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# Does Agriculture Generate Local Economic Spillovers? Short-Run and Long-Run Evidence from the Ogallala Aquifer[†]

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*Agriculture may support the local nonagricultural economy in rural areas, though agricultural expansion may also crowd-out nonagricultural activity. On the United States Plains, areas over the Ogallala aquifer experienced windfall agricultural gains when post-WWII technologies increased farmers' access to groundwater. Comparing counties over the Ogallala with similar counties, nonagricultural sectors experienced only short-run relative benefits. Despite substantial and persistent agricultural gains, there was no long-run relative expansion of nonagricultural sectors in Ogallala counties. Agricultural development may still encourage regional or national nonagricultural development, but agriculture does not appear to generate local economic spillovers that differentially encourage local nonagricultural activity.* (*JEL* Q12, Q15, Q18, Q25, R11)

Many governments subsidize agriculture and, particularly in arid environments, these subsidies often include artificially-low costs of water for agricultural production. Allowing farmers to sell water rights might increase water-use efficiency and compensate farmers (Rosegrant and Binswanger 1994; Thobani 1997; Easter, Rosegrant, and Dinar 1998), though calibrated input-output models are generally consistent with policy concerns that agricultural water-use supports the local nonagricultural economy (Howe, Lazo, and Weber 1990; Howe and Goemans 2003). While agricultural production may support the local economy in rural areas, expansion of the agricultural sector may also crowd-out local nonagricultural production (Foster and Rosenzweig 2004). Economic spillovers from agriculture are central to economic policy (World Bank 2008; United States Department of Agriculture (USDA) 2012), but there are few settings to estimate in detail how exogenous gains in the agricultural sector affect the nonagricultural economy over both the short-run and long-run.

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This paper estimates local economic spillovers from a windfall gain to the agricultural sector, exploiting variation in United States Plains counties' access to the Ogallala aquifer. The Ogallala was formed long ago by runoff from the Rocky Mountains, and its distinct irregular boundary cuts across modern soil groups. The Ogallala was discovered in the 1890s, but its groundwater remained mainly inaccessible for agriculture. After World War II, improved pumps and center pivot irrigation technology made Ogallala groundwater available for large-scale irrigated agriculture. Access to Ogallala groundwater greatly increased counties' agricultural land values and revenues, as agricultural production adapted toward greater water intensity (Hornbeck and Keskin 2014).

Expansion of the agricultural sector could benefit the local nonagricultural economy, though there are two competing channels through which other economic activity may be restricted. First, increased agricultural land values may increase nonagricultural sectors' costs for land and labor. Second, some agricultural practices may create disamenities for the local population and increase labor costs in nonagricultural sectors. For the agricultural sector to benefit local nonagricultural sectors, these negative impacts must be outweighed by productivity spillovers, shared infrastructure, or increased demand for locally traded goods. These competing effects are reflected in a simple Roback-style general equilibrium model.

The empirical specifications compare changes in counties over the Ogallala with changes in counties in the same state, controlling for counties' soil, climate, longitude, and latitude (as in Hornbeck and Keskin 2014). We merge historical county-level data with a United States Geological Survey map of the Ogallala's boundary. Ogallala counties and non-Ogallala counties were generally similar prior to the 1940s, consistent with the identification assumption that Ogallala counties would otherwise have changed similarly to non-Ogallala counties. These empirical specifications estimate local economic impacts in Ogallala counties, relative to changes in non-Ogallala counties, but do not identify potential spillover effects on non-Ogallala counties.

Increased access to Ogallala groundwater generated substantial gains within the local agricultural sector, but the empirical estimates do not indicate positive long-run impacts on the local nonagricultural economy in Ogallala counties. Rural farm population increased in counties over the Ogallala, relative to changes in nearby counties, but Ogallala counties experienced statistically insignificant relative declines in total population. In counties over the Ogallala, there were no detectable long-run relative changes in the manufacturing, wholesale, retail, or service sectors. Ogallala counties had some short-run increases in nonagricultural sales, just as agricultural land values were increasing substantially, but these impacts were short-lived. Historical perspective highlights the absence of sustained long-run gains in these rural areas' nonagricultural economies, relative to nearby counties, from a large windfall gain in the local agricultural sector.

In understanding the mechanisms through which the agricultural sector affects local nonagricultural sectors, any coagglomeration benefits may be small and counterbalanced by increased production costs for nonagricultural sectors. Land values increased in Ogallala counties and, while historical wage data are unavailable, there are some indications of temporarily higher local labor costs. Labor costs may also have increased and nonfarm workers been displaced due to increased consumption disamenities from local agricultural production (e.g., commercial fertilizers, agricultural chemicals, and noxious swine farms).

With the benefit of long-run historical perspective, a large windfall gain in the agricultural sector did not encourage differential expansion of nonagricultural activity in counties over the Ogallala. Our interpretation of the results emphasizes relative impacts on the local economy in Ogallala counties, as the empirical analysis is unable to rule out geographic spillover impacts on non-Ogallala counties. In interpreting the results, guided by the theoretical model, we also consider how the estimated impacts might vary in other contexts, particularly where product markets are less integrated, labor mobility is more restricted, and agricultural production is less mechanized. This historical episode highlights how environmental resources can be of central importance to the local agricultural sector, yet have limited indirect influence on local nonagricultural activity.

## I. Background on the Ogallala Aquifer and Its Impacts on Agriculture

The Ogallala aquifer lies under 174,000 square miles of the Great Plains, making it one of the world's largest underground freshwater sources.[1] The Ogallala was formed long ago by runoff from the Rocky Mountains, such that its boundaries are fixed by the location of ancient valleys and hills. The United States Geological Survey first discovered the Ogallala in the 1890s, but the aquifer initially had limited impacts on agriculture through the use of early pumps, windmills, and older irrigation techniques. Prior to the 1940s, agricultural outcomes were similar in counties over the Ogallala and nearby non-Ogallala counties (Hornbeck and Keskin 2014).

After World War II, improvements in pumping technologies allowed farmers to access Ogallala groundwater cheaply and in large volumes. Groundwater irrigation increased further with the invention of center pivot irrigation. It has been prohibitively costly for farmers in nearby counties to access Ogallala groundwater, however, through pipelines or any system of exchange.[2]

As a consequence, agricultural land values increased substantially in counties over the Ogallala, relative to changes in non-Ogallala counties. Over time, Ogallala counties' land-use adjusted toward water-intensive crops and agricultural revenues increased further (Hornbeck and Keskin 2014).

This paper reproduces earlier "first-stage" estimates, in which the Ogallala impacts the agricultural sector, before turning to the "reduced-form" impacts of the Ogallala on nonagricultural sectors. To interpret the reduced-form estimates as the impact of agricultural expansion on nonagricultural sectors, an important assumption is that the Ogallala does not directly impact nonagricultural sectors. While agriculture accounts for the majority of Ogallala groundwater extraction, Ogallala groundwater may also be used for nonagricultural purposes. To the extent

[1] Our discussion of the Ogallala aquifer, and its estimated impacts on agriculture, draws heavily from our related research (Hornbeck and Keskin 2014) that also provides more detailed historical background and references.

[2] Most areas over the Ogallala retain sufficient groundwater to supply irrigation pumps; as water levels decline, however, small sections of the Ogallala have become unavailable for large-scale irrigation.

that Ogallala groundwater directly benefits nonagricultural sectors, the empirical analysis would overstate positive impacts of the agricultural sector on the local nonagricultural economy.

## II. A Model of Cross-Sector Spillover Impacts

To explore the impacts on nonagricultural sectors from a windfall gain in the agricultural sector, we outline a basic two-sector Roback-style model (Roback 1982).[3] Sectors affect each other through shared factor markets. The agricultural sector may also create consumption disamenities for the local population (e.g., through agricultural chemicals) or production amenities for the local nonagricultural sector (e.g., through shared infrastructure). In a later section, we consider how the predictions vary in alternative contexts, such as if some goods are traded locally or if labor mobility is restricted.

### A. *Two-Sector Model with Internationally Traded Goods and Labor Mobility*

We allow for two production sectors: agriculture and industry. In each sector, firms use labor $L$, capital $K$, and land $T$ to produce an internationally traded good whose price is fixed and is normalized to one. Firms in each county $c$ and sector $s$ maximize:

$$\max_{L,K,T} f^s(A_c^s, L, K, T) \; - \; w_c L \; - \; r_c K \; - \; q_c T,$$

where $w_c$, $r_c$, and $q_c$ are input prices in each county. Sector-specific productivity $(A_c^s)$ is influenced by whether county $c$ can access groundwater from the Ogallala aquifer.

The supply of land is fixed in each location. Labor is supplied by workers who live in each location. Workers' indirect utility depends on wages and the cost of housing, which is increasing in the price of land. We assume that workers are fully mobile across locations and sectors. Capital is internationally traded, so its price is fixed across counties.

When counties over the Ogallala aquifer become able to access its groundwater, agricultural productivity increases. The demand for farmland increases over the Ogallala, and, if the demand for industrial land is inelastic, Ogallala counties' land price can increase substantially with little increase in total farmland. Increased land prices raise the cost of housing, such that workers must receive higher wages to remain in the county. Industrial firms' cost of land and labor both increase, so industrial output and the industrial workforce decline.

Predicted changes in population depend on assumptions about the production function. As access to Ogallala groundwater was associated with an increased

[3] This model is similar to the framework outlined by Foster and Rosenzweig (2004), though we allow for perfect labor mobility in focusing on the United States rather than India. This model captures a similar theoretical tradeoff as that between increased agglomeration spillovers within manufacturing and increased competition for local inputs following the opening of a large manufacturing plant (Greenstone, Hornbeck, and Moretti 2010).

intensity of agricultural production (Hornbeck and Keskin 2014), we assume that access to the Ogallala increases agricultural labor demand. As a consequence, Ogallala access is predicted to increase counties' rural farm population. The predicted change in total population depends on how much agricultural labor demand increases, compared to how much higher land prices and wages decrease demand for labor in the industrial sector.

In the absence of any consumption disamenities or production amenities, the model predicts increases in housing costs and wages. Workers' indirect utility may be decreasing in local agricultural output, however, reflecting increased exposure to agricultural chemicals, fertilizers, and noxious swine farms. In this case, wages increase further to compensate workers and housing costs increase by less (or may even decline). The local industrial sector continues to face higher input costs, so there continues to be a decline in industrial output and the industrial workforce.

Agricultural production may also create production amenities for the industrial sector, similar to agglomeration spillovers observed within the industrial sector (Ellison, Glaeser, and Kerr 2010; Greenstone, Hornbeck, and Moretti 2010). Expansion of the agricultural sector may improve local infrastructure that is also productive for nonagricultural sectors, or there may be direct productivity spillovers among local firms across sectors. If industrial productivity is increasing in local agricultural output, regardless of the mechanism, then the industrial sector may also expand despite higher input costs. Higher labor demand and higher wages attract workers into the county until land prices and housing costs increase sufficiently to establish equilibrium.

Combining the changes in input costs, consumption disamenities, and production amenities, the competing effects on the industrial sector can be summarized by considering changes in the initial level of profits for incumbent industrial firms. We consider the "short-run" change in industrial firms' profits after a county gains access to the Ogallala, the agricultural sector expands, and population adjusts, but before changes in the size of the industrial sector.[4] If firms are price takers and all factors are paid their marginal product in equilibrium, the total derivative of an industrial firm's short-run profits with respect to a change in access to the Ogallala is:

$$(1) \qquad \frac{d\Pi^*}{dO} = \left(\frac{\partial f}{\partial A} \times \frac{\partial A}{\partial O}\right) - \frac{\partial w}{\partial O} L^* - \frac{\partial q}{\partial O} T^*.$$

Equation (1) makes clear that industrial firms are affected through three channels. The first term increases industrial firm profits and encourages expansion, if access to the Ogallala causes the agricultural sector to create production amenities for the industrial sector. The second term decreases industrial firm profits and encourages contraction, if access to the Ogallala increases local wages through higher housing costs for workers and/or increased consumption disamenities. The third term also

[4] We write the "short-run" level of industrial firm profits, $\Pi^*$, as: $\Pi^* = f^I[A^I(O), L^*(w(O), r, q(O)), K^*(w(O), r, q(O)), T^*(w(O), r, q(O))] - w(O)L^*(w(O), r, q(O)) - rK^*(w(O), r, q(O)) - q(O)T^*(w(O), r, q(O))$, where productivity, wages, and land prices depend on the agricultural sector's access to the Ogallala. Each sector's optimal level of labor inputs $(L^{s*}(w, r, q))$, capital inputs $(K^{s*}(w, r, q))$ and land inputs $(T^{s*}(w, r, q))$ reflect the county's wage, the national cost of capital, and the county's land price.

decreases industrial firm profits and encourages contraction, if access to the Ogallala increases local land prices through increased demand for agricultural land.

As access to Ogallala groundwater leads to expansion of the agricultural sector, there are three main empirical predictions. First, nonagricultural sectors contract over the Ogallala, unless production amenities compensate for higher costs of land and labor. Second, local wages increase over the Ogallala, despite perfect labor mobility, due to consumption disamenities from the agricultural sector or higher housing costs. Third, housing costs may decrease or increase, depending on the relative magnitude of consumption disamenities and competition for land from the agricultural sector.

## B. *Variation in Predictions across Contexts*

In the above model, the predictions depend on assumptions chosen to reflect the United States Plains in the mid-twentieth century. In particular, we assumed that agricultural goods are exported internationally, such that agricultural expansion over the Ogallala does not impact local prices of agricultural goods. Further, we assumed that labor is fully mobile, such that increased agricultural labor demand does not itself bid up local wages. In this section, we consider how the theoretical predictions change under alternative assumptions that might be more appropriate in other contexts.

*Locally Traded Goods*.—As market integration declines and goods are traded more locally, expansion of the agricultural sector generally has a more positive impact on the local industrial sector. Further, increased access to Ogallala groundwater may then generate geographic spillover impacts on nearby non-Ogallala counties.

If some portion of agricultural goods are consumed locally, then agricultural expansion over the Ogallala decreases agricultural prices in Ogallala counties. Decreased agricultural prices could encourage the expansion of local industry through three channels. First, if the industrial sector uses inputs supplied by the local agricultural sector, then lower input prices encourage industrial expansion. Second, if workers directly consume local agricultural products, then industrial firms can pay workers lower wages. Third, lower agricultural prices mute increases in the price of land.

If agricultural markets are regional, then nearby non-Ogallala counties may also be affected by increased access to Ogallala groundwater. Agricultural expansion over the Ogallala decreases agricultural prices in nearby non-Ogallala counties, lowering agricultural land values in non-Ogallala counties. Decreased land values attract workers and industrial firms to these areas.

If some portion of industrial goods are consumed locally, then expansion of the agricultural sector may increase demand for the local industrial sector. In particular, if the agricultural sector uses inputs supplied by the local industrial sector, then increased demand from the agricultural sector will encourage expansion of the industrial sector. This increase in local demand can be represented, in a reduced-form way, by a greater impact of the agricultural sector on production amenities in the industrial sector. Further, local customer-supplier relationships may increase productivity or lower transaction costs if some outputs of the industrial sector are intermediate inputs for the agricultural sector and vice versa.

*Restricted Labor Mobility.*—As labor mobility declines, expansion of the agricultural sector generally has a more negative impact on local nonagricultural sectors through increased local wages. Foster and Rosenzweig (2004) develop a similar model for the Indian context, in which greater labor demand from the agricultural sector increases competition for local workers and increases labor costs for nonagricultural sectors.

Further, as labor mobility declines, nearby non-Ogallala counties may also be impacted by agricultural expansion over the Ogallala. If migration costs increase with geographic distance, then workers may be disproportionately drawn from or displaced to nearby non-Ogallala areas. In addition, if workers are able to work in Ogallala areas and live in nearby non-Ogallala areas, thereby avoiding some portion of the agricultural sector's consumption disamenities, then there will be additional geographic spillover effects on nearby non-Ogallala areas.

## III. Data Construction and County Differences by Ogallala Share

Historical county-level data are drawn from the United States Censuses of Agriculture and Population (Gutmann 2005; Haines 2005).[5] The main variables of interest include: irrigated acres and total acres of farmland; value of agricultural land and revenue; total population and rural farm, rural nonfarm, and urban population; the number of establishments and total sales in the manufacturing, wholesale, retail, and service sectors; retail sales per capita; manufacturing payroll per worker; median dwelling value; and median dwelling rent. The empirical analysis uses a balanced panel of Plains counties, from 1920 to 2002, for which data are available in every period of analysis. We adjust county-level data in later periods to maintain 1920 county definitions (Hornbeck 2010).

Figure 1 maps the Ogallala aquifer, overlaid with county borders in 1920. The sample is restricted to counties within 100 kilometers of the aquifer boundary. The shaded area represents the United States Geological Survey (USGS) original boundary of the aquifer, prior to intensive use for agriculture. Changes in water levels are potentially endogenous to agricultural activity, so the empirical analysis assigns groundwater availability using USGS predevelopment Ogallala boundaries.

The empirical research design exploits the sharp spatial variation in counties' access to Ogallala groundwater, comparing changes in counties over the Ogallala with changes in similar counties. To focus on comparisons among "similar counties," as in Hornbeck and Keskin (2014), the empirical specifications control for average differences by state, soil, climate, longitude, and latitude.[6]

[5] We thank Haines and collaborators for providing additional data.

[6] State fixed effects capture differences in region, state agricultural extension services, and other state-level policies. Soil group fixed effects proxy for detailed regional determinants of agricultural production: for example, "Alluvial Soils" occur along major rivers and predict higher irrigation in 1935 and "Sand and Silt" in North-Central Nebraska is unproductive for agriculture. The Ogallala boundary cuts across major soil groups; importantly, as

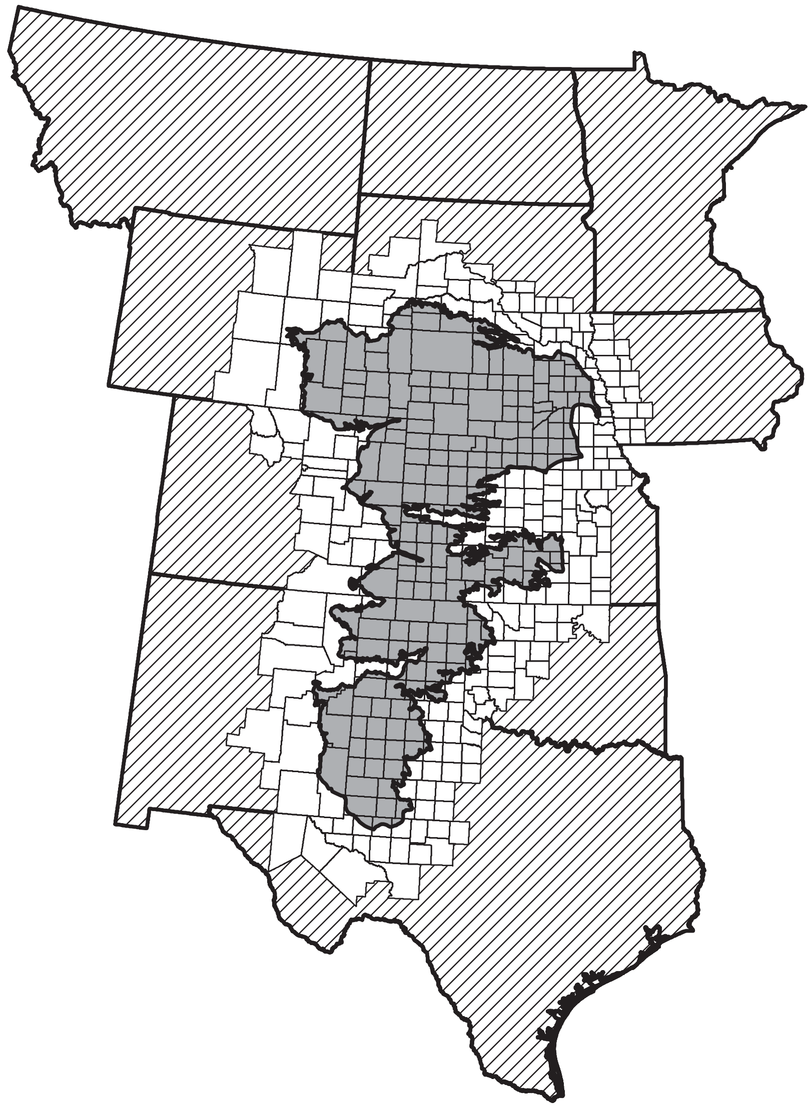

FIGURE 1. OGALLALA REGION AND COUNTIES WITHIN 100 KM

*Notes:* The shaded area represents the original boundary of the Ogallala Aquifer, as mapped by the United States Geological Survey. This map is overlaid with county borders, as defined in 1920, for all counties within 100 km of the Ogallala boundary.

Table 1 reports differences between Ogallala and non-Ogallala counties in 1940, prior to the widespread availability of Ogallala groundwater for irrigation. For the outcome variables of interest, there are some unconditional differences between

the analysis effectively compares Ogallala and non-Ogallala counties within the same soil group. We also include controls for each county's soil suitability for corn and wheat, average precipitation and temperature, average degree days between 10°C and 29°C and degree days above 29°C, and centroid longitude and latitude. Because non-Ogallala counties surround the Ogallala region, there is variation in Ogallala access within similar climate, longitude, and latitude.

Table 1—Average County Characteristics in 1940 and Differences by Ogallala Share

| | | Coefficient on Ogallala share: | | | |
|---|---|---|---|---|---|
| Per county acre: | County mean (1) | No controls (2) | State fixed effects (3) | State and soil group (4) | State, soil, climate, X/Y (5) |
| *Panel A. Agriculture (per county acre)* | | | | | |
| Farmland | 0.851 | 0.118** | 0.046* | 0.005 | −0.019 |
| | (0.174) | (0.025) | (0.023) | (0.026) | (0.027) |
| Irrigated farmland | 0.007 | −0.001 | −0.001 | −0.003 | −0.002 |
| | (0.020) | (0.002) | (0.002) | (0.003) | (0.004) |
| log value of farmland and farm buildings | 2.26 | 0.343* | −0.164 | −0.107 | 0.006 |
| | (1.05) | (0.150) | (0.122) | (0.088) | (0.107) |
| log value of farm revenue | 0.668 | 0.214 | −0.170 | −0.129 | −0.103 |
| | (0.958) | (0.132) | (0.134) | (0.096) | (0.118) |
| log value of farm revenue per farm population | 6.20 | −0.092 | −0.121 | −0.003 | −0.252* |
| | (0.637) | (0.109) | (0.103) | (0.090) | (0.113) |
| *Panel B. Population* | | | | | |
| Total population | 14,318 | −7,763** | −8,505** | −5,197* | −7,364* |
| | (15,960) | (1,674) | (2,227) | (2,481) | (3,098) |
| Rural farm population | 5,136 | −1,118* | −1,498** | −1,409* | −1,501 |
| | (4,081) | (510) | (471) | (636) | (936) |
| Rural nonfarm population | 3,863 | −1,712** | −1,617** | −669 | −1,391 |
| | (3,109) | (405) | (418) | (544) | (751) |
| Urban population | 5,319 | −4,933** | −5,390** | −3,119 | −4,472* |
| | (12,134) | (1,186) | (1,799) | (1,870) | (2,170) |
| *Panel C. Nonagricultural sector establishments and output* | | | | | |
| log manufacturing establishments | 1.95 | −0.629** | −0.654** | −0.375 | −0.604* |
| | (1.09) | (0.163) | (0.184) | (0.226) | (0.266) |
| log manufacturing value added | 12.42 | −1.124** | −0.915* | −0.403 | −0.967 |
| | (1.69) | (0.335) | (0.360) | (0.478) | (0.495) |
| log wholesale establishments | 3.13 | −0.150 | −0.199 | −0.050 | −0.152 |
| | (0.937) | (0.130) | (0.137) | (0.156) | (0.178) |
| log wholesale sales | 13.98 | −0.371* | −0.300 | −0.047 | −0.099 |
| | (1.30) | (0.184) | (0.200) | (0.238) | (0.285) |
| log retail establishments | 5.02 | −0.555** | −0.547** | −0.309* | −0.327 |
| | (0.863) | (0.112) | (0.116) | (0.139) | (0.176) |
| log retail sales | 14.7 | −0.601** | −0.540** | −0.243 | −0.311 |
| | (1.10) | (0.147) | (0.150) | (0.181) | (0.229) |
| log service establishments | 3.91 | −0.412** | −0.495** | −0.253 | −0.230 |
| | (0.924) | (0.124) | (0.135) | (0.155) | (0.202) |
| log service receipts | 11.65 | −0.600** | −0.614** | −0.376 | −0.392 |
| | (1.24) | (0.168) | (0.186) | (0.215) | (0.277) |

(*Continued*)

Ogallala and non-Ogallala counties (column 2). For specifications that include control variables, however, there are fewer statistically significant differences by county Ogallala share (columns 3–5). When data are available for these outcome variables prior to 1940, subsequent tables generally report small differential prechanges by county Ogallala share. These estimates are consistent with the identification assumption that Ogallala counties would have changed similarly to non-Ogallala counties, if not for increased access to Ogallala groundwater.

TABLE 1—AVERAGE COUNTY CHARACTERISTICS IN 1940 AND DIFFERENCES BY OGALLALA SHARE (*Continued*)

| | | Coefficient on Ogallala share: | | | |
|---|---|---|---|---|---|
| Per county acre: | County mean (1) | No controls (2) | State fixed effects (3) | State and soil group (4) | State, soil, climate, X/Y (5) |
| *Panel D. Housing costs and income proxies* | | | | | |
| log median swelling value (owner-occupied) | 7.14 | 0.170 | 0.044 | 0.021 | −0.054 |
| | (0.535) | (0.087) | (0.087) | (0.090) | (0.102) |
| log median dwelling rent (renter-occupied) | 2.45 | 0.029 | 0.090 | 0.059 | −0.025 |
| | (0.331) | (0.050) | (0.052) | (0.060) | (0.065) |
| log retail sales per capita | 5.52 | −0.094 | −0.051 | 0.052 | 0.013 |
| | (0.441) | (0.064) | (0.062) | (0.077) | (0.094) |
| log manufacturing payroll per worker | 7.12 | −0.079 | −0.105* | −0.048 | −0.119* |
| | (0.20) | (0.044) | (0.047) | (0.049) | (0.056) |

*Notes:* Column 1 reports average county characteristics in 1940, except for irrigated farmland acres and log manufacturing payroll per worker for which data are first available in 1935 and 1930 respectively. County averages are weighted by county acres, and standard deviations are reported in parentheses. Columns 2 through 5 report estimates from regressing each outcome on the fraction of county area over the Ogallala. Column 2 reports the unconditional difference. Column 3 controls for state fixed effects. Column 4 also controls for the fraction of county area in each soil group. Column 5 also controls for linear functions of county soil suitability for corn and wheat, average precipitation, average temperature, average degree days between 10°C and 29°C, average degree days above 29°C, longitude, and latitude. The regressions are weighted by county acres, and robust standard errors are reported in parentheses.

**Significant at the 1 percent level.

*Significant at the 5 percent level.

## IV. Empirical Framework

For the initial empirical specifications, following Hornbeck and Keskin (2014), outcome $Y$ in county $c$ is regressed on the fraction of county area over the Ogallala, state fixed effects $\alpha_s$, the fraction of county area in each soil group $\gamma_g$, and linear functions of eight county characteristics $\mathbf{X}_c$ (soil suitability for corn and wheat, average precipitation and temperature, degree days between 10°C and 29°C, degree days above 29°C, longitude, and latitude). Each coefficient is allowed to vary in each time period, effectively pooling the cross-sectional specifications across all time periods:

$$Y_{ct} = \beta_t Ogallala_c + \alpha_{st} + \gamma_{gt} + \theta_t \mathbf{X}_c + \epsilon_{ct}. \tag{2}$$

Each estimated $\beta$ reports the average difference in that year between counties entirely over the Ogallala and counties entirely not over the Ogallala. The analysis weights the regressions by county size, thereby reporting the impact of the Ogallala on the average acre of land.

The estimated $\beta$s reflect the impact of the Ogallala in each year, given the identification assumption that sample counties would average the same outcomes in the absence of the Ogallala. In practice, this identification assumption must hold after controlling for other differences correlated with soil, climate, and geography. In this sense, identification exploits the spatial variation created by the Ogallala's irregular boundary.

The change in $\beta$s, from one year to another, reflects the changing impact of the Ogallala, given the weaker identification assumption that sample counties would average the same changes in the absence of the Ogallala. Equation (2) is modified to report directly the estimated changes in county-level outcomes, relative to 1940:

$$Y_{ct} - Y_{c1940} = \beta_t Ogallala_c + \alpha_{st} + \gamma_{gt} + \theta_t \mathbf{X}_c + \epsilon_{ct}. \tag{3}$$

The estimated coefficients report relative changes for counties over the Ogallala, compared to any differences in 1940. For the statistical inference, standard errors are clustered at the county level to adjust for heteroskedasticity and within-county correlation over time. The geographical contiguity of the data raises a natural question about whether county observations are independent, though county-level changes exhibit little spatial correlation. Indeed, when allowing for spatial correlation in county-level changes, the estimated standard errors are similar.[7]

## V. Results

### A. *Estimated Impacts on the Agricultural Sector*

Table 2 reports estimated direct impacts of the Ogallala on the agricultural sector. From estimating equation (2), columns 1–5 report year-specific cross-sectional differences by Ogallala share in: acres of irrigated farmland per county acre, acres of total farmland per county acre, the log value of agricultural land and buildings, the log value of agricultural revenue, and the log value of agricultural revenue per person living on a farm.

In 1935, irrigation was a statistically insignificant 0.2 percentage points lower in Ogallala counties than in non-Ogallala counties (column 1). By 1950, irrigation was 1.4 percentage points higher in Ogallala counties than in non-Ogallala counties. As groundwater irrigation technology improved and agricultural production adjusted, this difference increased to 12.1 percentage points by 1978. Ogallala counties maintained substantially higher irrigation levels through 1997.

The fraction of county land in farms was similar in Ogallala and non-Ogallala counties through the 1950s, though higher in some periods (column 2). Since the 1960s, the fraction of county land in farms has been consistently higher by 4 to 5 percentage points in Ogallala counties.

The value of agricultural land and buildings became consistently higher in counties over the Ogallala in the 1950s (column 3), after the introduction of improved pumping and irrigation technologies. The land value premium rose to 36 percent in 1950 (0.309 log points), peaked at 58 percent in 1964 (0.459 log points), and has since declined to 23 percent in 2002 (0.207 log points).

[7] Spatial correlation among counties is assumed to be declining linearly up to a distance cutoff and zero after that cutoff (Conley 1999). For distance cutoffs of 100 kilometers (km) or 200 km, the estimated Conley standard errors are similar to the standard errors when clustering at the county level. Consistent with these estimates, maps of county-level residual changes show little spatial correlation.

Table 2—Estimated Differences in Agricultural Outcomes, by Ogallala Share and Year

| In year: | Irrigated farmland per county acre (1) | Farmland acres per county acre (2) | log value per county acre (3) | log revenue per county acre (4) | log revenue per farm pop (5) |
|---|---|---|---|---|---|
| 1920 | | −0.032 | −0.028 | 0.093 | |
| | | (0.039) | (0.132) | (0.130) | |
| 1925 | | −0.053 | 0.021 | 0.188 | |
| | | (0.036) | (0.120) | (0.138) | |
| 1930 | | 0.004 | 0.277* | 0.234* | −0.009 |
| | | (0.030) | (0.113) | (0.113) | (0.106) |
| 1935 | −0.002 | 0.031 | 0.191 | | |
| | (0.004) | (0.026) | (0.101) | | |
| 1940 | | −0.019 | 0.006 | −0.103 | −0.250* |
| | | (0.027) | (0.107) | (0.118) | (0.114) |
| 1945 | | 0.014 | 0.160 | 0.418** | |
| | | (0.028) | (0.097) | (0.115) | |
| 1950 | 0.014 | −0.016 | 0.309** | 0.511** | 0.267** |
| | (0.007) | (0.026) | (0.089) | (0.119) | (0.086) |
| 1954 | 0.027** | 0.007 | 0.381** | 0.450** | |
| | (0.008) | (0.031) | (0.095) | (0.132) | |
| 1959 | 0.051** | −0.026 | 0.383** | 0.567** | 0.228** |
| | (0.010) | (0.030) | (0.097) | (0.126) | (0.074) |
| 1964 | 0.063** | 0.006 | 0.459** | 0.557** | |
| | (0.010) | (0.026) | (0.090) | (0.140) | |
| 1969 | 0.082** | 0.027 | 0.453** | 0.698** | 0.257* |
| | (0.010) | (0.025) | (0.081) | (0.138) | (0.099) |
| 1974 | 0.102** | 0.034 | 0.450** | 1.003** | |
| | (0.012) | (0.023) | (0.078) | (0.147) | |
| 1978 | 0.121** | 0.041 | 0.276** | 0.946** | |
| | (0.014) | (0.022) | (0.081) | (0.144) | |
| 1982 | 0.112** | 0.053* | 0.280** | 1.068** | 0.659** |
| | (0.014) | (0.022) | (0.079) | (0.146) | (0.127) |
| 1987 | 0.101** | 0.052* | 0.218** | 1.021** | |
| | (0.013) | (0.022) | (0.077) | (0.146) | |
| 1992 | 0.114** | 0.039 | 0.267** | 1.154** | |
| | (0.014) | (0.024) | (0.082) | (0.166) | |
| 1997 | 0.126** | 0.045 | 0.305** | 1.292** | |
| | (0.015) | (0.025) | (0.077) | (0.170) | |
| 2002 | | 0.037 | 0.207* | 1.384** | |
| | | (0.023) | (0.092) | (0.172) | |
| Sample counties | 368 | 368 | 368 | 368 | 367 |

*Notes:* Each column reports estimates from equation (2): the indicated outcome variable is regressed on the share of county area over the Ogallala, state fixed effects, the fraction of county area in each soil group, and linear functions of county soil suitability for corn and wheat, average precipitation and temperature, average degree days between 10°C and 29°C and above 29°C, longitude, and latitude. All coefficients are allowed to vary in each year. The regressions are weighted by county acres, and robust standard errors clustered by county are reported in parentheses.

**Significant at the 1 percent level.

*Significant at the 5 percent level.

Agricultural revenues have been higher over the Ogallala since the late 1940s (column 4), increasing further in the 1970s as agriculture shifted toward greater corn acreages over the Ogallala (Hornbeck and Keskin 2014).[8] There were increases in

[8] The impact on revenues has increased in recent periods, as land values have declined, suggesting that the marginal return to water remains high and decreased land values reflect market expectations of groundwater exhaustion.

Table 3—Estimated Changes in Population by Ogallala Share, Relative to 1940

| | | Population: | | | |
|---|---|---|---|---|---|
| Relative to 1940: | log population (1) | Total (2) | Rural farm (3) | Rural nonfarm (4) | Urban (5) |
| 1920 | −0.084 | −23 | | | 870 |
| | (0.077) | (1,049) | | | (698) |
| 1930 | −0.006 | −296 | 12 | −454* | 146 |
| | (0.050) | (556) | (252) | (224) | (378) |
| 1940 | 0 | 0 | 0 | 0 | 0 |
| 1950 | 0.090* | −440 | 600** | 291 | −1,330 |
| | (0.044) | (1,229) | (190) | (342) | (1,059) |
| 1960 | 0.057 | −3,913 | 1,183** | −277 | −4,819 |
| | (0.076) | (3,865) | (387) | (833) | (3,247) |
| 1970 | 0.037 | −7,907 | 1,399* | −183 | −9,122 |
| | (0.095) | (6,702) | (545) | (788) | (6,297) |
| 1980 | −0.005 | −12,194 | 1,367* | −821 | −12,741 |
| | (0.107) | (9,258) | (629) | (987) | (9,041) |
| 1990 | −0.085 | −18,093 | | | |
| | (0.128) | (13,021) | | | |
| 2000 | −0.140 | −26,432 | | | |
| | (0.139) | (16,730) | | | |
| Sample counties | 368 | 368 | 368 | 368 | 368 |

*Notes:* Each column reports estimates from equation (3): the change in the indicated outcome variable, relative to 1940, is regressed on the share of county area over the Ogallala, state fixed effects, the fraction of county area in each soil group, and linear functions of county soil suitability for corn and wheat, average precipitation and temperature, average degree days between 10°C and 29°C and above 29°C, longitude, and latitude. All coefficients are allowed to vary in each year. The regressions are weighted by county acres, and robust standard errors clustered by county are reported in parentheses.

**Significant at the 1 percent level.

*Significant at the 5 percent level.

agricultural revenue per person living on a farm, as agricultural production expanded with relatively smaller increases in agricultural workers.

Subsequent specifications estimate changes in counties' nonagricultural outcomes, relative to 1940, as the Ogallala began to have a consistent direct impact on the agricultural sector over the 1940s.

### B. *Estimated Impacts on Population*

Table 3 reports estimated impacts of the Ogallala on relative changes in population, from estimating equation (3). As the Ogallala became used for widespread irrigation through the 1950s and 1960s, total population was relatively unchanged in logs (column 1) and levels (column 2). There was some long-run decline in total population, but this decline is not statistically significant at the 5 percent level.

Estimating the change in population by category, Ogallala counties experienced moderate detectable relative increases in rural farm population (column 3). By contrast, there were some statistically insignificant long-run declines in rural nonfarm population (column 4) and urban population (column 5).

Figure 2 summarizes the estimated trends in agriculture and population. Panel A graphs the substantial increase in agricultural land values, panel B graphs the

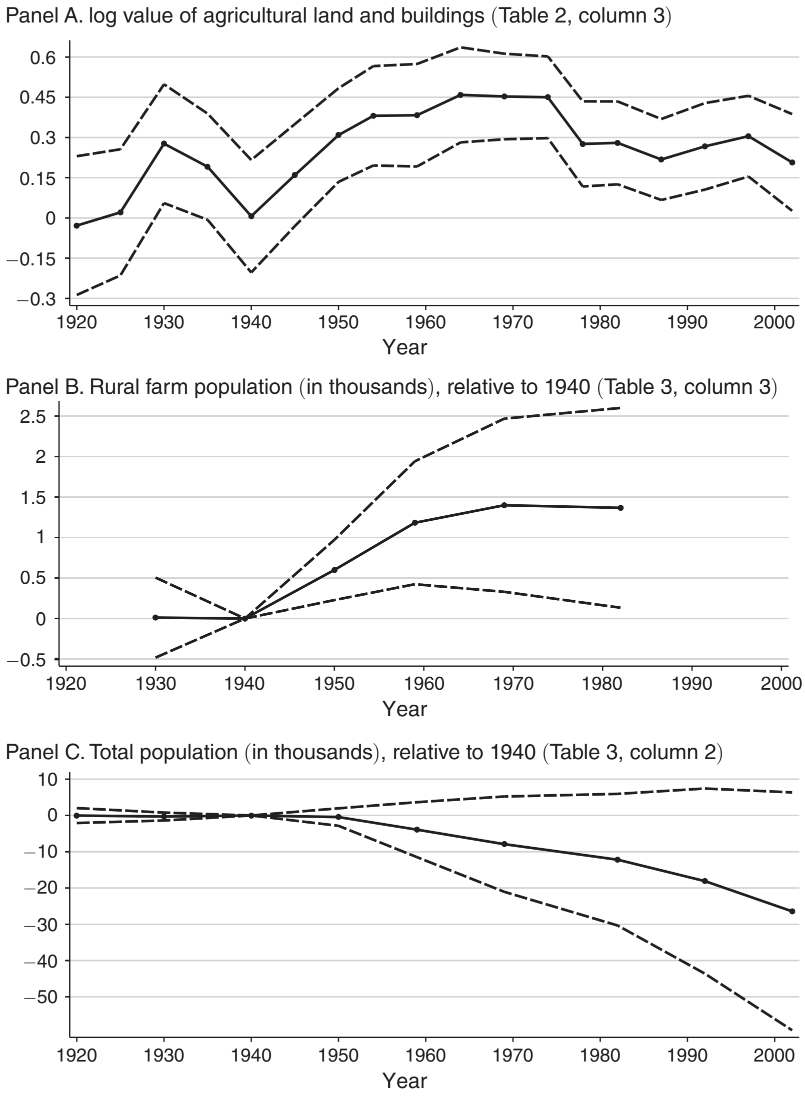


Figure 2. Estimated Impacts of the Ogallala on Agriculture and Population

*Notes:* Panel A reports estimated differences in Ogallala counties in each year, relative to non-Ogallala counties, from estimating equation (2). Panels B and C report estimated changes in Ogallala counties, relative to 1940 and relative to non-Ogallala counties, from estimating equation (3). Dashed lines reflect 95 percent confidence intervals.

moderate increase in rural farm population, and panel C graphs the decline in total population. These estimates, along with the estimates below, are not driven by changes in very populated or sparsely-settled counties.[9]

[9] The estimates are similar when restricting the sample to 332 counties with total population in 1940 within the fifth and ninety-fifth percentiles.

Table 4—Estimated Changes in Nonagricultural Sectors by Ogallala Share, Relative to 1940

| | log manufacturing | | log wholesale | | log retail | | log service | |
|---|---|---|---|---|---|---|---|---|
| Relative to 1940: | Establishments (1) | Value added (2) | Establishments (3) | Sales (4) | Establishments (5) | Sales (6) | Establishments (7) | Receipts (8) |
| 1920 | 0.009 | | | | | | | |
| | (0.185) | | | | | | | |
| 1930 | −0.154 | | | | | | | |
| | (0.139) | | | | | | | |
| 1940 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1950 | 0.029 | 0.486 | 0.101 | 0.547** | 0.031 | 0.231** | 0.021 | 0.199** |
| | (0.098) | (0.273) | (0.068) | (0.134) | (0.036) | (0.051) | (0.065) | (0.075) |
| 1959 | 0.003 | 0.412 | 0.024 | −0.000 | 0.071 | 0.271** | −0.081 | −0.095 |
| | (0.131) | (0.300) | (0.090) | (0.180) | (0.054) | (0.076) | (0.082) | (0.124) |
| 1969 | 0.214 | 0.519 | −0.059 | 0.175 | 0.074 | 0.273** | 0.001 | −0.097 |
| | (0.168) | (0.410) | (0.101) | (0.195) | (0.065) | (0.104) | (0.086) | (0.124) |
| 1978 | 0.143 | 0.534 | 0.165 | 0.260 | −0.015 | 0.017 | −0.083 | −0.068 |
| | (0.185) | (0.473) | (0.135) | (0.267) | (0.085) | (0.127) | (0.106) | (0.170) |
| 1987 | 0.167 | 0.645 | −0.075 | −0.092 | −0.074 | −0.154 | −0.258 | −0.308 |
| | (0.218) | (0.569) | (0.150) | (0.280) | (0.103) | (0.151) | (0.160) | (0.192) |
| 1997 | | | −0.090 | −0.131 | −0.131 | −0.222 | | |
| | | | (0.178) | (0.252) | (0.132) | (0.173) | | |
| Sample counties | 200 | 149 | 352 | 231 | 367 | 333 | 359 | 340 |

*Notes:* Each column reports estimates from equation (3): the change in the indicated outcome variable, relative to 1940, is regressed on the share of county area over the Ogallala, state fixed effects, the fraction of county area in each soil group, and linear functions of county soil suitability for corn and wheat, average precipitation and temperature, average degree days between 10°C and 29°C and above 29°C, longitude, and latitude. All coefficients are allowed to vary in each year. The regressions are weighted by county acres, and robust standard errors clustered by county are reported in parentheses.

**Significant at the 1 percent level.

*Significant at the 5 percent level.

## C. *Estimated Impacts on Nonagricultural Sectors*

Table 4 reports estimated impacts of the Ogallala on relative changes in four nonagricultural sectors: manufacturing, wholesale, retail, and services. After the Ogallala became available for agricultural production, counties over the Ogallala experienced little detectable long-run expansion of nonagricultural sectors.[10] There were some substantial and statistically significant short-run increases in nonagricultural sector sales (columns 2, 4, 6, 8), but little change in the number of nonagricultural sector establishments (columns 1, 3, 5, 7). Figure 3 displays the estimated changes in nonagricultural sector sales.

Estimated short-run increases in sales coincide with the large increase in agricultural land values, but were not sustained as agricultural production expanded into the 1970s. One potential interpretation is that booming land values induced a temporary burst of sales associated with land transactions or increased wealth.

Substantial and persistent gains in the agricultural sector do not appear to have induced long-run growth of the local nonagricultural economy. There may be important short-run and long-run spillover effects on particular nonagricultural firms that

[10] The sample of counties varies across outcomes because data by sector are missing for some counties in some years.

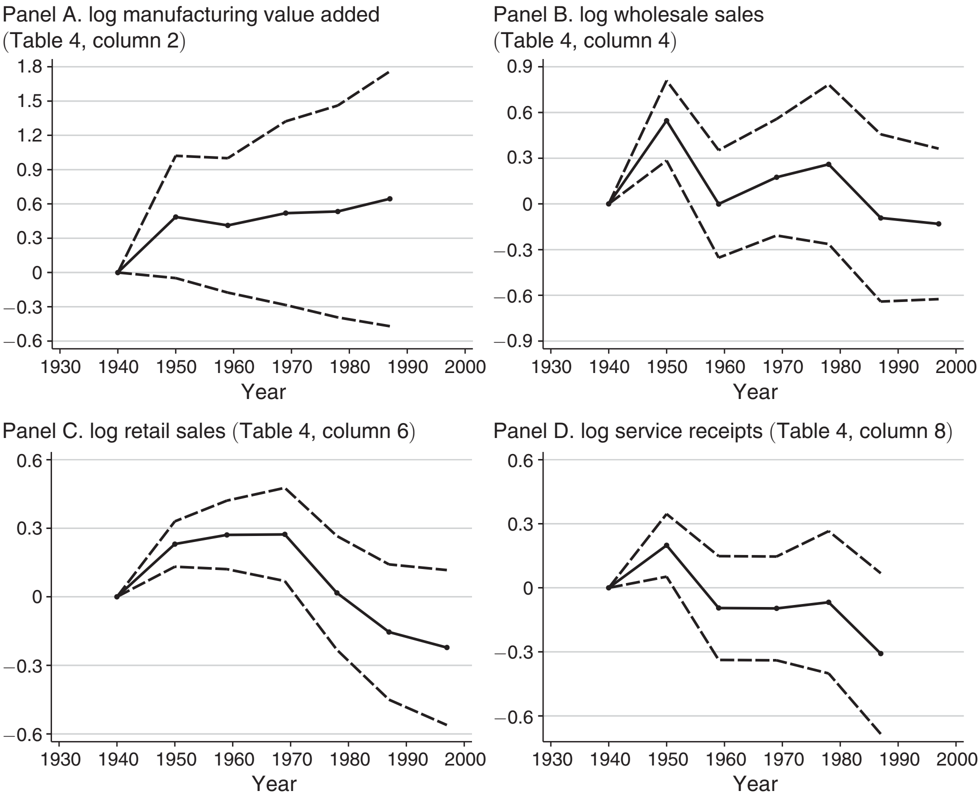


Figure 3. Estimated Impacts of the Ogallala on Nonagricultural Sector Sales

*Notes:* Relative to the omitted year of 1940, each panel reports estimated changes in Ogallala counties compared to changes in non-Ogallala counties (from estimating equation (3) in the text). The dashed lines reflect 95 percent confidence intervals around the estimated coefficients (reported in Table 4).

specialize in agricultural machinery, sales, and services, but these detailed historical data are unavailable.

### D. *Estimated Impacts on Housing Costs and Income Proxies*

To help understand the mechanisms through which the agricultural sector affects nonagricultural sectors, Table 5 reports estimated impacts of the Ogallala on available proxies for housing costs and labor costs. As agricultural land values increased from 1940 to 1950, there were moderate but statistically insignificant increases in median dwelling values (column 1) and median dwelling rents (column 2).[11] Despite substantially higher agricultural land values, housing costs may have been kept from rising further by increased consumption disamenities associated with agricultural production. Appendix Table 1 reports higher usage among Ogallala

[11] Historical data are unavailable to control for house characteristics, however, which limits the estimates' statistical precision.

Table 5—Estimated Changes in Housing Costs and Income Proxies, Relative to 1940

| Relative to 1940: | log median dwelling value (owner occupied) (1) | log median dwelling rent (renter occupied) (2) | log retail sales per capita (3) | log manufacturing payroll per worker (4) |
|---|---|---|---|---|
| 1940 | 0 | 0 | 0 | 0 |
| 1950 | 0.064 | 0.104 | 0.112* | 0.059 |
| | (0.066) | (0.061) | (0.053) | (0.094) |
| 1959 | 0.051 | −0.019 | 0.199** | 0.121 |
| | (0.082) | (0.067) | (0.059) | (0.101) |
| 1969 | 0.051 | −0.025 | 0.243** | −0.023 |
| | (0.086) | (0.069) | (0.064) | (0.107) |
| 1982 | −0.014 | −0.043 | −0.021 | |
| | (0.100) | (0.068) | (0.087) | |
| 1992 | −0.026 | −0.008 | −0.073 | |
| | (0.101) | (0.065) | (0.081) | |
| Sample counties | 343 | 298 | 357 | 174 |

*Notes:* Each column reports estimates from equation (3): the change in the indicated outcome variable, relative to 1940, is regressed on the share of county area over the Ogallala, state fixed effects, the fraction of county area in each soil group, and linear functions of county soil suitability for corn and wheat, average precipitation and temperature, average degree days between 10°C and 29°C and above 29°C, longitude, and latitude. For column 4, data in 1940 are unavailable and the reported changes are relative to 1930. All coefficients are allowed to vary in each year. The regressions are weighted by county acres, and robust standard errors clustered by county are reported in parentheses.

**Significant at the 1 percent level.

*Significant at the 5 percent level.

counties of commercial fertilizers, agricultural chemicals, and noxious swine farms, which may mask increased real housing costs in Ogallala counties.

Table 5, column 3, reports changes in retail sales per capita, which is an available historical proxy for average income (Fishback, Horrace, and Kantor 2005; Hornbeck 2012). This proxy for income increased as the Ogallala became increasingly exploited and farm populations increased in Ogallala counties, though this measure declined in later periods. Average manufacturing payroll per worker increased in some initial periods, though the estimates are not statistically significant (column 4). These measures provide only a rough proxy for local labor costs, however, and data are unavailable to control for worker characteristics.

In understanding the mechanisms through which the agricultural sector affects nonagricultural sectors, there are only limited indications that nonagricultural activity was discouraged by higher local input costs. The absence of long-run changes in local input costs, combined with the absence of systematic increases in nonagricultural activity, suggests that agricultural expansion creates few production amenities for local nonagricultural sectors.

### E. *Potential Geographic Spillover Effects*

The empirical methodology identifies relative impacts of the Ogallala, comparing changes in Ogallala counties to changes in non-Ogallala counties. In our main theoretical model, non-Ogallala counties are not affected by agricultural expansion over the Ogallala. If some goods are traded locally or if labor mobility is restricted, however, then non-Ogallala counties may also be affected by increased access to Ogallala groundwater.

The empirical methodology is inherently limited in its ability to estimate spillover effects on non-Ogallala areas, but we do consider whether the main estimates reflect large impacts on nearby non-Ogallala areas. First, we verify that the previous estimates are substantively similar when excluding 24 non-Ogallala counties within 20 km of the Ogallala boundary or 71 counties within 50 km of the boundary. Second, to estimate local geographic spillover effects, we compare counties near the Ogallala to counties further from the Ogallala. Restricting the sample to counties with zero Ogallala share, equation (3) is modified to estimate the impact of distance to the Ogallala boundary:

$$(4) \quad Y_{ct} - Y_{c1940} = \beta_t Distance\_to\_Ogallala_c + \alpha_{st} + \gamma_{gt} + \theta_t \mathbf{X}_c + \epsilon_{ct}.$$

For ease of interpretation, distance is measured in units of 100 km and made negative. The estimated coefficients are interpreted as the impact of the Ogallala on the nearest sample counties, relative to the impact of the Ogallala on the furthest sample counties.

Table 6 reports changes in nonagricultural outcomes in counties near the Ogallala, relative to changes in counties further from the Ogallala. There is some indication of lower agricultural population and higher nonagricultural population in nearby non-Ogallala counties, which may reflect displacement from Ogallala counties, though these estimates are not generally statistically significant. There is little indication of systematic impacts on nonagricultural sector sales in nearby non-Ogallala counties, relative to further non-Ogallala counties, though these estimates are statistically underpowered.

An important limitation of this geographic spillover analysis is that spillover effects on non-Ogallala counties may not vary largely with geographic distance. Spillover impacts might follow railroads or highways, for example, though the sample region had a high density of railroads and highways over this time period. In general, agricultural expansion over the Ogallala may impact nonagricultural activity in ways that are diffused throughout the domestic or international economy. Identifying these spillover effects is beyond the scope of our empirical analysis; as a consequence, this paper focuses on the local economic impact in Ogallala counties relative to nearby similar non-Ogallala counties. This relative comparison does not identify aggregate spillover effects on nonagricultural sectors, however, to the extent that nearby counties are also affected by agricultural expansion over the Ogallala.

## VI. Interpretation and Conclusion

Counties over the Ogallala aquifer experienced windfall agricultural gains when post-WWII technologies increased farmers' access to groundwater. This historical episode provides an opportunity to estimate how the local agricultural sector disproportionately affects local nonagricultural activity, both in the short-run and over the long-run.

Table 6—Estimated Geographic Spillovers:
Nearby Non-Ogallala Counties versus Counties 100 km from the Ogallala

| | Population: | | | | Value added or total sales: | | | |
|---|---|---|---|---|---|---|---|---|
| Relative to 1940: | log (1) | Rural farm (2) | Rural nonfarm (3) | Urban (4) | Manufacturing (5) | Wholesale (6) | Retail (7) | Services (8) |
| 1920 | −0.241* | | | −2,948 | | | | |
| | (0.109) | | | (1,704) | | | | |
| 1930 | −0.035 | −105 | −53 | −391 | | | | |
| | (0.054) | (422) | (549) | (476) | | | | |
| 1940 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1950 | 0.080 | −238 | 769 | 1,303 | −0.035 | 0.521 | 0.025 | 0.209 |
| | (0.087) | (285) | (705) | (2,764) | (0.436) | (0.311) | (0.057) | (0.188) |
| 1960 | 0.035 | −894* | 3,681* | 5,510 | −0.074 | 0.527 | 0.029 | 0.039 |
| | (0.182) | (450) | (1,538) | (6,779) | (0.429) | (0.389) | (0.109) | (0.259) |
| 1970 | −0.046 | −892 | 2,042 | 9,511 | −0.121 | 0.443 | −0.009 | −0.001 |
| | (0.180) | (530) | (1,518) | (10,462) | (0.411) | (0.343) | (0.173) | (0.274) |
| 1980 | −0.112 | −1,068 | 2,180 | 12,993 | −0.134 | 0.845 | −0.021 | −0.402 |
| | (0.201) | (606) | (1,644) | (15,339) | (0.487) | (0.576) | (0.240) | (0.331) |
| 1990 | −0.059 | | | | −0.244 | 1.087 | 0.035 | −0.039 |
| | (0.243) | | | | (0.653) | (0.595) | (0.298) | (0.412) |
| 2000 | −0.071 | | | | | | | |
| | (0.266) | | | | | | | |
| Sample counties | 136 | 136 | 136 | 136 | 72 | 84 | 116 | 132 |

*Notes:* For counties with zero area over the Ogallala, each column reports estimates from equation (4): coefficients report the impact of "Negative Distance to Ogallala Boundary," measured in 100 km units. Coefficients reflect average outcomes in counties next to the Ogallala boundary, relative to counties 100 km away. Otherwise, the specifications are as described in Tables 3–5.

**Significant at the 1 percent level.
*Significant at the 5 percent level.

Despite substantial and persistent gains in the agricultural sector, there was no long-run relative expansion in Ogallala counties' nonagricultural economic activity. The absence of positive spillover impacts is particularly striking, as the empirical research design would overstate positive spillovers if workers or nonagricultural sectors directly benefited from access to Ogallala groundwater. Rural farm populations increased relatively over the Ogallala, but there was no general increase in population in Ogallala counties. Nonagricultural sectors experienced some short-run relative increases in sales, as land values increased over the Ogallala, but these impacts were short-lived and there was little impact on these sectors' number of establishments. Indeed, these results highlight the value of historical perspective in exploring the impacts of sectoral expansion on local economic activity.

Estimated impacts on the local nonagricultural economy reflect a net impact of potential negative and positive spillovers from the agricultural sector. Negative spillovers through increased costs for land and labor may be counterbalanced by positive spillovers through increased demand for local goods, shared infrastructure, or direct productivity spillovers. There are only limited indications of increased costs for land and labor, however, suggesting that positive spillovers may also be small.

In other contexts, local economic spillover effects might differ substantially in both sign and magnitude. On the United States Plains, in the middle of the twentieth century, markets were well-integrated, agriculture was mechanized, and labor mobility was high. By contrast, as declining groundwater levels threaten agricultural production in India (Sekhri 2014), relatively limited market integration might imply greater losses to local nonagricultural sectors in those rural areas. However, relatively lower labor mobility in India might imply greater inflow of nonagricultural activity to employ former agricultural workers (Foster and Rosenzweig 2004). In settings where agriculture is less mechanized, both of these effects are more pronounced: greater declines in agricultural labor demand decrease local input costs and decrease local demand for nonagricultural goods and services. While the theoretical model provides some guidance on how the empirical estimates might vary in other contexts, additional empirical research is needed to quantify local spillover effects at other times in other places.

An important limitation of this paper, inherent to the empirical research design, is its inability to estimate spillover effects on non-Ogallala counties from agricultural expansion over the Ogallala. The empirical analysis identifies relative effects on Ogallala counties, which are net of any impacts on non-Ogallala counties. Thus, our interpretation of the results focuses on how agricultural expansion appears not to support differential expansion of the local nonagricultural economy. On a regional or national level, agricultural growth may still support nonagricultural economic development (Vogel 1994; Johnson 2000; Gollin, Parente, and Rogerson 2002; Nunn and Qian 2011). We find limited evidence of population displacement to nearby non-Ogallala counties, relative to further non-Ogallala counties, and little evidence for spillover effects on nearby nonagricultural sectors. These estimates are underpowered, however, and are limited to spillover effects that vary with geographic proximity. Quantifying spillover effects throughout the economy will generally require stronger theoretical assumptions and empirical variation in the magnitude of spillover effects (e.g., Donaldson and Hornbeck 2013; Kline and Moretti 2014).

This paper suggests that environmental resources can have limited local economic impacts, despite having large impacts on the local agricultural sector. As many areas face the destruction of local environmental resources, whether through depletion or a changing climate, policy responses might focus on farmers themselves. Expansion of the agricultural sector has less local benefit than the limited gains from expansion of the mining sector (Black, McKinnish, and Sanders 2005), and much less local benefit than agglomeration spillovers from large manufacturing plant openings (Greenstone, Hornbeck, and Moretti 2010). Limited coagglomeration between agriculture and nonagriculture, in contrast to stronger coagglomeration within manufacturing (Ellison, Glaeser, and Kerr 2010), suggests that local policy focus on attracting manufacturing rather than agriculture. One particular policy implication is that subsidies to agricultural production, particularly through artificially-low costs of water, might be decreased without substantively decreasing nonagricultural activity in rural agricultural areas. Agricultural development might still support broader economic development on an aggregate level, but this historical episode highlights that agricultural expansion may not support local nonagricultural expansion in those rural areas.

## Appendix

Table A1—Estimated Differences in Agricultural Disamenities by Ogallala Share and Year

| Coefficient in year: | log expenditure on commercial fertilizer (1) | log expenditure on agricultural chemicals (2) | log swine (3) |
|---|---|---|---|
| 1920 | | | 0.049 |
| | | | (0.178) |
| 1930 | | | 0.394** |
| | | | (0.133) |
| 1940 | | | 0.225 |
| | | | (0.166) |
| 1950 | | | 0.390* |
| | | | (0.181) |
| 1954 | 0.073 | | 0.381* |
| | (0.321) | | (0.187) |
| 1959 | | | 0.625** |
| | | | (0.183) |
| 1964 | 1.245** | | 0.773** |
| | (0.288) | | (0.202) |
| 1969 | 1.313** | 1.298** | 0.861** |
| | (0.217) | (0.211) | (0.224) |
| 1974 | 1.672** | 1.588** | 0.746** |
| | (0.258) | (0.231) | (0.282) |
| 1982 | 1.398** | 1.612** | 0.694* |
| | (0.200) | (0.252) | (0.273) |
| 1987 | 1.326** | 1.164** | 0.870** |
| | (0.203) | (0.187) | (0.299) |
| 1992 | 1.464** | 1.202** | 0.659* |
| | (0.210) | (0.211) | (0.321) |
| 2002 | 1.397** | 1.576** | 1.509** |
| | (0.221) | (0.236) | (0.560) |
| Sample counties | 352 | 356 | 247 |

*Notes:* Each column reports estimates from equation (2): the indicated outcome variable is regressed on the share of county area over the Ogallala, state fixed effects, the fraction of county area in each soil group, and linear functions of county soil suitability for corn and wheat, average precipitation and temperature, average degree days between 10°C and 29°C and above 29°C, longitude, and latitude. All coefficients are allowed to vary in each year. The regressions are weighted by county acres, and robust standard errors clustered by county are reported in parentheses.

**Significant at the 1 percent level.

*Significant at the 5 percent level.

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