**Explaining Rural Conservatism:
Political Consequences of Technological Change in the Great Plains¹**

Word Count: 11981

Aditya Dasgupta²

Elena Ruiz Ramirez³

ABSTRACT

How did rural areas become conservative electoral strongholds in the US and other advanced capitalist economies? This paper argues that technological change transformed not only agriculture but rural political preferences during the twentieth century. It studies a natural experiment: the post-WWII introduction of improved groundwater pumps and center-pivot irrigation, which enabled farmers to irrigate otherwise arid land in the Great Plains. These innovations mainly benefited counties overlying the Ogallala aquifer – a pattern we validate with computer-vision estimates of technology diffusion using satellite imagery. Difference-in-difference analyses exploiting this differential impact indicate that technological change played a large role in the region’s long-term conservative electoral transformation. Additional tests, including comparison of individual policy preferences inside/outside of the Ogallala aquifer, support the hypothesis that this was due to increasingly capital-intensive agriculture and the growing power of agribusiness interests which benefit from conservative economic policies. The findings demonstrate how new technologies made new politics in rural America.

¹ For feedback and helpful discussion, we thank Gary Cox, Carles Boix, Mark Brilliant, Christopher Ojeda, Adriane Fresh, Jeff Jenkins, Devesh Kapur, Marika Landau-Wells, Debra Leiter, Bryan Leonard, Tesalia Rizzo, Melissa Rogers, Pavi Suryanarayan, Jessica Trounstein, Steven White, Daniel Ziblatt and seminar participants at: Johns Hopkins SAIS; Hoover Institution, Stanford University; WZB Social Science Center; PIPE workshop, University of Southern California; Historical Political Economy working group meeting, Cornell University; HPE virtual workshop; and APSA annual meeting 2020. Thanks to Osvaldo Valencia and Iven Morales for valuable research assistance. Thanks to Carlos Algara for sharing data and librarians at the National Archives for assistance with maps.

² Assistant Professor, Department of Political Science, University of California, Merced. W. Glenn Campbell and Rita Ricardo-Campbell National Fellow, Hoover Institution, Stanford University. Corresponding author. Email: adasgupta3@ucmerced.edu. Mail: 5200 North Lake Road, Merced, CA, 95343, USA.

³ PhD Student, Department of Political Science, University of California, Merced. Email: eramirez278@ucmerced.edu. Mail: 5200 North Lake Road, Merced, CA, 95343, USA.

1. Introduction

Conservative parties thrive electorally in rural areas in the United States and other advanced capitalist economies (Cramer 2016; Rodden 2019). Especially given the political over-representation of rural areas, the countryside is a critical source of electoral support for right-wing political parties. Yet this was not always the case historically (see e.g. Lipset 1950; Luebbert 1987). In the case of the United States, rural voters were relatively centrist in their politics and often supported left-wing politicians, like those belonging to the Populist party, in the late nineteenth and early twentieth century.

What, then, explains the long-term transformation of rural areas into conservative electoral strongholds? In an important debate stoked by Frank's (2007) book – which asked “What’s the Matter with Kansas?” – scholars have puzzled over the growing dominance of the conservative Republican party in comparatively poor and rural states, a phenomenon that appears to contradict canonical class-based theories of voting. Yet closer inspection of micro-level survey data demonstrates that within these states, it is affluent individuals that are most conservative in their voting patterns (see e.g. Bartels 2006; Gelman 2009).

Building on these debates, this paper explores the role of technological and economic change in political change in rural areas. Long-term technological change transformed American agriculture in the twentieth century with innovations ranging from the improvement of crop and animal varieties, to the refinement of fertilizers and pesticides, to various forms of mechanization, to the development of new methods for harnessing water for irrigation, especially

groundwater (Anderson 2009; Olmstead and Rhode 2001, 2008; Worster 1992). Due to technological change, agricultural output quadrupled over the twentieth century in the US despite an 80 percent decline in labor usage (Pardey and Alston 2021).

Long-term technological change made agriculture more productive but also more capital-intensive, generating economies of scale which resulted in the winnowing of unproductive and precarious family farms, and their replacement by highly productive, business-like farms as well as the spatial agglomeration of agricultural industries – known jointly as agribusiness – which benefit from conservative economic policies, including limited government regulation and pro-business tax and spending policies. The growing economic and political power of agribusiness interests in rural areas has, this paper argues, played an important role in the long-term conservative transformation of rural political preferences and the increasing electoral success of the Republican party in rural areas.

To test the argument, this paper exploits a historical natural experiment in the American Great Plains: the post-war introduction of new irrigation technologies, which enabled farmers to profitably irrigate otherwise arid land – but only in areas with access to groundwater (Edwards and Smith 2018; Hornbeck and Keskin 2014; Splinter 1976). Without irrigation, the arid climate of the Great Plains is suitable mainly for extensive agriculture (attempts at intensive farming without controlled irrigation were partially responsible for the Dust Bowl which followed the droughts of the 1930s). Though the Ogallala aquifer, one of the largest in the world, spans a large part of the Great Plains, until the 1940s available technology made it uneconomical to pump and distribute this groundwater on a large scale.

Following World War II, two innovations unleashed a process of technological change that transformed the Great Plains. The first was the adaptation of petroleum engines to groundwater extraction at scale through deep well pumps. The second was the invention of center-pivot irrigation, a system for irrigating large circular fields from a central well with a rotating arm affixed with sprinklers. Together, these innovations – “perhaps the most significant mechanical innovation in agriculture since the replacement of draft animals by the tractor” (Splinter 1976, p. 90) – enabled the spread of irrigation and the emergence of highly productive, capital-intensive farms operated by increasingly wealthy farmers as well as the spatial agglomeration of downstream industries like animal feedlots and meatpacking plants. As a result, the Great Plains turned into one of the most industrialized and productive agricultural regions in the world.

However, these technologies primarily benefited areas with access to groundwater, the main source of which is the Ogallala aquifer. To validate this key source of variation in exposure to technological change, we develop computer vision estimates of the diffusion of center-pivot irrigation based on a convolutional neural network trained to detect the technology’s signature circular cropping patterns in historical satellite imagery. This exercise motivates the difference-in-differences identification strategy, which exploits time variation arising from the post-war introduction of the new technologies together with cross-sectional variation in aquifer coverage in a spatially matched sample of counties along the boundary of the Ogallala aquifer to investigate whether counties more impacted by the technological shock also became more conservative in their voting patterns over time.

Empirically, we use GIS to measure the share of county land overlying the Ogallala aquifer. We link this information to county-level panel data on the Republican party's share of the two-party vote in presidential, senatorial, and gubernatorial elections between 1920 and 2000. Difference-in-differences analyses – which in preferred specifications prune the sample of counties to 200km and 100km buffer zones along the boundary of the Ogallala aquifer in each state and also control for state-time-period fixed effects – indicate that technological change played a large role in the region's long-term conservative electoral transformation. Decade-by-decade analyses suggest that a positive association between aquifer coverage and conservative voting emerged precisely when the new irrigation technologies were introduced and was not driven by potentially confounding pre-trends.

Additional tests indicate that the conservative electoral shift was driven by the spread of capital-intensive agriculture and the growing economic and political power of agribusiness interests. After WWII, counties with greater aquifer coverage experienced a large relative increase in the capital-intensity of agriculture as measured by the density and market value of farms. By contrast, tests do not support alternative commonly posited explanations for rural conservatism, such as intrinsic differences between rural and urban voters, religiosity or race-related political polarization. The conservative shift began in the 1940s, well before the race-related realignment of the 1960s in the US south. Counties with greater aquifer coverage experienced little depopulation and a relative *increase* in urbanization, due to the emergence of small towns in areas of intensive agriculture. Counties with greater aquifer coverage experienced little relative change over time in religiosity as proxied by church membership.

Analysis of Cooperative Congressional Election Survey (CCES) data suggests that contemporary mass policy preferences differ systematically between individuals residing in zip codes just inside the Ogallala aquifer compared to those residing just outside, reflecting the long-term political legacy of the post-war technological shock. Individuals living inside the boundaries of the Ogallala aquifer, where capital-intensive agriculture and agribusiness-dependent local political economies thrive, are today systematically more opposed to environmental and labor regulation and to taxation and the welfare state. Attitudes also differ with regards to some moral/cultural issues. These attitudinal spillovers may reflect feedback effects of the strategic bundling of economic and social issues by political parties.

The findings contribute to two main areas of research. First, they contribute to research on the origins of the urban-rural political divide, one of the defining features of politics in advanced capitalist economies (Cramer 2016; Rodden 2019). Important work shows that urban-centered technological dynamics like industrialization and the rise of the knowledge economy were pivotal in the historical emergence of left-wing politics in cities (Rodden 2019). We show that technological change in agriculture – a process that transformed politics in many other settings (Boix 2015; Dasgupta 2018; Moore 1966) – played an equally important role in the emergence of right-wing politics in the countryside, as precarious homesteads operated by yeoman farmers (the base of left-wing agrarian movements of the past like the Populist party) gave way to a sector dominated by capital-intensive farms and agricultural industries opposed to regulation and taxation. Our findings in combination with past work demonstrate how spatial political polarization has emerged as a result of technology-driven structural transformation in the twentieth century. Though this paper does not identify the cumulative political effects of all the

agricultural innovations that have taken place in this time period, it leverages one particularly large post-war technological shock to provide causally identified evidence on how new technologies have made new politics in rural America

The findings also provide a new answer to longstanding debates in American politics about “what’s the matter with Kansas” – i.e. why the party of the rich, the Republican party, thrives in comparatively poor and rural states (Bartels 2006; Frank 2007; Gelman 2009; Hacker and Pierson 2020; Walsh 2012). Frank’s explanation emphasizes the role of the “culture wars” in distracting poor and rural voters from class-based conflict, echoing theoretical models in political science which suggest that cross-cutting cleavages can weaken political support for redistribution in democracies (see e.g. Iversen 2006; Lee and Roemer 2006). While not incompatible with these explanations, this paper shows that much of the rise of rural conservatism can be traced to economic self-interest conceptualized in terms of the *industries* geographically concentrated in rural areas. Long-term technological change led to the emergence of agribusiness-dependent rural political economies, many residents of which, especially land and business owners but also the non-affluent, instrumentally support the Republican party. Indeed, new research finds that local economic dependence on other regulation averse industries common in rural areas, like fracking, is associated with conservatism (Cooper, Kim, and Urpelainen 2018; Sances and You Forthcoming). In the paper, we detail how agribusiness exerts outsized political influence in rural areas where it is a dominant industry, due to the “structural” dependence of rural communities on the agribusiness economy (Przeworski and Wallerstein 1988), as well as the organized activism of agribusiness interests. In this sense, the findings also contribute to the literature on business power (Hacker et al. 2021).

The remainder of the paper is structured as follows. It first describes the historical setting. It then discusses the theoretical mechanisms linking technological change to the rise of rural conservatism. It then presents the empirical strategy and results before concluding.

2. Technological and Political Change in the Great Plains

Agriculture in the Great Plains – a broad expanse of grassland spanning the American states of Texas, New Mexico, Oklahoma, Colorado, Kansas, Wyoming, Nebraska, South Dakota, Montana, and North Dakota – dates to the Homestead Act of 1862, which encouraged migration and agricultural development west of the Mississippi river with the promise of property rights to 160 acres of land to settlers who could offer proof of having settled and cultivated the land for five years. By the 1890s, the Great Plains were extensively populated by settlers, turning what had been a frontier region into a center of agriculture.

The conversion of arid prairie land into family farms – motivated by the widely held (but incorrect) belief that “rain follows the plow” – had devastating long-run ecological consequences (Libecap and Hansen 2002). The elimination of prairie grasses that held the soil in place contributed to soil erosion, culminating in the Dust Bowl of the 1930s, a combination of prolonged drought, dust storms, and soil erosion that devastated agricultural production (Cook, Miller, and Seager 2009; Hornbeck 2012).

In the midst of collapsing demand and falling prices of the Great Depression, the Dust Bowl contributed to mass outmigration, in spite of New Deal programs that sought to mitigate falling prices and provide a safety net to farmers by paying them to cull livestock and reduce crop acreage. Agriculture in the region began to recover in the late 1930s and early 1940s. The newly created Soil Conservation Service (SCS) disseminated dryland agricultural practices, including the conversion of cropland to pastureland and the dissemination of drought-resistant crops. Many of the small family farms abandoned by debt-ridden small farmers were reclaimed by banks, resulting in the consolidation of agricultural land into larger farms, alleviating some of the coordination problems associated with adopting environmentally sustainable practices (Hansen and Libecap 2004).

Yet, agriculture remained relatively unproductive and susceptible to droughts until the introduction of two post-WWII inter-related improvements in irrigation technology. The first was the adaptation of petroleum-powered engines to the task of extracting groundwater, resulting in much cheaper costs of lifting large volumes of groundwater. The pre-existing technology for extracting groundwater was the windmill pump, which was constrained in the depth and quantity of water it could draw, generally limiting its use to water supply for the household and livestock. While more powerful pumps existed, their operating costs were prohibitively expensive for usage in agricultural irrigation (Opie 2000, p. 126). Petroleum-powered irrigation pumps, based initially on the adaptation of automobile engines to deep well pumps, became widely available after World War II, making it much cheaper and economical to extract groundwater on a scale sufficient to irrigate crops, resulting in the spread of pump-based deep well groundwater irrigation from the 1940s and 1950s onward.

The second, closely related innovation, necessitated by the first, was the invention of center-pivot irrigation, a system for irrigation based on the sprinkler-based distribution of water from a central well through rotating arms up to a half-mile in radius. Invented by Frank Zybach in the 1940s and patented in 1952, center-pivot irrigation spread rapidly from the 1950s onward, resulting in the signature circular cropping patterns that dominate large parts of the Great Plains. The combination of cheaper extraction of groundwater as well as an efficient method for distributing water over a large area from a central source represented one of the most important technological innovations in agricultural history, enabling farmers to irrigate from the Ogallala aquifer, one of the largest in the world. This enabled farmers to cultivate lucrative but water-intensive feed crops like corn and also contributed to the spatial agglomeration of downstream agricultural industries like animal feedlots and meatpacking plants – transforming the Great Plains into one of the most industrialized and productive agricultural regions of the world despite the arid climate (Cunfer 2005; Opie 2000).

The technological revolution in the Great Plains coincided with a *political* revolution: the growing dominance of the Republican party in elections in a region that had historically been relatively centrist in its politics (in the sense of mirroring national trends) and where left-wing politics sometimes thrived. During the period of national Republican party dominance in the nineteenth century, farmers in the Great Plains also tended to support the Republican party, especially because of its support for the westward expansion of the railroad network (Aldrich 1995). In the late nineteenth and early twentieth century, left-wing politics found considerable success in the Great Plains, first in the form of the Populist party – which promised to nationalize

the railways, eliminate the gold standard, and enact other redistributive policies intended to help poor and indebted farmers. Congressional representatives, majorities in state legislatures, and/or governors belonging to the Populist party were elected from five (Colorado, Kansas, South Dakota, Nebraska, and Montana) Great Plains states (see e.g. Ostler 1993). Subsequently, reflecting national trends, both major political parties registered electoral victories in Great Plains states over time, including the Democratic party under Franklin Delano Roosevelt, whose New Deal policies were popular among poor farmers.

Following World War II, however, the Great Plains states became increasingly pro-Republican in their voting patterns, a trend that has proceeded unabated up to the present. Today, the region is an outlier in the degree of its staunch support for the Republican party. Eight out of 10 Great Plains states are “red” states – defined as states in which Republican presidential candidates have won at least three of the five presidential elections over the 2000-16 period (Grumbach, Hacker, and Pierson 2021) – a transformation that has led to debates among scholars and journalists about the historical origins of this conservative electoral shift. One conjecture emphasizes the “culture wars” which have purportedly distracted poor and rural voters from issues of redistribution and won them over to the side of the Republican party due to their social conservatism (Frank 2007). Others have pointed out, however, that in survey data household income remains a robust predictor of Republican party voting (Bartels 2006), though red states like Kansas are also characterized by an “intercept shift” or greater individual propensity to vote for the Republican party at all income levels (Gelman 2009). Together, these stylized facts challenge the “culture wars” hypothesis but also raise the question of where the aggregate long-term shift in conservative voting originates.

Figure 1 provides systematic data on this long-term political transformation, providing a map of Great Plains counties shaded according to the Republican party's percentage of the two-party vote in presidential elections between 1920 and 1940 in panel A and between 1980 and 2000 in panel B. As the map illustrates, over this period, the Great Plains evolved from a mostly "purple" (centrist) region into a consistently "red" (pro-Republican) region in elections.

FIGURE 1 ABOUT HERE

3. How New Technologies Made New Politics

We develop a new explanation for the conservative transformation of rural political preferences that emphasizes not the culture wars but the role of long-term technological change in contributing to the emergence of capital-intensive agriculture and agribusiness, the growing economic and political power of which has played an important role in the increasing conservative electoral tilt of the region.

Until the post-war technological shock, homesteaders and farmers on the Great Plains were typically poor and precarious, and struggled to make a living on marginal and arid lands suitable mainly for dryland farming. Unsurprisingly, many of these small producers were the worst victims of the Dust Bowl and Great Depression of the 1930s and important beneficiaries from the system of agricultural safety nets implemented in exchange for production controls enacted by the Agricultural Adjustment Act (AAA) of 1933, which granted the federal government the

authority to “secure voluntary reduction of the acreage of basic crops....and to direct payments for participation in acreage control programs” as well as to license, regulate, and tax agricultural activities. In process of policy making politics, this legislation mobilized farmers into politics, giving rise to the “farm lobby”, the influence of which historically spanned both major American political parties (Finegold and Skocpol 1995; Hansen 1991; Sheingate 2003) , with both the Democratic and Republican parties competing for the votes of farmers with bipartisan federal farm bills laden with subsidies.

However, as new irrigation technologies made agriculture more productive in areas with access to groundwater, they also brought sweeping changes to rural economic structure and political preferences. In a process found in other rural areas of the US (McWilliams 1939; Pardey and Alston 2021; Worster 1992), the increasing capital intensity of agriculture led to a winning of small producers, who lacked the economies of scale needed to survive in an environment with increasing costs of land, machinery, and inputs. In their place emerged increasingly capital-intensive, mechanized, and productive farms, operated by upwardly mobile farmers in a new form of business-like agriculture which came to be known as “agribusiness”.⁴ As one contemporaneous study of the impact of new irrigation technologies in a rural Kansas county put it: “Farming had become agribusiness...The average size farm of 1200 acres represented a considerable capital outlay, and rising operating costs were all but eliminating the marginal farmer in 1965. (Mays 1968, p. 36)” Over time, downstream industries reliant on water-intensive agriculture like feedlots and meat-packing plants – characterized by high levels of industrial

⁴ The term “agribusiness” entered the English lexicon in the 1950s (Hamilton 2014).

concentration due to extensive vertical integration and interlocking relationships – also agglomerated on the Great Plains. These transformations are documented by Opie (2000, p. 268): “As irrigation brought prosperity to the High Plains, smaller farmers were pushed out of the way...the shift from the family farm toward large-scale centralized agribusiness operations can be compared to the demise of ‘ma-and-pa’ neighborhood grocery stores after World War Two as supermarkets became commonplace.”

Unlike the small producers which comprised a core constituency of the New Deal interventionist farm policies of the 1930s, dependency on intensive utilization of land, groundwater, and hired labor pitted affluent farmers and agribusiness interests against regulation by government agencies. For instance, from the 1960s onward, as groundwater levels fell, landowners in the Great Plains lobbied to restrain government attempts to meter and regulate groundwater through groundwater management districts (Bessire 2021; Bloomquist, Williams, and Bridger 2002; Opie 2000). More recently, toxic waste-producing agribusiness sites like animal feedlots, which can produce as much waste and pollution as small-sized towns, have come into conflict with government regulations under the Clean Air Act (enacted in 1963) and Clean Water Act (enacted in 1972). Meatpacking plants, which from the 1960s onwards relocated from cities to small rural towns both to move closer to the feedlot industry as well to cut labor costs, are large-scale employers of labor and are well-known to oppose stringent labor regulation, such as higher minimum wages, employer insurance obligations, workplace safety laws, and union-friendly policies (Pachirat 2011).

As farmers became wealthier, they also became more opposed to taxation and redistribution, consistent with canonical theories of class-based fiscal conflict (Meltzer and Richard 1981). By the 1970s, according to agricultural censuses the average market value of farms across counties in the Great Plains was over \$1.5 million, up from around \$200,000 in the 1930s in 2016 dollars (as we will show, the increase in farm values was concentrated in irrigated counties overlying the Ogallala aquifer). As farms have become lucrative assets, protection of assorted tax breaks, exclusion from estate taxes, write-offs and deductions has become a major area of lobbying on the part of industry associations like the Farm Bureau. Large-scale farms and agribusinesses have also sought over time to reshape the farm subsidy system, seeking to delink subsidies from production controls – the lynchpin of the New Deal-era farm policies – in favor of a “market-oriented” regime linking subsidies to the quantity of a farm’s output, concentrating subsidies in the largest farms (Dimitri, Effland, and Conklin 2005; Sheingate 2003).

In rural areas where agribusiness has become a dominant industry, the power of agribusiness is “structural”, not unlike the power of the coal industry in former “company towns” or the oil and gas industry in shale regions (Cooper, Kim, and Urpelainen 2018; Gaventa 1982; Przeworski and Wallerstein 1988; Sances and You Forthcoming). Not just land and business owners but entire rural communities depend upon the agribusiness economy. As a result, the post-war economic boom that benefited counties overlying the Ogallala aquifer produced a sense of shared sectoral interest that leads the non-affluent, like middle-class residents and workers, to internalize the policy preferences of agribusiness. As Anderson (2018) puts it: “Water for irrigation and large-scale animal feeding didn’t only grow crops and livestock, it gave life to the Great Plains communities that depended on agriculture. Families and laborers shopped at local retailers and

deposited wages in local banks, keeping small towns alive, and irrigators paid the property taxes that sustained local governments. Center pivot irrigation supported ... a whole way of life that would have literally dried up if the fields were less productive.”

Despite significant rural inequality, class-based conflict has been superseded by a sectoral rural political identity, partly because the rural poor are far less organized than are land and business owners. For instance, low-wage workers in Great Plains meatpacking factories are completely un-unionized (Stull, Broadway, and Griffith 1995), due to right-to-work laws and other challenges to labor organizing, including a largely migrant workforce. By contrast, agribusiness interests are highly organized through industry associations like the Farm Bureau, which influences rural public opinion by circulating mailers, organizing events, and endorsing candidates in elections. Once an extension service, today the local branches of the Farm Bureau are deeply conservative advocacy organizations. Moreover, government agencies, ranging from groundwater management districts to the USDA, institutionalize the representation of land and business owners in a variety of policymaking arenas but not other rural stakeholders, like workers, further tipping the scales against their organization.

The role of technological change in the conservative transformation of rural political preferences is documented in repeated rural community studies of Haskell County – overlying the Ogallala aquifer in southwestern Kansas – conducted by sociologists over a 50-year period spanning the pre- and post-technological shock eras. In the initial study, Bell (1942) found a community that had been recently devastated by the Dust Bowl and Depression of the 1930s, and which suffered from a boom-and-bust pattern of wheat harvests due to volatile precipitation. This generated, he

observed, a “gambler’s psychology” which affected the entire community: “Agriculture dominates [the entire populace’s] existence and influences their attitudes in much the way that mining does a village in which the whole population derives its living from the mine. (p. 55)” Consistent with theories linking precarity to preferences for social insurance (Rawls 1999), a consequence was widespread belief in the legitimate role of government intervention: “Everyone interviewed, whether in favor of or opposed to the Government farm program was unanimous in the opinion that, as one man said: ‘If it had not been for the Government program, none of us would be here now. We simply could not have made it.’ (p. 66)”

When Mays (1968) revisited the county 25 years later, political attitudes had been transformed by the introduction of groundwater irrigation. With growing prosperity came a shift from a “gambler’s psychology” to a business-like belief in success linked to individual effort and increasing opposition to government intervention: “The [Haskell County farm operator] believes that he has won through to his present-day successes by virtue of his own efforts...if the government will remove its many controls, he can grow abundantly all that the country needs and receive good prices for his produce” (p. 112). These changes in attitudes extended beyond the affluent farmer: “The population now accepts as their ideal-type the farmer-capitalist, or agribusinessman, who has won out against great odds.” When sociologists revisited the county another 30 years later in 1993, they noted the emergence of factory-style industries like animal feedlots and meatpacking plants. They also documented the mass government skepticism that is characteristic of contemporary rural consciousness (Cramer 2016): “When asked about the problems facing their community, the two most frequently mentioned issues were increasing taxation and the loss of local control to the state and federal governments. (Williams and

Bloomquist 1996, p. 27)” Figure 2 presents aerial images of Haskell County taken in 1954 and 2006, respectively, illustrating the technological changes which have transformed not only the landscape but the politics of the county.

FIGURE 2 ABOUT HERE

As the conservative party on the economic dimension of political party competition in the United States (Poole and Rosenthal 2000), the Republican party’s pro-business orientation made it the electoral beneficiary of the spread of capital-intensive agriculture and the conservative transformation of rural political preferences. By contrast, the Democratic party’s association with pro-labor and environmental regulation as well as redistributive taxation have made it a comparative threat to agribusiness interests. These differences in party platforms have existed for at least a century but have hardened and polarized over time, especially since the Republican party’s embrace of a hardline anti-regulation stance during the 1980s, as well as the spatial polarization of the Republican and Democratic parties into rural- and urban-centered political coalitions, respectively (Hacker and Pierson 2010; Rodden 2019).

FIGURE 3 ABOUT HERE

As summarized in Figure 3, the central observable implication of the argument, therefore, is that areas more exposed to the post-war irrigation technology shock became more conservative (pro-Republican) in their voting patterns over time. In terms of mechanisms, we hypothesize that this was due to the increasing capital-intensity of agriculture and the growing economic and political

power of agribusiness interests with preferences for conservative economic policies, including limited regulation as well pro-business tax and spending policies. These interests exert broader influence on mass policy preferences through their “structural” and organizational power in agribusiness-dependent rural political economies. We therefore also expect to observe differences in mass attitudes concerning government taxation and regulation across areas more or less exposed to the post-war technological shock.

4. Empirical Strategy

To test the impact of the technological change on the rise of conservative voting in the Great Plains, this paper exploits the differential impact of the post-war irrigation technology shock across counties with different degrees of overlap with the Ogallala aquifer, an approximately 174,000-square-mile body of groundwater that underlies parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. The differential impact of the post-war technology shock is evidenced in a number of ways, for instance in large differences in the capitalized market value of farmland with and without access to the Ogallala aquifer (Hornbeck and Keskin 2014).

To validate this source of variation in exposure to technological change that underpins our empirical strategy, we develop estimates of the diffusion of center-pivot irrigation, using tools from the field of computer vision to detect the technology’s signature circular cropping patterns in historical satellite imagery. A detailed discussion is provided in the Online Appendix. In brief, we train a convolutional neural network (CNN) to count the number of center-pivot irrigation

circles observable in Landsat satellite imagery across counties over time in the Great Plains. CNNs are supervised learning algorithms which take images as input and as output make predictions about image characteristics (for a primer see e.g. Torres and Cantú 2022), in our case an estimate of the number of visible center-pivots.

We train a 15-layer CNN to take as input the 70×70 pixel Landsat 5 satellite image of a Public Land Survey System (PLSS) section – the 1 square mile unit of the grid that governs property rights in the western United States – and as output estimate the number of center-pivot irrigation systems visible in the image. To train the model, we use as “ground truth” labels a geo-coded inventory of center-pivot irrigation systems that was compiled through hand counting of crop circles in Landsat satellite imagery by a team of researchers for the state of Nebraska (Carlson 1989). We use this data to label the count of center-pivot irrigation systems in clipped satellite images – from which we compute the normalized difference vegetation index (NDVI) – for all PLSS sections in Nebraska between 1985 and 1987 ($N \approx 220,000$). With a CNN trained on this data, we count center-pivot irrigation systems visible in Landsat 5 satellite imagery in a massive number of PLSS sections across all of the Great Plains states for every year between 1985 and 2000 ($N \approx 10$ million), aggregating and normalizing by land area to get county-level estimates of technology adoption (center-pivots per 1000 sq kilometers) with near-human accuracy (R^2 of 0.94 in regressions of ground truth against our computer vision estimates in a test set). As Figure 4 illustrates in the case of Kansas, our procedure shows that center-pivot irrigation diffusion was heavily concentrated within the Ogallala aquifer boundary (a pattern we subject to formal statistical tests later in the paper).

FIGURE 4 ABOUT HERE

These patterns motivate the identification strategy, which exploits the timing of the post-war irrigation technology shock together with cross-sectional variation in groundwater availability in a spatially matched sample of counties along the boundary of the Ogallala aquifer in a difference-in-differences framework. In the main specifications, the paper estimates OLS regressions of the form,

$$Conservative_{it} = \alpha Aquifer_i + \beta Aquifer_i \times Post_t + \sum_s (\theta_s I_i^s + \theta_s I_i^s \times Post_t) + \varepsilon_{it},$$

where the outcome variable $Conservative_{it}$ is the Republican party's share of the two-party in vote in presidential, senatorial, or gubernatorial elections in county i and time period t (a pre-shock period averaging between 1920-1940 and a post-shock period averaging between 1980-2000). This data comes from Amlani and Algara (2021). In the equation, the variable $Aquifer_i$ represents the share of county overlying the Ogallala aquifer, which is computed using GIS analysis of shapefiles of county boundaries and a digital map of the aquifer's boundary assembled by the US Geological Survey (Qi 2010). The variable $Post_t$ is a time dummy variable which takes a value of one for the post-shock period and zero otherwise. All specifications control for state-period fixed effects $\sum_s (\theta_s I_i^s + \theta_s I_i^s \times Post_t)$. This means that the coefficient β represents the estimate of the change in outcomes from the pre-shock period to the post-shock period in a county with complete aquifer coverage relative to a county with no aquifer coverage, comparing between counties located within the same state.

For robustness, we estimate the difference-in-differences regression equation above in a spatially matched sample of counties along the boundary of the Ogallala aquifer. To implement the spatial matching in a manner that preserves the within-state difference-in-differences design we: i) identify the line segment of the Ogallala aquifer boundary intersecting each state; ii) compute the geodesic distance of each county centroid in each state to the nearest point on the within-state line segment; and iii) prune from the sample any counties beyond a given buffer (200 kilometers or 100 kilometers) based on this distance metric. This ensures that all estimates are derived strictly from over-time comparisons between spatially proximate counties along the border of the Ogallala aquifer within the same state.

FIGURE 5 ABOUT HERE

The spatial matching is motivated by Tobler’s Law First Law of Geography (“near things are more related than distant things”). By limiting analysis to spatially proximate counties, we mitigate concerns about potentially confounding non-parallel trends that may result from comparing fundamentally dissimilar counties that are located far away from each other. However, a concern that arises is spatial spillovers – exposure to the technological shock potentially impacted the economies and electoral outcomes of nearby counties. To address this concern, in some specifications we prune counties on the boundary itself, so that the sample is restricted to “pure” treatment (completely within the aquifer) and control (completely outside of the aquifer) counties with those most at risk for spillovers pruned from the sample. Figure 5 depicts a comparison of the counties that are included in the full sample and those which are included in the spatially matched samples.

FIGURE 6 ABOUT HERE

Figure 6 provides a scatter plot representing the logic behind the empirical strategy. Panel A depicts the relationship between aquifer coverage and conservative voting across counties within 200km of the Ogallala aquifer boundary in the pre-technological shock period, after partialing out state fixed effects. For illustrative purposes, Kansas counties are represented with shaded points. We highlight the point that corresponds to Haskell County with a red diamond. As the scatter plot and fitted OLS regression line make clear, there was little association between aquifer coverage and the Republican party's share of the two-party presidential vote in the pre-shock period 1920-1940. A county like Haskell, which lies completely within the boundaries of the Ogallala aquifer, was no more conservative in its voting patterns than other counties in the same state with less overlap with the Ogallala aquifer.

Panel B depicts the same relationship in the post-shock period 1980-2000. As the scatterplot and fitted OLS regression line illustrate, counties with greater aquifer coverage experienced a greater improvement in the Republican party's electoral performance compared to counties with less aquifer coverage. Haskell County, for instance, evolved into one of the most conservative counties in Kansas. The scatter plot suggests that this pattern is not idiosyncratic to Haskell but is systematic. Counties with greater aquifer coverage on average experienced a greater long-term improvement in the Republican party's electoral performance compared to counties in the same state with less aquifer coverage, plausibly because they were more exposed to the post-war irrigation technology shock that transformed the Great Plains.

The identifying assumption in the difference-in-differences analyses is the parallel trends assumption, which in this case assumes that, counter-factually absent the post-war irrigation technology shock, counties with greater overlap with the Ogallala aquifer would have followed parallel electoral trends over time as compared to other spatially proximate counties within the same state with less overlap. In an additional set of specifications, to study pre- and post-technological shock time trends, this paper estimates regressions on a full county-year panel election dataset which flexibly interact the aquifer coverage variable with decadal dummy variables, while also controlling for state-year effects. If the parallel trends assumption is valid, then there should have been no trend in the association between aquifer coverage and conservative voting in the decades preceding the technological shock but a large and positive relationship that emerged in the decades following the technological shock.

To account for correlation of errors within counties over time, as well as correlation of errors across space in a given election, we estimate standard errors adjusted for two-way clustering within counties and within state-periods. We also estimate Conley standard errors which correct for spatial correlation within a given radius of county centroids (we use a 200km radius) as well as serial correlation. Throughout, we limit the sample to counties (93 percent of the sample) with stable boundaries between the start year of 1920 and the end year of 2000 (the preceding decades of the 1900s and 1910s were characterized by a large number of boundary changes, including the admission of New Mexico and Oklahoma as new states). We drop counties in Montana and North Dakota as they do not intersect with the Ogallala aquifer and therefore do not contribute to estimation because they are fully absorbed by state-period fixed effects.

4. Main Results

Table 1 presents the main set of results. Panel A reports analyses using the full sample of counties, panel B for the 200km buffer sample of counties and panel C for the 100km buffer sample of counties. Columns (1)-(3) report coefficient estimates for the baseline specification, which indicate that the post-war irrigation technology shock had a large impact on conservative (pro-Republican) voting. For instance, the coefficients on the interaction term in panel B (the 200km buffer sample) suggest that compared to a spatially proximate county with no aquifer coverage in the same state, a county with full aquifer coverage experienced a 9.7 percentage point relative increase in the Republican party's share of the two-party vote in presidential elections, a 7.8 percentage point relative increase in senatorial elections, and a 6.4 percentage point relative increase in gubernatorial elections from the pre- to the post-technological shock period. By contrast, the coefficients on the lower order term indicate that there was no association between aquifer coverage and conservative voting across counties in the pre-technological shock period.

TABLE 1 ABOUT HERE

Columns (4)-(6) additionally control for county-level exposure to two pre-treatment shocks which affected the Great Plains: the Dust Bowl, the drought and dust storms which wracked much of the region, as well as the New Deal, which greatly impacted rural areas. To measure county-level exposure to the Dust Bowl, we digitize historical soil erosion maps published by the

Soil Conservation Service and compute a measure of the share of county land impacted by “severe wind erosion” by 1937 (see Online Appendix for details). To compute exposure to the New Deal, we use a summary measure of spending across major programs per capita based on the dataset assembled by Fishback, Horrace, and Kantor (2005). We include these variables as lower order terms as well as in interaction with post-technological shock time-based dummy variable in order to absorb potential non-parallel trends across counties as a function of these pre-treatment shock variables. While the coefficients of interest shrink slightly, they remain large and positive across specifications.

Columns (7)-(9) address concerns about spatial spillovers by pruning counties partially intersecting the boundary of the Ogallala aquifer, so that the sample is comprised only of “pure” treatment counties fully contained within the aquifer and control counties fully outside of the aquifer. Consistent with the existence of spatial spillovers, the coefficients tend to become larger in this specification. Estimates from the 200km buffer sample suggest that compared to a spatially proximate county with no aquifer coverage in the same state, a county with full aquifer coverage experienced a 10.8 percentage point relative increase in the Republican party’s share of the two-party vote in presidential elections, a 8.1 percentage point relative increase in senatorial elections, and a 6.7 percentage point relative increase in gubernatorial elections from the pre- to the post-technological shock period.

This helps to make sense of a noticeable pattern: across empirical specifications, though the coefficients remain substantively large and statistically significant, the estimated magnitude of the impact of the technological shock tends to be smaller in specifications that prune the sample

to a smaller buffer along the boundary of the Ogallala aquifer. While some of this may be due to the elimination of potentially confounding differences between spatially distant counties, it may also be due to the existence of spatial spillovers, which tend to attenuate estimates, especially in spatially proximate samples.

Another empirical pattern that emerges from the estimates is that across samples and specifications, the coefficient estimates are consistently greater in magnitude in the case of presidential voting than in senatorial elections, and greater in senatorial elections than in gubernatorial elections. One reason for this may be due to the dynamics of party positioning. In national elections, the platforms of the Democratic and Republican parties are sharply polarized, whereas in more state-specific elections, the Democratic party may have greater scope to moderate its platforms to win over rural voters. For instance, in a state like Kansas, a Democratic presidential candidate has not won the state's electoral college votes since 1964. However, Democratic candidates routinely win gubernatorial elections in the state and the party remains competitive with the Republican party.

Were these effects plausibly due to the disproportionate impact of the post-war irrigation technology shock in counties with greater overlap with the Ogallala aquifer? Table 2 estimates the same type of regressions but now looks at measures of irrigation technology adoption as the outcome variable. Columns (1)-(3) look at impacts on the percentage of county farmland that is irrigated according to agricultural censuses. The coefficient estimate in column (2) based on a 200km buffer sample suggests that a county with full aquifer coverage experienced an approximately 13.8 percentage point improvement in irrigation from the 1920-1940 period to the

1980-2000 period, relative to a spatially proximate county with no aquifer coverage in the same state. Columns (4)-(6) look at a particularly capital-intensive form of irrigation – center-pivot irrigation – as estimated from satellite imagery. The estimate from column (5) suggests that a county with full aquifer coverage gained approximately 105 additional center-pivot irrigation systems per 1000 sq km from the 1920-1940 period to the 1980-2000 period, relative to a county with no aquifer coverage in the same state.

Putting together the estimates from Table 1 and Table 2, we find robust evidence that counties with greater aquifer coverage experienced a relative improvement in irrigation as well increase in electoral conservatism following the post-war irrigation technology shock. For instance, combining estimates from the specifications based on a spatially matched sample of counties within a 200km distance to the Ogallala aquifer boundary, the estimates suggest that for every 1 percentage point relative improvement in irrigated farmland due to greater aquifer coverage, the Republican party experienced an approximately 0.7 percentage point relative improvement in its share of the two-party vote in presidential elections.

An important question concerns the timing of these impacts. Table 3 reports coefficients from flexible specifications using a full county-year panel dataset of election returns and reporting coefficients on decadal dummy variables interacted with the aquifer coverage variable, controlling for state-year fixed effects. Columns (1)-(3) examine the Republican party's share of the two-party vote in presidential elections, while columns (4)-(6) examine senatorial elections, and columns (7)-(9) gubernatorial elections. The coefficients indicate that across empirical samples and type of election, there was no statistically detectable association between aquifer

coverage and conservative voting in the 1910s, 1920s and 1930s and that this null relationship was stable until a positive relationship began to emerge in the 1940s and 1950s, exactly when the new irrigation technologies were introduced. These effects grew over time, consistent with the gradual uptake of irrigation technologies. Columns (10)-(12) report a parallel set of results for the spread of irrigation. These show that, prior to the availability of technology needed to exploit groundwater at scale, there was no association between county-level aquifer coverage and the irrigation but a large and positive relationship that emerged from the post-shock period onwards.

TABLE 3 ABOUT HERE

Figure 7 subjects the association between aquifer coverage and conservative voting to statistical tests for pre- and post-shock trends by omitting the interaction term between aquifer coverage and the dummy variable indicating the 1930s (the decade preceding the introduction of the new irrigation technology) and including state-year fixed effects and county fixed effects (to deal with sample selection issues as some counties drop out in the 1910s). This permits an analysis of whether the relationship between aquifer coverage and outcomes displayed a statistically detectable difference relative to that existing in the 1930s. As panels A through C indicate, there was no visibly confounding pre-trend in the estimated relationship between aquifer coverage and conservative voting prior to the technological shock, but a large positive trend that emerged thereafter, due to the disproportionate spread of irrigation to counties with greater aquifer overlap from the 1940s onward as documented in panel D.

FIGURE 7 ABOUT HERE

5. Tests of Channels

Were these effects due to the spread of increasingly capital-intensive agriculture and agribusiness interests with conservative policy preferences, as has been argued? Or were they potentially due to other factors? This section of the paper explores potential channels by empirically examining the impact of the technological shock on a range of intermediate outcomes measured from agricultural, population, and religious censuses (descriptive statistics are available in the Online Appendix).

TABLE 4 ABOUT HERE

FIGURE 8 ABOUT HERE

Table 4 investigates the decade-by-decade association between aquifer coverage and different outcomes. Columns (1) and (2) investigate the impact of the post-war irrigation technology shock on the capital intensity of agriculture, as proxied by the natural log of the average market value of farms in 2016 dollars (computed from agricultural censuses by dividing the total market value of farm land, buildings, and machinery by the number of farms in a county) and the number of farms per 1000 acres of county land. As the coefficients indicate, farms in counties with greater aquifer coverage were no more valuable than in counties with less and actually slightly less dense in the decades preceding the post-war shock. Areas with greater aquifer coverage experienced a large relative increase in both the market value and density of farms

following the technological shock. Panels A and B of Figure 8 subject these time trends to a statistical test and gives a sense of their magnitude by scaling the vertical axis by plus or minus a standard deviation of the outcome variable.

Column (3) looks at the share of the employed population working in agricultural occupations (an under-estimate as it includes only those working directly on farms but excludes those working in related industries) as reported by population censuses. The estimates show that counties with greater aquifer coverage employed a larger share of the population in agriculture to begin with, though this did not change over time in absolute terms. In relative terms, however, counties with greater aquifer coverage remained more agricultural in their workforce in a context of long-term secular decline in farm employment. In the Great Plains, 13 percent of the working population was employed in agricultural occupations in the 1990s, down from 51 percent in the 1930s. In this context, retention of an additional five percentage points of the workforce in the farm sector in the 1990s implies a difference that is large in percent terms. Panel C of Figure 8 demonstrates this by taking the natural log of the agricultural employment variable so that coefficients have a percent change interpretation. These results suggest that the increasing capital intensity of farming, together with the entrenchment of local economic dependence upon the agricultural sector, plausibly played an important role in the increasing electoral conservatism of counties more impacted by the post-war irrigation technology shock as a result of greater overlap with the Ogallala aquifer.

But could the conservative electoral shift in counties with greater aquifer coverage be explained by alternative mechanisms? One explanation for rural conservatism, the race-related polarization

that led to party realignment in the US south following the civil rights movement and the passage of the voting rights act, does not appear to be very relevant in this context. Those processes gained steam in the 1960s, whereas analyses of the timing of effects suggest that counties with greater aquifer coverage started to shift in a conservative electoral direction relative to counties with less nearly 20 years earlier beginning in the 1940s. Moreover, due to the inclusion of state-period fixed effects, all estimates are identified from within-state comparisons, so broad regional or state-level realignments cannot be driving the increase in conservative voting in areas impacted by the new irrigation technologies.

One of the best cross-sectional predictors of county-level voting patterns is a county's population density (Rodden 2019). Could the results be driven by a process of de-population and de-urbanization, as improved agriculturally productivity keeps places relatively more rural? This is not supported by the data. Column (4) of Table 4 and panel D of Figure 8 reveal that counties with greater aquifer coverage experienced a modest relative decline in their levels of population density over time relative to counties with less aquifer coverage, though they were slightly less dense to begin with. Column (5) of Table 4 and panel E of Figure 8 show that counties with greater aquifer experienced a relative *improvement* in urbanization (the percent of the population living in census-defined urban areas) over time, plausibly due to the formation of small towns in areas of intensive agriculture. These set of results do not support the idea that the conservative shift was driven by intrinsic differences in the degree of rurality as measured with differences in population density or urbanization rates.

Finally, could the conservative shift be explained by the spread of social conservatism in rural places? Column (5) looks at decadal associations between aquifer coverage religiosity as proxied by the church membership per capita, computed by summing county-level membership reported by all churches and religious bodies to religious censuses and dividing by the total county population as reported in the next decennial census. The coefficients reveal a modest but statistically insignificant relative increase in religiosity, casting doubt on this channel. To the extent that we observe some relative increase in the religiosity of counties with greater aquifer coverage, this may have been a long-term *feedback effect* of these areas' alignment with the Republican party, as the following analyses demonstrate.

6. Contemporary Policy Preferences

This section assembles geo-coded survey data on contemporary policy preferences and compares the reported preferences of individuals residing inside the Ogallala aquifer, where capital intensive agriculture thrives as a result of the long-term legacy of the post-war irrigation technology shock, to those of individuals residing outside of the aquifer. We utilize data from the Cooperative Congressional Election Survey (CCES) waves conducted between 2006 and 2020 (Kuriwaki 2021), comprising tens of thousands of respondents in annual nationally representative samples, which together provide a large sample of respondents located in the Great Plains who can be geo-coded to the zip code level, an area of aggregation even smaller than that of the county.

The explanatory variable is the share of a respondent's zip code that overlies the Ogallala aquifer. Depending upon specification we prune the sample to zip codes within 200km or 100km distance to the boundary of the Ogallala aquifer in each state. In the preferred specification, we use the 100km buffer and prune from the sample zip codes partially overlying the Ogallala aquifer. We control for state-survey wave fixed effects, so that the estimates are driven by comparisons between individuals who live in zip codes completely (but barely) within the boundaries of the Ogallala aquifer and individuals who live in zip codes completely (but barely) outside of the boundaries, comparing between individuals in the same state and surveyed in the same year. All regressions are estimated by weighted least squares, utilizing cumulative survey weights, with standard errors clustered by state-survey wave and county.

FIGURE 9 ABOUT HERE

TABLE 5 ABOUT HERE

Table 5 reports the results, looking at how reported policy preferences differ across individuals living just inside versus outside of the boundaries of the Ogallala aquifer on nine different issues reflecting conservatism on regulation, tax and spending, and cultural issues. Column (1)-(3) of panel D (the preferred specification) indicates that people living just inside the boundaries of the Ogallala aquifer are about 10 percentage points more likely to express opposition to strengthened enforcement of the Clean Air Act and Clean Water Act if it costs US jobs, consistent with the opposition of agribusiness interests to environmental regulation. They are about 6.5 percentage points more likely to support the repeal of the Affordable Care Act, which imposes health

insurance mandates on large-scale employers of hired labor. Column (3) suggests that they are 6 percentage points more likely to oppose fines for employers hiring undocumented laborers, a practice common at agribusiness firms and farms. Some coefficients are imprecisely estimated, though this is due to a loss of statistical power as the sample is pruned; the coefficient estimates in Panel D are virtually identical to those of specifications (in panels A through C) which use larger samples and report statistically significant coefficient estimates due to a greater number of observations and smaller standard errors.

Columns (4)-(6) investigate differences in policy preferences regarding tax and spending issues. Column (4) indicates that respondents living inside the Ogallala aquifer boundary are 10.1 percentage points more likely to support prohibiting immigrants from access to public services, consistent with preferences for small government, especially forms of spending that would benefit workers. Column (5) indicates that people residing inside the boundaries of the Ogallala aquifer are relatively more likely to favor cutting spending, as opposed to raising taxes, in order to pay for a budget deficit, also indicating a preference for small government. Column (6) indicates that respondents living inside the Ogallala aquifer boundary are about 7.9 percentage points more likely to support cutting government spending on welfare, a stance consistent with opposition to redistributive taxation and spending.

Columns (7)-(9) investigate policy preferences on polarizing “culture war” issues as opposed to purely economic issues. Column (7) indicates that respondents living inside the boundaries of the Ogallala aquifer are about 9 percentage points more likely to oppose always giving a woman the right to choose to have an abortion under any circumstances. Column (8) suggests that

respondents living inside versus outside of the boundary of the aquifer do not significantly differ in their attitudes towards requiring background checks for all gun purchases. Column (9) indicates that respondents are slightly (about 2.4 percentage points) more likely to express opposition to affirmative action, a question that touches on issues related to race. These results suggest that technological change may have had some spillover effects on social/moral attitudes. This may reflect the strategic bundling of social and economic issues by political parties, and is a topic that deserves further research.

7. Conclusion

At the turn of the twentieth century, the Great Plains were a politically centrist region which often supported left-wing parties and politicians like those belonging to the Populist movement. But by the end of the twentieth century, large swathes of the Great Plains had evolved into some of the most conservative and pro-Republican areas in the United States, typifying the conservative electoral shift that took place across rural America and that indeed has taken place in the rural sector in other advanced capitalist economies.

What explains this puzzling transformation? In a lively debate (Bartels 2006; Frank 2007; Gelman 2009), scholars have debated the extent to which the culture wars and other cleavages which cut across class-based divides have contributed to the rise of rural conservatism. In this paper, we have suggested that much of the historical rise of rural conservatism can be traced to economic self-interest conceptualized in terms of the industries that dominate in rural areas. Long-term technological change gave rise to increasingly capital-intensive agriculture and the

growing economic and political power of agribusiness interests which benefit from conservative economic policies. These agricultural transformations have had far-reaching consequences, playing a major role in the long-term transformation of rural states into red states – whose political power is amplified by a territorial upper chamber – as well as the spatial polarization of politics into a right-left, rural-urban divide (Cramer 2016; Grumbach, Hacker, and Pierson 2021; Rodden 2019).

Drawing on a historical natural experiment – the post-war introduction of new irrigation technologies which disproportionately impacted counties with greater overlap with the Ogallala aquifer – this paper has provided causally identified evidence that technological change played a large role in the long-term rise of rural conservatism. The legacy of the post-war irrigation technology shock is visible from space in the circular irrigated fields that dominate land inside the Ogallala aquifer. It is also visible in the distinctly conservative economic policy preferences that differentiate individuals living just inside the boundaries of the Ogallala aquifer from those living just outside.

The results indicate several pathways for future research. It is important to further explore *how* affluent farmers and agribusiness interests exercise outsized political influence in rural America. We have argued that this is due both to the “structural” power of agribusiness in rural economies as well as the organizational advantages of land and business owners, though future qualitative and quantitative research could provide more direct evidence on these dynamics. We have also documented potential spillover effects of long-term technological and economic change on social/moral attitudes, potentially due to the feedback effects of the strategic bundling of

economic and social issues by political parties. Studying the micro-dynamics of how affluence translates into influence in rural areas, and how economic policy preferences and cultural beliefs co-evolve, are important tasks for future empirical research.

7. References

- Aldrich, John H. 1995. *Why Parties? The Origin and Transformation of Political Parties in America*. University of Chicago Press.
- Amlani, Sharif, and Carlos Algara. 2021. "Partisanship & Nationalization in American Elections: Evidence from Presidential, Senatorial, & Gubernatorial Elections in the US Counties, 1872–2020." *Electoral Studies* 73: 102387.
- Anderson, Joseph. 2009. *Industrializing the Corn Belt: Iowa Farmers, Technology and the Midwestern Landscape, 1945-1972*. Northern Illinois University Press.
- . 2018. "How Center Pivot Irrigation Brought the Dust Bowl Back to Life." *Smithsonian Magazine*.
- Bartels, Larry M. 2006. "What's the Matter with What's the Matter with Kansas?" *Quarterly Journal of Political Science* 1(2): 201–26.
- Bell, Earl H. 1942. *Culture of a Contemporary Rural Community: Sublette, Kansas*. Washington DC: United States Department of Agriculture.
- Bessire, Lucas. 2021. *Running Out: In Search of Water on the High Plains*. Princeton University Press.
- Bloomquist, Leonard, Duane Williams, and J. Bridger. 2002. "Sublette, Kansas: Persistence and Change in Haskell County." *Persistence and Change in Rural Communities*. CABI Publishing, Wallingford, Oxford: 23–43.
- Boix, Carles. 2015. *Political Order and Inequality*. Cambridge University Press.
- Carlson, Marvin P. 1989. "The Nebraska Center-Pivot Inventory: An Example of Operational Satellite Remote Sensing on a Long-Term Basis." *Photogramm. Eng. Remote Sens* 55: 587–90.
- Cook, Benjamin I., Ron L. Miller, and Richard Seager. 2009. "Amplification of the North American 'Dust Bowl' Drought through Human-Induced Land Degradation." *Proceedings of the National Academy of Sciences* 106(13): 4997–5001.
- Cooper, Jasper, Sung Eun Kim, and Johannes Urpelainen. 2018. "The Broad Impact of a Narrow Conflict: How Natural Resource Windfalls Shape Policy and Politics." *The Journal of Politics* 80(2): 630–46.
- Cramer, Katherine J. 2016. *The Politics of Resentment: Rural Consciousness in Wisconsin and the Rise of Scott Walker*. University of Chicago Press.
- Cunfer, Geoff. 2005. *On the Great Plains: Agriculture and Environment*. Texas A&M University Press.

- Dasgupta, Aditya. 2018. “Technological Change and Political Turnover: The Democratizing Effects of the Green Revolution in India.” *American Political Science Review* 112(4): 918–38.
- Dimitri, Carolyn, Anne Effland, and Neilson Conklin. 2005. “The 20th Century Transformation of US Agriculture and Farm Policy.” *Economic Research Service-United States Department of Agriculture Bulletin* No. 3.
- Edwards, Eric C., and Steven M. Smith. 2018. “The Role of Irrigation in the Development of Agriculture in the United States.” *The Journal of Economic History* 78(4): 1103–41.
- Finegold, Kenneth, and Theda Skocpol. 1995. *State and Party in America’s New Deal*. University of Wisconsin Press.
- Fishback, Price V., William C. Horrace, and Shawn Kantor. 2005. “Did New Deal Grant Programs Stimulate Local Economies? A Study of Federal Grants and Retail Sales during the Great Depression.” *The Journal of Economic History* 65(1): 36–71.
- Frank, Thomas. 2007. *What’s the Matter with Kansas? How Conservatives Won the Heart of America*. Metropolitan Books.
- Gaventa, John. 1982. *Power and Powerlessness: Quiescence and Rebellion in an Appalachian Valley*. University of Illinois Press.
- Gelman, Andrew. 2009. *Red State, Blue State, Rich State, Poor State*. Princeton University Press.
- Grumbach, Jacob M., Jacob S. Hacker, and Paul Pierson. 2021. “The Political Economies of Red States.” *The American Political Economy: Politics, Markets, and Power*: 209.
- Hacker, Jacob S., Alexander Hertel-Fernandez, Paul Pierson, and Kathleen Thelen. 2021. *The American Political Economy: Politics, Markets, and Power*. Cambridge University Press.
- Hacker, Jacob S., and Paul Pierson. 2010. “Winner-Take-All Politics: Public Policy, Political Organization, and the Precipitous Rise of Top Incomes in the United States.” *Politics & Society* 38(2): 152–204.
- . 2020. *Let Them Eat Tweets: How the Right Rules in an Age of Extreme Inequality*. Liveright Publishing.
- Hamilton, Shane. 2014. “Agribusiness, the Family Farm, and the Politics of Technological Determinism in the Post–World War II United States.” *Technology and Culture*: 560–90.
- Hansen, John. 1991. *Gaining Access: Congress and the Farm Lobby, 1919–1981*. University of Chicago Press.
- Hansen, Zeynep K., and Gary D. Libecap. 2004. “Small Farms, Externalities, and the Dust Bowl of the 1930s.” *Journal of Political Economy* 112(3): 665–94.

- Hornbeck, Richard. 2012. "The Enduring Impact of the American Dust Bowl: Short-and Long-Run Adjustments to Environmental Catastrophe." *American Economic Review* 102(4): 1477–1507.
- Hornbeck, Richard, and Pinar Keskin. 2014. "The Historically Evolving Impact of the Ogallala Aquifer: Agricultural Adaptation to Groundwater and Drought." *American Economic Journal: Applied Economics* 6(1): 190–219.
- Iversen, Torben. 2006. "Capitalism and Democracy." In *The Oxford Handbook of Political Science*, Oxford University Press.
- Kuriwaki, Shiro. 2021. "Cumulative CCES Common Content (2006-2020)." URL: <https://doi.org/10.7910/DVN/II2DB6>.
- Lee, Woojin, and John E. Roemer. 2006. "Racism and Redistribution in the United States: A Solution to the Problem of American Exceptionalism." *Journal of public Economics* 90(6–7): 1027–52.
- Libecap, Gary D., and Zeynep Kocabiyik Hansen. 2002. "'Rain Follows the Plow' and Dryfarming Doctrine: The Climate Information Problem and Homestead Failure in the Upper Great Plains, 1890–1925." *The Journal of Economic History* 62(1): 86–120.
- Lipset, Seymour Martin. 1950. *Agrarian Socialism*. University of California Press.
- Luebbert, Gregory M. 1987. "Social Foundations of Political Order in Interwar Europe." *World Politics* 39(4): 449–78.
- Mays, William E. 1968. *Sublette Revisited: Stability and Change in a Rural Kansas Community After a Quarter Century*. New York: Florham Park Press.
- McWilliams, Carey. 1939. *Factories in the Field: The Story of Migratory Farm Labor in California*. Little, Brown & Co.
- Meltzer, Allan H., and Scott F. Richard. 1981. "A Rational Theory of the Size of Government." *Journal of political Economy* 89(5): 914–27.
- Moore, Barrington. 1966. *Social Origins of Dictatorship and Democracy: Lord and Peasant in the Making of the Modern World*. Beacon Press.
- Olmstead, Alan L., and Paul W. Rhode. 2001. "Reshaping the Landscape: The Impact and Diffusion of the Tractor in American Agriculture, 1910-1960." *Journal of Economic history*: 663–98.
- . 2008. *Creating Abundance*. Cambridge University Press.
- Opie, John. 2000. *Ogallala: Water for a Dry Land*. University of Nebraska Press.

- Ostler, Jeffrey. 1993. *Prairie Populism: The Fate of Agrarian Radicalism in Kansas, Nebraska, and Iowa, 1880-1892*. University Press of Kansas.
- Pachirat, Timothy. 2011. *Every Twelve Seconds: Industrial Slaughter and the Politics of Sight*. Yale University Press.
- Pardey, Philip G., and Julian M. Alston. 2021. “Unpacking the Agricultural Black Box: The Rise and Fall of American Farm Productivity Growth.” *The Journal of Economic History* 81(1): 114–55.
- Poole, Keith T., and Howard Rosenthal. 2000. *Congress: A Political-Economic History of Roll Call Voting*. Oxford University Press.
- Przeworski, Adam, and Michael Wallerstein. 1988. “Structural Dependence of the State on Capital.” *American Political Science Review* 82(1): 11–29.
- Qi, Sharon. 2010. *Digital Map of Aquifer Boundary for the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming*. US Geological Survey.
- Rawls, John. 1999. *A Theory of Justice: Revised Edition*. Harvard University Press.
- Rodden, Jonathan A. 2019. *Why Cities Lose: The Deep Roots of the Urban-Rural Political Divide*. Basic Books.
- Sances, Michael W., and Hye Young You. Forthcoming. “Voters and Donors: The Unequal Political Consequences of Fracking.” *Journal of Politics*.
- Sheingate, Adam D. 2003. *The Rise of the Agricultural Welfare State: Institutions and Interest Group Power in the United States, France, and Japan*. Princeton University Press.
- Splinter, William E. 1976. “Center-Pivot Irrigation.” *Scientific American* 234(6): 90–99.
- Stull, Donald D., Michael J. Broadway, and David Griffith. 1995. *Any Way You Cut It: Meat Processing and Small-Town America*. University Press of Kansas.
- Torres, Michelle, and Francisco Cantú. 2022. “Learning to See: Convolutional Neural Networks for the Analysis of Social Science Data.” *Political Analysis* 30(1): 113–31.
- Walsh, Katherine Cramer. 2012. “Putting Inequality in Its Place: Rural Consciousness and the Power of Perspective.” *American Political Science Review* 106(3): 517–32.
- Williams, Duane, and Leonard Bloomquist. 1996. *From Dust Bowl to Green Circles: A Case Study of Haskell County, Kansas*. Bulletin 662. Agricultural Experiment Station, Kansas State University.
- Worster, Donald. 1992. *Rivers of Empire: Water, Aridity, and the Growth of the American West*. Oxford University Press.

FIGURE I. County-level Republican Vote Share in Presidential Elections

Notes: Panel A and B depict counties shaded by average Republican percentage of the two-party vote in presidential elections between 1920 and 1940 and between 1980 and 2000, respectively. See Online Appendix for comparable maps for Senatorial and Gubernatorial Elections.

FIGURE II. Aerial Imagery of Haskell County, Kansas

Notes: Left-hand image is aerial photograph taken on December 19, 1954. Right-hand image is aerial photograph taken on June 18, 2006. Source: USGS Earth Explorer. For more details on the post-war technological shock, see the Online Appendix.

FIGURE III. Theoretical Diagram

FIGURE IV. Computer Vision Estimates of Technology Diffusion

(b) Counting Center-pivots in Satellite Imagery

(a) Convolutional Neural Network Architecture

(c) Section-wise Estimates for Kansas 2000

Notes: Panel A depicts 15-layer CNN architecture that takes a 70x70 pixel image as input and makes a regression estimate of number of center-pivots. Panel B depicts estimates of center-pivot irrigation by PLSS section (base layer is NDVI computed from Landsat 5 imagery) in Haskell County, KS, 2000 (total center-pivots counted is ≈ 813). Panel C depicts rounded estimates of center-pivot irrigation across all PLSS sections in Kansas in year 2000 (total center-pivots counted is ≈ 21662). Panel D depicts county-level quartile of center-pivots per 1000 sq km averaged between 1985-2000.

(d) County-level Technology Adoption

FIGURE V. Spatial Matching

Notes: Panels depict counties included in different spatially matched samples of counties. Counties shaded by degree of aquifer coverage.

FIGURE VI. Aquifer Coverage and Conservative Voting Before and After Technological Shock

Notes: Unit of analysis is the county (200km buffer zone sample). Shaded points correspond to counties in Kansas. Panel A and B depict residual correlation between county level aquifer coverage and the Republican share of the two-party vote in presidential elections after partialling out state fixed effects in the pre-shock (1920–1940) and post-shock (1980–2000) period, respectively.

TABLE I. Impact of Technological Shock on Conservative Voting

	Republican Share of Two-party Vote								
	Baseline			Time-interacted Covariates			Pure Treatment/Control		
	President	Senator	Governor	President	Senator	Governor	President	Senator	Governor
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
<i>Panel A: Full Sample</i>									
Aquifer×Post-shock	0.117*** (0.022) [0.021]	0.103*** (0.022) [0.019]	0.086*** (0.015) [0.019]	0.085*** (0.019) [0.019]	0.073*** (0.020) [0.018]	0.060*** (0.014) [0.017]	0.122*** (0.022) [0.020]	0.100*** (0.020) [0.017]	0.088*** (0.012) [0.019]
Aquifer	0.007 (0.015) [0.012]	0.003 (0.013) [0.011]	0.012 (0.012) [0.012]	0.017 (0.014) [0.012]	0.009 (0.015) [0.012]	0.012 (0.013) [0.011]	0.005 (0.018) [0.013]	0.007 (0.010) [0.010]	0.015 (0.009) [0.012]
Observations	1,350	1,350	1,350	1,350	1,350	1,350	1,072	1,072	1,072
Adjusted R ²	0.774	0.857	0.815	0.775	0.859	0.817	0.765	0.855	0.816
<i>Panel B: 200km Sample</i>									
Aquifer×Post-shock	0.097*** (0.024) [0.019]	0.078*** (0.021) [0.017]	0.064*** (0.017) [0.018]	0.071*** (0.021) [0.019]	0.055** (0.021) [0.018]	0.046** (0.017) [0.018]	0.108*** (0.025) [0.019]	0.081*** (0.020) [0.016]	0.067*** (0.014) [0.018]
Aquifer	0.006 (0.019) [0.011]	0.007 (0.015) [0.010]	0.014 (0.015) [0.011]	0.014 (0.016) [0.012]	0.013 (0.017) [0.011]	0.012 (0.015) [0.011]	0.003 (0.023) [0.012]	0.010 (0.013) [0.009]	0.018 (0.014) [0.011]
Observations	826	826	826	826	826	826	548	548	548
Adjusted R ²	0.788	0.861	0.806	0.790	0.863	0.809	0.780	0.859	0.807
<i>Panel C: 100km Sample</i>									
Aquifer×Post-shock	0.072** (0.025) [0.021]	0.055** (0.021) [0.019]	0.042** (0.018) [0.020]	0.053** (0.022) [0.019]	0.038* (0.020) [0.017]	0.029 (0.017) [0.017]	0.082** (0.029) [0.019]	0.057** (0.023) [0.019]	0.042** (0.017) [0.021]
Aquifer	0.017 (0.019) [0.011]	0.019 (0.014) [0.010]	0.024 (0.016) [0.012]	0.019 (0.017) [0.011]	0.018 (0.016) [0.011]	0.018 (0.015) [0.011]	0.015 (0.024) [0.011]	0.022 (0.014) [0.009]	0.029 (0.016) [0.012]
Observations	562	562	562	562	562	562	284	284	284
Adjusted R ²	0.821	0.880	0.829	0.822	0.882	0.834	0.819	0.884	0.839
State-period Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time-interacted Controls	No	No	No	Yes	Yes	Yes	No	No	No
Pure treatment/Control	No	No	No	No	No	No	Yes	Yes	Yes

Notes: Unit of analysis is county-period average (pre-period is 1920-1940 and post-period is 1980-2000). Republican Vote is the Republican party's share of the two-party vote in presidential, senatorial, or gubernatorial elections, depending on specification. Aquifer is a cross-sectional measure of the share of county land overlying Ogallala aquifer. Post-shock is a time dummy variable taking a value of one for the post-shock period and zero otherwise. Control variables are per capita New Deal spending and share of county land exposed to severe wind erosion during the Dust Bowl, interacted with time. Analysis estimated by OLS. Standard errors adjusted for clustering by county and state-period reported in parentheses: *p<0.1; **p<0.05; ***p<0.01. Conley standard errors adjusted for serial correlation and spatial correlation within a 200km radius of county centroids reported in brackets.

TABLE II. Impact of Technological Shock on Irrigation Uptake

	<i>Dependent variable:</i>					
	Irrigation (% Farmland)			Center-Pivots (per 1000 sq km)		
	(1)	(2)	(3)	(4)	(5)	(6)
Aquifer×Post-shock	14.025*** (2.421) [2.355]	13.891*** (1.964) [2.222]	15.576*** (2.350) [2.423]	106.745*** (20.300) [19.411]	104.533*** (22.015) [20.715]	125.598*** (18.035) [19.932]
Aquifer	−1.238 (1.333) [0.666]	−0.539 (0.855) [0.473]	−0.327 (0.871) [0.524]	0.000 (0.000) [0.000]	0.000 (0.000) [0.000]	0.000 (0.000) [0.000]
County FE	Yes	Yes	Yes	Yes	Yes	Yes
State-period FE	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Full	200-km	100-km	Full	200-km	100-km
Observations	1,350	826	562	1,045	697	473
Adjusted R ²	0.409	0.438	0.485	0.579	0.553	0.594

Notes: Unit of analysis is county-period average (1920-1940 average comprises pre-period and 1980-2000 average comprises post period). Irrigation is average percentage of farmland that is irrigated as computed from agricultural censuses conducted in 1920, 1925, 1930, 1935, 1940 (pre-period) and 1982, 1987, 1992, and 1997 (post-period). Center pivots is computer vision estimate of center-pivot irrigation systems per 1000 sq kilometers from satellite imagery averaged 1985-2000 (the variable takes a value of zero for all counties in the pre-shock period as the technology did not exist at this time). Analysis estimated by OLS. Standard errors adjusted for clustering by county and state-period reported in parentheses. Conley standard errors adjusted for serial correlation and spatial correlation within a 200km radius of county centroids reported in brackets.

TABLE III. Technological Change and Elections Over Time

	President (Republican Share)			Senator (Republican Share)			Governor (Republican Share)			Irrigation (% Farmland)		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Aquifer×1910s	-0.038*** (0.012)	-0.013 (0.014)	0.008 (0.015)	-0.008 (0.016)	0.006 (0.015)	0.016 (0.014)	-0.002 (0.013)	0.018 (0.011)	0.027*** (0.010)	-2.447 (2.541)	-1.793 (1.984)	-1.587 (1.881)
Aquifer×1920s	0.029 (0.019)	0.023** (0.011)	0.032** (0.013)	0.013 (0.014)	0.016 (0.015)	0.023 (0.015)	0.001 (0.015)	0.010 (0.013)	0.019 (0.014)	-1.606 (1.414)	-0.744 (0.799)	-0.476 (0.781)
Aquifer×1930s	-0.021 (0.015)	-0.020 (0.016)	-0.006 (0.014)	-0.010 (0.011)	-0.009 (0.012)	0.004 (0.011)	0.021 (0.014)	0.017 (0.012)	0.027** (0.012)	-1.167 (0.935)	-0.547 (0.680)	-0.415 (0.795)
Aquifer×1940s	0.004 (0.013)	0.017 (0.016)	0.026 (0.016)	0.009 (0.010)	0.012 (0.012)	0.015 (0.013)	0.006 (0.008)	0.009 (0.009)	0.014 (0.009)	-0.322 (0.556)	-0.055 (0.392)	0.072 (0.372)
Aquifer×1950s	0.033 (0.020)	0.030* (0.016)	0.042** (0.019)	0.030 (0.018)	0.033** (0.015)	0.039** (0.015)	0.016* (0.009)	0.013 (0.010)	0.013 (0.010)	5.593** (2.422)	5.519** (2.145)	5.871*** (2.140)
Aquifer×1960s	0.081*** (0.021)	0.063*** (0.020)	0.064*** (0.021)	0.066*** (0.017)	0.052*** (0.017)	0.055*** (0.019)	0.045*** (0.014)	0.038*** (0.014)	0.041*** (0.015)	10.451*** (3.020)	10.150*** (2.832)	10.759*** (2.747)
Aquifer×1970s	0.054*** (0.018)	0.039** (0.017)	0.042** (0.017)	0.067*** (0.011)	0.062*** (0.012)	0.056*** (0.015)	0.052*** (0.018)	0.044** (0.020)	0.042** (0.020)	13.715*** (2.515)	13.904*** (2.322)	15.242*** (2.295)
Aquifer×1980s	0.105*** (0.015)	0.084*** (0.014)	0.076*** (0.016)	0.091*** (0.016)	0.074*** (0.015)	0.066*** (0.016)	0.091*** (0.012)	0.071*** (0.012)	0.061*** (0.013)	12.216*** (1.675)	12.796*** (1.527)	14.576*** (1.789)
Aquifer×1990s	0.142*** (0.012)	0.121*** (0.013)	0.101*** (0.015)	0.117*** (0.012)	0.093*** (0.011)	0.080*** (0.012)	0.102*** (0.011)	0.082*** (0.011)	0.070*** (0.012)	13.357*** (1.807)	13.909*** (1.577)	15.922*** (1.928)
State-year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Full	200-km	100-km	Full	200-km	100-km	Full	200-km	100-km	Full	200-km	100-km
Observations	15,486	9,467	6,438	21,249	12,935	8,824	24,081	14,731	10,122	11,780	7,205	4,908
Adjusted R ²	0.777	0.816	0.837	0.782	0.800	0.814	0.842	0.842	0.856	0.327	0.384	0.413

Notes: Unit of analysis is county-year (election year in the case of electoral outcomes and agricultural census year in the case of irrigation). Analysis estimated by OLS. Standard errors adjusted for clustering by county and state-year reported in parentheses.

FIGURE VII. Pre- and Post-technological shock Trends

Notes: Plot depicts coefficient on aquifer coverage variable interacted with decadal dummy variables, with the 1930s left out as the reference category. Vertical bars are 95% confidence intervals. Vertical axis range is plus or minus one standard deviation of the outcome in panels A through C and two standard deviations in panel D. All specifications control for state-year and county fixed effects and are based on 100km buffer sample of counties. Analysis estimated by OLS. Standard errors adjusted for clustering within counties and state-years.

TABLE IV. Potential Channels

	<i>Dependent variable:</i>					
	Capitalized Value (Log Per Farm Value \$)	Farms Density (# per 1000 Acres)	Agricultural Employment (%)	Population Density (People per 1000 Acres)	Urbanization (%)	Religiosity (Members Per Capita)
	(1)	(2)	(3)	(4)	(5)	(6)
Aquifer×1910s	−0.082 (0.202)	−1.433*** (0.382)	− (0.000)	−12.552** (4.228)	−6.592*** (1.722)	− (0.000)
Aquifer×1920s	0.075 (0.113)	−1.226*** (0.286)	− (0.000)	−12.199** (4.901)	−4.840** (2.029)	−0.055* (0.029)
Aquifer×1930s	0.062 (0.070)	−1.118*** (0.382)	5.111** (1.735)	−12.224* (5.668)	−5.415* (2.429)	−0.041*** (0.010)
Aquifer×1940s	−0.053 (0.067)	−0.985*** (0.364)	4.408** (1.842)	−11.755* (6.028)	−6.690** (2.648)	− (0.000)
Aquifer×1950s	− (0.000)	−0.667** (0.313)	4.324* (1.874)	−11.518 (7.094)	−4.066 (3.178)	−0.047* (0.028)
Aquifer×1960s	0.315*** (0.072)	−0.402* (0.226)	6.486*** (1.791)	−14.172 (8.850)	−5.638 (3.515)	− (0.000)
Aquifer×1970s	0.281*** (0.076)	−0.295 (0.183)	5.327** (1.537)	−17.428 (10.158)	−3.375 (3.671)	−0.024 (0.028)
Aquifer×1980s	0.239** (0.106)	−0.252 (0.157)	5.433*** (1.387)	−20.524* (10.724)	−0.855 (3.686)	−0.003 (0.028)
Aquifer×1990s	0.210** (0.096)	−0.200 (0.137)	5.934*** (1.108)	−27.709* (13.361)	−0.212 (4.055)	−0.018 (0.032)
Sample	100km	100km	100km	100km	100km	100km
State-year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3,082	4,769	2,248	2,800	2,876	1,672
Adjusted R ²	0.829	0.587	0.468	0.004	0.090	0.333

Notes: Unit of analysis is county-year (agricultural, population or religious census year depending on outcome). Capitalized value is the log of the inflation-adjusted average market value of farm land and buildings. Farm density is the number of farms per 1000 acres of county land. Population density is the number of people per 1000 acres of county land. Urbanization is the percentage of the county population living in census-defined urban areas. Agricultural employment is the percentage of workforce employed in agriculture. Religiosity is church membership per capita. Data from the US Census of Religion Bodies conducted in 1926, 1936; the survey of Churches and Church Membership conducted by the National Council of Churches in 1952, 1971, 1980 and 1990. Analysis estimated by OLS. Standard errors adjusted for clustering by county and state-year.

FIGURE VIII. Potential Channels

Notes: Plot depicts coefficient on aquifer coverage variable interacted with decadal dummy variables, with the 1930s left out as the reference category. Vertical bars are 95% confidence intervals. In each plot, vertical axis range is plus or minus one standard deviation of the outcome variable. All specifications control for state-year and county fixed effects and are based on 100km buffer sample of counties. Analysis estimated by OLS. Standard errors adjusted for clustering within counties and state-years.

FIGURE IX. Zip Codes of Respondents in CCES Data

Notes: Plots depict zip codes in Cooperative Congressional Election Survey (CCES) Data in different empirical samples.

TABLE V. Contemporary Policy Preferences Inside and Outside of the Ogallala Aquifer

	Oppose Regulation			Pro-business Tax/Spend			Cultural issues		
	Oppose EPA Enforcement (1)	Repeal ACA (2)	No Fine Employer (3)	No Immigrant Services (4)	Oppose Taxes (5)	Cut Welfare (6)	Oppose Abortion (7)	Oppose Gun Checks (8)	No Affirmative Action (9)
Panel A: Full sample									
Aquifer	0.118*** (0.027)	0.094*** (0.031)	0.052*** (0.018)	0.058* (0.028)	2.861*** (1.067)	0.089** (0.034)	0.092*** (0.027)	0.022 (0.020)	0.040** (0.016)
Observations	26,623	36,676	23,040	15,889	35,190	12,432	27,833	29,853	66,146
Adjusted R²	0.018	0.022	0.016	0.063	0.009	0.006	0.011	0.012	0.472
Panel B: 200-km									
Aquifer	0.075* (0.039)	0.056 (0.036)	0.031 (0.033)	0.057 (0.036)	2.853** (1.300)	0.077 (0.055)	0.066** (0.032)	0.004 (0.023)	0.045** (0.019)
Observations	8,785	12,367	8,059	5,633	12,287	4,094	9,123	9,822	22,165
Adjusted R²	0.028	0.038	0.024	0.072	0.015	0.007	0.025	0.024	0.488
Panel C: 100-km									
Aquifer	0.073 (0.045)	0.060 (0.036)	0.060* (0.030)	0.058* (0.031)	2.938* (1.587)	0.089** (0.039)	0.087*** (0.030)	0.015 (0.027)	0.034 (0.024)
Observations	4,519	6,522	4,330	3,054	6,441	2,068	4,701	5,065	11,575
Adjusted R²	0.035	0.036	0.030	0.055	0.022	0.007	0.028	0.034	0.498
Panel D: 100-km + no partial overlap									
Aquifer	0.103 (0.062)	0.065 (0.043)	0.060 (0.038)	0.101** (0.039)	2.986 (2.338)	0.079* (0.042)	0.092** (0.038)	0.011 (0.037)	0.024 (0.022)
Observations	3,928	5,645	3,733	2,631	5,541	1,803	4,081	4,395	9,940
Adjusted R²	0.029	0.042	0.038	0.059	0.020	0.014	0.025	0.026	0.494
Response Mean	0.469	0.532	0.629	0.437	60.052	0.370	0.449	0.140	0.291

Notes: Unit of analysis is individual, across Cooperative Congressional Election Surveys (CCES) completed between 2006 and 2020. Oppose EPA is indicator for whether respondent expresses opposition to "strengthening enforcement of Clean Air Act and Clean Water Act even if it costs US jobs" (question in 2014-2019 survey waves). Repeal ACA is indicator for supporting repeal of Affordable Care Act (2012-2019 survey waves). Oppose fine is indicator for whether respondent expresses opposition to fining US businesses that hire illegal immigrants (2007, 2010, 2013-2017 waves). Prohibit immigrant is indicator for whether respondent supports "prohibit[ing] illegal immigrants from using emergency hospital care and public schools" (2012-14 waves). Oppose taxes is preference scale from 0 (increasing taxes) to 100 (spending cuts) in response to budget deficit (2006-2008, 2010-2017 waves). Cut welfare is indicator for whether respondent indicates preference for reducing welfare spending (2016 and 2018 waves). Limit abortion is indicator for whether respondent opposes "always allow[ing] a woman to obtain an abortion as a matter of choice" (2014-2019 waves). Oppose gun check is indicator for whether respondent opposes requiring background checks for all gun sales (2013-2019 waves). No affirmative action is an indicator for somewhat or strong opposition to affirmative action (2008-14 waves). Standard errors adjusted for two-way clustering within state-survey wave and county.

Online Appendix

Contents

1	Details of Technological Shock	58
1.1	Pre-existing Technology	58
1.2	Image of Windmill Pump	59
1.3	Post-war Technology Shock	60
1.4	Images of Improved Groundwater Pumps and Center-pivot Irrigation	61
2	Maps of Voting in Senatorial and Gubernatorial Elections	64
2.1	County-level Map of Voting in Senatorial Elections	64
2.2	County-level Map of Voting in Gubernatorial Elections	65
3	Computer Vision Estimates of Center-pivot Irrigation	66
3.1	Processing Satellite Imagery in Google Earth Engine	66
3.2	Ground Truth Annotations from the Nebraska Center-pivot Inventory	66
3.3	Model Architecture, Training, and Testing Accuracy	67
3.4	State-by-State Center-pivot Counts	72
4	Notes on GIS Analysis	80
4.1	Source of Shapefiles	80
4.2	Software and Packages Used in GIS Analysis	80
4.3	Defining Stable County Boundaries	80
5	Measuring Exposure to the Dust Bowl	81
5.1	Soil Conservation Service Map	81
6	Descriptive Statistics for Major Variables	82
6.1	Decadal Averages of Major Variables in Full Sample	82
6.2	Decadal Averages of Major Variables in 200km Buffer Sample	83
6.3	Decadal Averages of Major Variables in 100km Buffer Sample	84

1 Details of Technological Shock

1.1 Pre-existing Technology

Prior to the post-WWII irrigation technology shock, virtually no agricultural land in the Great Plains was irrigated. What little irrigation existed was typically based on surface irrigation from seasonal rivers and streams. As the 1920 Agricultural Census section on irrigation in Kansas put it: “On the High Plains there is ground water, but it occurs at such great depths that the cost of pumping is too great for a large use of water from wells. (p. 179)”

Agriculture west of the 100th meridian (most of the Great Plains), which is typically taken to divide arid from subhumid climates in the western United States, was typically unproductive and highly susceptible to droughts.¹ Subsequent Homestead Acts (of 1904 and 1909) following the original legislation enacted in 1862, revised the law to grant larger landholdings (640 acres, equivalent to a quarter-section in the Public Land Survey System) to farmers settling lands in the Great Plains, where it was recognized that 160 acres was too small to sustain family farms on sub-marginal land where only uproductive dryland farming was possible.

Episodic precipitation often brought bumper crops and waves of settlement, followed by prolonged multi-year droughts which resulted in mass farm failures and mass outmigration. This culminated in the Dust Bowl, the combination of prolonged drought, dust storms, and soil erosion that devastated agriculture in the region between 1930 and 1936 and resulted in mass outmigration to more agriculturally productive regions.²

The pre-existing technology for accessing groundwater was the windmill pump, which was typically limited to drawing water from a maximum of 30 feet under the ground. The per-acre foot cost did not justify the windmill’s deployment in large-scale crop irrigation. As one scholar puts it: “the average windmill kit a farmer could buy from a local manufacturer cost \$75 for an eight-foot mill, \$100 for a ten-foot mill, and \$135 for a twelve-foot mill. As costs declined, in 1909 a farmer could build his own reservoir and install two twelve-foot windmills with ten-inch pumps for \$330...farmers learned regretfully that their costly \$330 investment might at best water a total of eight acres...the inherent pumping limits of windmill technology were quickly reached and did little to aid the wheat farmer on his 640-acre section.”³

In the 1920s, new and improved pumping technologies emerged, but remained prohibitively expensive to provide large-scale crop irrigation. These included, for example, steam-powered centrifugal pumps. More cost-efficient electric irrigation pumps existed, but farmers typically lacked widespread access to electricity connections. In any case, by the time these technologies became available in the 1920s, farmers in the Great Plains were at the beginning of a 20-year depression in crop prices that made it uneconomical to employ either technology on a large scale for irrigation given their still exorbitant pumping costs.

¹Seager, Richard, et al. "Whither the 100th meridian? The once and future physical and human geography of America's arid-humid divide. Part I: The story so far." *Earth Interactions* 22.5 (2018): 1-22.

²See e.g. Cook, Benjamin I., Ron L. Miller, and Richard Seager. "Dust and sea surface temperature forcing of the 1930s “Dust Bowl” drought." *Geophysical Research Letters* 35.8 (2008).; Gregory, James Noble. *American exodus: the dust bowl migration and Okie culture in California*. Oxford University Press, USA, 1991.

³Opie, John. *Ogallala: Water for a Dry Land*. University of Nebraska Press, 2000, p. 117

1.2 Image of Windmill Pump

FIGURE I. Image of Windmill Pump

6. A homemade jumbo windmill, ca. 1890s. Many farmers could not afford \$300 for a factory-made windmill, so they often worked from rough sketches they made after looking at a neighbor's jumbo. Frequently a windmill was made from scrap wood lying around in the farmyard. Courtesy of the Nebraska Historical Society, W765.32.

Notes: From Opie, John. *Ogallala: Water for a Dry Land*. University of Nebraska Press, 2000, p. 118

1.3 Post-war Technology Shock

Post-WWII advances in groundwater pumping technology finally made it economical for the typical farmer to irrigate crops on a large scale. Improved petroleum-powered groundwater pumps based on the adaptation of used automobile engines originated in the late 1930s, but did not become widely available until commercialization and mass production, and diffusion through demonstration effects led to widespread uptake in areas overlying the Ogallala aquifer the 1950s. These new pumps were much more efficient in terms of per acre-foot cost than the pre-existing technology: "Compared to earlier operating expenses of about \$6.00 per acre-foot, the 1938 irrigator could flood his field for \$3.20 to \$4.50, including installed well and equipment, interest and depreciation, and fuel and maintenance...Advances in technology would soon give the ordinary farmer access to irrigation, but it would be two more decades before it would be commonplace."⁴

The ability to draw from the Ogallala aquifer on a large scale led to a second problem – how to distribute this water efficiently across a typical 640-acre quarter-section farm. Flood and ditch irrigation systems were both costly to build, in terms of labor and materials, and were also water inefficient as they depended upon immersing fields in water in a context of loamy, permeable soils that are susceptible to rapid dissipation of moisture. A solution arrived in the form of center-pivot irrigation, a system for irrigating large circular fields with a rotating arm affixed with sprinklers. Designed initially to irrigate a 640-acre quarter-section (with a rotating arm about a quarter mile in length), over time center-pivot irrigation systems evolved in scale so that the largest units could irrigate an entire PLSS section (with a rotating arm about a half mile in length).

The main benefit of center-pivot irrigation was that it eliminated the need to build labor-intensive irrigation systems and was much more water efficient, providing water evenly across large circular fields at a rate that could be controlled by the farmer. Center-pivot irrigation was patented in 1952 by its inventor Frank Zybach and spread rapidly across the Great Plains from the 1950s and 1960s onward. The patent for center-pivot irrigation was purchased by Valmont in 1954, which played a major role in the commercialization, mass production and diffusion of the new technology across the Great Plains. In the state of Nebraska, much of which intersects with the Ogallala aquifer, a team of researchers utilizing manual counting of circular fields from Landsat satellite imagery found that the number of center-pivot irrigation systems in the state increased rapidly, from over 4000 in 1973 (when satellite images are first available) to nearly 10,000 in 1976.⁵

The spread of center-pivot irrigation supplied by petroleum-powered deepwell pumps transformed the Great Plains, resulting in the signature irrigated crop circles that are visible from space as well as the quasi-industrial revolution in agriculture that made the Great Plains one of the most agriculturally productive regions in the world. As one observer in the 1970s put it: "What is being observed is perhaps the most significant mechanical innovation in agriculture since the replacement of draft animals by the tractor."⁶

⁴Opie, John. *Ogallala: Water for a Dry Land*. University of Nebraska Press, 2000, p. 132

⁵Splinter, William E. "Center-pivot irrigation." *Scientific American* 234.6 (1976): 90-99.

⁶Splinter, William E. "Center-pivot irrigation." *Scientific American* 234.6 (1976): 90.

1.4 Images of Improved Groundwater Pumps and Center-pivot Irrigation

FIGURE II. Image of Petroleum-powered Pumps

9. A typical modern pumping system in southwestern Kansas. *Top*: Centrifugal pump using a rebuilt V-8 automobile engine fueled by natural gas, serving water to an open ditch for flood irrigation. *Bottom*: One of Keith Allen's commercial large-scale pumps and natural-gas engines used to flood his alternative-crop fields. Photos taken in 1988 by the author.

Notes: From Opie, John. Ogallala: Water for a Dry Land. University of Nebraska Press, 2000, p. 135

FIGURE III. Image of 1952 Center-pivot Irrigation Patent

July 22, 1952

F. L. ZYBACH

2,604,359

SELF-PROPELLED SPRINKLING IRRIGATING APPARATUS

Filed June 27, 1949

3 Sheets-Sheet 1

INVENTOR.
FRANK L. ZYBACH
BY
Lampson & VanValkenburg
ATTORNEYS

FIGURE IV. Image of Center-Pivot Irrigation System

Notes: Each circle covers approximately a PLSS quarter-section or 640 acres. In Haskell County, Kansas today, the cash rent per acre of irrigated land is approximately \$112 compared to \$35 per acre of unirrigated cropland or a 320% premium.

2 Maps of Voting in Senatorial and Gubernatorial Elections

2.1 County-level Map of Voting in Senatorial Elections

FIGURE V. County-level Republican Vote Share in Senatorial Elections

Notes: Panel A depicts counties shaded by average Republican percentage of the two-party vote in senatorial elections between 1920 and 1940. Panel B depicts counties shaded by average Republican percentage of the two-party vote in senatorial elections between 1980 and 2000.

2.2 County-level Map of Voting in Gubernatorial Elections

FIGURE VI. County-level Republican Vote Share in Gubernatorial Elections

Notes: Panel A depicts counties shaded by average Republican percentage of the two-party vote in gubernatorial elections between 1920 and 1940. Panel B depicts counties shaded by average Republican percentage of the two-party vote in gubernatorial elections between 1980 and 2000.

3 Computer Vision Estimates of Center-pivot Irrigation

3.1 Processing Satellite Imagery in Google Earth Engine

Our goal is to count the area-normalized number of center-pivot irrigation systems in operation in all counties in the Great Plains states in each year between 1985 and 2000 (Landsat 5 satellite imagery becomes available from 1984 onwards). We exclude Texas, which does not use the Public Land Survey System (PLSS) from this exercise as well as Montana and North Dakota, which do not intersect with the Ogallala aquifer and are not a part of our empirical strategy. Our focus is therefore on measuring the density of center-pivot irrigation technology adoption for all counties in Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota between 1985 and 2000.

For each state-year, we compute a state-wide raster layer comprised of the normalized difference vegetation index (NDVI), which highlights areas of greenery and cropping. The NDVI is defined as $(\text{NIR} - \text{R}) / (\text{NIR} + \text{R})$, where NIR is Near Infrared surface reflectance values and R is Red surface reflectance values. In the case of Landsat 5, this is $(\text{Band 5} - \text{Band 4}) / (\text{Band 5} + \text{Band 4})$. We compute this index for each pixel by taking pixel-level median values computed from all cloud-free images of a given pixel taken between July and August in a given year. Some pixels are missing due to cloud cover. Computing and processing this satellite imagery required us to process and analyze terabytes of satellite imagery. All computations were performed on the cloud in Google Earth Engine (code available on request).

We clip these state-year raster files to the extent of individual PLSS sections, rescaling each to a 70×70 pixel image. Given Landsat 5 resolution (each pixel is 30 square meters) this is approximately the typical size in satellite imagery of a PLSS section, which is about 1 mile on a side (with deviation). Shapefiles of PLSS sections are obtained from the Bureau of Land Management. As part of our data pre-processing before we feed images to a convolutional neural network, we also re-scale the NDVI index to a measure that ranges between 0 (minimum possible value) and 1 (maximum possible value).

There are a total of $\approx 621,000$ PLSS sections in each of 16 years for which we have imagery or nearly 10 million images which we wish to make predictions about the number of center-pivot irrigation systems contained therein. Once we have these predictions, it is possible to aggregate up to the county level by counting all the center-pivot irrigation systems in PLSS sections contained within a county, and normalizing by total land area to get a measure of the number of center-pivots per 1000 square kilometers.

3.2 Ground Truth Annotations from the Nebraska Center-pivot Inventory

Manually counting center-pivot irrigation systems in nearly 10 million PLSS sections is beyond human ability. As a result, we turn to tools from computer vision to automate this process. We train a convolutional neural network (CNN) that takes as input the 70×70 pixel image of a PLSS section and as output makes a prediction of the number of center-pivot irrigation systems contained therein. CNNs are supervised learning algorithms and require labeled training data where the labels represent “ground truth” estimates of the count of center-pivot irrigation

systems in an image.

To obtain ground-truth labels, we utilize a geo-coded inventory of center-pivot irrigation systems that was compiled through hand counting of crop circles in Landsat satellite imagery by a team of researchers for the state of Nebraska.⁷ The inventory consists of a spreadsheet of every center-pivot irrigation system observed manually in Landsat satellite imagery for each year between 1972 and 1987 with longitude and latitude coordinates.

Since geo-coding was performed by hand, there is some noise in the recorded coordinates (i.e. when coordinates are overlaid with accurately geo-referenced satellite imagery, they do not exactly correspond to center-pivot irrigation systems). This makes certain approaches to counting, for instance those based on dot-annotated density maps,⁸ difficult to implement. However, it is possible to obtain highly accurate estimates of the number of center-pivot irrigation systems contained within aggregated spatial units, in our case PLSS sections.

A typical PLSS section contains between 0 and 4 center-pivot irrigation systems in predictable arrangements (see Figure 7 below). We use three years of ground truth annotations (1985- 1987) overlapping with our years of interest to label the count of center-pivot irrigation systems in clipped satellite images of all PLSS sections in Nebraska, which comprises our training dataset ($N \approx 220,000$). We use a 80:20 training/testing split, stratified by county-year, where 80 percent of the data is used for training and validation of the CNN model and 20 percent of the data is used to test the model's out-of-sample predictive performance. That is, we randomly sample 20% of all county-year pairs in Nebraska for the years 1985-1987 and allocate all images of PLSS sections taken in each of these county-year pairs to the test set and allocate the remaining images to the training set. There are 93 counties in Nebraska observed over three years or 279 county-year pairs; of these, 223 were allocated to the training set and 56 to the test set. This stratified construction of a test set permits us to measure the predictive accuracy of the algorithm at two levels: at the PLSS section and at the county-year level.

3.3 Model Architecture, Training, and Testing Accuracy

We utilize a modified version of the VGG16 network architecture to design our convolutional neural network.⁹ We modify it in the following ways. First, we modify the input dimensions of the model so that it takes as input the $70 \times 70 \times 1$ dimension image (i.e. a 70 by 70 pixel image in a single color channel) of a PLSS section. Second, we replace the softmax activation layer with a linear activation layer so that as output the model make a continuous regression estimate of the number of center-pivots in the image. Third, since we have a relatively focused task, we replace the two 4096 neuron dense layers at the bottom of the standard VGG16 network architecture with a much smaller single 128 neuron dense layer. This convolutional neural network model has a total of 14,975,937 trainable parameters.

⁷Carlson, Marvin P. "The Nebraska Center-Pivot Inventory: An example of operational satellite remote sensing on a long-term basis." *Photogramm. Eng. Remote Sens* 55 (1989): 587-590.

⁸Arteta, Carlos, Victor Lempitsky, and Andrew Zisserman. "Counting in the wild." *European conference on computer vision*. Springer, Cham, 2016.

⁹Simonyan, Karen, and Andrew Zisserman. "Very deep convolutional networks for large-scale image recognition." *arXiv preprint arXiv:1409.1556* (2014).

FIGURE VII. Example of Labeled Training Data

Notes: Images represent examples of Landsat 5 satellite imagery (NDVI index) of PLSS sections from Nebraska with “ground truth” labels corresponding to the number of center-pivot irrigation systems in the image according to the Nebraska center-pivot inventory.

FIGURE VIII. Visualization of CNN architecture

Notes: Image represents layers of convolutional neural network which takes as input a 70 by 70 pixel image of a PLSS section in a single channel and as output makes a linear regression estimate of the number of center-pivot irrigation systems in the image. Our approach treats counting center-pivot irrigation systems as a regression problem, requiring as labels only the total number of objects per training image.

Our general approach is in the spirit of “learning to count” objects in images with deep neural networks without object localization, in which counting is treated as a regression problem, requiring as labels only the total number of objects per training image. Similar approaches have

been taken to counting objects ranging from fruits and leaves to animals in imagery.¹⁰ While there may be some degree of idiosyncratic error in the predictions in the case of individual PLSS sections, as we aggregate to the county-year level, much of this prediction error ‘cancels out’ (in the sense that the variance of the sum of at least partially uncorrelated random variables is less than the sum of their variances). This is also why we opt for a linear activation layer that makes a continuous estimate of the number of center-pivots in supplied images rather than softmax classification of the image into whole integer categories. Numerical over- and under-predictions relative to an integer-valued target label contain useful information about classification ambiguity that improves overall predictive power when we aggregate up to the county-year level.

In terms of a loss function, we minimize the mean squared error (MSE) of predictions. The model was trained on the Nebraska training data for a total of 10 epochs using a the Root Mean Squared Propagation (RMSprop) optimizer and a learning rate of $1e-4$. Training was implemented in the *keras* package in R which uses TensorFlow in Python as a backend. In test data for the state of Nebraska 1985-87, when “ground truth” labels were regressed on predicted counts in PLSS sections in Nebraska, the coefficient on the predicted count variable was 0.98 and the R^2 was 0.73. This implies a high level of accuracy at the PLSS section level (for examples see Figure 9). But accuracy is even better when counts are aggregated to the county-year level and the idiosyncratic prediction error in PLSS section counts cancel each other out as we aggregate to higher levels.

Using the trained model, we can make predictions for a massive number of PLSS sections (approximately 10 million) across all of the Great Plains states for each year between 1985 and 2000. We then aggregate up to the county level and divide by total county land area (omitting PLSS sections missing predictions due to cloud cover) to get a panel dataset on center-pivot irrigation density (center-pivots/1000 sq kilometers) at the county-year level. We achieve near-human predictive accuracy at this level. When we regress ground-truth measures (based on manual counts from the Nebraska center-pivot inventory) of center-pivot irrigation density for the 56 county-year pairs in Nebraska that were allocated to the test set to our computer vision estimates of center-pivot irrigation density, the coefficient on the predicted density variable is 1.1 and the R^2 is 0.94. The accuracy of our computer vision estimates is even higher ($R^2 = 0.98$) when we predict total center-pivots (see Figure 10).

Below we provide images of predicted center-pivot irrigation counts at the PLSS section and county level for Oklahoma, New Mexico, Kansas, Colorado, Nebraska, Wyoming, and South Dakota between 1985 and 2000. Figure 11 provides a map of counties shaded by the quartile of center-pivots per 1000 square kilometers averaged between 1985 and 2000. As the map illustrates, center-pivot irrigation was overwhelmingly concentrated within the boundaries of the Ogallala aquifer. Images 12-18 provide state-by-state maps of center-pivot irrigation counts at the PLSS section level and then aggregated to the county level.

¹⁰Rahnemoonfar, Maryam, and Clay Sheppard. "Deep count: fruit counting based on deep simulated learning." *Sensors* 17.4 (2017): 905; Hoekendijk, Jeroen, et al. "Counting using deep learning regression gives value to ecological surveys." *Nature scientific reports* 11.1 (2021): 1-12.

FIGURE IX. Predicted Counts against 'Ground Truth' in PLSS Section Images

Notes: Images represent 32 randomly selected examples of Landsat 5 satellite imagery (NDVI index) of PLSS sections from Nebraska with predicted center-pivot counts estimated by the CNN (top left of each image) and "ground truth" (top right) labels corresponding to the number of center-pivot irrigation systems in the image according to the Nebraska center-pivot inventory. These are images from test set (i.e. the CNN did not see these examples during training).

FIGURE X. Accuracy of Computer Vision Estimates of Technology Adoption at County Level

Notes: Points represent test-set county-year observations from Nebraska for which we can compare “ground truth” estimates of center-pivot irrigation (based on manual counts from the Nebraska center-pivot inventory) against computer vision estimates of technology adoption. Estimates constructed by using trained CNN to count the number of center-pivots in every PLSS section image in a given county-year and then aggregating these counts to the county level and normalizing by land area. Red line represents fitted regression line. Dashed blue line represents $x=y$ diagonal. Adjusted R^2 in panel A (where the measure is center-pivots per 1000 sq km) is 0.94. Adjusted R^2 in panel B (where the measure is total center-pivot count) is 0.98.

3.4 State-by-State Center-pivot Counts

FIGURE XI. County Estimates Across Great plains

Notes: Map depicts county-level quartile of center-pivots per 1000 sq km averaged between 1985-2000. Note that Texas is excluded because it does not use the PLSS system. Light blue polygon is Ogallala aquifer boundary.

FIGURE XII. Nebraska

Notes: Top panel depicts rounded estimates of center-pivot irrigation across all PLSS sections in Nebraska in year 2000 (total center-pivots counted is ≈ 35851). Bottom panel depicts county-level quartile of center-pivots per 1000 sq km averaged between 1985-2000. Light blue polygon is Ogallala aquifer boundary.

FIGURE XIII. Kansas

Notes: Top panel depicts rounded estimates of center-pivot irrigation across all PLSS sections in Kansas in year 2000 (total center-pivots counted is ≈ 21662). Bottom panel depicts county-level quartile of center-pivots per 1000 sq km averaged between 1985-2000. Light blue polygon is Ogallala aquifer boundary.

FIGURE XIV. New Mexico

Notes: Top panel depicts rounded estimates of center-pivot irrigation across all PLSS sections in New Mexico in year 2000 (total center-pivots counted is ≈ 4054). Bottom panel depicts county-level quartile of center-pivots per 1000 sq km averaged between 1985-2000. Light blue polygon is Ogallala aquifer boundary.

FIGURE XV. Oklahoma

Notes: Top panel depicts rounded estimates of center-pivot irrigation across all PLSS sections in Oklahoma in year 2000 (total center-pivots counted is ≈ 7411). Bottom panel depicts county-level quartile of center-pivots per 1000 sq km averaged between 1985-2000. Light blue polygon is Ogallala aquifer boundary.

FIGURE XVI. Colorado

Notes: Top panel depicts rounded estimates of center-pivot irrigation across all PLSS sections in Colorado in year 2000 (total center-pivots counted is ≈ 12117). Bottom panel depicts county-level quartile of center-pivots per 1000 sq km averaged between 1985-2000. Light blue polygon is Ogallala aquifer boundary.

FIGURE XVII. Wyoming

Notes: Top panel depicts rounded estimates of center-pivot irrigation across all PLSS sections in Wyoming in year 2000 (total center-pivots counted is ≈ 3919). Bottom panel depicts county-level quartile of center-pivots per 1000 sq km averaged between 1985-2000. Light blue polygon is Ogallala aquifer boundary.

FIGURE XVIII. South Dakota

Notes: Top panel depicts rounded estimates of center-pivot irrigation across all PLSS sections in South Dakota in year 2000 (total center-pivots counted is ≈ 5304). Bottom panel depicts county-level quartile of center-pivots per 1000 sq km averaged between 1985-2000. Light blue polygon is Ogallala aquifer boundary.

4 Notes on GIS Analysis

4.1 Source of Shapefiles

To measure county boundaries, we utilize shapefiles published by the IPUMS National Historical Geographical Information System (NHGIS).¹¹ NHGIS provides decennial shapefiles of county boundaries. These files contain polygons representing county boundaries at 10-year intervals corresponding to population censuses.

To measure the boundaries of the Ogallala aquifer, we utilize a shapefile produced by the US Geological Survey.¹² This shapefile contains a polygon representing the boundaries of the Ogallala aquifer, as synthesized from a range of historical and local geological surveys.¹³

4.2 Software and Packages Used in GIS Analysis

All GIS and spatial analyses are performed in the R programming language. The *rgdal* package is used to load, store, and project shapefiles into a coordinate reference system (WGS84 is used throughout).

The package *rgeos*, which provides an R interface to GEOS (an open-source C package for analyzing spatial geometries), is used to perform spatial operations, including computation of county centroids and the intersection county and aquifer boundaries in order to compute the degree to which a county overlaps with the Ogallala aquifer.

The packages *geosphere* is used to measure spatial distances and areas. This package is used to compute the geodesic distance of county centroids from the Ogallala aquifer boundary in each state as well as to compute the share of each county's surface area that overlies the Ogallala aquifer.

4.3 Defining Stable County Boundaries

To identify counties that possessed "stable" boundaries between 1920 and 2000, we compute polygons representing the union and intersection of the boundary of a given county (identified by name and ICPSR code) in 1920 and in 2000. If the county exists in both years and the intersection is at least 99 percent of the union in terms of land area, it is considered to have stable boundaries over this time period (and not if either condition is not satisfied).

¹¹<https://www.nhgis.org/>

¹²Qi, Sharon. Digital Map of Aquifer Boundary for the High Plains Aquifer in Parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming. No. 543. US Geological Survey, 2010

¹³For details, see: <https://water.usgs.gov/GIS/metadata/usgswrd/XML/ds543.xml>

5 Measuring Exposure to the Dust Bowl

5.1 Soil Conservation Service Map

FIGURE XIX. Exposure to Dust Bowl Computed from Soil Erosion Map

Notes: Map represents Soil Conservation Service's estimates of areas exposed to different degrees of soil erosion by 1937. Exposure to the Dust Bowl is defined as the share of county land exposed to severe wind erosion based on geo-referenced map. This map was geo-referenced in ArcGIS and polygons were manually constructed to represent areas of "severe wind erosion" in the Great Plains states. The measure of exposure to the Dust Bowl is the share of county land that was exposed to severe wind erosion according to this measure. For comparable analyses, see: Hornbeck, Richard. "The enduring impact of the American Dust Bowl: Short-and long-run adjustments to environmental catastrophe." *American Economic Review* 102.4 (2012): 1477-1507. Source: National Archives.

6 Descriptive Statistics for Major Variables

6.1 Decadal Averages of Major Variables in Full Sample

	Presidential Vote Share	Senatorial Vote Share	Gubernatorial Vote Share	Irrigation Farmland %	Farm Value \$1000s	Farms Density #/1000 Acres	Agricultural Employment %	Population Density People/1000 Acres	Urbanization Urban %	Religiosity Members per Capita
1920s	0.53	0.47	0.41	1.77	244.16	3.04	–	32.84	13.94	0.34
1930s	0.28	0.36	0.34	1.69	215.55	3.24	51.12	37.23	17.36	0.34
1940s	0.41	0.39	0.38	0.81	184.28	2.71	46.53	38.25	20.62	–
1950s	0.60	0.42	0.36	2.72	–	2.02	36.87	41.63	27.81	0.49
1960s	0.51	0.51	0.42	4.02	868.52	1.52	26.80	48.60	32.58	–
1970s	0.60	0.49	0.43	5.51	1530.75	1.28	18.95	54.68	35.27	0.34
1980s	0.63	0.53	0.51	5.60	1249.43	1.27	16.02	64.84	36.33	0.39
1990s	0.60	0.60	0.56	6.17	917.60	1.20	12.65	79.25	36.19	0.37

Notes: Data represent decadal averages for full sample of data (all counties with stable boundaries between 1920 and 2000 in Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, South Dakota, Wyoming). Vote share variables are the Republican party's county-level share of the two-party vote in presidential, senatorial, or gubernatorial elections. Irrigation is average percentage of farmland that is irrigated as computed from agricultural censuses conducted in 1920, 1925, 1930, 1935, 1940, 1945, 1950, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, and 1997. Farm value is inflation-adjusted average market value of farm land, machinery and buildings in 2016 dollars (source: agricultural censuses). Farm density is the number of farms per 1000 acres of county land (source: agricultural censuses). Population density is the number of people per 1000 acres of county land (source: decennial population censuses). Urbanization is the percentage of the county population living in census-defined urban areas (source: decennial population censuses). Agricultural employment is the percentage of workforce employed in agriculture (source: decennial population censuses). Religiosity is church membership per capita (data from the US Census of Religion Bodies conducted in 1926, 1936; the survey of Churches and Church Membership conducted by the National Council of Churches in 1952, 1971, 1980 and 1990).

6.2 Decadal Averages of Major Variables in 200km Buffer Sample

	Presidential Vote Share	Senatorial Vote Share	Gubernatorial Vote Share	Irrigation Farmland %	Farm Value \$1000s	Farms Density #/1000 Acres	Agricultural Employment %	Population Density People/1000 Acres	Urbanization Urban %	Religiosity Members per Capita
1920s	0.59	0.53	0.46	1.06	300.52	2.35	—	24.26	12.18	0.32
1930s	0.33	0.43	0.41	1.23	266.54	2.56	50.56	28.12	16.06	0.34
1940s	0.47	0.47	0.47	0.60	217.50	2.18	46.75	27.31	18.97	—
1950s	0.64	0.49	0.44	2.98	—	1.76	39.26	29.52	25.20	0.49
1960s	0.56	0.56	0.47	4.97	960.81	1.36	30.40	33.92	29.85	—
1970s	0.62	0.53	0.46	7.01	1687.97	1.15	22.84	36.53	31.87	0.37
1980s	0.67	0.57	0.54	7.23	1356.80	1.06	20.00	40.80	33.32	0.43
1990s	0.64	0.63	0.58	8.02	1001.27	0.95	15.67	45.33	33.27	0.40

Notes: Data represent decadal averages for 200km buffer sample of data (counties within 200km distance of the Ogallala aquifer boundary in each state with stable boundaries between 1920 and 2000 in Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, South Dakota, Wyoming). Vote share variables are the Republican party's county-level share of the two-party vote in presidential, senatorial, or gubernatorial elections. Irrigation is average percentage of farmland that is irrigated as computed from agricultural censuses conducted in 1920, 1925, 1930, 1935, 1940, 1945, 1950, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, and 1997. Farm value is inflation-adjusted average market value of farm land, machinery and buildings in 2016 dollars (source: agricultural censuses). Farm density is the number of farms per 1000 acres of county land (source: agricultural censuses). Population density is the number of people per 1000 acres of county land (source: decennial population censuses). Urbanization is the percentage of the county population living in census-defined urban areas (source: decennial population censuses). Agricultural employment is the percentage of workforce employed in agriculture (source: decennial population censuses). Religiosity is church membership per capita (data from the US Census of Religion Bodies conducted in 1926, 1936; the survey of Churches and Church Membership conducted by the National Council of Churches in 1952, 1971, 1980 and 1990).

6.3 Decadal Averages of Major Variables in 100km Buffer Sample

	Presidential Vote Share	Senatorial Vote Share	Gubernatorial Vote Share	Irrigation Farmland %	Farm Value \$1000s	Farms Density #/1000 Acres	Agricultural Employment %	Population Density People/1000 Acres	Urbanization Urban %	Religiosity Members per Capita
1920s	0.59	0.52	0.46	0.71	300.42	2.26	–	22.60	11.09	0.32
1930s	0.32	0.42	0.40	0.95	274.98	2.47	51.88	26.29	15.30	0.35
1940s	0.47	0.46	0.47	0.47	212.60	2.10	47.83	25.34	18.19	–
1950s	0.64	0.49	0.43	3.52	–	1.73	39.89	27.37	24.35	0.49
1960s	0.56	0.56	0.47	6.18	957.43	1.35	31.43	31.58	29.26	–
1970s	0.63	0.53	0.46	8.87	1700.78	1.15	24.11	33.22	31.28	0.39
1980s	0.68	0.57	0.55	9.00	1347.11	1.06	21.35	36.25	32.17	0.46
1990s	0.66	0.64	0.59	10.08	1013.83	0.93	16.75	39.86	32.29	0.42

Notes: Data represent decadal averages for 100km buffer sample of data (counties within 100km distance of the Ogallala aquifer boundary in each state with stable boundaries between 1920 and 2000 in Texas, Oklahoma, New Mexico, Kansas, Colorado, Nebraska, South Dakota, Wyoming). Vote share variables are the Republican party's county-level share of the two-party vote in presidential, senatorial, or gubernatorial elections. Irrigation is average percentage of farmland that is irrigated as computed from agricultural censuses conducted in 1920, 1925, 1930, 1935, 1940, 1945, 1950, 1954, 1959, 1964, 1969, 1974, 1978, 1982, 1987, 1992, and 1997. Farm value is inflation-adjusted average market value of farm land, machinery and buildings in 2016 dollars (source: agricultural censuses). Farm density is the number of farms per 1000 acres of county land (source: agricultural censuses). Population density is the number of people per 1000 acres of county land (source: decennial population censuses). Urbanization is the percentage of the county population living in census-defined urban areas (source: decennial population censuses). Agricultural employment is the percentage of workforce employed in agriculture (source: decennial population censuses). Religiosity is church membership per capita (data from the US Census of Religion Bodies conducted in 1926, 1936; the survey of Churches and Church Membership conducted by the National Council of Churches in 1952, 1971, 1980 and 1990).