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DOES AGRICULTURE GENERATE LOCAL ECONOMIC SPILLOVERS? SHORT-RUN AND LONG-RUN EVIDENCE FROM THE OGALLALA AQUIFER

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ABSTRACT

Agricultural development may support broader economic development, though agricultural expansion may also crowd-out local non-agricultural 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 nearby similar counties, local non-agricultural sectors experienced only short-run benefits. Despite substantial persistent agricultural gains, there was no long-run expansion of local non-agricultural sectors and there are some indications of crowd-out. With the benefit of long-run historical perspective, supporting local agricultural production does not appear to generate local economic spillovers that might justify its distortionary impacts.

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Many governments subsidize agriculture and, particularly in arid environments, these subsidies often include artificially-low costs of water for agricultural production. Development of the agricultural sector may support broad economic development (Vogel 1994; Johnson 2000; Gollin, Parente, and Rogerson 2002; Nunn and Qian 2011), though expansion of the agricultural sector may also crowd-out non-agricultural production (Foster and Rosenzweig 2004). This issue is central to economic policy (World Bank 2008; USDA 2012) and, while agricultural development often coincides with broader economic development, there are few empirical settings to examine in detail how exogenous gains for the agricultural sector affect the broader economy over time.

This paper estimates short-run and long-run economic impacts from a windfall gain to the agricultural sector, exploiting local variation in United States Plains counties' access to the Ogallala aquifer. The Ogallala was formed by ancient runoff from the Rocky Mountains, trapped below the modern Great Plains, and it maintains distinct irregular boundaries that cut across modern soil groups. The Ogallala was first discovered in the 1890s, but it remained mainly inaccessible. Following 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 (Hornbeck and Keskin 2011).

Expansion of the agricultural sector could benefit the local non-agricultural economy, though there are two competing channels through which other economic activity may be restricted. First, increased agricultural land values may increase non-agricultural sectors' costs for land and labor. Second, some agricultural practices may create disamenities for the local population and increase labor costs in non-agricultural sectors. For the agricultural sector to benefit local non-agricultural sectors, these negative impacts must be outweighed by productivity spillovers, shared infrastructure, or increased demand for non-tradable 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 nearby counties in the same state and soil group, controlling for longitude, latitude, average precipitation, and average temperature (Hornbeck and Keskin 2011). Historical county-level data are merged with a United States Geological Survey map of the Ogallala's boundary. Ogallala counties and non-Ogallala counties were similar prior to improved groundwater availability, lending support to the identification assumption that Ogallala counties would otherwise have changed similarly to non-Ogallala counties.

Increased access to Ogallala groundwater generated substantial gains within the agricultural sector, but the empirical estimates do not indicate positive impacts on the long-run development of the local non-agricultural economy. Rural farm population increased relatively in counties over the Ogallala, but urban population declined and contributed to statistically insignificant relative declines in total population. Counties over the Ogallala experienced no long-run relative change in manufacturing, wholesale, retail, or service sectors. Ogallala counties had some short-run increases in non-agricultural sales, concurrent with the increase in agricultural land values, but these sectoral spillover impacts were short-lived.

In understanding the mechanisms through which the agricultural sector affects non-agricultural sectors, there are only limited indications of temporarily higher housing costs and wages. Despite substantially higher agricultural land values, housing costs may be kept from rising due to increased consumption disamenities associated with agricultural production, such as estimated increases in commercial fertilizers, agricultural chemicals, and noxious swine farms. There is only limited evidence of displacement of non-farm population to nearby non-Ogallala counties, and otherwise there are few detectable geographic spillover effects on nearby counties.

Overall, with the benefit of long-run historical perspective, a large windfall gain in the agricultural sector does not appear to have encouraged broader economic development of the local non-agricultural economy. There are indications of short-lived gains in non-agricultural sectors, however, that might give the impression of broader economic spillovers if only short-run data were available. If the agricultural sector might support broader economic development in small open economies, these impacts should be expected following the Ogallala's substantial benefits for agriculture in these rural Plains counties.[1] The absence of positive spillover impacts is particularly striking, as the empirical research design would overstate positive spillovers if Ogallala groundwater had direct benefits for non-agricultural sectors.

Thus, even from a local perspective, public support of the agricultural sector does not appear to generate positive economic spillovers that might justify its distortionary impacts. Expansion of the agricultural sector is estimated to have less local benefit than the limited gains from expansion of the mining sector (Black, McKinnish, and Sanders 2005), and certainly less local benefit than large manufacturing plant openings (Greenstone, Hornbeck, and Moretti 2010). Reducing agricultural subsidies, particularly by allowing higher agricultural water costs, may increase economic efficiency without discouraging non-agricultural economic activity.[2]

[1] In closed economies, or at the aggregate level of the world economy, agricultural development should still promote non-agricultural development. Agricultural subsidies, however, may simply encourage agricultural development in one area at the expense of another.

[2] For the case of water subsidies, 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). One policy concern, consistent with estimates from calibrated input-output models (Howe, Lazo, and Weber 1990; Howe and Goemans 2003), has been that allowing farmers to sell water rights and decrease irrigated acreages would depress the local non-agricultural economy.

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.[3] The Ogallala was formed by ancient runoff from the Rocky Mountains. Its modern boundary is sharply defined by the location of ancient valleys and hills, which have long since been covered and obscured on the surface.

The Ogallala was first discovered by the United States Geological Survey in the 1890s, but was initially considered of limited agricultural importance. Ogallala groundwater was only available to farmers on a limited scale through the use of early pumps, windmills, and irrigation techniques. Prior to the 1940's, agricultural outcomes were similar in counties over the Ogallala and nearby non-Ogallala counties (Hornbeck and Keskin 2011).

After World War II, automobile engines were adapted to power improved pumps that lifted groundwater cheaply and in larger volumes. Groundwater irrigation increased with the subsequent introduction and adoption of center pivot technology. Agricultural land values increased substantially in counties over the Ogallala; over time, land-use adjusted toward water-intensive crops and agricultural revenues increased further (Hornbeck and Keskin 2011).[4]

Agriculture accounts for the majority of Ogallala groundwater extraction, though Ogallala groundwater may also be used for non-agricultural purposes. To the extent that Ogallala groundwater directly benefits non-agricultural sectors, the empirical analysis will overstate positive impacts of the agricultural sector on the local non-agricultural economy.

Farmers in nearby counties do not access Ogallala groundwater using pipelines or any system of exchange. Agriculture over the Ogallala may indirectly affect non-Ogallala counties through other economic channels, but agricultural outcomes are estimated to change similarly in nearby non-Ogallala counties and further non-Ogallala counties (Hornbeck and Keskin 2011).

Appendix Figure 1 maps counties over the Ogallala and counties within 100km of the Ogallala boundary, shaded to reflect the irrigated percent of county land (from Hornbeck and Keskin 2011). In 1935, there was little irrigation in all sample counties, aside from a few counties on major rivers (panel A). By 1974, irrigation increased substantially in counties over the Ogallala, while counties within 100km were relatively unchanged (panel B).

Appendix Figure 2 shows spatial patterns in agricultural land values that are consistent with substantial economic gains in the agricultural sector from increased access to Ogallala groundwater (from Hornbeck and Keskin 2011). There are strong regional determinants of

[3] See Hornbeck and Keskin (2011) for more-detailed historical background and references.

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

land values; within local areas, however, Ogallala counties and non-Ogallala counties had similar land values in 1920 (panel A). By 1964, land values are generally higher over the Ogallala than in nearby counties not over the Ogallala (panel B).[5]

II A Model of Cross-Sector Spillover Impacts

To explore the impacts on non-agricultural sectors from a windfall gain in the agricultural sector, we outline a basic two-sector Roback-style model (Roback 1982).[6] Sectors affect each other through shared factor markets. We also allow for the agricultural sector to create consumption disamenities for the local population (e.g., through increased use of agricultural chemicals) or production amenities for the local non-agricultural sector (e.g., through customer-supplier relationships or shared infrastructure). Second, we consider the within-county sectoral effects and cross-county geographic effects when goods are not traded internationally and workers are able to commute.

II.A Two-Sector Model with Internationally Traded Goods

We allow for two production sectors: agriculture and industry. In each sector, all 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 the following expression:

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

where w_c, r_c, and q_c are input prices and A_c^s is a sector-specific productivity shifter. In particular, A_c^A is allowed to depend on whether county c can access groundwater from the Ogallala aquifer.

Let $L^{s*}(w, r, q)$ be the optimal level of labor inputs in sector s, given the prevailing wage, cost of capital, and cost of land. Similarly, let $K^{s*}(w, r, q)$ and $T^{s*}(w, r, q)$ be the optimal level of capital and land, respectively. In equilibrium, the marginal product of each factor is set equal to its price.

The supply of land is fixed in each location. Capital is internationally traded, so its price does not depend on local demand or supply conditions. Labor is supplied by the workers who live in each location; for simplicity, we assume that all residents provide a fixed amount of labor. Workers' indirect utility depends on wages and the cost of housing, which is increasing

[5] Counties are shaded in each year to reflect their quintile in the distribution of counties' average value of agricultural land per county acre.

[6] 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. If labor mobility is restricted, there are larger crowd-out effects of the agricultural sector on the non-agricultural sector through increased local wages.

in the price of land. We assume that workers are fully mobile.[7]

When counties over the Ogallala aquifer become able to access its groundwater, the demand for farmland increases over the Ogallala. If the demand for industrial land is inelastic, then the county-wide price of land can increase substantially with little increase in total farmland. Due to an increase in the opportunity cost of land, the cost of housing increases and workers are only willing to remain if wages increase. Industrial firms' cost of labor and land both increase, so industrial output and the industrial workforce decline.[8]

The predicted change in total population depends on how much access to the Ogallala increases demand for labor in the agricultural sector, compared to how much higher land prices and wages decrease demand for labor in the industrial sector. The rural farm population is predicted to increase, while the rural non-farm population and the urban population are predicted to decline.[9] In the absence of any consumption disamenities or production amenities, the model predicts increases in land values, housing costs, and wages.

Agricultural Disamenities for Local Population: Agricultural production may create consumption disamenities for the local population. Consider the case in which a person's indirect utility is decreasing in total agricultural output; in practice, this may reflect particular agricultural practices associated with groundwater access, such as increased exposure to agricultural chemicals, fertilizers, and noxious swine farms.

When counties now gain access to the Ogallala aquifer, there is still an increase in the demand for farmland and the value of agricultural land. The cost of housing will increase by less, or may even decline, yet workers must receive a wage premium to remain in Ogallala counties. The industrial sector faces higher costs for land and labor, so there will be a decline in industrial output and the industrial workforce.

Agricultural Amenities for Local Industrial Firms: Agricultural production may also create production amenities for the industrial sector. While recent estimates of agglomeration and co-agglomeration spillovers have focused on relationships within the industrial sector (Ellison, Glaeser, and Kerr 2010; Greenstone, Hornbeck, and Moretti 2010), agricultural production may affect the industrial sector through similar channels. For example, local customer-supplier relationships may increase productivity or lower transaction costs if some outputs of the agricultural sector are intermediate inputs for the industrial sector and vice versa.[10] Expansion of the agricultural sector may also increase local infrastructure that is

[7]If labor were imperfectly mobile, then expansion of the agricultural sector (and increased labor demand) would increase labor costs further for the non-agricultural sector (Foster and Rosenzweig 2004).

[8]Industrial land may be worth more than agricultural land on average, but these should be equalized on the margin.

[9]In principle, access to Ogallala groundwater may be labor-saving and the rural farm population could also decline.

[10]We continue to assume that final goods are traded internationally, though this assumption is relaxed in

productive for non-agricultural sectors.[11] Rather than extend the model to include intermediate goods, productivity spillovers, or shared infrastructure, we simply allow for industrial productivity to be increasing in total county agricultural output.[12]

For interpreting any increases in the industrial sector as evidence for production amenities, a crucial assumption is that Ogallala groundwater is not a direct input for the industrial sector. In practice, some industrial firms may use Ogallala groundwater as a direct input, which would overstate the presence of production amenities from the agricultural sector. Similarly, workers may directly consume Ogallala groundwater, which would lower local wages and overstate the presence of production amenities.

When counties gain access to the Ogallala aquifer, the primary impacts are an increase in the demand for farmland and the value of agricultural land. Agricultural production increases; if agriculture generates production amenities for industry that outweigh higher costs for land and labor, then the industrial sector may also expand. Higher labor demand (and higher wages) attract workers into the county until land prices (and housing costs) increase sufficiently to establish equilibrium.

Combined Comparative Statics: Combining the direct price effects, 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. We write the "short-run" level of industrial firm profits, Π^*, as:

$$\begin{aligned} \Pi^* &= f^I\left[A^I(O), L^*\left(w(O), r, q(O)\right), K^*\left(w(O), r, q(O)\right), T^*\left(w(O), r, q(O)\right)\right] \\ &- w(O)L^*\left(w(O), r, q(O)\right) - rK^*\left(w(O), r, q(O)\right) - q(O)T^*\left(w(O), r, q(O)\right), \end{aligned}$$

where we now allow for productivity, wages, and land prices to depend on the agricultural sector's access to the Ogallala.

Consider the total derivative of an industrial firm's short-run profits with respect to a

the next section.

[11]In this case, "infrastructure" may be public or private and could also reflect financial services or any other local services with economies of scale.

[12]Productivity spillovers between both the agricultural and industrial sectors could generate multiple equilibria; for theoretical simplicity, we only allow for spillovers from the agricultural sector to the industrial sector. In practice, the empirical results could capture changes from a lower-output equilibrium to a higher-output equilibrium.

change in access to the Ogallala:

$$\begin{aligned}\frac{d\Pi^*}{dO} &= \left(\frac{\partial f}{\partial A}\times\frac{\partial A}{\partial O}\right) \\ &+ \frac{\partial w}{\partial O}\left\{\left[\frac{\partial L^*}{\partial w}\left(\frac{\partial f}{\partial L}-w\right)-L^*\right]+\left[\frac{\partial K^*}{\partial w}\left(\frac{\partial f}{\partial K}-r\right)\right]+\left[\frac{\partial T^*}{\partial w}\left(\frac{\partial f}{\partial T}-q\right)\right]\right\} \\ &+ \frac{\partial q}{\partial O}\left\{\left[\frac{\partial L^*}{\partial q}\left(\frac{\partial f}{\partial L}-w\right)\right]+\left[\frac{\partial K^*}{\partial q}\left(\frac{\partial f}{\partial K}-r\right)\right]+\left[\frac{\partial T^*}{\partial q}\left(\frac{\partial f}{\partial T}-q\right)-T^*\right]\right\}.\end{aligned} \tag{1}$$

If firms are price takers and all factors are paid their marginal product, equation (1) simplifies to:

$$\frac{d\Pi^*}{dO}=\left(\frac{\partial f}{\partial A}\times\frac{\partial A}{\partial O}\right)-\frac{\partial w}{\partial O}L^*-\frac{\partial q}{\partial O}T^*. \tag{2}$$

Equation (2) 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 increased consumption disamenities or higher housing costs for workers.[13] The third term also 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, the main empirical predictions are:

1) Non-agricultural sectors will contract, unless production amenities compensate for higher costs of land and labor.

2) Wages will increase, even if workers are fully mobile, due to consumption disamenities from the agricultural sector or higher housing costs.

3) Housing costs may decrease or increase, depending on the relative magnitude of consumption disamenities and competition for land from the agricultural sector.

II.B Extended Model with Locally Traded Goods and Commuting

The above model assumes that goods are traded internationally; as this assumption is relaxed, expansion of the agricultural sector has a more positive impact on the local industrial sector. Ogallala counties may also generate spillover impacts on nearby non-Ogallala counties.

If some portion of industrial goods are consumed locally, then expansion of the agri-

[13] If workers are imperfectly mobile, then wages may also increase due to increased competition for labor from the agricultural sector (Foster and Rosenzweig 2004).

cultural 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 (aside from any associated productivity spillovers).[14] This increase in local demand can be represented, in a reduced-form way, by a greater impact of the agricultural sector on (revenue) production amenities in the industrial sector.

If some portion of agricultural goods are consumed locally, then agricultural prices will fall in Ogallala counties. First, if the industrial sector uses inputs supplied by the local agricultural sector, then lower input prices would encourage industrial expansion. Second, if workers directly consume local agricultural products, then workers would be willing to accept lower wages and industrial firms would benefit from lower labor costs.[15]

If agricultural markets are local, then agricultural land values would also decline in nearby non-Ogallala counties. Lower land values in nearby areas would attract workers and industrial firms to these areas.[16] There would be particular displacement of workers from Ogallala counties to nearby non-Ogallala counties if workers are able to commute and if commuting avoids some portion of the agricultural sector's consumption disamenities.

The main additional empirical predictions are:

1) Local markets for industrial goods are observationally similar to "production amenities," encouraging expansion of the industrial sector and increased population.

2) Local markets for agricultural goods are reflected in decreased agricultural land values in nearby non-Ogallala counties; through a decrease in land values, this may encourage expansion of the industrial sector and population in nearby non-Ogallala counties.

3) If workers are able to commute, then geographic spillover effects will be more pronounced, particularly if commuting workers are able to avoid consumption disamenities from agriculture over the Ogallala.

III Data Construction and County Differences by Ogallala Share

Historical county-level data are drawn from the US Censuses of Agriculture and Population (Gutmann 2005; Haines 2005).[17] The main variables of interest include: irrigated acres and total acres of farmland; value of agricultural land and revenue; total population and population by rural farm, rural non-farm, and urban; the number of establishments and

[14] If local workers own land or if agricultural renters capture a substantial portion of increased returns (Kirwan 2009), then higher agricultural land values will also increase local workers' assets and their demand for industrial goods.

[15] Depending on changes in the industrial sector, local changes in industrial prices would also affect workers.

[16] If the agricultural sector creates production amenities that increase industrial productivity in nearby counties, then industrial firms will also be attracted to nearby non-Ogallala areas.

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

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 focuses on a balanced panel of Plains counties, from 1920 to 2002, for which data are available in every period of analysis. To account for occasional changes in county borders, data are adjusted in later periods to maintain 1920 county definitions (Hornbeck 2010).

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

The empirical research design exploits spatial variation in access to Ogallala groundwater, comparing counties over the Ogallala with nearby similar counties. To focus on comparisons among "nearby similar counties," as in Hornbeck and Keskin (2011), the empirical specifications control for average differences by state, soil group, longitude, latitude, average precipitation, and average temperature.[18]

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

IV Empirical Framework

In the initial empirical specifications, outcome Y in county c is regressed on the fraction of county area over the Ogallala, state fixed effects α_s, the fraction of county area in each soil

[18] 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 the analysis effectively compares Ogallala and non-Ogallala counties within the same soil group. Climate and geographic location may also influence agricultural production, even within-state and within-soil group. Because non-Ogallala counties surround the Ogallala region, there is variation in Ogallala access within similar climate, longitude, and latitude.

group γ_g, and linear functions of four county characteristics X_c (average rainfall, average temperature, longitude, and latitude). These cross-sectional specifications are pooled across all time periods, with each coefficient allowed to vary in each time period:

$$Y_{ct} = \beta_t OgallalaShare_c + \alpha_{st} + \gamma_{gt} + \theta_t X_c + \epsilon_{ct} \tag{3}$$

In each time period, the estimated β reports the average difference between counties entirely over the Ogallala and counties never over the Ogallala.[19]

The estimated β's can be interpreted as the impact of the Ogallala in each year, under the identification assumption that sample counties would have had the same average outcomes in each year if not for the Ogallala. In practice, this identification assumption must hold after controlling for other differences correlated with state, soil group, precipitation, temperature, longitude, and latitude. In this way, the research design exploits the sharp spatial discontinuity created by the Ogallala's irregular boundary.

Differences in the estimated β's, from one year to another year, report the average change for an Ogallala county relative to a non-Ogallala county over that time period. The change in β's can be interpreted as the changing impact of the Ogallala, under the weaker identification assumption that sample counties would have had the same average changes if not for the Ogallala. Differencing the estimated coefficients is numerically equivalent to estimating equation (3) in differences or with county fixed effects.[20]

Equation (3) is modified to report directly the estimated changes in county-level outcomes, relative to 1940:

$$Y_{ct} - Y_{c1940} = \beta_t OgallalaShare_c + \alpha_{st} + \gamma_{gt} + \theta_t X_c + \epsilon_{ct} \tag{4}$$

The estimated coefficients report relative changes for counties over the Ogallala, compared to any differences in 1940.

The Ogallala's impact may vary over the analyzed region. For example, the Ogallala may have less impact in areas with unproductive soil and more impact in areas with water deficiencies. For simplicity, the analysis reports the impact of the Ogallala on the average

[19]Some counties are partly over the Ogallala, and this specification assumes that the effect of the Ogallala is linear in the fraction of county area over the Ogallala. From graphing county residual changes in irrigated farmland against county residual Ogallala shares, the effect of the Ogallala appears roughly linear in the share of county area over the Ogallala.

[20]Differencing and fixed effects are equivalent for two time periods; for this multi-period regression, the specification is essentially separable for any two time periods. The explanatory variables are fully interacted with time, such that the impact of each variable is allowed to vary in each year. The sample is also balanced in each regression, such that every county has data in every analyzed period. Thus, the estimated coefficients in any one year are not influenced by county outcomes in any other year.

acre of land over the Ogallala. For this purpose, the regressions are weighted by county size.

For the statistical inference, standard errors are clustered at the county level to adjust for heteroskedasticity and within-county correlation over time. When allowing for spatial correlation among sample counties, the estimated standard errors increase by approximately 20%.[21]

V Results

V.A Estimated Impacts on the Agricultural Sector

Table 2 reports estimated direct impacts of the Ogallala on the agricultural sector (Hornbeck and Keskin 2011). From estimating equation (3), columns 1 – 4 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, and the log value of agricultural revenue.

In 1935, irrigation was a statistically insignificant 0.4 percentage points lower in Ogallala counties than in non-Ogallala counties (Column 1). By 1950, irrigation was 1.3 percentage points higher in Ogallala counties than in non-Ogallala counties. As groundwater irrigation technology improved and agricultural production adjusted, this difference increased to 11.3 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 1950's, though higher in some periods (Column 2). Since the 1960's, the fraction of county land in farms has been consistently higher by 5 to 7 percentage points in Ogallala counties. This small relative increase mainly reflects a slower absolute decline in farmland than in non-Ogallala counties.

In the 1950's, after the introduction of improved pumping and irrigation technologies, the value of agricultural land and buildings became consistently higher in counties over the Ogallala (Column 3).[22] The land value premium rose to 31% in 1950 (0.273 log points), peaked at 51% in 1964 (0.415 log points), and has since declined to 19% in 2002 (0.178 log points).

Agricultural revenues have been higher over the Ogallala since the late 1940's, but increased substantially in the 1970's as agriculture shifted toward greater corn acreages over

[21] Spatial correlation among counties is assumed to be declining linearly up to a distance cutoff and zero after that cutoff (Conley 1999). For a distance cutoff of 100 miles or 200 miles, the estimated Conley standard errors are approximately 20% higher (on average) than the standard errors when clustering at the county level, depending on the outcome variable.

[22] Over this long time period, data are only available for the combined value of agricultural land and buildings. From 1900 to 1940, when data are available separately for land and buildings, the value of land is the much larger component.

the Ogallala. 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.

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

V.B Estimated Impacts on Population

Table 3 reports estimated impacts of the Ogallala on population, which provides a summary proxy for aggregate economic activity. Relative to the omitted year of 1940, each column compares changes in Ogallala counties and non-Ogallala counties from estimating equation (4). As the Ogallala became available for widespread irrigation, and agricultural land values increased substantially, 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% level.

Estimating the change in population by category, Ogallala counties experienced a moderate increase in rural farm population (column 3). By contrast, there were some declines in rural non-farm 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 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 large or very small counties.[23]

V.C Estimated Impacts on Non-Agricultural Sectors

Table 4 reports estimated impacts of the Ogallala on four non-agricultural sectors: manufacturing, wholesale, retail, and services. We expect that these four sectors are ordered from producing more internationally-traded goods to more locally-traded goods, so we expect the impacts of local demand to be concentrated in the latter sectors. Any sector may experience spillover impacts through shared infrastructure or productivity spillovers.

After the Ogallala became available for agricultural production, counties over the Ogallala experienced no long-run expansion of non-agricultural sectors.[24] There were some substantial short-run increases in non-agricultural sector sales (columns 2, 4, 6, 8), but little change in the number of non-agricultural sector establishments (columns 1, 3, 5, 7). Figure 3 displays

[23]The estimates are robust to restricting the sample to 333 counties with total population in 1940 within the 5th and 95th percentiles.

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

the estimated changes in non-agricultural sector sales.

Estimated increases in sales coincide with the large increase in agricultural land values, and were not sustained as agricultural production expanded into the 1970's. There may be positive spillover effects on particular non-agricultural firms that specialize in agricultural machinery, sales, and services, but these detailed historical data are unavailable. Overall, substantial and persistent gains in the agricultural sector were not associated with long-run growth of the local non-agricultural economy.

V.D Estimated Impacts on Housing Costs and Income Proxies

To help understand the mechanisms through which the agricultural sector affects non-agricultural sectors, Table 5 reports estimated impacts of the Ogallala on the available proxies for housing costs and income. As agricultural land values increased from 1940 to 1950, there was a moderate but statistically insignificant increase in median dwelling values (column 1). As agricultural land values declined in more recent periods, median dwelling values also declined. Historical data are unavailable to control for house characteristics, however, which limits the estimates' statistical precision. Median dwelling rents show less of an increase in housing costs, and decline while agricultural land values remained high (column 2).

Despite higher agricultural land values, housing costs may have been kept from rising by increased consumption disamenities associated with agricultural production. Appendix Table 1 reports higher usage among Ogallala counties of commercial fertilizers, agricultural chemicals, and noxious swine farms.

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, though it declined in recent periods. Average manufacturing payroll per worker also increased, though the estimates are not statistically significant (column 4). These measures provide only a rough proxy for local wages, and data are unavailable to control for worker characteristics.

Overall, in understanding the mechanisms through which the agricultural sector affects non-agricultural sectors, there are only limited indications that higher local input costs discouraged non-agricultural activity. Increased real housing costs may be masked, however, by increased consumption disamenities associated with agricultural production.

V.E Estimated Geographical Spillover Impacts

The Ogallala may have spillover impacts on nearby non-Ogallala counties, such that estimated impacts on local non-agricultural sectors understate aggregate impacts on the non-agricultural economy. The existence of spatial spillover impacts are also of independent interest. There are minimal direct spillovers in access to water, as Ogallala water is not directly transferred to non-Ogallala counties for agricultural use.

The Ogallala should have limited indirect effects on agricultural prices because the Ogallala region represents a small share of national and world agricultural production. However, to the extent that some markets are more local, nearby non-Ogallala counties may be affected by changes in factor availability and terms-of-trade.

To explore local 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 in each year of distance to the Ogallala boundary. For ease of interpretation, distance is measured in units of 100km 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 spatial spillover impacts on non-agricultural outcomes in counties near the Ogallala, relative to counties further from the Ogallala. The estimates indicate little spatial spillover impacts from the Ogallala. There is some indication of higher non-agricultural population in nearby non-Ogallala counties, which may reflect displacement from Ogallala counties, though these estimates are not generally statistically significant. From estimating the same specification, there is no substantial or statistically significant impact of the Ogallala on agricultural outcomes in nearby non-Ogallala counties (Hornbeck and Keskin 2011). When expanding the sample to counties within 200km of the Ogallala boundary, for increased statistical power, there remains little detectable geographic spillover impact.

The absence of large spatial spillovers makes interpretation of the main estimates more simple, which focus on a relative comparison between counties over the Ogallala and non-Ogallala counties within 100km. In this case, the "control" counties do not appear to be largely affected by agricultural expansion over the Ogallala. As a similar check on the results' interpretation, the estimates are similar when excluding 71 non-Ogallala counties that are within 50km of the Ogallala boundary.

VI Interpretation and Conclusion

Areas over the Ogallala aquifer experienced windfall agricultural gains when post-WWII technologies increased farmers' access to groundwater. This historical episode provides a unique opportunity to explore both short-run and long-run economic spillovers from agriculture to the local non-agricultural economy, comparing counties over the Ogallala to nearby similar counties.

As agricultural land values increased over the Ogallala, non-agricultural sectors experienced substantial short-run increases in sales. There was little change, however, in non-agricultural sectors' number of establishments. Rural farm populations increased, yet non-farm populations were unchanged in the short-run.

Despite substantial and persistent gains in the agricultural sector, there was no long-run expansion in Ogallala counties' non-agricultural economic activity. Short-run increases in non-agricultural sector sales disappeared over time, and there remained little change in the number of non-agricultural sector establishments. As a summary measure of local economic activity, total population gradually declined despite increases in rural farm population. This episode highlights the value of historical perspective in evaluating the local impact of sectoral expansion on broader economic growth.

Estimated impacts on the local non-agricultural economy reflect a net impact of potential negative and positive spillovers. 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 any positive spillovers may also be small.

Identifying local economic spillovers requires that access to Ogallala groundwater did not directly benefit non-agricultural sectors. Violation of this assumption, however, would cause the empirical estimates to overstate positive local economic spillovers.

Local economic benefits should be especially pronounced in this region and time period, where the agricultural sector forms a substantial share of the local economy. In other contexts where trade is more restricted and local demand more important, positive spillover impacts may be greater. In other contexts where labor mobility is more restricted, however, there may be stronger negative crowd-out effects through increased local wages.

The Ogallala may have contributed to economic growth in non-Ogallala counties, yet there is little evidence for spatial spillover impacts on agricultural or non-agricultural outcomes in nearby non-Ogallala counties compared to further non-Ogallala counties. The empirical results are also robust to excluding the closest non-Ogallala counties. The empirical analysis is unable to identify spillover impacts at the aggregate level of the entire economy, yet typical agricultural policies are designed to support agriculture in particular areas with the hope of generating local economic spillovers.

Overall, with the benefit of long-run historical perspective, supporting local agricultural production does not appear to generate local economic spillovers that might justify its distortionary impacts. Access to Ogallala groundwater generated substantial and persistent gains in the agricultural sector, but had little detectable benefit for the long-run development of the local non-agricultural economy.

REFERENCES

Black, D., T. McKinnish, and S. Sanders. 2005. "The Economic Impact of the Coal Boom and Bust." *Economic Journal*, Vol. 115, No. 50, pp. 449-476.

Conley, T. 1999. "GMM estimation with cross sectional dependence." *Journal of Econometrics*, Vol. 92, No. 1, pp. 1-45.

Easter, K., M. Rosegrant, and A. Dinar, eds. 1998. Markets for Water: Potential and Performance. Kluwer Academic Publishers.

Ellison, G., E. Glaeser, and W. Kerr. 2010. "What Causes Industry Agglomeration? Evidence from Coagglomeration Patterns." *American Economic Review*, Vol. 100, No. 3, pp. 1195-1213.

Fishback, P., W. Horrace, and S. Kantor. 2005. "Did New Deal Grant Programs Stimulate Local Economies? A Study of Federal Grants and Retail Sales During the Great Depression." *Journal of Economic History*, Vol. 65, No. 1, pp. 36-71.

Foster, A. and M. Rosenzweig. 2004. "Agricultural Productivity Growth, Rural Economic Diversity, and Economic Reforms: India, 1970 – 2000." *Economic Development and Cultural Change*, Vol. 52, No. 3, pp. 509-542.

Gollin, D., S. Parente, and R. Rogerson. 2002. "The Role of Agriculture in Development." *American Economic Review: Papers and Proceedings*, Vol. 92, No. 2, pp. 160-164.

Greenstone, M., R. Hornbeck, and E. Moretti. 2010. "Identifying Agglomeration Spillovers: Evidence from Winners and Losers of Large Plant Openings." *Journal of Political Economy*, Vol. 118, No. 3, pp. 536-598.

Gutmann, M. 2005. *Great Plains Population and Environment Data: Agricultural Data*, ICPSR.

Haines, M. 2005. *Historical, Demographic, Economic, and Social Data: US, 1790-2000*, ICPSR.

Hornbeck, R. 2012. "The Enduring Impact of the American Dust Bowl: Short- and Long-run Adjustments to Environmental Catastrophe." *American Economic Review*, Vol. 102, No. 4, pp. 1477-1507.

Hornbeck, R. 2010. "Barbed Wire: Property Rights and Agricultural Development," *Quarterly Journal of Economics*, Vol. 125, No. 2, pp. 767–810.

Hornbeck, R. and P. Keskin. 2011. "The Evolving Impact of the Ogallala Aquifer: Agricultural Adaptation to Groundwater and Climate." NBER Working Paper #17625.

Howe, C.W., J.K. Lazo, and K.R. Weber. 1990. "The Economic Impacts of Agriculture-to-Urban Water Transfers on the Area of Origin: A Case Study of the Arkansas River Valley in Colorado." *American Journal of Agricultural Economics*, Vol. 72, No. 5, pp. 1200-1204.

Howe, C.W. and C. Goemans. 2003. "Water Transfers and their Impacts: Lessons from Three Colorado Water Markets." *Journal of the American Water Resources Association*, October, pp. 1055-1065.

Johnson, D. 2000. "Population, Food, and Knowledge." *American Economic Review*, Vol. 90, No. 1, pp. 1-14.

Kirwan, B. 2009. "The Incidence of U.S. Agricultural Subsidies on Farmland Rental Rates." *Journal of Political Economy*, Vol. 117, No. 1, pp. 138-164.

Nunn, N. and N. Qian. 2011. "The Potato's Contribution to Population and Urbanization: Evidence from a Historical Experiment." *Quarterly Journal of Economics*, Vol. 126, pp. 593-650.

Roback, J. 1982. "Wages, Rents, and the Quality of Life." *Journal of Political Economy*, Vol. 90, pp. 1257-1278.

Rosegrant, M. and H. Binswanger. 1994. "Markets in Tradable Water Rights: Potential for Efficiency Gains in Developing Country Water Resource Allocation." *World Development*, Vol. 22, No. 11, pp. 1613-1625.

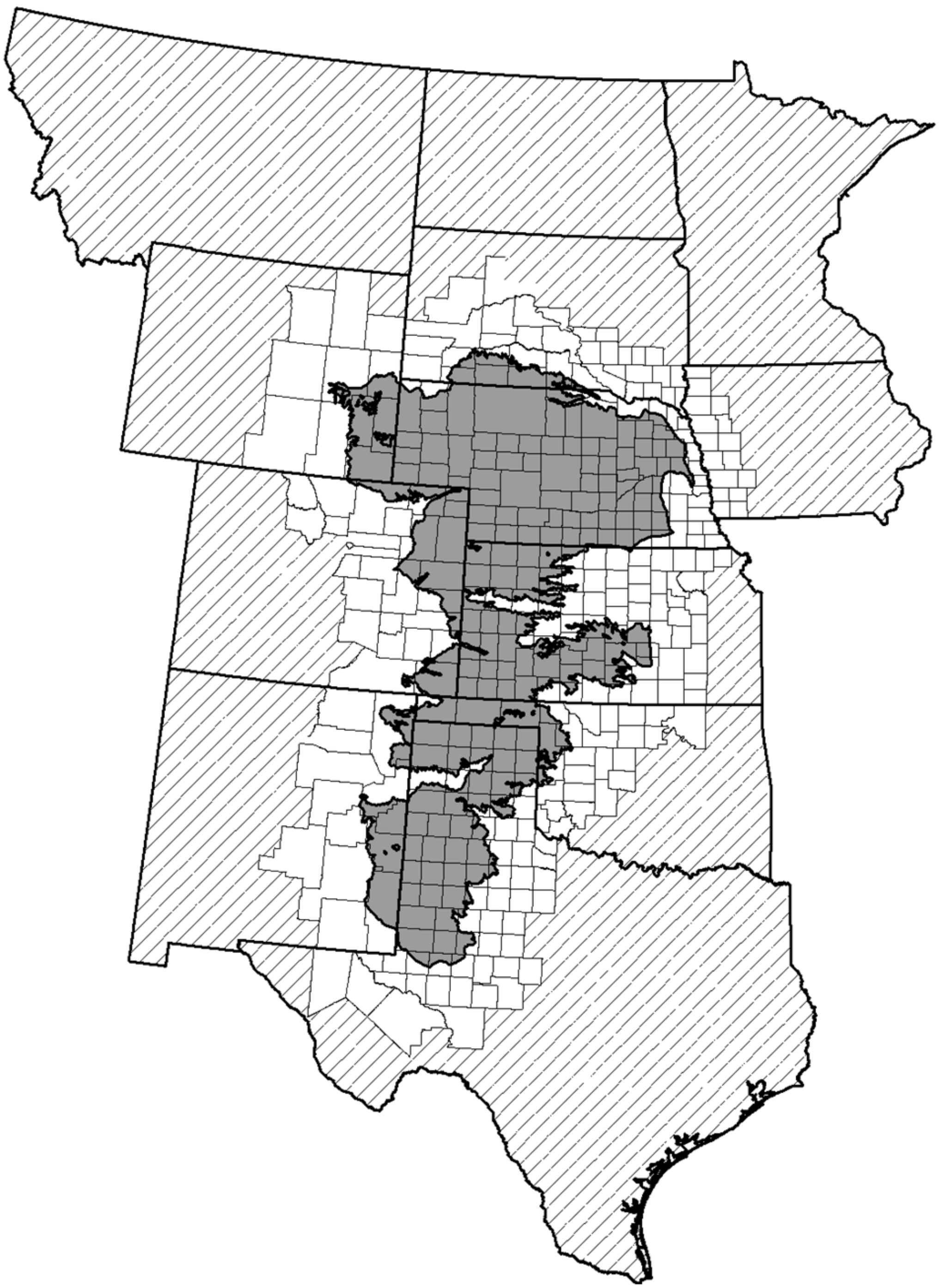
Thobani, M. 1997. "Formal Water Markets: Why, When, and How to Introduce Tradable Water Rights." *World Bank Research Observer*, Vol. 12, No. 2, pp. 161-79.

USDA. 2012. "Agricultural Trade Multipliers: 2010 Data Overview." Effects of Trade on the U.S. Economy, Economic Research Service, United States Department of Agriculture.

Vogel, S. 1994. "Structural Changes in Agriculture: Production Linkages and Agricultural Demand-Led Industrialization." *Oxford Economic Papers*, Vol. 46, No. 1, pp. 136-156.

World Bank. 2008. "World Development Report: Agriculture for Development." The World Bank: Washington DC.

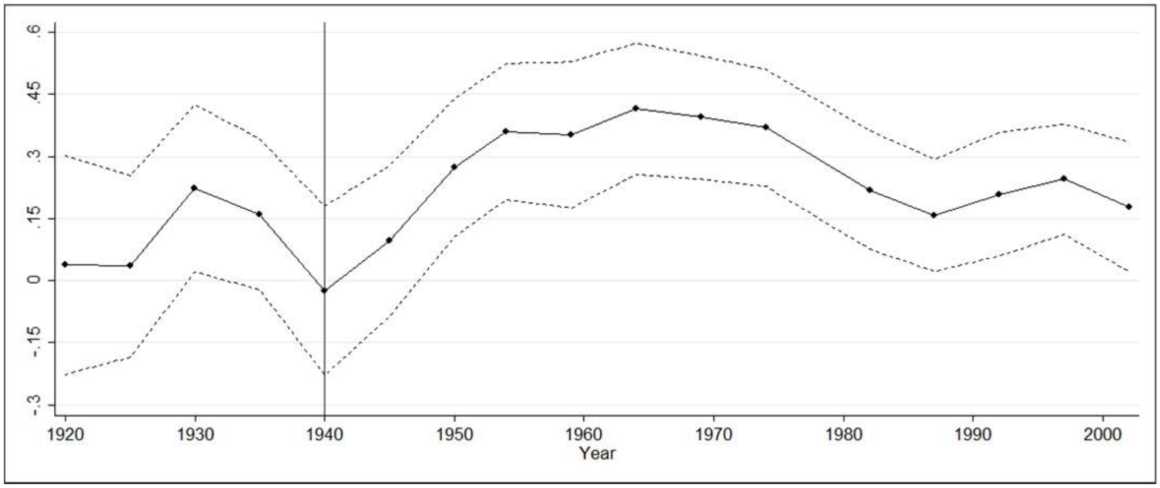
Figure 1. Ogallala Region and Counties within 100km



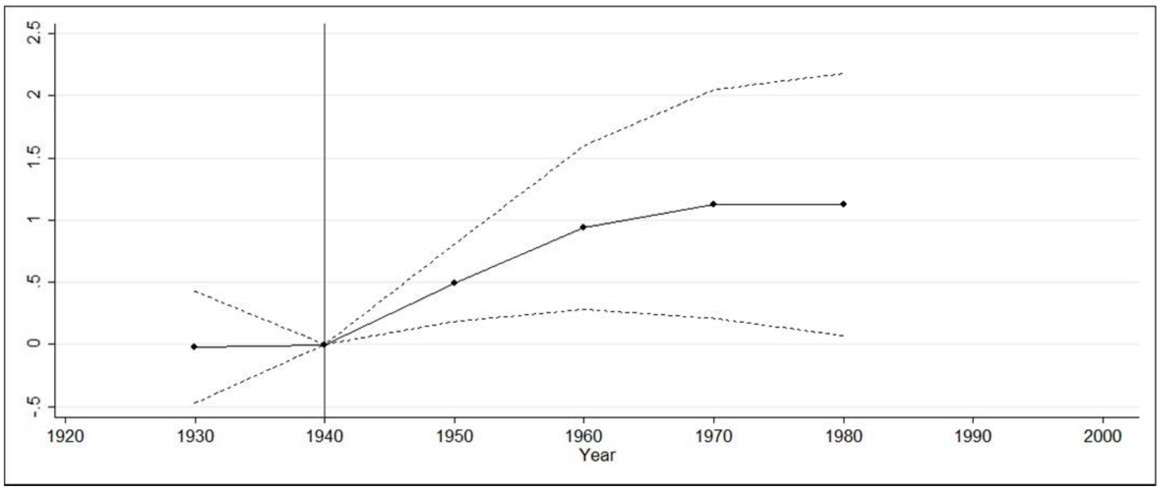
Notes: The shaded area represents the original boundary of the Ogallala Aquifer, as mapped by the United States Geological Survey. This map is overlaid with county borders, as defined in 1920, for all counties within 100km of the Ogallala boundary.

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

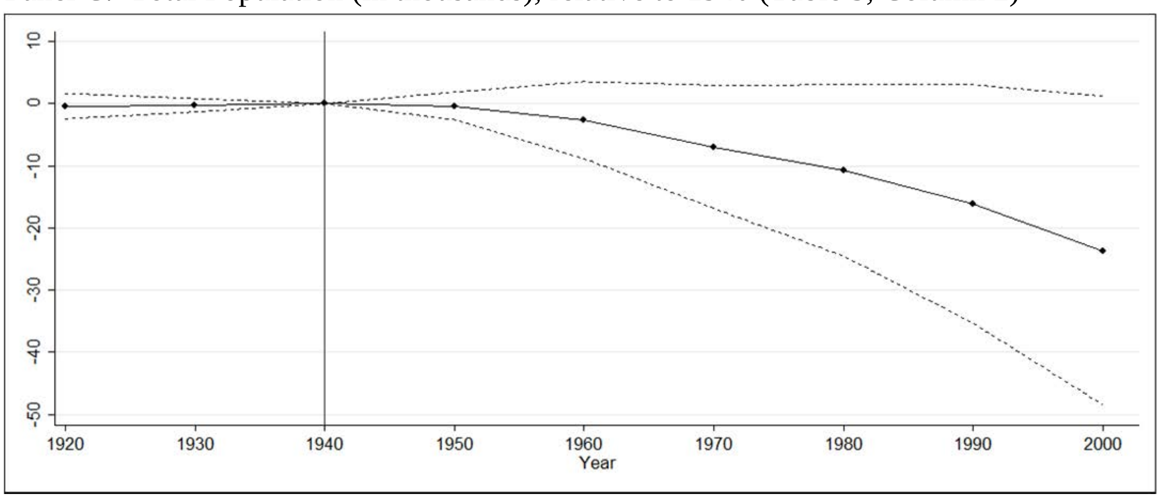
Panel A. Log Value of Agricultural Land and Buildings (Table 2, Column 3)



Panel B. Rural Farm Population (in thousands), relative to 1940 (Table 3, Column 3)



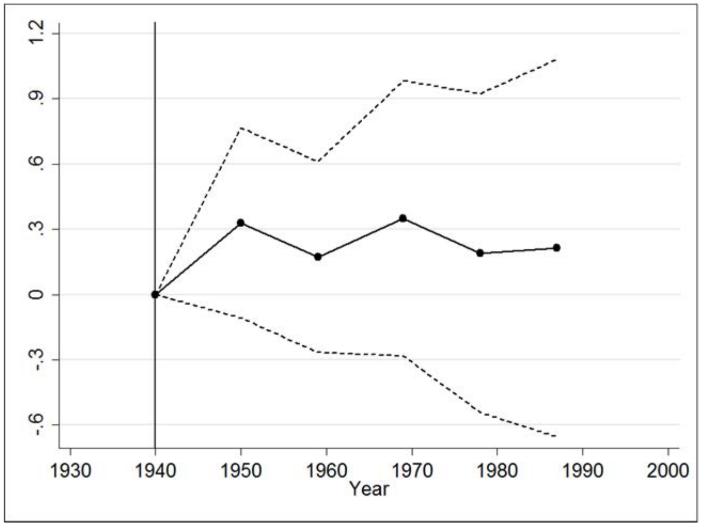
Panel C. Total Population (in thousands), relative to 1940 (Table 3, Column 2)



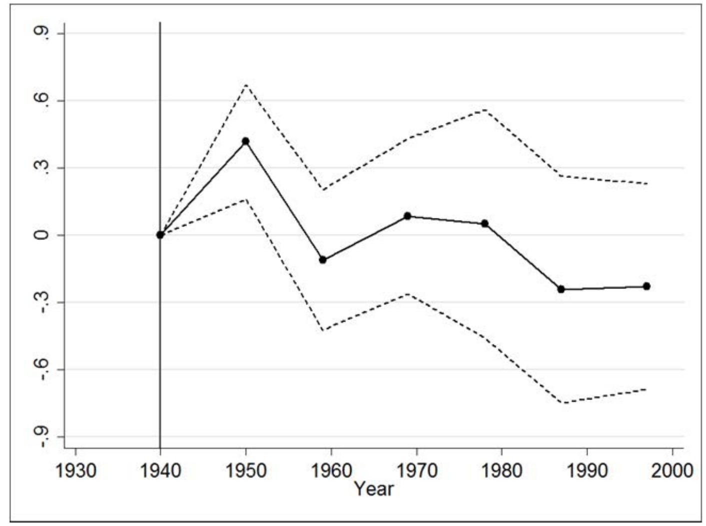
Notes: Relative to the omitted year of 1940, each panel reports estimated changes in Ogallala counties compared to changes in non-Ogallala counties (from estimating equation 4 in the text). The dashed lines reflect 95% confidence intervals around the estimated coefficients (reported in Table 2 and 3).

Figure 3. Estimated Impacts of the Ogallala on Non-Agricultural Sector Sales

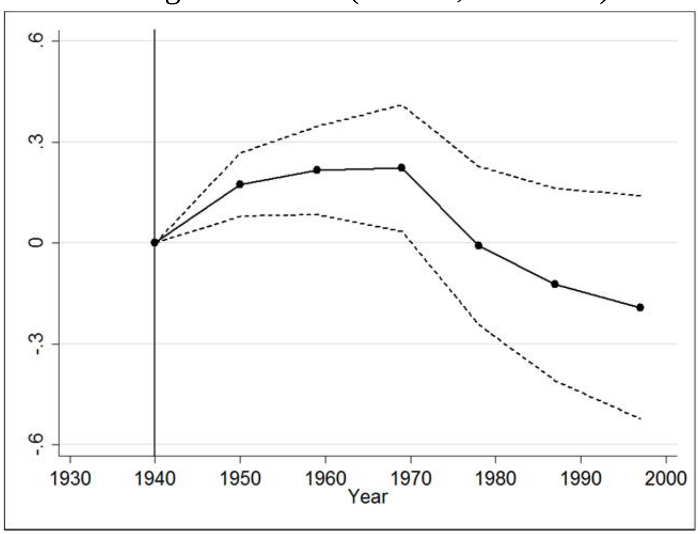
Panel A. Log Manufacturing Value Added (Table 4, Column 2)



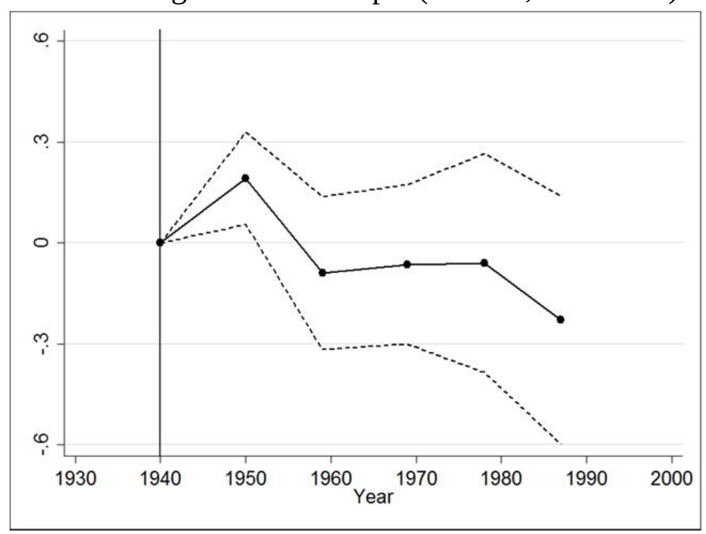
Panel B. Log Wholesale Sales (Table 4, Column 4)



Panel C. Log Retail Sales (Table 4, Column 6)



Panel D. Log Service Receipts (Table 4, Column 8)



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 4 in the text). The dashed lines reflect 95% confidence intervals around the estimated coefficients (reported in Table 4).

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

		Coefficient on Ogallala Share:			
	County Mean	No Controls	State Fixed Effects	State and Soil Group	State, Soil, Climate, X/Y
Per county acre:	(1)	(2)	(3)	(4)	(5)
Panel A. Agriculture (per county acre)					
Farmland	0.851	0.118**	0.046*	0.005	0.013
	(0.174)	(0.025)	(0.023)	(0.026)	(0.029)
Irrigated Farmland (1935)	0.007	-0.001	-0.001	-0.003	-0.004
	(0.020)	(0.002)	(0.002)	(0.003)	(0.003)
Log Value of Farmland	2.261	0.343*	-0.164	-0.107	-0.024
and Farm Buildings	(1.050)	(0.150)	(0.122)	(0.088)	(0.104)
Log Value of Farm	0.668	0.214	-0.170	-0.129	-0.080
Revenue	(0.958)	(0.132)	(0.134)	(0.096)	(0.112)
Panel B. Population					
Total Population	14318	-7763**	-8505**	-5197*	-4756
	(15960)	(1674)	(2227)	(2481)	(2970)
Rural Farm Population	5136	-1118*	-1498**	-1409*	-1191
	(4081)	(510)	(471)	(636)	(810)
Rural Non-Farm	3863	-1712**	-1617**	-669	-287
Population	(3109)	(405)	(418)	(544)	(693)
Urban Population	5319	-4933**	-5390**	-3119	-3278
	(12134)	(1186)	(1799)	(1870)	(2154)
Panel C. Non-Agricultural Sector Establishments and Output					
Log Manufacturing	1.95	-0.63**	-0.65**	-0.38	-0.37
Establishments	(1.09)	(0.16)	(0.18)	(0.23)	(0.25)
Log Manufacturing	12.42	-1.12**	-0.92*	-0.40	-0.55
Value Added	(1.69)	(0.34)	(0.36)	(0.48)	(0.53)
Log Wholesale	3.13	-0.15	-0.20	-0.05	0.00
Establishments	(0.94)	(0.13)	(0.14)	(0.16)	(0.18)
Log Wholesale Sales	13.98	-0.37*	-0.30	-0.05	0.04
	(1.30)	(0.18)	(0.20)	(0.24)	(0.27)
Log Retail	5.02	-0.56**	-0.55**	-0.31*	-0.25
Establishments	(0.86)	(0.11)	(0.12)	(0.14)	(0.15)
Log Retail Sales	14.70	-0.60**	-0.54**	-0.24	-0.18
	(1.10)	(0.15)	(0.15)	(0.18)	(0.20)
Log Service	3.91	-0.41**	-0.50**	-0.25	-0.14
Establishments	(0.92)	(0.12)	(0.14)	(0.16)	(0.18)
Log Service Receipts	11.65	-0.60**	-0.61**	-0.38	-0.25
	(1.24)	(0.17)	(0.19)	(0.22)	(0.25)
Panel D. Housing Costs and Income Proxies					
Log Median Dwelling	7.14	0.17	0.04	0.02	-0.06
Value (Owner-Occupied)	(0.53)	(0.09)	(0.09)	(0.09)	(0.10)
Log Median Dwelling	2.45	0.03	0.09	0.06	-0.01
Rent (Renter-Occupied)	(0.33)	(0.05)	(0.05)	(0.06)	(0.06)
Log Retail Sales	5.52	-0.09	-0.05	0.05	0.02
per capita	(0.44)	(0.06)	(0.06)	(0.08)	(0.08)
Log Manufacturing	8.01	0.04	0.02	0.05	0.07
Payroll per worker (1950)	(0.41)	(0.08)	(0.08)	(0.09)	(0.10)

Notes: Column 1 reports average county characteristics in 1940, except for irrigated farmland for which data are first available in 1935. 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 average precipitation, average temperature, longitude, and latitude. The regressions are weighted by county acres, and robust standard errors are reported in parentheses. ** denotes statistical significance at the 1% level, * at the 5% level.

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

Coefficient in year:	Irrigated Farmland per county acre (1)	Farmland Acres per county acre (2)	Log Value Farmland per county acre (3)	Log Farm Revenue per county acre (4)
1920		-0.003	-0.038	-0.010
		(0.038)	(0.135)	(0.128)
1925		-0.015	-0.035	0.044
		(0.036)	(0.112)	(0.131)
1930		0.044	0.223*	0.207
		(0.032)	(0.103)	(0.107)
1935	-0.004	0.054*	0.160	
	(0.003)	(0.023)	(0.093)	
1940		0.013	-0.024	-0.080
		(0.029)	(0.104)	(0.112)
1945		0.052	0.096	0.355**
		(0.029)	(0.093)	(0.105)
1950	0.013	0.016	0.273**	0.423**
	(0.007)	(0.029)	(0.085)	(0.112)
1954	0.030**	0.039	0.360**	0.382**
	(0.009)	(0.032)	(0.084)	(0.121)
1959	0.051**	0.008	0.352**	0.480**
	(0.010)	(0.030)	(0.090)	(0.116)
1964	0.062**	0.043	0.415**	0.464**
	(0.010)	(0.027)	(0.081)	(0.129)
1969	0.080**	0.055*	0.394**	0.584**
	(0.010)	(0.024)	(0.076)	(0.126)
1974	0.097**	0.052**	0.369**	0.888**
	(0.012)	(0.020)	(0.072)	(0.133)
1978	0.113**	0.060**	0.239**	0.813**
	(0.014)	(0.019)	(0.072)	(0.129)
1982	0.104**	0.071**	0.219**	0.935**
	(0.013)	(0.020)	(0.073)	(0.132)
1987	0.093**	0.058**	0.158*	0.880**
	(0.012)	(0.020)	(0.069)	(0.130)
1992	0.105**	0.051*	0.209**	1.016**
	(0.013)	(0.022)	(0.076)	(0.145)
1997	0.114**	0.064**	0.245**	1.177**
	(0.014)	(0.023)	(0.068)	(0.150)
2002		0.055*	0.178*	1.291**
		(0.021)	(0.080)	(0.155)
Sample Counties	368	368	368	368

Notes: Each column reports estimates from equation (3): 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 average precipitation, average temperature, 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. ** denotes statistical significance at the 1% level, * at the 5% level.

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

		Population:			
	Log Population	Total	Rural Farm	Rural Non-Farm	Urban
Relative to 1940:	(1)	(2)	(3)	(4)	(5)
1920	-0.092	-390			500
	(0.083)	(1036)			(735)
1930	0.007	-265	-22	-132	-111
	(0.046)	(549)	(229)	(226)	(398)
1940	0	0	0	0	0
1950	0.068	-369	496**	73	-938
	(0.042)	(1133)	(159)	(386)	(945)
1960	0.066	-2652	941**	-287	-3306
	(0.068)	(3156)	(336)	(712)	(2692)
1970	0.030	-6973	1129*	-802	-7300
	(0.084)	(5055)	(469)	(646)	(4774)
1980	0.018	-10739	1125*	-1619	-10246
	(0.096)	(7041)	(538)	(842)	(6865)
1990	-0.050	-16174			
	(0.117)	(9789)			
2000	-0.083	-23637			
	(0.128)	(12673)			
Sample Counties	368	368	368	368	368

Notes: Each column reports estimates from equation (4): 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 average precipitation, average temperature, 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. ** denotes statistical significance at the 1% level, at the 5% level.

Table 4. Estimated Changes in Non-Agricultural Sectors by Ogallala Share, Relative to 1940

	Log Manufacturing		Log Wholesale		Log Retail		Log Service	
	Establishments	Value Added	Establishments	Sales	Establishments	Sales	Establishments	Receipts
Relative to 1940:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1920	-0.055							
	(0.179)							
1930	-0.175							
	(0.114)							
1940	0	0	0	0	0	0	0	0
1950	-0.009	0.330	0.101	0.417**	0.059	0.173**	0.059	0.192**
	(0.087)	(0.223)	(0.066)	(0.130)	(0.036)	(0.048)	(0.061)	(0.070)
1959	-0.034	0.173	-0.029	-0.110	0.082	0.215**	-0.078	-0.090
	(0.113)	(0.224)	(0.084)	(0.160)	(0.052)	(0.067)	(0.077)	(0.116)
1969	0.151	0.351	-0.079	0.085	0.094	0.222*	0.015	-0.064
	(0.147)	(0.323)	(0.092)	(0.177)	(0.059)	(0.096)	(0.078)	(0.121)
1978	0.073	0.191	0.107	0.051	0.023	-0.008	-0.075	-0.060
	(0.156)	(0.374)	(0.122)	(0.260)	(0.079)	(0.120)	(0.100)	(0.166)
1987	0.062	0.214	-0.104	-0.243	-0.039	-0.124	-0.194	-0.230
	(0.179)	(0.443)	(0.142)	(0.258)	(0.098)	(0.146)	(0.147)	(0.188)
1997			-0.136	-0.229	-0.061	-0.192		
			(0.154)	(0.234)	(0.125)	(0.169)		
Sample Counties	200	149	352	231	367	333	359	340

Notes: Each column reports estimates from equation (4): 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 average precipitation, average temperature, 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. ** denotes statistical significance at the 1% level, at the 5% level.

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	0.071	0.036	0.075	0.058
	(0.067)	(0.063)	(0.051)	(0.096)
1959	0.075	-0.028	0.123*	0.152
	(0.079)	(0.066)	(0.060)	(0.100)
1969	0.064	-0.026	0.189**	0.070
	(0.087)	(0.069)	(0.064)	(0.096)
1982	0.039	-0.014	-0.065	
	(0.096)	(0.070)	(0.082)	
1992	0.027	-0.001	-0.091	
	(0.096)	(0.061)	(0.082)	
Sample Counties	343	298	357	174

Notes: Each column reports estimates from equation (4): 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 average precipitation, average temperature, 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. ** denotes statistical significance at the 1% level, at the 5% level.

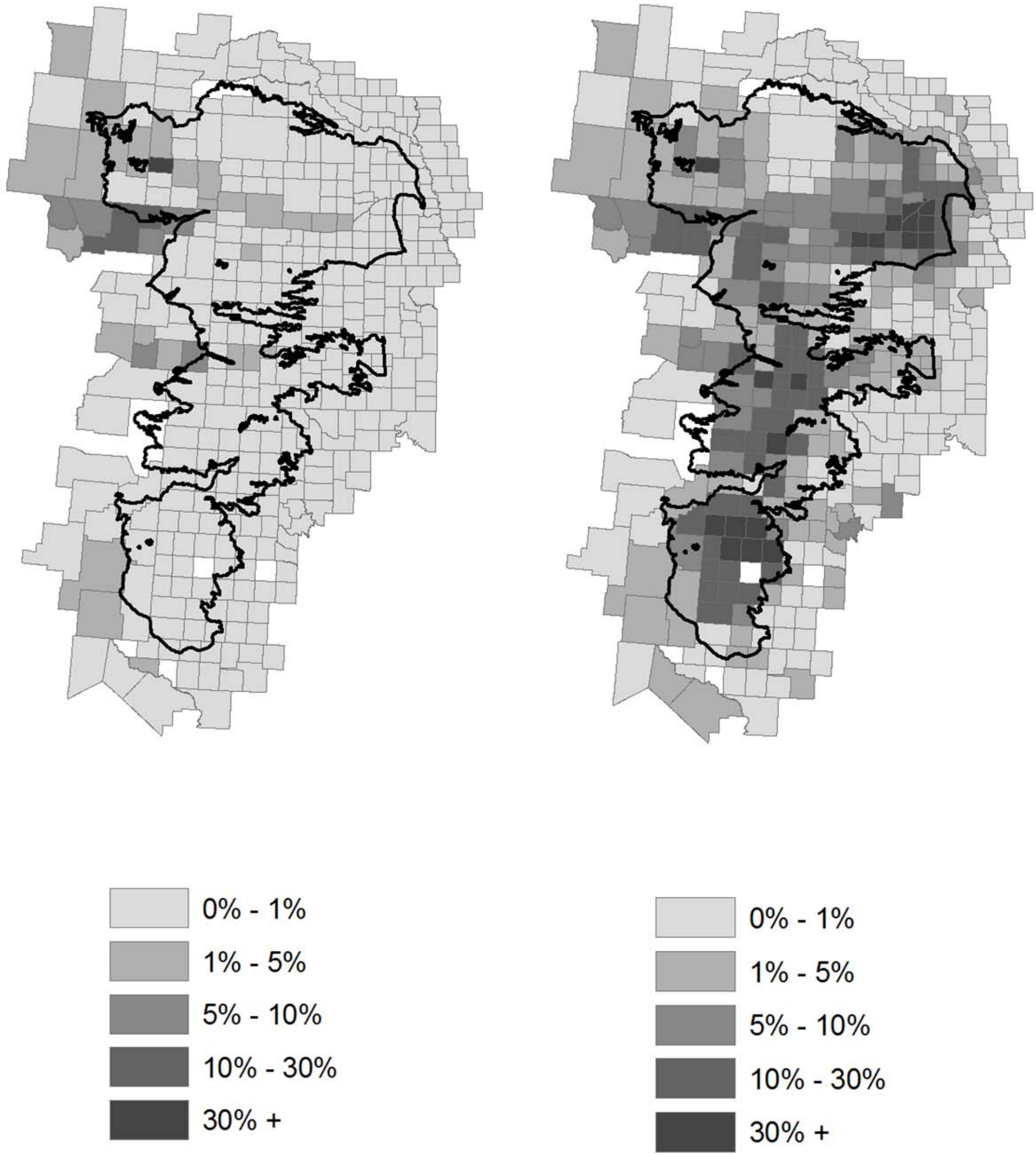
Table 6. Estimated Geographic Spillovers: Nearby Non-Ogallala Counties vs. Counties 100km from the Ogallala

	Population:				Value Added or Total Sales:			
	Log	Rural Farm	Rural Non-Farm	Urban	Manufacturing	Wholesale	Retail	Services
Relative to 1940:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1920	-0.203*			-2867				
	(0.099)			(1458)				
1930	-0.012	-3	-153	-415				
	(0.049)	(399)	(537)	(466)				
1940	0	0	0	0	0	0	0	0
1950	0.095	-57	742	1907	-0.103	0.238	0.016	0.127
	(0.083)	(274)	(660)	(2326)	(0.381)	(0.402)	(0.058)	(0.162)
1960	0.046	-727	3634*	7341	-0.270	0.317	0.065	0.054
	(0.165)	(453)	(1550)	(6169)	(0.361)	(0.480)	(0.113)	(0.227)
1970	-0.069	-696	1787	13311	-0.500	0.382	-0.002	0.038
	(0.167)	(543)	(1392)	(11198)	(0.435)	(0.467)	(0.165)	(0.249)
1980	-0.135	-830	1738	18335	-0.110	0.601	-0.035	-0.361
	(0.184)	(629)	(1553)	(16493)	(0.588)	(0.660)	(0.209)	(0.298)
1990	-0.115				-0.076	0.889	0.073	0.077
	(0.220)				(0.783)	(0.674)	(0.260)	(0.360)
2000	-0.131							
	(0.234)							
Sample Counties	136	136	136	136	72	84	116	132

Notes: For counties with zero area over the Ogallala, each column reports estimates from a modified equation (4): coefficients report the impact of "Negative Distance to Ogallala Boundary," measured in 100km units. Coefficients reflect average outcomes in counties next to the Ogallala boundary, relative to counties 100km away. Otherwise, the specifications are as described in Tables 3-5. ** denotes statistical significance at the 1% level, at the 5% level.

Appendix Figure 1. Irrigated Percent of County Area in 1935 and 1974

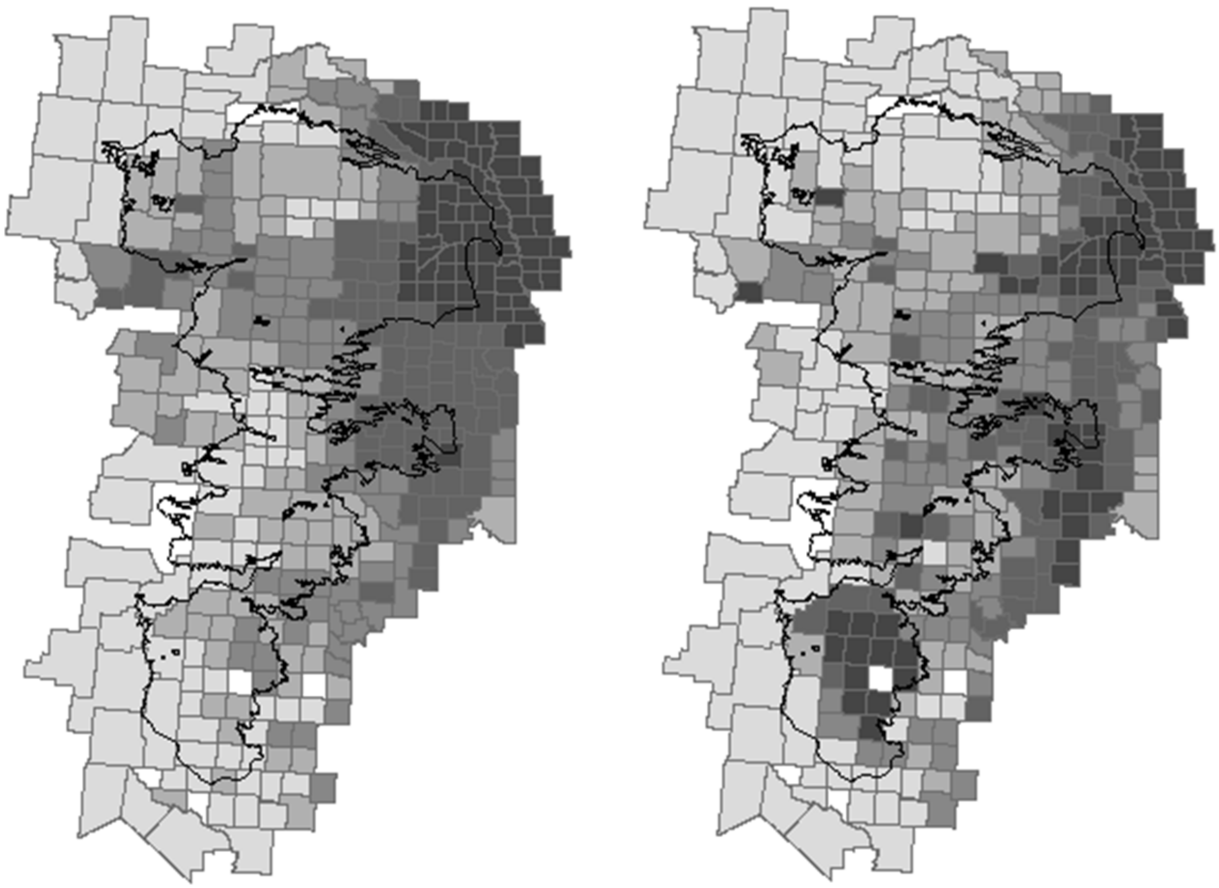
A. Irrigation in 1935 B. Irrigation in 1974



Notes: Appendix Figures 1a and 1b show 368 counties within 100km of the Ogallala boundary, shaded to reflect the percent of county land irrigated in 1935 and 1974. White areas are omitted from the sample.

Appendix Figure 2. Value of Agricultural Land per County Acre, Shaded by Quintile

A. Land Value in 1920 B. Land Value in 1964



Notes: Counties are shaded to reflect their quintile in the distribution of counties' average value of agricultural land per county acre in 1920 (Panel A) and 1964 (Panel B). The lightest gray represents the 20% least valuable counties in each year, while the darkest gray represents the 20% most valuable counties in each year. White areas are omitted from the sample.

A1. Estimated Differences in Agricultural Disamenities by Ogallala Share and Year

	Log Expenditure on Commercial Fertilizer	Log Expenditure on Agricultural Chemicals	Log Swine
Coefficient in year:	(1)	(2)	(3)
1920			0.133
			(0.172)
1930			0.573**
			(0.139)
1940			0.311
			(0.167)
1950			0.459*
			(0.182)
1954	0.230		0.409*
	(0.316)		(0.179)
1959			0.599**
			(0.173)
1964	1.160**		0.662**
	(0.262)		(0.189)
1969	1.149**	0.986**	0.716**
	(0.198)	(0.190)	(0.206)
1974	1.548**	1.199**	0.659**
	(0.242)	(0.204)	(0.252)
1982	1.247**	1.191**	0.616*
	(0.182)	(0.226)	(0.254)
1987	1.205**	0.902**	0.747**
	(0.195)	(0.169)	(0.271)
1992	1.250**	0.927**	0.532
	(0.187)	(0.187)	(0.291)
2002	1.302**	1.244**	1.099*
	(0.225)	(0.222)	(0.504)
Sample Counties	352	356	247

Notes: Each column reports estimates from equation (3): 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 average precipitation, average temperature, 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. ** denotes statistical significance at the 1% level, at the 5% level.