Rebound Effect of Irrigation Technologies? The Role of Water Rights

Haoyang Li
Department of Economics; Environmental Science & Public Policy Program
Michigan State University
lihaoya2@msu.edu

Jinhua Zhao[1]
Department of Economics; Dept. of Ag, Food and Res. Econ
Environmental Science & Public Policy Program
Michigan State University
jzhao@msu.edu

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Abstract

In this paper, we study the role of water rights in limiting the rebound effects of LEPA irrigation in the High Plains Aquifer region of Kansas, and farmer incentives to preserve their water rights. We find that the rebound effect is moderated by water rights and is high only when a well has large water rights, and limiting water rights raises farmer incentives to adopt LEPA. Reducing water rights thus can limit the undesirable rebound effects of new technologies without hurting incentives to adopt them. A significant portion of the effects of LEPA in raising water uses is through farmers switching to more water intensive crops such as corn and soybean, and through farmers raising their irrigated acreages after the adoption of LEPA. We also find that farmers have incentive to preserve water rights even when irrigation is not needed in the current period. The incentive is the highest if the farmer expects to use a large volume of water to irrigate, and is the lowest if the farmer expects not to use any water at all in the next period.

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1. Introduction

Irrigation is one of the major factors influencing agriculture's capacity to adapt to global climate change. Facing higher average temperature, greater variability in rainfall and increased likelihood and severity of droughts, production agriculture will be more dependent on irrigation to meet the global food demand (Zilberman, Zhao and Heiman, 2012). Over 60% of the world's consumption of water is used for irrigation, making agriculture the largest consumer of water (Wada and Bierkens 2014, FAO 2016). However, irrigation as an adaptation strategy is limited by the worldwide depletion of surface and groundwater resources. For example, the California drought over the past several years has resulted in increased irrigation using groundwater, leading to substantial depletion of groundwater resources in the Central Valley (Famiglietti et al. 2011). Similarly, in the High Plains region, irrigation water use since as early as 1930s has depleted over half of the aquifer capacity in the southern part of the Ogallala-High Plains aquifer (henceforth HPA) that overlies Texas and New Mexico (McGuire 2009; Haacker, Kendall, and Hyndman 2015). Consequently, more efficient irrigation technologies such as LEPA (Low Energy Precise Application) irrigation and drip irrigation have been called upon to improve irrigation efficiency, thereby reducing water needs for the same level of output (Schoengold and Zilberman 2007; Zilberman, Zhao and Heiman 2012).

However, more efficient irrigation technologies do not always reduce water use. Pfeiffer and Lin (2014) finds significant rebound effect of LEPA in HPA: water use increased significantly after farmers switched from central pivot to LEPA, and the increase occurred both at the intensive margin (i.e., water use per acre of irrigated field) and at the extensive margin (i.e., size of field irrigated). Ward and Pulido-Velazquez (2008) finds that adoption of water conservation technologies may raise total water use due to the conversion of more land into production agriculture. Such rebound effects limit the potential of new technologies in promoting agricultural adaptation and sustainability.

Economists have long recognized the limitations of purely technological solutions, and argued that resilient and effective institutions can be effective adaptation strategies (Zilberman, Zhao and Heiman 2012). Examples of such institutions include property rights over both surface and ground water, water markets and trading, and water use organizations that help develop and enforce water use regulations. At least theoretically, effective institutions can not only promote the adoption and diffusion of efficient technologies but also limit or even eliminate undesirable rebound effects of these technologies.

In this paper, we study the interaction of institutions and new technologies by investigating the role of water rights in reducing water use, promoting the adoption of LEPA, and limiting the rebound effects of LEPA in the HPA region of the state of Kansas. Using a panel data set that includes well level water use and water right during 1992 – 2009, we show that a large part of LEPA's effect in raising water use is moderated by the associated water rights, indicating that reducing water rights can effectively limit

LEPA's rebound effect, even when water rights are not strictly binding. Kansas follows a prior appropriation water right system with a three year use-it-or-lose-it (UIOLI) clause. We find that farmers have incentive to apply a small amount of water in order to preserve their water rights even when irrigation is not profit maximizing. This incentive is higher when LEPA is adopted since the technology reduces the cost of water application due to the lower pressure requirement. We assess the potential water savings if UIOLI is removed.

As shown in Pfeiffer and Lin (2014a), increases in water use due to LEPA can occur on the extensive margin through acres irrigated and on the intensive margin through crop choices and irrigation intensity decisions. Extending Pfeiffer and Lin (2014a), we show the channels through which LEPA and water rights affect water use. Specifically, we show that a large part of LEPA's effect on water use is mediated by crop choices, while the majority of water right's effect on water use is mediated by irrigated acreages. That is, LEPA causes more water use mainly through farmers switching to more water intensive crops such as corn, while water rights leads to more water use mainly through farmers irrigating larger areas of their fields.

There is a sizable literature on the effects of new irrigation technologies on water use in general (Ward and Pulido-Velazquez 2008; Whittlesey and Huffaker 1995; Ellis, Lacewell and Reneau 1985; Scheierling, Young and Cardon 2006; Khanna, Isik and Zilberman 2002; and Hanak et al 2010) and specifically in the HPA region of Kansas (Pfeiffer and Lin 2012, 2013, 2014a, 2014b; Hendricks and Peterson 2012; Peterson and Ding 2005). Our work is closest to Pfeifer and Lin (2014a), which forcefully demonstrates the existence of rebound effects of LEPA. Our innovations include explicitly modeling water rights and farmer incentives to preserve water rights, identifying the moderating effects of water rights on LEPA, and quantifying the channels of the rebound effects through formally estimating the mediating effects of crop choices and irrigated acreages. Further, our data span a longer time period (1992 – 2009 vs 1996 – 2005 in Pfeifer and Lin (2014a)), and we use a different instrument variable for LEPA adoption based on neighbor influences. Finally, building on Wooldridge (2010) and Biewen (2009), we jointly estimate the water use and water right preservation models, achieving more efficient estimation of LEPA's effects on water use.

The paper is organized as follows. In Section 2, we describe the water right system in Kansas, providing the background for our estimation model. We develop the theoretical and estimation models in Section 3, and describe the data in Section 4. We present and discuss our estimation results in Section 5 and conclude in Section 6.

2. High Plains Aquifer and Water Rights in Kansas

Our study area is the HPA region of the state of Kansas, which relies heavily on irrigation water withdrawal from HPA. Widely considered the breadbasket of the US, the High Plains Region is facing the double threat of declining water table of the HPA and climate change. HPA is also the largest freshwater aquifer in the world (Miller & Appel, 1997) and has variable recharge rates from the north to the south. In Kansas, HPA has a low recharge rate, and irrigation is essentially equivalent to mining a nonrenewable resource.

Kansas has a prior appropriation water right system (Peck 1995, 2007), with each water right specifying the maximum amount of water that can be extracted from the HPA in a given year. The relationship between water rights and the points of diversion (i.e., irrigation wells) can be classified into four types: a single well assigned with a single water right (Type 1), a single well assigned with multiple water rights (Type 2), multiple wells sharing a single water right (Type 3), and multiple wells sharing multiple water rights (Type 4). We focus on Type 1 wells, which account for about 80% of the wells that reported the use of certain types of irrigation technologies during our study period.

Seniority of a water right is determined by the time when the water right application was recorded. Among the Type 1 wells in our sample, most of the application dates are in 1970s. There is effectively a moratorium on new water right applications after 1990s (Peck 1995). Figure 1 shows the distribution of Type 1 wells by application dates. In principle, when water availability cannot satisfy the total demand, a well with a more senior water right can block wells with junior water rights from extracting water from HPA. By far this scenario has never occurred in Kansas.

Water rights in Kansas are not always strictly binding. First, water use is self-reported by farmers. Although water pumping is accurately metered, it is possible that farmers might misreport their actual water use. Second, in drought years, farmers are allowed to go beyond the water right limits. In our sample, about 10% of the wells reported water use above their water rights. However, as shown in Figure 2, this percentage has been going down, especially after 2002.

The water right system in Kansas also has a three year use-it-or-lose-it (UIOLI) clause, implying that the water rights of a well without water use for three consecutive years are subject to cancellation. Under the Kansas Administrative Procedure Act (KAPA), a farmer can appeal to the Kansas Department of Water Resources to keep the water rights if he/she can establish “due and sufficient cause for non-use” (Peck 1995). Such causes include sufficient rainfall, enough surface water as diversion source, soil and water conservation such as CRP, etc. Among the Type 1 wells in our sample period, about 10% experienced three consecutive years of no water use. Among these three year no-water use wells, about 32% successfully kept their water rights.

Although farmers can appeal against the UIOLI clause, the burden of proof for establishing the due and sufficient causes for non-use lies with the farmer. Due to the transaction costs involved, farmers might have incentive to use a small amount of water when irrigation is not needed in order to preserve their water rights. We will test this hypothesis in this paper.

3. Model Specification

A farmer might irrigate a particular field multiple times during a single growing season, e.g., at planting, after emergence of crops, etc. At any point of time during the growing season, the farmer faces decisions of whether or not to irrigate, and if yes, how much to irrigate. There is a fixed cost of irrigation, arising from the minimum pressure required in order for the irrigation equipment to start. There are also uncertainties about future irrigation needs within the same growing season. For instance, at the start of the growing season, the farmer might not know for sure how much irrigation water is needed for the reminder of the season due to weather uncertainties and future crop/energy prices. Facing the constraint of a water right, the farmer may thus decide to limit the amount of water applied during the early season to leave more options open for increased water use during the later season. Therefore, it is possible that water rights affect the total irrigation water use within the entire growing season even when *ex post* the farmer ends up using less water than the water right limit.

LEPA reduces the fixed costs of irrigation since the required water pressure is lower. As a result, it is more common for farmers to apply a small amount of water (e.g., one round of irrigation) using LEPA than central pivot. However, the tendency to do so might be limited by water rights, especially during early periods of the growing season if the farmer expects a higher level of irrigation in later season under LEPA. These considerations lead to two hypotheses that we will test:

- The rebound effect of LEPA irrigation is limited by the associated water rights,
- Farmers do have incentives to preserve water right and the strength of the incentive depends on their expectation of irrigation profitability in the future and the associated water rights.

To test these hypotheses, we develop and estimate two models: one on irrigation water use, and one on farmer incentives to preserve water rights. We focus on the effects of LEPA relative to central pivot, limiting ourselves to wells that have used one or both of the two technologies during our sample period.

<u>Correlated Random Effect Tobit Model of Water Extraction</u>

Let y_{it} be the observed water extraction of well i at year t and y_{it}^* be the latent variable representing the profit maximizing water extraction *without* considering fixed cost of irrigation. In reduced form, profit-maximizing level of water extraction (y_{it}^*) depends on the field characteristics, weather conditions, management practices, irrigation technology and water rights. To test the first hypothesis, we include the interaction of LEPA dummy and authorized water extraction amount in y_{it}^* equation. In addition, water right might also directly influences farmer's water extraction due to intra-season planning. We assume a linear form of y_{it}^*:

$$y_{it}^* = \beta_0 + R_i\beta_1 + AC_{it}\beta_2 + LEPA_{it}\beta_3 + LEPA_{it} * R_i\beta_4 + s_{it}\beta_5 + w_{it}\beta_6 + G_g + \varphi_t + c_i + \varepsilon_{it} \qquad (1)$$

where R_i is the time-invariant annual authorized water extraction amount specified by the water right; AC_{it} is acres irrigated of well i in year t; $LEPA_{it}$ is a dummy variable that equals to 1 if the irrigation technology is LEPA and 0 otherwise; s_{it} is a vector of soil characteristics of the field (e.g., depth to water); w_{it} is a vector of weather conditions; and G_g and φ_t capture the ground water management district fixed effect and time fixed effect, respectively. ε_{it} is iid error term across wells and years and c_i is a well specific unobserved error. Coefficient β_4 captures the *mediation effect* of water right R_i on LEPA's impact on water use.

Let $\bar{S}$ be an auxiliary level of water extraction threshold. Given the fixed cost of irrigation, the profit maximizing water extraction excluding the fixed cost must be above $\bar{S}$ to guarantee a positive profit. That is, a farmer would not want to irrigate even if the profit maximizing water extraction (without considering the fixed cost) y_{it}^* is positive if it is smaller than $\bar{S}$. As a result, we can treat all observations with $0 < y_{it} < \bar{S}$ and $y_{it} = 0$ as censored at corner $\bar{S}$. In this model, the only reason that we still have observations with $0 < y_{it} < \bar{S}$ is that farmers apply a small amount of water in order to preserve their water rights.[2] (We will illustrate this point in greater detail later.)

We denote x_{it}^y as the variables included in water use equation (1) and assume $\varepsilon_{it} \sim N(0, \sigma_\varepsilon^2)$. The per-period conditional likelihood function (conditional on c_i) of well i is:

$$f(y_{it}|x_{it}^y) = \left[\frac{1}{\sigma_\varepsilon}\phi(\frac{y_{it} - c_i - x_{it}^y\beta}{\sigma_\varepsilon})\right]^{1(y_{it}>\bar{S})}\left[1 - \Phi\left(\frac{c_i + x_{it}^y\beta - \bar{S}}{\sigma_\varepsilon}\right)\right]^{1(y_{it}\leq\bar{S})}$$

Correspondingly, the conditional likelihood function for a specific well across all sample periods *T* is:

$$f(y_i|x_i^y, c_i) = \prod_{t=1}^{T} f(y_{it}|c_i, x_{it}^y)$$

[2] This makes sense when we are given a small $\bar{s}$ – the small water extraction rate definitely won't compensate fixed cost for using the irrigation equipment. We set $\bar{s}$ to be 5 acre-feet, while the mean of irrigation water extraction across the sample is 144 acre-feet and the maximum to be 500 acre-feet.

Since the water rights is time invariant for a specific well, we use a random effects specification. Specifically, we adopt the correlated random effect (CRE) framework in Chamberlain-Mundlak Device:

$$c_i = \gamma_0 + \overline{AC}_i\gamma_1 + \overline{LEPA}_i\gamma_2 + \overline{AC}_i * R_i\gamma_3 + \overline{w}_i\gamma_4 + a_i \quad (2)$$

where $a_i \sim N(0, \sigma_a^2)$. The bars over variables are time average of time-varying variables across all sample period for well *i*. Thus c_i follows a normal distribution and we denote its pdf by $h(c_i|x_i^y, \theta_y)$. As a result, the unconditional likelihood function (again, unconditional on c_i) becomes:

$$f(y_i|x_i^y) = \int \prod_{t=1}^{T} f(y_{it}|c_i, x_{it}^y) h(c_i|x_i^y, \theta_y) dc_i \qquad (3)$$

The calculation of Average Partial Effects (Marginal Effects) follows the standard method in Tobit model.

Mediation Effect – Intensive and Extensive Margins

We next model the channels through which LEPA and water rights affect water extraction. Following Pfeiffer & Cynthia (2014a), we study the effects on the intensive margin through crop choices and on the extensive margin through irrigated acres. Different from Pfeiffer and Cynthia (2014a), we formally estimate a mediation effect model that involves three estimation equations or steps. Step 1: equation (1), i.e., regressing water use on LEPA and water rights without the mediators. Step 2: regressing the mediators on LEPA and water rights. Step 3: augmenting (1) with the mediators, i.e., regressing water use on the variables in (1) as well as the mediators. We consider two mediators, irrigated acres and crop choices.

Mediation effects are present when LEPA and water rights are significant in Step 1, but its magnitude and/or significance is reduced in Step 3, and they are significant in Step 2. Since our estimation models are nonlinear, we cannot formally calculate the magnitude of the mediation effects as in the Sobel test. Still, comparing the coefficients of LEPA and water rights in Steps 1 and 3 still provides a sense about the channels through which these variables affect water uses.

Correlated Random Effect Probit Model of Incentives to Preserve Water Rights

To test the second hypothesis, we develop and estimate a model of farmer incentives to use a small amount of water in order to preserve the water rights. As noted earlier, the only reason that we observe $0 < y_{it} < \bar{S}$ is that the farmer intends to preserve the water right. If no water is used, i.e., if $y_{it} = 0$, then the farmer does not have the incentive to preserve the water right. Finally, we assume that farmers also have the incentive to preserve water right when we observe $y_{it} \geq \bar{S}$. Let z_{it}^* be a latent variable representing the farmer's incentive to preserve water right and z_{it} to be the (observed) decision of preserving or not. Then we know

$$z_{it} = \begin{cases} 1, & if\ z_{it}^* \geq 0 \\ 0, & if\ z_{it}^* < 0 \end{cases}$$

The equation for the incentive latent variable z_{it}^* is specified as follows:

$$z_{it}^* = c_i + 1(y_{it+1} > \bar{S})y_{it+1}\alpha_1 + 1(0 < y_{it+1} \leq \bar{S})\alpha_2 + 1(y_{it+1} = 0)\alpha_3 + x_{it}^y\alpha_4 + \eta_{it} \quad (4)$$

Water use in year t+1, y_{it+1}, is included because the incentive to preserve water right now depends on the farmer's expected future water use. If the farmer expects that he will use a large amount of water in the future, his incentive to preserve the water right would be higher. Assuming rational expectations, y_{it+1} captures the expected future water use. Similar assumptions have been used in Chaloupka (1990) in modeling rational additive behavior of cigarettes. x_{it}^y includes all the variables used in the extraction equation (1) including time and GMD fixed effects. Specifically, we would like to test whether the water rights and LEPA are important considerations when deciding whether or not to preserve the water right. Since adopting LEPA involves sunk costs, the farmer might have a higher incentive to preserve his water rights after LEPA is adopted. And if the associated water right is high, the farmer again has incentive to preserve the right since giving it up involves losing a large amount of potential irrigation water. η_{it} is assumed to be iid $N(0,1)$ for identification purpose. The per-period conditional likelihood function (conditional on c_i) of well *i* is:

$$f(z_{it}|x_{it}^z) = [\Phi(c_i + x_{it}^z\alpha)]^{1(z_{it}=1)}[1 - \Phi(c_i + x_{it}^z\alpha)]^{1(z_{it}=0)}$$

Similarly, the conditional likelihood function for a specific well across all sample periods *T* is:

$$f(z_i|x_i^z, c_i) = \prod_{t=1}^{T} f(z_{it}|c_i, x_{it}^z)$$

Again, integrating c_i out from the equation above, we get the unconditional likelihood function:

$$f(z_i|x_i^z) = \int \prod_{t=1}^{T} f(z_{it}|c_i, x_{it}^z)h(c_i|x_i^z, \theta_z)dc_i \quad (5)$$

<u>Robustness Check – A Dynamic Joint Estimation Framework</u>

Water use equation (1) and water right equation (4) will be estimated separately and under standard assumptions will give consistent estimates. However, since the incentive to preserve water rights depends on actual water use in (4), estimating the two equations jointly will improve the estimation efficiency. We will estimate the dynamic system of equations but only use the results for the purpose of robustness checks since the dynamic estimation model is much more time consuming and the calculation of marginal effects is much more complex.

The dynamic model will be estimated as follows:

First, re-define y_{it}:

$$y_{it}\begin{cases} = y_{it}^{*}, & y_{it}^{*} > \bar{S}\ z_{it}^{*} > 0 \quad (\boldsymbol{c1}) \\ \in (0,\bar{S}], & y_{it}^{*} \le \bar{S},\ z_{it}^{*} > 0 \quad (\boldsymbol{c2}) \\ = 0, & y_{it}^{*} \le \bar{S},\ z_{it}^{*} \le 0 \quad (\boldsymbol{c3}) \end{cases}$$

Under this specification, water extraction falls into one of three possible ranges, consistent with the interpretations in (1) and (4). First, if it is profitable to irrigate in the current year ($y_{it}^{*} > \bar{S}$), we will observe an extraction level higher than $\bar{S}$. We assume that in this case the farmer also has incentive to preserve his water rights. Second, a small but positive amount of water is extracted. In this case, it is not profitable to irrigate in the current year ($y_{it}^{*} \le \bar{S}$) but the farmer has incentive to preserve his water rights ($z_{it}^{*} \ge 0$). Third, no water is extracted in year t. In this case, it is not profitable to irrigate this year ($y_{it}^{*} < \bar{S}$) and the farmer has no incentive to preserve his water rights.

We then re-specify the two latent variable equations (1) and (4):

$$y_{it}^{*} = c_i + R_i\beta_1 + AC_{it}\beta_2 + LEPA_{it}\beta_3 + AC_{it} * R_i\beta_4 + s_i\beta_5 + w_{it}\beta_6 + G_g + \varphi_t + \varepsilon_{it} \qquad (6)$$

$$z_{it}^{*} = rc_i + 1(y_{it+1} > \bar{S})y_{it+1}\alpha_1 + 1(0 < y_{it+1} \le \bar{S})\alpha_2 + 1(y_{it+1} = 0)\alpha_3 + x_{it}^{y}\alpha_4 + \eta_{it} \quad (7)$$

Equation (6) is exactly as equation (2). The only difference between equations (7) and (4) is that the well-specific term c_i is scaled by a multiplier *r* following Biewen (2009) to represent a different fixed effect compared to equation (6).

We assume that $\varepsilon_{it} \sim N(0,\sigma_{\varepsilon}^{2})$ and $\eta_{it} \sim N(0,1)$ and they are both *iid*. We further assume that $cov(\varepsilon_{it},\eta_{it}) = 0$. Note that σ_{η}^{2} needs to be normalized to 1 in the estimation. The per-period density function for y_{it} has three possible different cases:

Under condition (c1):

$$f_{c1}\left(y_{it}|y_{it+1},c_i,x_{it}^{y}\right) = \frac{1}{\sigma_{\varepsilon}}\phi(\frac{y_{it} - c_i - x_{it}^{y}\beta}{\sigma_{\varepsilon}})] * \Phi(\frac{rc_i + 1(y_{it+1} > \bar{S})y_{it+1}\alpha_1 + 1(0 < y_{it+1} \le \bar{S})\alpha_2 + 1(y_{it+1} = 0)\alpha_3 + x_{it}^{y}\alpha_4}{\sigma_{\eta}})$$

Under condition (c2):

$$f_{c2}\left(y_{it}|y_{it+1}, c_i, x_{it}^{y}\right)$$
$$= [1 - \Phi\left(\frac{c_i + x_{it}^{y}\beta - \bar{S}}{\sigma_{\varepsilon}}\right)]$$
$$* \Phi(\frac{rc_i + 1(y_{it+1} > \bar{S})y_{it+1}\alpha_1 + 1(0 < y_{it+1} \leq \bar{S})\alpha_2 + 1(y_{it+1} = 0)\alpha_3 + x_{it}^{y}\alpha_4}{\sigma_{\eta}})$$

Under condition (c3):

$$f_{c3}(y_{it}|y_{it+1}, c_i, x_{it})$$
$$= [1 - \Phi\left(\frac{c_i + x_{it}^{y}\beta - \bar{S}}{\sigma_{\varepsilon}}\right)] * [1$$
$$- \Phi\left(\frac{rc_i + 1(y_{it+1} > \bar{S})y_{it+1}\alpha_1 + 1(0 < y_{it+1} \leq \bar{S})\alpha_2 + 1(y_{it+1} = 0)\alpha_3 + x_{it}^{y}\alpha_4}{\sigma_{\eta}}\right)]$$

Together, the likelihood function for a particular well *i* at specific year *t* is:

$$f\left(y_{it}|y_{it+1}, c_i, x_{it}^{y}\right)$$
$$= [f_{c1}\left(y_{it}|y_{it+1}, c_i, x_{it}^{y}\right)]^{1(y_{it}>\bar{S})}[f_{c2}\left(y_{it}|y_{it+1}, c_i, x_{it}^{y}\right)]^{1(0<y_{it}\leq\bar{S})}[f_{c3}\left(y_{it}|y_{it+1}, c_i, x_{it}^{y}\right)]^{1(y_{it}=0)}$$

Utilizing the property of conditional density function, the full likelihood function (conditional on c_i) of well *i* over all years is given by a multiplication of per-period likelihood functions:

$$f\left(y_i|y_{iT}, c_i, x_{it}^{y}\right) = \prod_{t=1}^{T_i-1} f\left(y_{it}|y_{it+1}, c_i, x_{it}^{y}\right)$$

Finally re-specify the distribution for c_i:

$$c_i = \gamma_0 + \overline{Ac}_i\gamma_1 + \overline{Lepa}_i\gamma_2 + \overline{Ac}_i * R_i\gamma_3 + \bar{w}_i\gamma_4 + y_T\gamma_5 + a_i \quad (8)$$

The only difference between equation (8) and equation (2) is that c_i now is also a function of y_T, which is the "end condition". This is exactly analogous to the "initial condition" used in the dynamic panel estimation proposed by Wooldridge (2010).

Assuming $a_i \sim N(0, \sigma_a^2)$, c_i also conforms to a normal distribution. Denote this distribution by $h(c_i|x_i, y_{T_i}, \theta)$. Then the unconditional likelihood contribution (unconditional on c_i) becomes:

$$f\left(y_i|y_{iT}, x_{it}^{y}\right) = \int f\left(y_i|y_{iT}, c_i, x_{it}^{y}\right) h(c_i|x_i, y_{T_i}, \theta) dc_i \quad (9)$$

Endogeneity of LEPA Irrigation

The adoption of LEPA irrigation might be endogenous in the water use equation (1) – some unobserved factors might affect LEPA adoption and water extraction at the same time. Pfeiffer and Lin (2014a) uses the county level subsidies for LEPA adoption as instruments. In this paper, we use a different instrument, namely the adoption of LEPA by one's neighbors. There is a large literature on herd behavior and information cascades that have demonstrated the existence of neighbor influences in technology adoption decisions, including adoption of agriculture production technologies (Zhao 2007). The influence is mainly through learning about the performance of the new technology, but can also arise due to network externalities, e.g., when marketing services are established after a certain number of farmers have adopted the technology. In this paper, for the instrument we use the number of LEPA adopters in the previous year among a well's closest five neighbors. This variable is not likely to influence the well's own water use due to the time lag and the fact that we are controlling for a rich set of weather and soil characteristics. After we run the first stage regression of LEPA adoption on IV and other control variables, the predicted Generalized Residual is plugged in the second stage water extraction equation as a control function to solve the endogeneity problem.

4. Data

The data used for our estimation is drawn from multiple sources. Information about the points of diversions (i.e. wells) is from the Water Information Management and Analysis System (WIMAS) maintained by the Kansas Water Office. As indicated earlier, there are four types of wells depending on how they are related to the water rights. We focus on Type 1 wells for two reasons: (i) the relationship between this type of wells and their water rights is fairly straightforward, and (ii) little information will be lost due to the high frequency of Type 1 wells in our sample. After deleting point of diversions that have no irrigation technologies reported during the study period (1992-2009), we are left with 16187 wells in total, among which 12503 wells belong to Type 1 defined above, accounting for 77% of all wells.

We further remove outliers consistent with Pfeiffer & Lin (2014), including those that use more than 500 acre-feet of water in a given year, and those with the maximum irrigated acres during the study period greater than 640 acres or smaller than 60 acres. This reduces the total number of wells in our study period down to 10891. Finally, we delete point of diversions that have records of flood irrigation[3] during the study period and as well as those that are abandoned before the end of the study period (year 2009) to form a balanced panel, leaving 5395 wells in the ultimate dataset. Since most applications for water rights occurred in 1970s and all water rights in our sample were applied more than five years before the

[3] Wells using Center Pivot and LEPA irrigation technology account for more than 80% of the full sample during this period.

beginning of our sampling period (cf. Figure 1), we can take the water rights as exogenous in our estimations.

Spatially explicit soil characteristics are obtained from SSURGO soil survey on the website of USDA Natural Resources Conservation Service. These characteristics include detailed soil information about Depth to Ground Water (DTW), slope, Available Water Capcity (AWC), Irrigated Capacity Class (ICC) and Saturated Hydraulic Conductivity (SHC). Weather data are obtained from North America Land Data Assimilation System (NLDAS) maintained by NASA that reports geo-referenced information about annual precipitation and potential evapotranspiration.

Finally, the well data (and also water right data) obtained from WIMAS are matched to soil and weather data using spatial join function in ArcGIS.

5. Estimation Results

Table 1 presents summary statistics of the variables used in our estimation models. The values of these variables are similar to those in Pfeiffer and Lin (2014).

<u>Estimation Results of Water Extraction</u>

The Tobit estimation results of the water use equation (1) are reported in Table 2. The coefficient of the control function is significant, demonstrating the success of the IV estimation strategy. The signs of coefficients of other variables are as expected. For example, water use goes up with the acres irrigated, with potential evapotranspiration (measuring crops' water demand) but decreases in precipitation (due to increased rainfall), depth to water (due to the higher energy expenditure in extracting water), and available water capacity (due to the increased ability of the soil in storing water for crop needs).

Consistent with Pfeiffer and Lin (2014), we find significant rebound effect of LEPA: the marginal effect of LEPA is 7.535, significantly different from zero. However, the direct effect of LEPA is not significant but its interaction term with water right is positive and significant. Thus, LEPA's effect on water use is mostly moderated by water rights: LEPA raises water uses more for wells with larger water rights. If institutional changes in Kansas reduce the water rights allocated to the existing wells, they can also limit the undesirable rebound effects of LEPA. This result is striking given that water rights are not always binding and are not always strictly enforced.

Table 3 shows the first stage estimation results for the adoption of LEPA. Water right has a significantly negative influence on LEPA adoption, though the magnitude of this effect is not large. A possible explanation is that farmers with lower water rights are more constrained by available water for irrigation and thus more likely to adopt LEPA to raise their water use efficiency. This conjecture is also supported by comparing the water uses relative to the water rights under LEPA and central pivot. Table 4 reports the average percentage of actual water use relative to the authorized amounts defined by the water rights for different levels of water rights and for different technologies. When the water rights are low (less than 100 af), the average water extraction exceeds the associated water rights by 5%. But this percentage is higher for wells using central pivot (10%) than for those using LEPA (2%). For larger wells, on average water extraction is lower than the water rights, but the percentage is higher for LEPA than for central pivot. Thus, adoption of LEPA is associated with less frequent violation of the water rights. The comparison also indicates that adoption of LEPA reduces water use on average for farmers with smaller water rights, and that the rebound effect of increasing water usage after adoption of LEPA mainly comes from farmers with larger water rights. Then limiting water rights, especially for those with larger water rights, will help limit the rebound effect.

Mediation Effects

The results above are about the overall effects of water rights, LEPA and their interaction on water extraction. The mediation test results in this section show the channels through which water rights and LEPA affect water extraction. Tables 5 - 7 contain mediation regression results for two mediators, crop choice and acres irrigated (and both). We selected seven most common crops in the Kansas High Plain Area to include in our analysis, with all other crops (or crop combinations) reported in the WIMAS dataset to be "others." Table 5 contains results of Steps 1 and 3, i.e., it compares the estimated coefficients before including the mediators (in column labeled "Before") and after including the mediators (in column labeled "After"). Tables 6 and 7 show the results of Step 2, i.e., the effects of the mediators of the independent variables, LEPA and water rights.

Table 6 shows the multinomial logit estimation of the effects of LEPA and water rights on crop choices. Both LEPA and water rights affect the crop choices significantly. Specifically, adoption of LEPA tends to increase the acreage of water intensive crops such as corn and soybean. Water rights have a similar effect, raising the acreages of corn and wheat and corn/soybean rotation. Table 7 shows that adoption of LEPA and larger water rights tend to increase the irrigated acreage. The effects of the independent variables LEPA and water rights are significant in the regressions of both mediators. Such significance is necessary for establishing the mediation effects.

In Table 5, comparing the coefficients of LEPA, water rights, and their interaction shows that the introduction of the mediators does change the magnitude of the estimated coefficients. Specifically, when crop choices are introduced (the first two columns), the estimated coefficients of LEPA and LEPA*water rights decrease, but the coefficient of water rights does not decrease. In contrast, when irrigated acres are introduced, the coefficient of water rights, LEPA and their interactions all decrease. When both mediators are included (the last two columns of Table 5), the coefficients of all three variables decrease. To further compare the effects of the mediators, the bottom two rows of Table 5 compares the marginal effects of LEPA and Water Rights with and without the mediators. The comparison shows that almost all the effect of Water Right is transmitted through irrigated acres (i.e. the more water extraction authorized by water right, the more acres to irrigate and thus more water is used). In contract, the effect of LEPA is transmitted through both crop choices and acres irrigated. The magnitudes of both transmission media are about the same (10.519 to 7.078 and 10.519 to 7.535).

Incentive to Preserve Water Right

The analysis above shows that water right plays an important role in determining a farmer's water extraction decisions through both extensive margin (i.e., acres irrigated) and its interaction with LEPA. We next discuss whether farmers have incentive to preserve their water rights, in response to the three year UIOLI clause.

Table 8 shows the Probit regression result specified by equation (4) and estimated by equation (5). Confirming our hypothesis that farmers' decisions are influenced by expectations about future water use, the coefficients of the three indicator variables (in the top three rows) are all positive and significant. Since the default is no water use in the next period, these results indicate that farmers have more incentive to preserve their water rights when they expect that they will again irrigate a small amount of water in order to preserve their water rights (i.e., when $0 < y_{it+1} \leq \bar{S}$), and when they expect that irrigation is needed during the next period (i.e., when $y_{it+1} > \bar{S}$. Further, this incentive is higher if the actual irrigation level is higher: the coefficient of $1(y_{it+1} > \bar{S})y_{it+1}$ is positive and significant.

LEPA has a positive and significant influence on the incentive to preserve water rights. A farmer is 36.1% more likely to have incentive to preserve his water right if LEPA has been adopted than if central pivot is still used. This arises since LEPA irrigation is typically more profitable and the adoption cost of LEPA is mostly sunk.

The coefficient of water rights is negative and significant, counter to our intuition. But its overall marginal effect is not significantly different from zero. The mixing results of water rights might be due to the fact that we have controlled for a large number of other variables in the estimation and the fact that farmers view water rights as providing irrigation services instead of having inherent asset value. That is, regardless of the size of the water rights, a farmer's incentive to preserve them depends on the future irrigation demand. Once the irrigation demand is controlled for, the size of the water rights itself does not contribute a large enough value to the farmer's payoffs and thus do not significantly affect their incentives to preserve the water rights.

<u>Robustness Check – the Dynamic Joint Estimation</u>

As discussed earlier, a more efficient estimation approach is to jointly estimate the water demand and water right preservation incentives. Table 9 shows the results of the dynamic joint estimation results, and compare them with the separate estimations (the Tobit model for water demand and the Probit model for water right incentives). The coefficients of most variables are similar. For irrigation water extraction, the coefficient of Water Right * LEPA is unchanged, while the coefficients of Water Right and LEPA are both higher in the dynamic model. Further, the coefficient of Irrigated Capacity Class is not significant in the dynamic model while being negative and significant in Tobit estimation. Since this variable captures the suitability of the land class for irrigation, the Tobit result of a negative coefficient is counter-intuitive. For the incentive to preserve water rights, the coefficients of most variables are similar across the dynamic and Probit models. The coefficient of Water Right is not significant in the dynamic model while it is negative and significant in the Probit model. Overall, the dynamic joint estimation results are similar to the separate estimation results, but in certain aspects, the dynamic results are more intuitive.

6. Conclusions

In this paper, we study the role of water rights in limiting the rebound effects of LEPA in the HPA region of Kansas, and farmer incentives to preserve their water rights. Consistent with previous results of Pfeiffer and Lin (2014), we find significant rebound effects of LEPA irrigation. However, the rebound effect is mediated by water rights and is high only when a well has large water rights: the estimated coefficient of the interaction of LEPA and water rights is positive and significant in water uses. Further, limiting water rights raises farmer incentives to adopt LEPA. These results indicate that institutional changes such as reducing water rights can limit the undesirable rebound effects of new technologies without hurting incentives to adopt them.

We also find that a significant portion of the effects of LEPA in raising water uses is through farmers switching to more water intensive crops such as corn and soybean, and through farmers raising their irrigated acreages after the adoption of LEPA. Almost all effects of water rights on water use are mediated by irrigated acreage: famers with higher water rights will irrigate larger areas of their fields. Understanding the mediation effects will help predict future impacts of new technologies and institutional changes.

More interestingly, we find that farmers have incentive to preserve water rights even when the optimal water use in a certain period is zero. This incentive depends on expected water use in the next period. It is the highest if the farmer expects to use a large volume of water to irrigate, and is the lowest if the farmer expects not to use any water at all in the next period. It is moderate if the farmer expects that he will continue to use a minimal amount of water to preserve the water rights for another period.

The main contribution of the paper is to highlight the role of water rights, even in a setting where water use is self-reported (although metered accurately) and water rights are fungible and not strictly enforced (reported water use exceeds water rights in about 10% of our sample). One can only expect the effects of water rights to further increase if the rights are enforced more strictly.

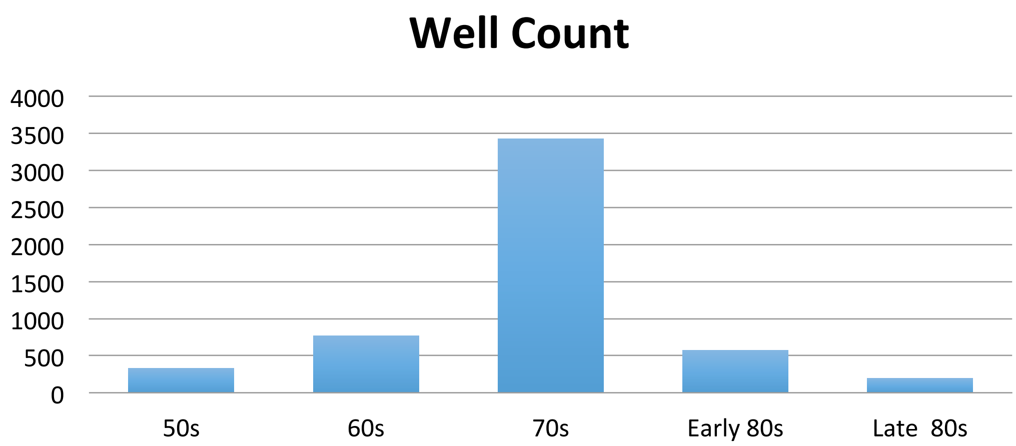

Figure 1. Distribution of Type 1 wells by application time

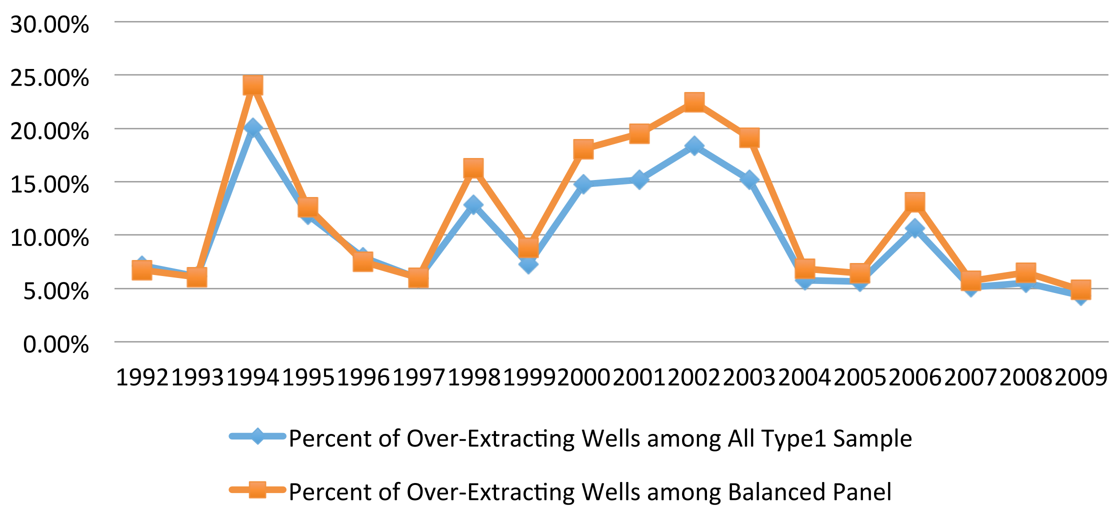

Figure 2. Annual percentage of wells extracting beyond their water rights

Table 1. Summary Statistics

Variables	Balanced Panel 1992-2009 (5395 wells)		
	N	Mean	Std. Dev
Total Use (AF)	97110	144.65	76.45
Use per acre (AF/Acre)	97110	1.10	0.48
LEPA (=1 if LEPA irrigation)	97110	0.608	0.488
Acres Irrigated (Acres)	97110	133.96	51.57
Precipitation (in)	97110	25.57	6.03
Evapotranspiration (in)	97110	112.69	9.39
Depth to Water (ft)	97110	93.68	71.71
Saturated Hydroconductivity (um/sec)	97110	29.04	33.21
Slope (% of distance)	97110	2.43	2.82
Available Water Capacity (cm/cm)	97110	0.16	0.04
Irrigated Capability Class (dummy)	97110	0.40	0.48
Percent of Wells Planting (%)			
Alfalfa	7.59		
Corn	43.53		
Sorghum	2.14		
Soybeans	8.27		
Wheat	3.55		
Corn and Soy	3.79		
Corn and Wheat	4.64		
Other	24.36		

Depth to water is the distance between the surface of ground water and the surface of land. Saturated Hydroconductivity is an indicator of how easy water moves in saturated soil. Slope is the gradient of soil. Available water capacity is the range of available water that can be stored in soil and available for growing crops. Irrigated Capacity Class equals to 1 if the land is suitable for irrigation and 0 otherwise.

Table 2. Tobit Estimation of Water Uses

Dependent var	
Total Extraction	
Water Right	-.004
Acres Irrigated	0.670***
Potential Evapotranspiration	1.650***
Precipitation	-1.763***
Depth to Water	-0.412***
Control Function	-3.003***
LEPA	0.148
Irrigated Capacity Class	-8.466***
Slope	-0.201
Available Water Capacity	-197.51***
Saturated Hydro Conductivity	-0.121***
Water Right*LEPA	0.031***
Marginal Effects	
Water Right	0.014
LEPA	7.535***

*** 1% significant level, ** 5% significance level, * 10% significance level.

Table 3. First Stage Regression of LEPA Adoption

Dependent var	LEPA
Water Right	-.004***
Acres_Irrigated	.006***
Potential Evaportranpiration	-.029**
Precipitation	-.046***
DTW	.024**
Irrigated Capacity Class	-1.101***
Slope	-.172***
Available Water Capacity	-4.732
Saturated Hydro Conductivity	-.022***
# Neighbors with LEPA LAST YEAR (**IV**)	.698***
Time Fixed Effect	Yes
GMD Fixed Effect	Yes
CRE form	Yes
N	97110
Marginal Effects of Water Right (at random effect = 0)	
Water Right	-0.005***

Table 4. Mean Percentage of Actual Extraction to Water Right Authorization

	Authorized Annual Extraction by Water Right (Acre-feet)		
Technologies	<=100	100~200	>=200
Pooled Sample	105%	72%	58%
Center Pivot	110%	69%	58%
LEPA	102%	74%	59%

Table 5. Regression Results of Mediation Tests

Mediators	Crop Choice		Acres Irrigated		Both	
Total Extraction	**Before**	**After**	**Before**	**After**	**Before**	**After**
Water Right	0.072***	.074***	0.072***	-.004	0.072***	0.006
Potential ET	1.672***	1.708***	1.672***	1.650***	1.672***	1.693***
Precipitation	-1.819***	-1.758***	-1.819***	-1.763***	-1.819***	-1.724***
DTW	-0.490***	-.453***	-0.490***	-0.412***	-0.490***	-0.393***
Control Function	-5.427***	-3.922***	-5.427***	-3.003***	-5.427***	-1.852**
LEPA	2.230	-.839	2.230	0.148	2.230	-2.209*
ICC	-12.37***	-11.24***	-12.37***	-8.466***	-12.37***	-6.822***
Slope	-1.156***	-.985***	-1.156***	-0.201	-1.156***	0.047
AWC	-186.2***	-158.5***	-186.2***	-197.5***	-186.2***	-150.6***
SHC	-0.211***	-.179***	-0.211***	-0.121***	-0.211***	-0.081***
WR*LEPA	0.035***	.033***	0.035***	0.031***	0.035***	0.030***
Acres Irrigated				0.670***		0.596***
Wheat		-50.41***				-45.89***
Soybeans		6.639***				9.709***
Sorghum		-16.29***				-12.55***
Corn		13.30***				16.42***
Alfalfa		8.787***				11.677***
Corn-Soybeans		13.827***				14.995***
Corn-Wheat		12.821***				8.519***
Fallow		-90.61***				-50.03***
Marginal Effects						
Water Right	0.093***	0.093***	0.093***	0.014	0.093***	0.024***
LEPA	10.519***	7.078***	10.519***	7.535***	10.519***	4.921***

* Note: The base category for crop choice is “others” defined above

Table 6. MNL Estimates of the Marginal Effects of LEPA and Water Right on Crop Choices

Dependent var	**LEPA**	**Water Right (@ LEPA = 1)**	**Water Right(@ LEPA = 0)**
Marginal Effects			
Wheat	-0.003***	-0.0000213***	-0.0000211***
Soybeans	0.033***	-0.0000474***	-0.0001253***
Sorghum	-0.083***	-0.0000790***	-0.0000435***
Corn	0.017***	0.0000212	-0.0000990***
Alfalfa	-0.001	-0.0001924***	-0.0001800***
Corn & Soy	-0.009***	0.0000308***	-0.0000162***
Corn & Wheat	-0.007***	0.0000931***	0.0001426***
Fallow	-0.002*	-0.0000080***	-0.0000080***
Others	-0.020***	0.0002029***	0.0003503***

Table 7. Tobit Estimates and Marginal Effects of LEPA and Water Right on Acres Irrigated

Dependent var	
Acres Irrigated	
Water Right	0.147***
Potential Evapotranspiration	0.042
Precipitation	-0.124***
Depth to Water	-0.131***
Control Function	-3.792***
LEPA	3.568***
Irrigated Capacity Class	-8.014***
Slope	-1.934***
Available Water Capacity	19.253
Saturated Hydro Conductivity	-0.184***
Water Right*LEPA	0.005***
Marginal Effects	
Water Right	0.151***
LEPA	4.922***

Table 8. Probit Results for Incentive to Preserve Water Right

Model	**Probit Model**
Incentive*	
$1(y_{it+1} > \bar{S})y_{it+1}$	.002***
$1(0 < y_{it+1} \leq \bar{S})$	.506***
$1(y_{it+1} > \bar{S})$	1.230***
Water Right	-0.001***
Potential Evapotranspiration	0.010**
Precipitation	-0.017***
Depth to Water	-0.005***
LEPA	0.293***
Irrigated Capacity Class	-0.092***
Slope	-.021***
Available Water Capacity	-0.517
Saturated Hydro Conductivity	-0.002*
Water Right*LEPA	0.0002
Time Fixed Effect	Yes
GMD Fixed Effect	Yes
N	97110
Marginal Effects	
LEPA	0.361***
Water Right	-0.000

*Note: the base category in Incentive equation is $1(y_{it+1} \leq 0)$

Table 9. Comparisons of the Dynamic Joint Model and Separately Estimated Models

Model	**Dynamic Model**	**Tobit Model**
Total Extraction		
Water Right	0.018**	-.004
Acres Irrigated	0.653***	0.670***
Potential Evapotranspiration	1.653***	1.650***
Precipitation	-1.794***	-1.763***
Depth to Water	-0.419***	-0.412***
Control Function	-3.322***	-3.003***
LEPA	0.640	0.148
Irrigated Capacity Class	-0.791	-8.466***
Slope	0.715***	-0.201
Available Water Capacity	-144.23***	-197.51***
Saturated Hydro Conductivity	-0.003	-0.121***
Water Right*LEPA	0.031***	0.031***
Incentive*		**Probit Model**
$1(y_{it+1} > \bar{S})y_{it+1}$	0.0006*	0.002***
$1(0 < y_{it+1} \leq \bar{S})$	0.911***	0.506***
$1(y_{it+1} > \bar{S})$	1.624***	1.230***
Water Right	0.0002	-0.001***
Potential Evapotranspiration	0.012***	0.010**
Precipitation	-0.003	-0.017***
Depth to Water	-0.004***	-0.005***
LEPA	0.116	0.293***
Irrigated Capacity Class	-0.018	-0.092***
Slope	-0.004	-.021***
Available Water Capacity	-0.385	-0.517
Saturated Hydro Conductivity	-0.001	-0.002*
Water Right*LEPA	0.002	0.000
Time Fixed Effect	Yes	Yes
GMD Fixed Effect	Yes	Yes
N	97110	97110

*Note: the base category in Incentive equation is $1(y_{it+1} = \bar{S})$

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