water use on an adjacent farmer's water use. Groundwater management strategies can act as a coordination mechanism that can reduce these negative externalities.

With this framework, we can define the optimal land value of land for parcel *i* as $V_i^* = g(\mathbf{X_i^*}, w_i^*, z)$. V_i^* is related to w_i^* and w_j^* as follows:

$$\frac{\partial V_i^*}{\partial w_i^*} > 0 \text{ and } \frac{\partial V_i^*}{\partial w_j^*} < 0$$

Intuitively this simply implies that the value of land increases with increase in own use of water and decreases with increase in others' use of water. With this context, we will discuss the expected changes in land values for irrigated and non-irrigated parcels under well-moratorium and water allocations.

Case 1: Effect of well moratorium on irrigated parcels

A well-moratorium does not change the current or future use of own water use (w_i^*). Thus change in water use for irrigated parcels under well-moratorium is zero. However, it does reduce the expected future water use by neighboring farmers that may occur due to more wells being constructed by adjacent farmers. Thus, the value of land for irrigated parcels under well moratorium rises compared to irrigated parcels in no regulation and the overall the land values of irrigated parcels are expected to be higher than the values under open access.

Case 2: Effect of water allocations on irrigated parcels.

The irrigated water use under water allocations is limited by an upper limit. Thus, own water use will reduce under water allocations compared to that under open access ($w_{ia}^* \leq w_i^*$), leading to a potential decline in land revenue, ceteris paribus. On the other hand, water allocations may decrease the negative externalities caused by water use by adjacent irrigators ($w_{ja}^* \leq w_j^*$), thus increasing the value of own land. Since the two effects are in the opposite direction, the overall effect of water allocations on non-irrigated parcels is uncertain.

Case 3: Effect of well moratorium on non-irrigated parcels.

The future potential of developing non-irrigated land to irrigated land is lost when a well-moratorium is placed. This will lead to a decrease in future expected stream of land revenues thus bringing down the overall cost of land value. Since the land is not irrigated (and cannot be irrigated in the future due to the moratorium), the issue of negative externalities is not applicable here. Thus, overall, well moratorium is expected to lower land values of non-irrigated parcels.

Case 4: Effect of water allocations on non-irrigated parcels

Water allocations will not have any effect on current land revenues of non-irrigated parcels. However, non-irrigated land may be developed into irrigated land in the future and the expected future stream of revenues will be lower under water allocations than under open access. Thus, water allocations are likely to decrease the value of the parcel. Similarly, there are no negative externalities on non-irrigated land due to other's use of groundwater. However, if a parcel is to be developed for irrigation in the future, water allocations can reduce potential negative externalities and thus lead to a rise and land values. Thus, overall, the effect of water allocations on non-irrigated parcels is uncertain.

Based on the above economic framework, we summarize four testable hypotheses in Table 1:

Table 1: Testable hypotheses based on economic framework

	Irrigated	Non-irrigated
Well moratorium	+	-
Water allocations	Uncertain	Uncertain

Data

The data for our analysis was obtained from several different sources. Information on farmland values, acreage, and geo-codes of farmland parcels in Nebraska for 2005-2021 were obtained Corelogic Inc. These data were extracted by Corelogic Inc. from county land transaction records. After dropping outliers and missing values, our analytical sample consisted of a repeated cross-section of 18,506 observations. Information on groundwater regulations were obtained from a detailed survey of administrative documents of all 23 NRDs. These were supplemented with interview and email communications with various NRD leaders. Data on parcel level irrigation status was obtained from Xie and Lark (2021). Soil characteristics data such as hydraulic conductivity, available water holding capacity, elevation of land and percentage of sand, silt, and clay were obtained from

SSURGO. Weather information was retrieved from data provided by the PRISM climate group and was used to construct 10-year rolling averages of growing season average daily temperatures, growing degree days, precipitation, and potential evapotranspiration. Data on land use, particularly cropping patterns, were obtained from the Cropscape data provided by the USDA. Distance from urban centers were calculated using Census information on population density.

Empirical strategy

We conduct a hedonic price analysis of farmland values using a Staggered Difference-In-Difference (DID) approach, closely following the procedure suggested by Wooldridge (2021). In a Staggered DID framework different units receive treatment at different points of time. This setup suits our context well since different NRDs were exposed to groundwater regulations at different times. The NRDs that were never treated serve as the control group. Following the economic framework, we also look at the heterogenous effect of treatment on irrigated and non-irrigated parcels.

The estimating equation is then as follows:

$$lnY_{ijt} = \alpha + \beta_r^m D_{it}^m \cdot Ir_i + \beta_r^a D_{it}^a \cdot Ir_i + \beta^m D_{it}^m + \beta^a D_{it}^a + \gamma Ir_i + \mathbf{X_{ijt}} \boldsymbol{\Delta} + c_j + v_t + \epsilon_{ijt}$$

Where, Y_{ijt} are real price per acre of parcel *i* in county *j* at time *t*, $D_{it}^m = 1$ if parcel *i* was exposed to well moratorium in time *t*, $D_{it}^a = 1$ if parcel *i* was exposed to water allocation in time *t*, $Ir_i = 1$ if parcel was irrigated in 2005 (baseline year), X_{ijt} is the vector of control variables. c_j are the county fixed effects and v_t are the time fixed effects. $\beta_r^m, \beta_r^a, \beta^m, \beta^a$ are the marginal effects of well moratorium on value of irrigated parcels, water allocation on value of irrigated parcel, well moratorium on non-irrigated parcel, and water allocation on non-irrigated parcel respectively. These are the parameters of interest. We estimate this equation using Pooled Ordinary Least Squares (POLS) and cluster the standard errors at the county level. Ideally, the standard errors should be clustered at the level of treatment, which in our case is the NRD (Abadie et al. 2023). However, there are only 23 NRDs (treatment groups) in our sample which does not satisfy the degrees of freedom rule of thumb of atleast 30-50 clusters. Thus, we cluster at the next largest group which is the county.

Identification of the estimates depend on the treatment being exogenous to unobservables that could be correlated to treatment. Groundwater regulations are likely to arise in areas which are heavily dependent on irrigation, where agriculture is a primary economic activity, and/or where rainfall is scarce. We control for these variables by including variables on irrigation in the baseline year, soil quality indicators and long-term weather means. We also control for the crops being grown on the parcel and the distance of the field from the nearest urban center.

Results

The results of the analysis are summarized in Table 2. Model (1) and (2) are the results without and with controls respectively. Overall, we do not find any statistically significant effect of either type of groundwater regulation on either irrigated or non-irrigated parcels. The magnitude of the estimates of effect of both well moratorium and water allocations are large (a decline of land values by 6.9% and 9.5%, respectively, compared to the control group). These estimates are also robust before and after controlling for explanatory variables. However, since the standard errors are also relatively large, the estimates are not statistically significant.

Table 2: Marginal effect of GwR on farmland values, Pooled OLS estimates

Type of GwR		(1)	(2)
Well-moratorium =1	Irrigated	0.017	-0.0090
		(0.0655)	(0.0472)
	Non-irrigated	-0.080	-0.069
		(0.0571)	(0.0401)
Water-allocation =1	Irrigated	-0.013	0.017
		(0.0725)	(0.0652)
	Non-irrigated	-0.094	-0.095
		(0.0598)	(0.0575)
Other controls		No	Yes
County dummies		Yes	Yes
Year dummies		Yes	Yes
Observations		18506	18506

Note: Standard Errors (SE) clustered at county level; GwR: Groundwater; Controls include measures of soil quality (saturated hydraulic conductivity, available water capacity, percentage of sand, silt and clay, and slope), long-term weather (ten years rolling averages of growing season precipitation, potential evapo-transpiration, growing degree days, and mean daily temperature), cropping pattern (share of land cropped with corn, soybeans, winter wheat, other crops and grassland), and distance from urban center.

Conclusion

In this paper we examine whether the groundwater regulations formulated by and imposed within the NRDs in Nebraska had an impact on farmland values. We find that the overall effect of groundwater regulations on farmland values is not statistically significant. The landscape of groundwater management in the western USA is evolving rapidly (e.g., California's Sustainable Groundwater Management Act). Understanding the costs and benefits of regulations seeking to rationalize the groundwater commons has become more urgent and important. This paper contributes to this growing literature by leveraging novel data and the unique institutional setting of Nebraska. Our results inform future policymaking efforts aiming to minimize the negative externalities of groundwater depletion and conserve aquifer resources for future generations.

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