The Value of Rural Electricity in the Short and Long Run: Evidence from the Rollout of the U.S. Power Grid*

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Abstract

This paper exploits the historical rollout of the U.S. power grid between 1930 and 1960 to study the impact of rural electrification on local economies in the short and long run. We find that rural electrification led to short-term increases in agricultural employment, farm population, and property values. Applying a standard Rosen–Roback style model to the reduced form estimates, we find that rural electrification led to large gains to rural residents primarily driven by improvements in the quality of rural housing. Over time, rural electrification spurred broader local development. Rural counties that gained early access to electricity experienced long-term economic growth that continued to persist even forty years after the country was fully electrified. In particular, we provide suggestive evidence that early electricity access may have facilitated suburbanization. Overall, the results suggest that the benefits of rural electrification far exceeded the historical costs of extending the grid, and imply that there might be a large scope to expand rural access in the developing world today.

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1 Introduction

In 2009, 1.3 billion people worldwide lacked access to electricity, over 80 percent of whom resided in rural areas (IEA, 2011). In an effort to expand electricity access, the World Bank has allocated more than 20 percent of its loans to electricity infrastructure projects, most of which target rural electrification.[1] These investments are motivated by a widely held view that electricity offers a range of welfare gains to rural communities. Nevertheless, there are key empirical challenges to evaluating the effects of investments in rural electrification. First, electricity offers a range of benefits that are difficult to quantify and are not captured by standard economic indicators. Second, long-run adjustments to this new technology could amplify or reverse the initial gains to the local economy.

This paper exploits the historical rollout of the U.S. power grid between 1930 and 1960 to tackle these challenges and shed new light on the impacts of rural electrification. First, we use detailed data on a range of local outcomes to study the immediate effects of electricity access on the rural population. The reduced form estimates for farmland values, housing prices, and wages are combined in a standard spatial equilibrium model (Rosen, 1979; Roback, 1982) to assess the short-run benefits to rural populations driven by improvements in agricultural productivity and non-market amenity gains associated with improved rural housing. Second, we use detailed data on a range of outcomes for the period 1960 to 2000 to track the evolving long-run impact of rural electrification on the local economy.

The historical U.S. setting provides an exceptional opportunity to study the effects of rural electrification. There were stark differences in the timing of rural and urban electrification. By 1930, less than 10 percent of farms were electrified whereas 85 percent of urban and rural non-farm residents were wired for electricity, as shown in Figure 1. By 1960, access to electricity was nearly universal. The timing of rural electrification was also driven by plausibly exogenous factors related to the cost of extending services to different communities based on their location. Furthermore, the historical U.S. censuses provide

[1] Between 1990 and 2010, 1.7 billion people gained access to electricity, compared with population growth of 1.6 billion. The World Bank estimates that the rate of electrification will have to double to meet the United Nations' 2011 target of universal access by 2030 (World Bank, 2013).

detailed data on a range of local outcomes, including farmland values, housing prices, and wages, which allow us to quantify the gains from rural electrification. Finally, the 70-year historical time horizon allows us to identify adjustments that occurred gradually over an extended period of time.

The empirical analysis combines information on county-level outcomes with a newly digitized dataset that provides detailed information on the location and characteristics of large power plants that opened between 1930 and 1960. The historical record indicates that decisions about where to site these plants were made largely independently of considerations for rural demand for power, a fact that is borne out in a number of specification tests. Once built, however, proximity to power plants played an important role in determining which rural communities electrified. The empirical analysis exploits plausibly exogenous variation in the timing of rural electrification driven by power plant openings.

We begin by studying the immediate impact of rural electrification on the local economy. The analysis focuses on the period 1930 to 1960, when roughly 90 percent of farms gained access to electricity. We estimate county fixed effects regressions that relate decadal changes in electricity access to changes in local outcomes, controlling for a range of baseline demographic and economic conditions. We find that rural electrification led to a short-run expansion in the rural sector. Within a decade of electricity provision, rural counties experienced increases in farm population, agricultural employment, the number of farms, and total farm revenue. Meanwhile, apart from slowing down manufacturing activity, there is little evidence that rural electrification generated local spillovers in non-agricultural sectors.

Rural electrification also led to increases in farmland values and modest decreases in agricultural wages. These relative effects are interpreted in a standard spatial equilibrium model in which the impacts of electricity on agricultural production and housing quality are immediately capitalized into local property values and wages. The results are consistent with a setting in which electrification led to considerable gains in rural welfare driven primarily by the non-market amenity of improved rural housing. Applying the reduced form estimates, we calculate that the average rural family would have been willing to forgo

24 percent of annual income to live in a home equipped with electrical services. Given the high upfront and operating costs of home generators, these benefits were likely not large enough to justify individual farm electrification, particularly if farm households were credit constrained. Nevertheless, the welfare gains exceeded the historical costs of extending the grid even at very low population densities.

To study the evolving long-run impact of rural electrification on the local economy, we focus on local adjustments for the period 1960 to 2000, when the U.S. was fully electrified. We adopt a difference-in-differences approach to compare the relative outcomes of early versus late electrifying rural counties with similar pre-1930s characteristics. The relative expansion in the agricultural sector was a short-lived phenomenon, and was completely reversed within 30 years. Nevertheless, rural electrification had persistent effects on the local economy. Early electrifying rural counties experienced relative population and employment growth in each decade between 1960 and 2000. By 2000, early electrifying rural counties were 19 percent more populous than similar rural counties that electrified a few decades later. Early electrification also led to persistent relative increases in property values and wages. Together, these findings suggest that the long-run adjustments to rural electrification amplified the initial gains to the local economy.

There are several potential explanations for the persistent long-run effects. First, endogenous local responses may have reinforced the initial effects. We find that early electrifying counties experienced relative increases local incomes, retail sales per capita, and the number of new housing starts. These results suggest that investments in local amenities may have reinforced the initial benefits brought by electrification, improving the relative attractiveness of early electrifying counties even after the country was fully electrified.

Second, electrified areas may have been particulary suitable sites for suburbanization that occurred during the second half of the 20th century.[2] To explore whether the long-run expansion was driven by the suburbanization of rural counties, we allow the effects of early electrification to vary according according to county distance to a metropolitan area. We

[2]In 1950, the fraction of the U.S. population that lived in rural areas and central cities was 36 percent and 30 percent, respectively. In 1990, those fractions were 25 percent and 15 percent, respectively.

find that the effects on population, employment, and property values were concentrated in rural counties located near metropolitan areas, suggesting that suburbanization was an important mechanism of these long-run adjustments.[3]

This paper makes two contributions towards understanding the full impact of rural electrification. First, our hedonic estimates show that electricity access brought large gains to rural residents primarily through non-market amenities associated with improvements in the quality of rural housing. Some studies in this growing literature have estimated electrification benefits to agricultural output (Fishback and Kitchens, 2015; Chakravorty, Emerick, and Ravago, 2016), local development (Lipscomb, Mobarak, and Barham, 2013; Severnini, 2014), female employment (Dinkelman, 2011; Lewis, 2016a), and health (Clay, Lewis, and Severnini, 2016; Lewis, 2016b).[4] Other studies have shown negligible or even negative impact on the local economy (Burlig and Preonas, 2016; Lee, Miguel, and Wolfram, 2016). Our new insight is that some important gains of rural electrification would not be captured by those standard economic indicators. Second, we provide the first credible evidence that gradual adjustments to rural electrification reinforced the initial local benefits in the long run. Because these adjustments occurred over a period of many decades, such gains were unlikely to be captured by short-term evaluations of rural electrification infrastructure investments.

This paper also adds to a growing literature that uses historical settings to identifying adjustments that occur over long periods of time (e.g., Davis and Weinstein, 2002; Redding and Sturm, 2008; Hornbeck, 2012). We show that endogenous responses to electrification reinforced the initial local advantage, which ultimately led to persistent differences in long-run outcomes even after the technology was universally adopted. These findings complement previous studies that document persistent effects of temporary natural advantages and place-based policies (e.g., Bleakley and Lin, 2012; Kline and Moretti, 2014).

[3]These results are not attributable solely to reductions in transportation costs associated with the construction of the interstate highway system. We find that both early electrification and planned highway expansions had distinctive effects on population and employment growth.

[4]A related literature examines the effects of improvements in reliability of rural services (e.g., Chakravorty, Pelli, and Marchand, 2014; Ryan, 2015).

The paper proceeds as follows. After this Introduction, Section 2 provides a historical background about the rural electrification in the U.S. Section 3 introduces a conceptual framework to highlight the role of electrification in local economies. Section 4 describes the data used in our analysis. Section 5 presents our empirical strategy to examine the impact of rural electrification in the short and long run. Section 6 reports our results, and provides interpretation in light of the conceptual framework. Lastly, Section 7 makes some concluding remarks.

2 Historical Background

Urban electrification rates rose throughout the first three decades of the 20th century. By 1930, 85 percent of urban and rural non-farm residents were wired for electricity, and virtually every major city and town was electrified. Despite widespread access to electricity in cities, fewer than 10 percent of farms were electrified by 1930. Throughout the 1920s, private power companies were reluctant to supply electricity to rural areas due to a widely held belief of high infrastructure costs per customer. As one publication described,"A mile of distribution line can serve 50 to 200 customers in a city; in the country the average is three customers to a mile" (*General Electric Digest*, April 1925). These beliefs were reinforced by several well-publicized experiments in the 1920s, which found that it was unprofitable to extend services to rural customers. For example, the National Electric Light Association (NELA) supervised the construction of twelve rural lines in 1923 to serve 359 families. The experiment lost $8,000 on a $94,000 investment (NELA, 1924).

During the 1930s, the federal government introduced several programs to promote rural electrification. In 1933, the Roosevelt administration created the Tennessee Valley Authority (TVA), which offered local rural residents access to low cost electricity, and by 1952 the TVA was supplying electricity to 175 counties in seven states (Kitchens, 2014). In 1935, the Rural Electrification Administration (REA) was established. This agency provided low-interest loans for the construction of power lines into rural areas and to wire farms for

electricity. Over the next 25 years, the REA funded over 1.4 million miles of distribution lines, and serviced over 4.8 million rural customers (U.S. Historical Statistics, 1976).[5] These programs, combined with the gradual expansion of rural services provided by the private sector, led to large increases in the proportion of farms that were electrified.

Figure 1 reports electrical services for nonfarm (urban and rural nonfarm) and farm households between 1900 and 1960. Virtually the entire expansion in nonfarm services occurred between 1900 and 1930; electrification rates rose by just 15 percentage points between 1930 and 1960. For farm households, access to electrical services was delayed, and fewer than 13 percent of farms were wired in 1935. Over the next twenty years, there was a sharp increase in rural electrification rates, with the proportion of farms with electrical services reaching 95 percent in 1955.

Electricity offered a range of positive effects on farm productivity. By 1960, more than 100 different types of farm machines driven by electric motors were in use on American farms. Electric milking machines reduced milking time by 50 percent and directly pumped milk into cooled storage tanks which reduced spoilage (Nye, 1990). Electric heaters and lights improved chicken and egg production. Between 1930 and 1960, egg production rose by 75%, and milk production per cow rose by almost 60% (U.S. Historical Statistics, 1976). In Western states, access to pumped water led to large increases in farm irrigation. Two-thirds of pumps were powered by electric motors. Increased use irrigation led to large increases in average farm size in these states.

Electricity offered benefits to rural households, independently of its effects on agricultural productivity. Electric lighting extended the day and reduced exposure to smoke from kerosene lamps. Electricity provided access to a range of labour-saving appliances, which dramatically reduced the time of home production. For example, washing machines alone saved roughly nine hours per week on housework, and pumped water saved rural housewives from walking roughly one mile per day to collect water.

To provide case study evidence on the potential uses of electricity on the farm, we

[5] Other major federal projects, such as the Bonneville dam power plant, offered new sources of electricity to rural residents.

collected data from the Red Wing rural electrification project. The Red Wing Project ran from late 1923 to early 1928 in Red Wing, Minnesota. Eleven participating farms received electrical services along with free access to a variety of household appliances and electrical farm equipment.[6]

We collected monthly data on electricity consumption by Red Wing participants by three broad categories: farm, home, and basic lighting and pumping. Figure 2 shows the pattern of consumption for each category. Together home and basic electricity accounted for 71 percent of consumption on the farm. There were large differences in electricity use across farms. The farm share range from 0.07 to 0.48, primarily due to of differences in the intensity of dairy production. Electricity consumption for lighting and pumped water displayed little seasonality and grew slowly from 1925 to 1927. This result is consistent with the fact that this basic consumption occurred primarily within the home, and was not influenced by the harvesting cycle. Home electricity consumption displayed a seasonal pattern with the highest consumption in the summer. This pattern can partly be attributed to seasonality in the use of refrigerators. Overall, household electricity consumption exceeded the national average of 35 Kwh per moth (U.S. Historical Statistics, 1976). The large gap is likely due to the fact that households in the Red Wing Project were provided access to a range of appliances, whereas the median electrified American home owned only a single major appliance. Farm consumption displayed the greatest variability, peaking during the harvesting season for barley, corn, oats, and wheat, around August-September in Minnesota (USDA, 1997).

Together, these results suggest that electricity was highly valued on the farm. Overall electricity consumption was 50 percent higher than initially predicted. The bulk of the benefits appear to have occurred within the home, which accounted for more than two-thirds of total electricity expenditure. Importantly, these findings cast doubt on a widely held view that it was unprofitable to provide rural electricity access, since electricity consumption more

[6]The Minnesota Power Company set a service charge of $6.90 per month plus 5 cents per Kwh for the first 30 Kwh, and 3 cents per Kwh for additional use. These rates were set to cover overhead and all variable costs based on an average of three customers per mile.

than covered carry costs. Moreover, the fact that consumption was concentrated within the home implied that overall electricity use remained relatively stable throughout the year. As a result, challenges to electricity providers in meeting variable loads were mitigated.

3 Conceptual Framework

To examine the local impacts of rural electrification, we set up a standard Rosen-Roback spatial equilibrium model (see details in Appendix A.2). This framework can be used to evaluate the effects of electrification on property values, wages, employment and population outcomes. The model also delivers equations that can be used to evaluate the local gains associated with electrification driven by both non-market amenities to rural residents and improvements in agricultural productivity.

In the model, there are a large number of counties, each with a fixed supply of land. Two sectors (agriculture and industry) produce tradeable goods using labor and land as inputs. Workers supply labor, and have preferences for a composite consumption commodity, residential land, and housing quality. Workers and firms are freely mobile across sectors and counties, and land values and wages are set such that all markets clear.

Rural electrifiaction is assumed to affect the local economy through two potential mechanisms: i) increases in the productivity of the agricultural sector, and ii) improvements in the quality of rural housing. Through both channels, an increase in rural electricity access should lead to an expansion in the rural sector with increases in agricultural employment, output, and farmland. The increased demand for farmland will drive up local land prices.

The response of land values and wages can be used to assess the impact of electrification driven by increases in agricultural productivity and/or improvements in the quality of rural housing. Consider the case in which the primary benefit of electrification is higher agricultural productivity. In this scenario, increased demand for farmland by rural producers will drive up local land prices. Because rural workers do not benefit directly from this technology at home, they must be compensated with higher wages. Alternatively, if elec-

tricity improved rural housing quality, rural workers should be willing to accept lower wages despite the rise in local land prices. In fact, the formal model delivers three equations that can be used to estimate i) the total gains to rural residents associated with electrification, ii) the gains driven by improvements in the quality of rural housing, iii) the gains driven by improvements in agricultural productivity. These three equations can be calculated directly from reduced form impacts of electrification on local property values and wages.

Figure ?? provides a graphical representation of the model and its predictions regarding the impact of rural electrification on the agricultural sector. The downward-sloping lines are combinations of wages w and rental rates q that equalize unit costs C at a given level of electricity access e. If electricity improves agricultural productivity, when electricity access expands in location 1, factor prices must be higher in order to equalize costs in both locations. Thus, the C line is shifted upward. Similarly, the upward-sloping lines represent w-q combinations such that indirect utility V is equalized across different levels of e. If electricity represents an amenity by improving the quality of rural housing, at high amenity location 1, workers must pay higher rents at every wage to be indifferent between the two locations. Hence, the V line is shifted upward as well. In the end, rental rates must be higher in location 1, where electricity access has been expanded, but the effect on wages is ambiguous.

Rural electrification can also affect the industrial sector through changes in local prices. On the one hand, the rise in local property values may crowd-out activity in the industrial sector. On the other hand, an expansion in the agricultural sector could positively affect the non-agricultural sector through either production complementarities or increased demand for local non-tradeable goods. Thus, the overall effect on non-farm population and employment is ambiguous.

4 Data

Historical county-level data from 1930 to 2000 are drawn from the Censuses of Agriculture and Population (Haines and ICPSR, 2010; DOC and ICPSR, 2012). The main variables of interest include population (total, rural farm, rural non-farm, and urban); employment (total and by sector), farm characteristics (farm revenue, number of farms, farmland, farm size, and number of tractors per farm), property values (value of farmland and farm buildings, median dwelling value, and median dwelling rent), and income proxies (retail sales per capita, and payroll per worker in agriculture, manufacturing, and retail sectors).

To construct a measure of electricity access, we rely on a set of seven maps produced by the Federal Power Commission in 1962. These maps identify the location of all power plants in the U.S., along with various plant characteristics. To limit concerns of endogenous power plant siting, we restrict the sample to large power plants with at least 30 megawatts of nameplate capacity. Using GIS software, we digitize this information, and link it to historical information on the timing of plant openings to construct a panel of plants for the period 1930 to 1960. We combine these data with county longitude and latititude, to construct a decadal variable for county-centroid distance to the nearest power plant. The empirical analysis uses county-centroid distance to the nearest power plant as a proxy for electricity access.[7]

Figure 1 displays the sample counties, overlaid with the location of power plants from the Federal Power Commission map. Power plants are categorized according to the period of initial operation. The main sample is a balanced panel of 2,162 non-MSA counties that were at least 50 percent rural and within 200 miles of a power plant in 1930.[8] Counties are shaded based on the change in distance to the nearest power plant between 1930 and 1960, with darker shades denoting larger decreases in distance.

[7] The identifying assumptions for the empirical analysis are discussed in Section 5.

[8] Restricting the sample to counties within 200 miles of a power plant limits misspecification due to the nonlinear relationship between power plant distance and access to electricity. Given transmission constraints, a decrease in county distance to a power plant will only affect residential electricity access within a certain distance (see Table 5).

5 Empirical Framework

We adopt two complementary empirical approaches to examine the contemporaneous short-run impact of rural electrification and the evolving long-run impact on the local economy. In both cases, our empirical strategy relies on cross-county differences in the timing of electricity access.

To study the immediate effects we regress each outcome variable Y in county c and time t on distance to the nearest large power plant, $DistPP30$, county fixed effects, η_c, year fixed effects, λ_t, and state-specific linear trends, $\delta_s t$. We also include a vector of baseline county characteristics (population, fraction white, agricultural employment, and manufacturing employment in 1930, and county-centroid latitude and longitude), $X_{c,1930}$, interacted with year fixed effects. These covariates allow for differential trends in outcomes across counties according to these initial conditions. The estimating equation also includes an error term, ϵ_{ct}, and is given by

$$Y_{ct} = \beta DistPP30_{ct} + \eta_c + \lambda_t + \delta_s t + \theta_t X_{c,1930} + \epsilon_{ct}. \quad (1)$$

The variable $DistPP30$ is measured in the negative of distance in tens of miles to reflect increases in electricity access. The coefficient β captures the reduced form impact of a decrease in power plant distance on contemporaneous decadal changes in the outcome variable across counties with similar baseline observable characteristics.

To study the longer term adjustments to rural electrification, we restrict the sample to rural counties that experienced above-median decreases in power plant distance between 1930 to 1960. We identify "early access" counties as those that experienced the majority of the reduction in distance between 1930 and 1940, and "late access" counties as those that experienced the majority of the reduction in distance between 1940 and 1960. The empirical analysis compares relative changes across early and late access counties for the period 1960 to 2000. Formally, outcome Y_{ct} is differenced from its value in 1930 and regressed on a county indicator for early access, $EarlyAccess_c$, state fixed effects, ϕ_s, year fixed effects,

λ_t, state-specific linear trends, $\delta_s t$, 1930 county characteristics, $X_{c,1930}$, interacted with year fixed effects, and an error term, ϵ_{ct}:

$$Y_{ct} - Y_{c,1930} = \beta_t EarlyAccess_c + \phi_s + \lambda_t + \delta_s t + \theta_t X_{c,1930} + \epsilon_{ct}. \quad (2)$$

Notice that the effects of early electricity access are allowed to vary by year. Each estimated coefficient β_t captures the average change in outcomes from 1930 to decade t for counties with early access relative to counties with late access to electricity, conditional on having similar characteristics in 1930. Because both early and late access counties were fully electrified by 1960, the estimates in equation (2) capture the extent to which the initial responses were amplified or reversed in the long run. $\beta_t > 0$ implies amplification, $\beta_t < 0$ implies reversal, and $\beta_t = 0$ implies constant effects over time.[9] For statistical inference, standard errors are clustered at the county level to adjust for heteroskedasticity and within-county correlation over time.[10]

The identifying assumption for the empirical analysis is that outcomes in counties granted electricity services would have trended similarly in the absence of changes in electricity access. It requires that decisions over the location and timing of power plant openings were not driven by trends in rural county outcomes.[11] This assumption is supported by the fact that rural consumption accounted for too small a share of the total electricity produced by these large power plants to have influenced site selection. Among the power plants used in the empirical analysis, less than 10 percent of total electricity generation would have been consumed by rural customers.[12] Given such a low demand, "private utilities insisted that extending service to these rural customers would be unprofitable, and refused to build the necessary lines" (Morton, 2000, p.29). Moreover, at a cost of $7,200 per mile (Beall, 1940), it would have been far cheaper to extend rural lines than to build power plants to meet rural

[9] This discussion assumes a positive short-run impact of electricity access on the outcome variable.

[10] Conley standard errors.

[11] In practice, this assumption must hold after controlling for baseline county characteristics and state-specific trends.

[12] Discuss calculation.

demand. In fact, starting in 1935 "the Federal government's Rural Electrification Administration made rapid progress in subsidizing service for these customers. The agency provided low-cost loans to consumer cooperatives that allowed the construction of lines to connect homes to existing commercial power grids" (Morton, 2000, p.29). Overall, the historical narrative indicates that the siting of large power plants was driven primarily by objectives to meet growing electricity demand in urban areas, to develop a more interconnected power grid across metropolitan areas, and to minimize construction and operating costs (refs).

Table 1 reports mean county characteristics in 1930 (column 1) and within-state differences in baseline characteristics according to post-1930 changes in county-centroid distance to power plants (columns 2 and 3). By and large, the table suggests that electricity access expansions in the 1930s and 1940s happened in counties lagging behind economically. Therefore, it does seem unlikely that electricity demand in those areas may have driven power plant openings. In any event, our empirical analysis controls flexibly for a number of trends based on county baseline characteristics ($\theta_t X_{c,1930}$).

6 Results

6.1 Short-Run Effects of Rural Electrification

6.1.1 Effects on population, employment, and farm output

Table 2 reports estimates of the direct effect of rural electricity access on the rural sector. Columns (2)-(4) report coefficients of $DistPP30$ estimated by equation (1) across several different specifications. Column (2) includes county and year fixed effects and a linear state trend to allow for different long-run trends across states; column (3) adds controls for county longitude and latitude interacted with year, to allow for differential trends based on geography; columns (3) and (4) add controls for baseline demographic and economic characteristics interacted with year fixed effects.

Panel A reports the estimates for rural population and agricultural employment. Across a range of specifications, access to electricity is associated with significant increases in farm

population and agricultural employment. The preferred estimates imply that a one standard deviation increase in electricity access is associated with a 2 percent increase in rural farm population and a 4 percent increase in agricultural employment. These results suggest that electrification slowed the pace of rural population decline. In sample counties, over four million workers left the agricultural sector between 1930 and 1960. Had electricity infrastructure remained at the 1930 level, an additional 200,000 workers would have left the sector.

Panel B reports estimates for agricultural output. The results suggest that electricity access led to an expansion in agricultural output. Decreases in power plant distance are associated with significant increases in farm revenue. This increase in farm output was driven both by a response on the extensive margin – electricity access led to increases in the number of farms and total county land devoted to agriculture –, and a response on the intensive margin – electricity access is associated with increases in average farm size and greater adoption of tractors. (Relate to literature here).

Table 3 reports the broader effects of rural electrification on the local economy. The top panel reports the estimated impacts on population. Expansions in rural electricity access had virtually no impact on total county population. This result stems from the fact that the relative growth in rural farm population was offset by decreases in county rural non-farm and urban populations. These findings are consistent with rural electrification having slowed within-county rural-urban migration.

Rural electrification could generate either positive or negative employment spillovers. An expansion in the agricultural sector could support broad local economic development through positive productivity spillovers and/or increased demand for locally-traded goods, or it could crowd-out non-agricultural production. To explore this question, the second panel of Table 3 reports the estimated effects on sectoral employment. The relative expansion in agricultural employment is roughly offset with a decline in manufacturing employment, but there was no change in retail or construction employment. These results suggest that, in the short run, by slowing the pace of rural outmigration, expansions in

rural electricity access depressed local non-agricultural industries.

In the bottom panel, we explore whether increases in electricity access affected investment in local amenities (retail sales per capita, a proxy for variety in local shops) or influenced the composition of the local labor force (percent of the adult population with a high school diploma, and the percent white) through cross-county sorting. As mentioned above, we find no evidence of a short-run migration response to rural electrification, suggesting that the estimated increases in farm output cannot be attributed to changes in composition of the rural workforce. In fact, we find no evidence of an inflow of whites and more educated individuals. We also find no evidence that increases in farm revenue triggered investment in local amenities, as measured by retail sales per capita.

6.1.2 Effects on property values and income

The positive effects on rural population and employment reported in Table 2 could reflect several different factors. Access to electricity may have improved the quality of rural life, which may have slowed the pace of migration to urban areas. Alternatively, increased demand for rural labor might be associated with technological advances on the farm. To shed light on the mechanisms, we examine the effects of rural electrification on local housing costs and wages.

Table 4 reports the estimated effects on property values and income. Panel A reports the impacts on property values. Access to electricity is associated with increases in farm values, median dwelling values, and median dwelling rents.[13] The point estimates are highly significant, and imply that a one standard deviation increase in electricity access raised rural property values by two percent. Panel B reports the results for various income proxies. We find no systematic evidence that rural electrification is associated with changes in local wages, although the estimates for farm revenue per worker are consistently negative and occasionally significant.

[13] Separate data on the values of agricultural land and buildings is not consistently available throughout the sample period. When these data are separately available, land accounts for the vast majority of total farm value.

Combined with the positive effects on rural farm population and agricultural employment, the results for property values provide consistent evidence that electrification brought gains to rural residents. The large increases in property values and modest decreases in local wages are consistent with a setting in which the benefits from rural electrification were primarily driven by improvements in the quality of rural housing rather than increases in agricultural productivity.

The reduced form estimates in Table 4 can be interpreted in a standard Roback-Rosen model (see model details in Appendix A.2) to derive estimates of the aggregate benefit of electricity to the rural sector, and the fraction accruing to rural residents and rural producers. The annual willingness-to-pay for a change in electricity access, de, is given by the sum of the willingness-to pay for the non-market amentiy, p_e^*, across all rural workers, N^R, and the decrease in the unit production costs, C_e, across all agricultural goods produced in the county, X^R. In Appendix A.2, we show that this aggregate willingness-to-pay is given by the following expression:

$$p_e^* N^R + \big[- C_e X^R \big] = \frac{d \log q}{de} \cdot L^R \cdot q, \tag{3}$$

where q denotes the annual value of an acre of farmland, L^R denotes the total number of acres used for farming in the county, and $\frac{d \log q}{de}$ denotes the impact of a change in electricity access on the logarithm of farmland values.

We combine the estimated impact of electricity access on farmland values (column 4 of Table 4) with sample means of q and L^R to calculate the rural willingness-to-pay for electricity. To derive an explicit measure of de, we rescale the effects by the impact of power plant distance on the fraction of farms with electricity, $\frac{de}{ddistPP30} = 0.0025$ (s.e. 0.0007). The resulting calculations reflect the rural benefits of an increase in the fraction of farms with electrical services from 0 percent to 100 percent.[14] These estimates are combined with

[14]These willingness-to-pay calculations might overestimate the benefits of rural electrification if power plant distance affected agricultural productivity independently of farm household electrification. For example, increased electricity infrastructure might spur investment in other local infrastructure. Later on, however, we provide evidence that rural electrification and the interstate highway system had *distinctive*

sample means for total acres in farming, $L^R = 306,245$, and the mean annual value of an acre of farmland, $q = \$12.85$ (1990 USD).[15] We calculate the following annual willingness-to-pay for electricity access: $p_e^* N^R + \left[-C_e X^R \right] = (0.0052/0.0025) \times 12.85 \times 306,245 = \$8,185,532$ per county. This estimate implies that a typical farm household would have been willing to forgo $4,226 per year to gain access to electricity, roughly 43 percent of annual income.

Next, we evaluate the extent to which the benefits associated with electrification were due to productivity gains or improvements in household amenities. In particular, we rely on the fact that the sum of the amenities to rural workers can be expressed as follows (see Appendix A.2):

$$p_e^* N^R = \left(k_l \cdot \frac{d \log q}{de} - \frac{d \log w}{de} \right) \cdot w \cdot N^R \tag{4}$$

where k_l denotes the fraction of the household's annual budget spent on residential land, which we set equal to 0.18 based on the fraction of household income spent on rent in the sample in 1950. The term w is annual rural wages, which we calculate to be $4,393.[16] The term $\frac{d \log w}{de}$ is the impact of electrification on local wages, which we set equal to zero given the generally statistically insignificant wage effects found in Table 4.[17] The value associated with household amenities is given by: $p_e^* N^R = 0.18 \times (0.0052/0.0025) \times 4,393 \times 2,605 = \$4,284,546$. These estimates imply that rural residents were willing to forgo 22 percent of annual farm revenue to reside in an electrified home, and that more than one half of the benefits from rural electrification occurred through non-market amenities rather than improvements in agricultural production.

Given the large benefits associated with rural electrification, it might seem surprising that individual farms did not electrify themselves. Small diesel generators were available to meet electricity demands for customers who could not easily connect to the grid, and in the early 20th century, a number of small isolated municipalities and individual industrial plants

long-run effects on U.S. counties (see Table 9).

[15] The latter term is derived by annualizing the sample mean value per acre over a 30 year time horizon with an annual interest rate of 4 percent.

[16] The rural wage is calculated by multiplying a labor share of 0.6 by the mean farm revenue per agricultural worker (refs).

[17] If electrification had a negative impact on local wages, these calculations will underestimate the importance of the amenity benefit as a fraction of the overall gains to welfare.

relied on them to produce their own power. Nevertheless, less than four percent of farms used home generations in 1930, and these were typically used only to meet basic household needs, such as lighting. The standard 1 kilowatt diesel generator that was typically purchased by farms households cost between $2,300 and $5,200, and the monthly operating costs could run from $45 to $450 (Nye, 1990). These costs would have been prohibitively expensive for the overwhelming majority of farmers.[18] On the other hand, the historical cost of extending the grid ranged from $13,500 to $16,000 per mile in the early 1930s, and quickly fell to $7,200 under the REA (Beall, 1940). Even at population densities of only 2 or 3 farms per mile, these line extensions could have been easily justified based on the value of this technology for the rural population.

6.1.3 Sensitivity analysis

In Table 5, we examine the robustness of the main estimates to several alternative specifications and samples. Column (1) reports the baseline estimates. In column (2), we add additional controls for baseline rural infrastructure (the fraction of farms with electricity and the fraction of farms with access to a hard surface road in 1930) interacted with year fixed effects. These models allow for differential trends in rural outcomes according to these baseline conditions. In practice, the covariates have little impact on the main results.

In column (3) we replace the state-year trend with state-by-year fixed effects. The estimates are similar, although slightly smaller in magnitude, a result that is unsurprising given that these models rely solely on within-state variation in the timing of electricity access.

Columns (4) to (7) explore the sensitivity of the results to alternative samples. In column (4), we exclude counties located within 30 miles of a power plant. This sample restriction addresses concerns that power plants were sited in response to changes in rural demand for electricity. This restriction also addresses concerns related to emissions from coal-fired power plants. In particular, pollution from electricity generation has been shown to have negative

[18] Nye (1990, p.295) argues that less than one in twenty farms could afford to purchase a generator.

effects on local property values (Clay, Lewis, and Severnini, 2016). In column (5) we drop counties west of the 100th meridian to address the concern that county-centroid distance to the nearest power plant is a noisier measure of electricity access in larger western counties. In column (6) we exclude counties in which more than 25 percent of farms were electrified by 1930, where there was less scope to expand rural access. In column (7) we exclude counties serviced by the TVA, which provided a range of local infrastructure investments that may have influenced rural outcomes independently of electrification (Kitchens, 2013; Kline and Moretti, 2014). The results are not sensitive to these various sample restrictions.

In the final two columns, we further address concerns related to the endogenous siting of power plants. In column (8), we re-estimated the baseline model using only power plants with at least 50 mw of nameplate capacity. Locational choices for these large plants is highly unlikely to have been influenced by rural demand for power. The last column relies solely on variation in county distance to private power plants. Because private utilities were less interested in servicing high cost rural customers, the siting of these power plants should not have been influenced by the characteristics of the rural population. The main findings are very similar in both models.

6.2 Long-Run Effects of Rural Electrification

6.2.1 Estimated local impacts of early electricity access

Next, we examine the long-run adjustments to rural electrification. As a general purpose technology, electricity access may trigger changes in household and farm production that cannot be captured in the short run. To motivate our empirical strategy, and assess the validity of the common trends assumption, Figure 5 plots the estimated β's from equation (2). These coefficients capture the change in outcomes in early electricity acccess counties relative to late electricity access counties in each census year for the period 1910 to 2000.[19] Panel A graphs the estimates for population and employment, panel B graphs the estimates

[19] Because equation (2) controls for the outcome variable in 1930, these changes are estimated relative to 1930. Discuss missing data pre-1930 here.

for rural outcomes, and panel C graphs the effects for property values and income.

We find little evidence of pre-trends across early and late electricity access counties. The estimated β's are small and generally insigificant prior to 1930, supporting the research design. Nevertheless, these two groups of counties experienced markedly different trends post-1960. Early electricity access counties experienced large and persistent growth in population and employment in the post-1960 period. Over time, these counties also experienced substantial relative increases in property values and modest increases in worker incomes. This expansion does not appear to have been driven by the rural sector. Early electricity access counties experienced relative decreases in rural population, agricultural employment, and total land in farming from 1960 and 2000.

Table 6 reports the estimates of β for the post-1960 period. Panel A reports the effects for population and employment. Early access counties experienced relative population and employment growth in each decade between 1960 and 2000. By 2000, these counties were 19 percent more populous relative to late access counties. The last four columns report the estimates for sectoral employment. Employment growth was not driven by the agricultural sector. In 1960 and 1970, agricultural employment decreased by 12 percent in early electrifying counties relative to late access counties. Instead, employment growth was concentrated in non-traded sectors. By 2000, relative employment in retail and construction was more than 25 percent higher in early electricity access counties.

Panel B reports the results for property values and local incomes. Again, the effects of early electricity access grew over time. All but one of the point estimates in 1960 are insignificant. Over time, however, counties that gained early access to electricity saw rises in local property values. By 1990, median dwelling values were 10 percent higher in early access counties. Similarly, there is evidence of rising local wages, as measured by retail sales per worker and manufacturing payroll per worker. Given long-term cross-county sorting of workers with different preferences and productivites, as it will be clear when we discuss Table 8, the homogeneity assumption in the standard Rosen-Roback framework is violated. As a result, the relative impacts on local property values and incomes cannot be directly used to

evaluate how the long-term benefits of early electrification were divided across workers and producers. Nevertheless, the results indicate that the relative short-run benefits of early electrification were reinforced over time.

Panecl C reports the results for rural outcomes. There is no evidence that relative population growth in early electrifying counties was driven by a long-term expansion of the agricultural sector. The point estimates imply relative decreases in total farm population and land used for farming. Meanwhile, early electrifying counties experienced a temporary relative increase in farm revenue per worker, which could have been driven by slow-moving investment adjustments in the agricultural sector.

6.2.2 Interpreting the long-term effects of early electricity access

The previous estimates show that differences in the timing of electricity access led to a cross-county divergence in outcomes that continued to persist even 40 years after the country was fully electrified. In this section, we investigate the channels through which early access to electricity spurred long-term local economic growth. We focus on two broad explanations: i) early electricity access as a coordination mechanism that continued to influence the geographic distribution of population and economic activity even after the initial advantage became obsolete, and ii) lagged investment responses to electrification that reinforced the initial effects.

Recent research in economic geography has shown that a temporary shock can permanently alter the location of economic activity (e.g., Bleakley and Lin, 2012; Kline and Moretti, 2014; Severnini, 2014). This situation can arise in a setting with increasing returns to density and fixed costs of relocation. In this setting, a temporary local advantage, such as early access to electricity, can continue to attract individuals and investments even after the local advantage has been eliminated. The temporary local advantage serves as a coordination mechanism in the selection of a spatial equilibrium. In addition, these temporary local shocks are more likely to influence the spatial outcomes prior to populations having coordinated on specific locations or during a tipping point period when there is a high rate

of population mobility.

The mid-20th century was a period in which the temporary advantages of electricity access were particularly likely to influence long-term economic outcomes. This period witnessed a sharp rise in suburbanization (Baum-Snow, 2007; Boustan, 2010; stats). Given this high degree of population mobility during the mid-20th century, it is plausible that the temporary local advantage associated with the rollout of electricity permanently altered the spatial distribution of the suburban expansion.

To evaluate the role of rural electrification in mid-20th century suburbanization, we re-estimate a generalized version of equation (2) in which the impact of early electricity access is interacted with indicators for counties below- or above-median distance to a metropolitan area in 1930. Intuitively, these models allow the for the effects of early electricity access to differ across counties that were more or less likely to be destinations for suburbanization.

The top panel of Table 7 reports the effects of early electricity access in counties located near a metropolitan area. The results suggest that the long-term growth associated with early electricity access was related to mid-20th century suburbanization. Columns (1) and (2) report substantial long-term population and employment growth in early electrifying counties near a metropolitan area. Columns (3) to (5) show that those early electrifying rural counties also experienced long-term increases in housing and land values. In the short run, access to electricity made rural counties more attractive to rural residents and producers. Even as electricity diffused nationwide, locations that gained early access continued to grow, as the former local advantage continued to serve as a coordination mechanism for the rising suburban population. Columns (6) to (8) report the estimates for farm outcomes. In rural counties near a metropolitan area, early electricity access is associated with decreases in rural population and total farmland, but had no consistent lasting impact on farm revenue per worker. These results indicate that the expansion of the suburban population may have crowded-out agriculture production. Interestingly, by 1980 the magnitude of the increases in median dwelling values and farmland value became virtually identical, suggesting that the urban and the rural land markets were indeed intrinsically connected.

The bottom panel of Table 7 reports the effects of early electricity access in counties located far from a metropolitan area. In these remote rural counties, early electrification had no long-term impact on population, employment, or housing value trends. Instead, the long-term effects were concentrated in the agricultural sector. Early electricity access led to persistent increases in farmland values and farm revenue per worker. These results could be driven either by the gradual adoption of complementary agricultural technologies (e.g. Assuncao, Lipscomb, and Mobarak, 2016) or long-term adjustments in the quality of land used in agriculture across early and late electrifying counties.

In Table 8, we further explore the mechanisms through which early electricity access fueled long-term suburban growth. Columns (1) to (3) show that in counties near a metropolitan area, early electrification led to persistent increases in local income proxies. Increases in incomes could be driven by long-term productivity adjustments of local producers, for example, if the temporary expansion in the agricultural sector had local spillover effects on non-agricultural producers. Alternatively, the results could reflect worker sorting across locations. To explore this possibility, columns (4) and (5) examine whether early electrification had long-term effects on the composition of the local population. We find that early electrification led to increases in the fraction of whites and increases in fraction of the adult population with a high school degree.[20] These changes coincide with previous evidence on the demographics of the rising suburban population (see Boustan, 2010, for example). We find some evidence that these changing demographics stimulated greater investment in local amenities, as measured by the fraction of new housing starts, the growth in construction employment, and the expansion of the retail sector (include them here).[21] This increased investment in housing amenities may have reinforced the upward pressure on local property values.

[20] Given this differential sorting of workers, the assumption of common worker preferences and productivities in the Roback model is violated, and we cannot compare the relative impacts on property values and incomes to assess whether the long-term gains from early electrification accrue to local workers or producers.

[21] Diamond (2015) also finds evidence of endogenous amenity investments driven by cross-city differences in the socioeconomic composition of the population.

7 Conclusion

This paper studies the historical impact of rural electrification in the U.S. from 1930 to 1960. Exploiting the non-uniform rollout of the U.S. power grid, we find that electrification led to an expansion in the agricultural sector. We estimate large immediate welfare gains to farm households, driven primarily by improvements in the quality of rural housing. The results also suggest that locations that gained early access to electricity experienced persistent growth, even 40 years after the country had been fully electrified.

Our findings have relevance for the current policy debate on how to electrify the developing world. Recent evidence from Kenya suggests that even in communities with high population density and extensive grid coverage, rural electrification rates remain very low, and households appear to be unable or unwilling to pay the $412 connection cost (Lee, et al., 2014). Given households' usual high willingness-to-pay for electricity access, our results suggest that lack of credit may be the key barrier to connection, and that government loans or subsidies for rural electrification offer potentially large welfare gains to rural residents. This situation is analogous to the historical U.S., where substantial government interventions were necessary to provide electricity access to the more rural parts of the country.

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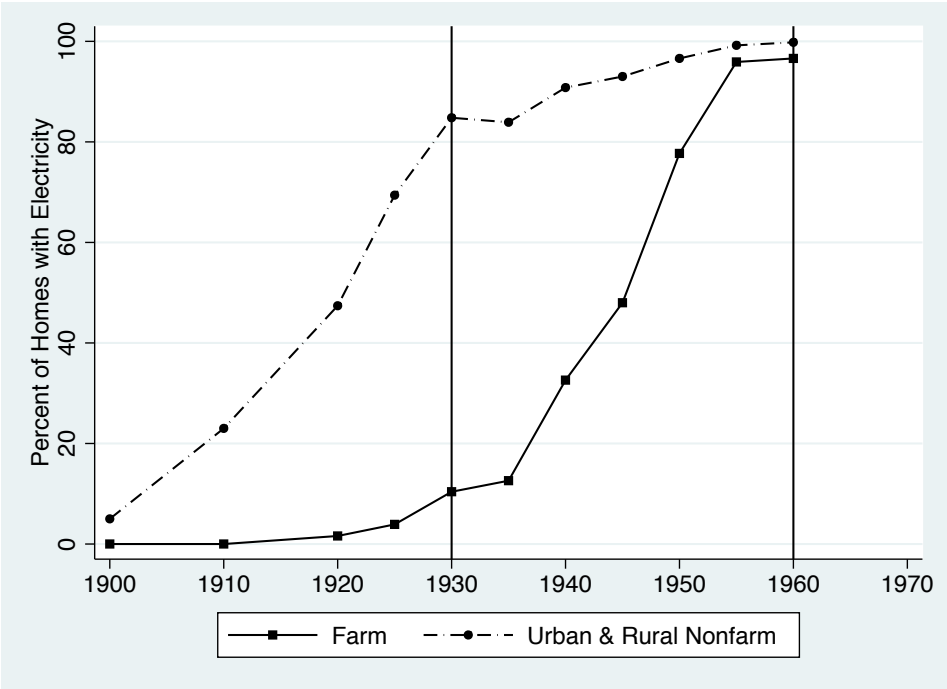
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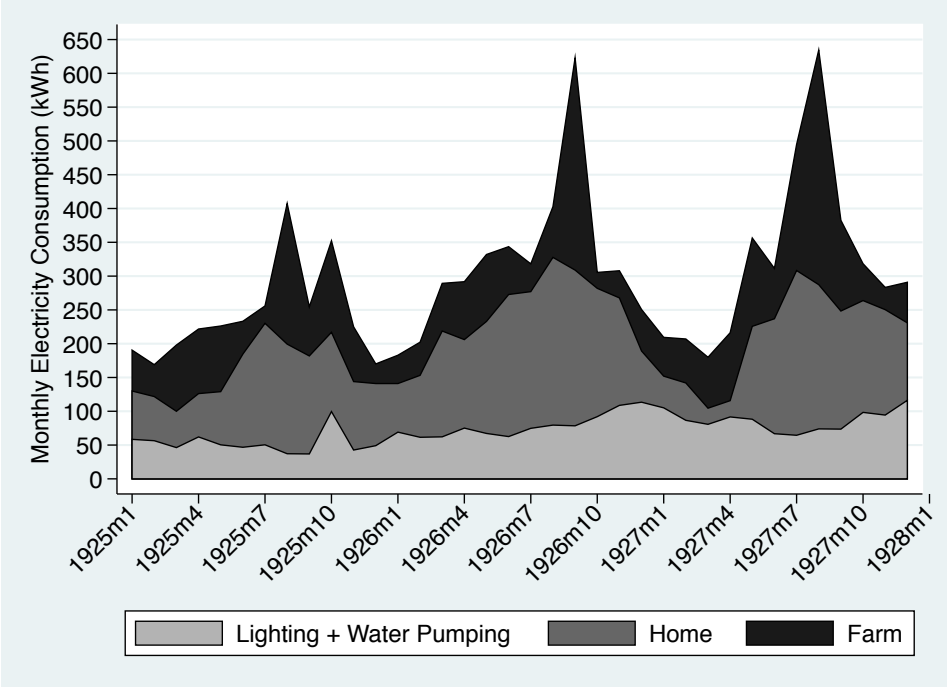
8 Figures and Tables

Figure 1: Percentage of farm and nonfarm households with electrical facilities



Source: Lebergott (1976); 1940, 1950, 1960 Census of Housing.

Figure 2: Electricity Consumption by Category – Red Wing Project (1924-1927)



Source: Author's calculation based on data from Stewart, Larson, and Romness (1927).

Figure 3: The impact of increase in electricity access on the rural sector

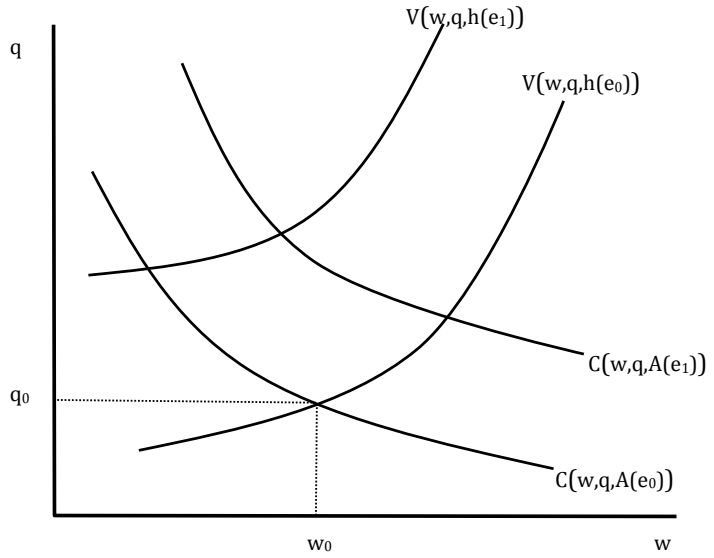
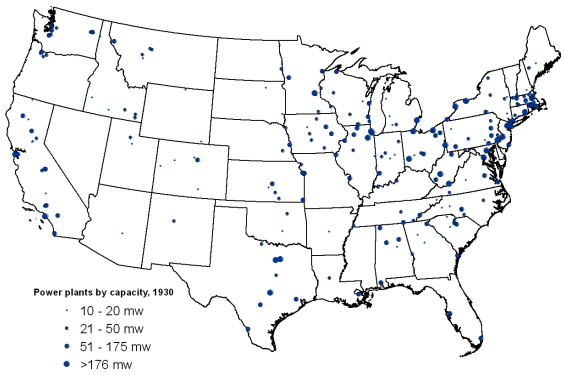
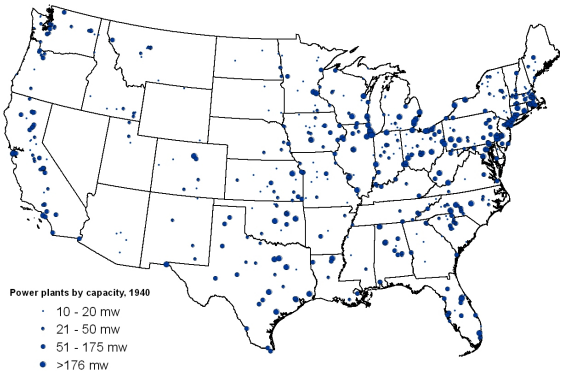


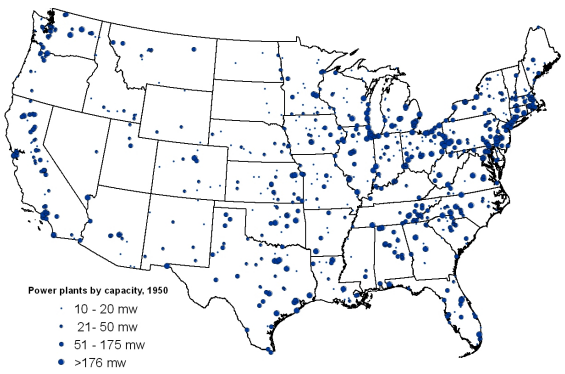
Figure 4: U.S. Power Plants: 1930 to 1960



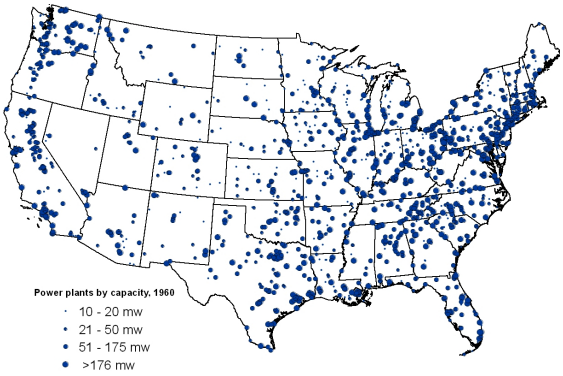
(a) 1930



(b) 1940



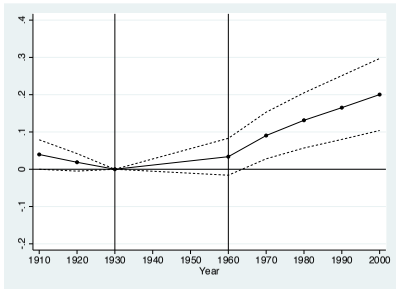
(c) 1950



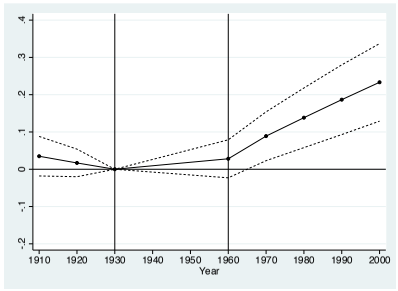
(d) 1960

Figure 5: Estimated differences in log outcomes between early electricity access and late electricity access rural counties

Panel A: Population and Employment

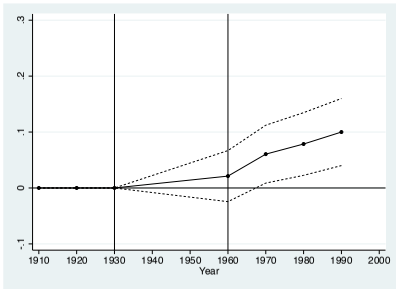


Population

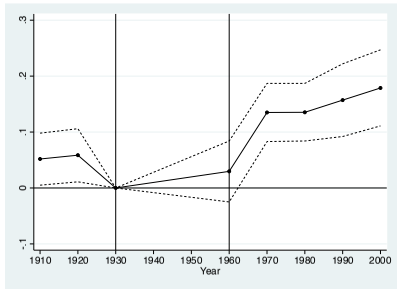


Employment

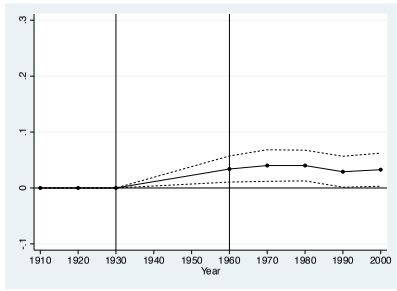
Panel B: Property Values and Income



Median Dwelling Value



Farmland Value

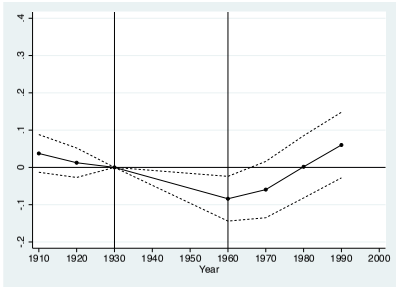


Retail Payroll per Worker

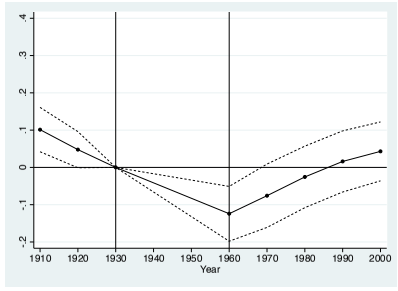


Manuf. Payroll Per Worker

Panel C: Rural Outcomes



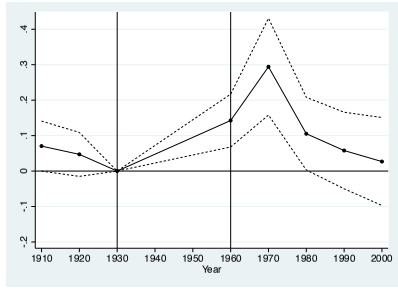
Rural Population



Agricultural Employment



Farmland



Farm Revenue per Worker

Notes: Each figure graphs the estimated coefficients (β) from equation (2). The solid line denotes the difference in log outcomes between early electricity access and late electricity access rural counties. The dashed lines denote the 95% confidence intervals.

Table 1: County characteristics in 1930, by changes in electricity access over 1930-1960 ($\Delta DistPP30$ 1930-1960)

		Above median relative to below median change in electricity access, $\Delta DistPP30$ 1930-1960		
	Sample mean (1)	Early Access (2)	Late Acess (3)	Difference (2)-(3) (4)
Panel A. Farm Outcomes				
Agriculture Employment	3,574	-156	76	-232*
Rural Farm Population	11,022	-153	84	-237
Number of farms	2,283	-86	-18	-69
Farmland, per 100 county acres	66.74	0.60	-0.39	0.99*
Farm Size	180.76	26.29*	40.96***	-14.66
Number of Tractors per Farm	0.14	-0.016***	0.009*	-0.024***
Panel B. Population and Employment				
Total Population	22,485	-1,552**	-2,109***	557
% Rural Non-Farm	31.50	-0.22	-1.76***	1.54*
% Urban	14.30	-1.66**	-0.11	-1.55
Total Employment	7,832	-710**	-731***	21
% Manufacturing	10.12	-0.47	-1.63***	1.16**
% Retail	8.35	-0.27	0.07	-0.34
% Construction	4.39	-0.31*	-0.15	-0.17
Panel C. Property Values and Income Proxies				
Log Value of Farmland and Farm Buildings	5.38	-0.15***	-0.09***	-0.07**
Log Median Dwelling Value (Owner-Occupied)	9.72	-0.07***	-0.05***	-0.02
Log Median Dwelling Rent (Renter-Occupied)	4.51	-0.064***	-0.02*	-0.04**
Log Farm Revenue Per Worker	1.22	-0.088***	0.12***	-0.21***
Log Retail Payroll Per Worker	2.14	-0.043***	-0.012**	-0.03***
Log Manufacturing Payroll Per Worker	1.95	-0.049***	-0.020*	-0.029*
N(counties)	2,162			

Notes: Column 1 reports average values for the 2,162 sample counties in 1930. Columns (2) and (3) report coefficients from a single regression of the county characteristic on dummy variables for counties with above-median decreases in power plant distance between 1930 and 1960. We allow this effect to vary according to whether the majority of the decrease occurred early (1930-1940) or late (1940-1960). Column (4) reports the difference between the coefficient estimates in columns (2) and (3). ***,**,* denote significance of robust standard errors at the 1%, 5%, and 10% level, respectively.

Table 2: The effect of electricity access on rural outcomes

	Mean Dep. Var.	Coefficient on *DistPP30*: Effect of a 10 mile decrease in power plant distance			
		(1)	(2)	(3)	(4)
Dependent Variables					
A. Population and Employment					
Agr. Employment	2,605	38.9***	37.9***	28.5***	25.5***
		(6.4)	(6.5)	(5.3)	(3.8)
Rural Farm Pop.	8,488	97.9***	83.2***	39.4***	40.6***
		(22.1)	(22.3)	(14.3)	(11.6)
B. Agricultural Output					
Log Farm Revenue	9.43	0.0060**	0.0074***	0.0061**	0.0062**
		(0.0028)	(0.0028)	(0.0027)	(0.0027)
Number of Farms	1,937	19.0***	14.6***	10.3***	10.0***
		(3.6)	(3.5)	(2.9)	(2.3)
Farmland	306,245	1,629***	1,430***	1,507***	1,491***
		(533)	(553)	(563)	(559)
Farm Size	252.0	7.56**	6.67**	5.92**	5.96**
		(3.14)	(3.06)	(3.01)	(3.03)
# Tractors per Farm	0.59	0.0047***	0.0050***	0.0050***	0.0054***
		(0.0017)	(0.0017)	(0.0017)	(0.0017)
County & Year FE		Y	Y	Y	Y
Linear State Trend		Y	Y	Y	Y
Geographic Covariates		N	Y	Y	Y
Demographic Covariates		N	N	Y	Y
Economic Covariates		N	N	N	Y
		N(Obervations) = 8,648		N(Counties)= 2,162	

Notes: All regressions include controls for county and year fixed effects. Each cell reports the point estimate from a different regression. Geographic covariates are county longitude and latitude interacted with year fixed effects. Demographic controls include baseline population density, fraction white, and percent urban interacted with year fixed effects. Economic covariates include baseline employment in manufacturing and agriculture interacted with year fixed effects. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 3: The effect of electricity access on other local outcomes

	(1)	(2)	(3)	(4)	(5)
Dep.Vars.		*Population*			
	Total	Rural farm	Rural Non-Farm	Urban	
DistPP30	2.94	40.58***	-26.87	-10.78	
	(71.69)	(11.60)	(28.61)	(59.12)	
Dep.Vars.			*Employment*		
	Total	Agriculture	Manufacturing	Retail	Construction
DistPP30	-0.20	25.45***	-29.28***	-1.43	-2.18
	(27.53)	(3.80)	(7.27)	(4.79)	(2.51)
Dep.Vars.		*Amenities and Sorting*			
	Log Retail Sales Per Capita	Percent 25+ with High School Diploma	Percent White		
DistPP30	-0.0002	0.2849	-0.0786		
	(0.0015)	(0.4177)	(0.0694)		
Full controls	Y	Y	Y	Y	Y

Notes: All regressions include controls for county and year fixed effects. Each cell reports the point estimate from a different regression. Geographic covariates are county longitude and latitude interacted with year fixed effects. Demographic controls include baseline population density, fraction white, and percent urban interacted with year fixed effects. Economic covariates include baseline employment in manufacturing and agriculture interacted with year fixed effects. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 4: The effect of electricity access on property values and income

	Mean Dep. Var.	Coefficient on *DistPP30*: Effect of a 10 mile decrease in power plant distance			
		(1)	(2)	(3)	(4)
Dependent Variables					
A. Property Values					
Log Value of Farmland and Farm Buildings	5.41	0.0053*** (0.0018)	0.0056*** (0.0019)	0.0051*** (0.0019)	0.0052*** (0.0019)
Log Median Dwelling Value (Owner-Occupied)	9.87	0.0071*** (0.0017)	0.0067*** (0.0017)	0.0056*** (0.0017)	0.0055*** (0.0016)
Log Median Dwelling Rent (Renter-Occupied)	4.83	0.0057*** (0.0013)	0.0046*** (0.0013)	0.0032*** (0.0012)	0.0033*** (0.0012)
B. Income Proxies					
Log Farm Revenue Per Worker	1.86	-0.0064*** (0.0025)	-0.0038 (0.0025)	-0.0051** (0.0025)	-0.0049* (0.0025)
Log Retail Payroll Per Worker	2.24	0.0008 (0.0009)	0.0010 (0.0009)	0.0007 (0.0009)	0.0006 (0.0009)
Log Manufacturing Payroll Per Worker	2.31 (Obs=7,465)	0.0012 (0.0021)	0.0005 (0.0021)	0.0008 (0.0021)	0.0008 (0.0021)
County & Year FE		Y	Y	Y	Y
Linear State Trend		Y	Y	Y	Y
Geographic Covariates		N	Y	Y	Y
Demographic Covariates		N	N	Y	Y
Economic Covariates		N	N	N	Y
		N(Obervations) = 8,648 N(Counties)= 2,162			

Notes: All regressions include controls for county and year fixed effects. Each cell reports the point estimate from a different regression. Geographic covariates are county longitude and latitude interacted with year fixed effects. Demographic controls include baseline population density, fraction white, and percent urban interacted with year fixed effects. Economic covariates include baseline employment in manufacturing and agriculture interacted with year fixed effects. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 5: Robustness tests

	Coefficient on *DistPP30*: Effect of a 10 mile decrease in power plant distance								
		Additional covariates		Alternate samples				Restrict power plants	
	Baseline estimates	Add controls for 1930 infrastructure	Add state-year fixed effects	Drop counties <30 miles from a power plant	Drop counties west of 100th meridian	Drop counties with high elect. access in 1930	Drop TVA counties	Use only power plants ≥ 50 MW	Use only private power plants
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
A. Population and Employment									
Agr. Employment	25.45***	28.28***	25.37***	19.87***	23.74***	24.15***	29.64***	15.74***	14.29***
	(3.80)	(3.79)	(4.08)	(4.95)	(3.92)	(4.07)	(4.06)	(3.53)	(5.09)
Rural Farm Population	40.58***	48.86***	31.30**	34.85***	17.04	34.03***	52.74***	29.03***	25.30*
	(11.60)	(11.55)	(12.42)	(12.75)	(13.63)	(11.99)	(11.77)	(11.18)	(14.15)
B. Farm Output									
Log Farm Revenue	0.0062**	0.0073***	0.0069**	0.0097***	0.0011	0.0066**	0.0086***	0.0004	0.0025
	(0.0027)	(0.0028)	(0.0029)	(0.0037)	(0.0028)	(0.0029)	(0.0029)	(0.0023)	(0.0036)
Number of Farms	10.0***	12.0***	9.6***	6.2**	9.0***	9.9***	13.0***	9.1***	7.0**
	(2.3)	(2.2)	(2.4)	(2.7)	(2.6)	(2.4)	(2.3)	(2.2)	(3.1)
Farmland	1,491***	1,478***	1,591***	2,187**	346	1,272**	1,747***	479	-137
	(559)	(557)	(598)	(925)	(398)	(559)	(606)	(330)	(681)
Farm Size	5.96**	4.80	6.20*	12.93**	1.56	3.48	6.74**	1.10	-2.42
	(3.03)	(3.01)	(3.32)	(5.12)	(3.24)	(3.17)	(3.35)	(2.00)	(3.58)
Tractors per Farm	0.0054***	0.0067***	0.0062***	0.0073***	0.0029*	0.0055***	0.0054***	-0.0037***	0.0012
	(0.0017)	(0.0017)	(0.0018)	(0.0023)	(0.0016)	(0.0018)	(0.0018)	(0.0014)	(0.0023)
C. Property Values									
Log Value of Farmland and Farm Buildings	0.0052***	0.0051***	0.0042**	0.0058**	0.0070***	0.0057***	0.0054***	0.0051***	0.0083***
	(0.0019)	(0.0019)	(0.0019)	(0.0026)	(0.0021)	(0.0020)	(0.0020)	(0.0014)	(0.0021)
Log Med. Dwell. Value (Owner-Occupied)	0.0055***	0.0046***	0.0055***	0.0059***	0.0078***	0.0059***	0.0050***	0.0026**	0.0054***
	(0.0016)	(0.0016)	(0.0017)	(0.0021)	(0.0018)	(0.0017)	(0.0017)	(0.0011)	(0.0018)
Log Med. Dwell. Rent (Renter-Occupied)	0.0033***	0.0025**	0.0030**	0.0023	0.0045***	0.0029**	0.0034***	0.0042***	0.0075***
	(0.0012)	(0.0012)	(0.0013)	(0.0015)	(0.0014)	(0.0013)	(0.0013)	(0.0016)	(0.0023)
D. Income Proxies									
Log Farm Revenue Per Worker	-0.0049*	-0.0057**	-0.0031	0.0012	-0.0091***	-0.0051*	-0.0036	-0.0089***	-0.0056*
	(0.0025)	(0.0025)	(0.0025)	(0.0034)	(0.0027)	(0.0026)	(0.0027)	(0.0020)	(0.0032)
Log Retail Payroll Per Worker	0.0006	0.0004	0.0008	-0.0006	0.0014	0.0003	-0.0002	0.0016**	-0.0007
	(0.0009)	(0.0009)	(0.0009)	(0.0012)	(0.0010)	(0.0010)	(0.0009)	(0.0008)	(0.0012)
Log Manuf. Payroll Per Worker	0.0008	0.0011	0.0013	-0.0005	0.0019	0.0015	0.0009	0.0030*	0.0030
	(0.0021)	(0.0022)	(0.0022)	(0.0034)	(0.0020)	(0.0023)	(0.0022)	(0.0017)	(0.0024)
Full controls	Y	Y	Y	Y	Y	Y	Y	Y	Y

Notes: All regressions include controls for county and year fixed effects. Each cell reports the point estimate from a different regression. Geographic covariates are county longitude and latitude interacted with year fixed effects. Demographic controls include baseline population density, fraction white, and percent urban interacted with year fixed effects. Economic covariates include baseline employment in manufacturing and agriculture interacted with year fixed effects. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 6: Long-run effects of early electricity access

Panel A: *Population and Employment Outcomes*

	Overall		Sectoral			
	Log Population	Log Employment	Log Emp. in Agr.	Log Emp. in Mfg.	Log Emp. in Retail	Log Emp. in Construction
Early Access ×						
1960	0.0281	0.0210	-0.1378***	0.1253*	0.0666	0.0865
	(0.0261)	(0.0275)	(0.0401)	(0.0708)	(0.0528)	(0.0683)
1970	0.0829**	0.0794**	-0.0940**	0.1129	0.1097*	0.1841***
	(0.0332)	(0.0349)	(0.0457)	(0.0719)	(0.0572)	(0.0712)
1980	0.1222***	0.1265***	-0.0483	0.0824	0.1796***	0.2357***
	(0.0388)	(0.0425)	(0.0444)	(0.0727)	(0.0629)	(0.0744)
1990	0.1540***	0.1724***	-0.0112	0.1097	0.2347***	0.2681***
	(0.0448)	(0.0493)	(0.0433)	(0.0766)	(0.0686)	(0.0800)
2000	0.1873***	0.2167***	0.0113	0.1513*	0.2729***	0.3088***
	(0.0505)	(0.0549)	(0.0413)	(0.0797)	(0.0729)	(0.0837)
N(counties)						

Panel B: *Property Values and Income*

	Property Values			Income Proxies	
	Log Med. Dwelling Value (Owner-Occ)	Log Med. Dwelling Rent (Renter-Occ)	Log Value Farmland and Farm Buildings	Log Retail Payroll per Worker	Log Mfg Payroll per Worker
Early Access ×					
1960	0.0212	0.0115	0.0117	0.0339***	0.0399
	(0.0233)	(0.0207)	(0.0281)	(0.0119)	(0.0274)
1970	0.0605**	0.0493**	0.1108***	0.0401***	0.0413
	(0.0264)	(0.0207)	(0.0262)	(0.0144)	(0.0268)
1980	0.0786***	0.0508**	0.1054***	0.0401***	0.0414
	(0.0286)	(0.0211)	(0.0268)	(0.0140)	(0.0286)
1990	0.1000***	0.0676***	0.1211***	0.0290**	0.0651**
	(0.0306)	(0.0228)	(0.0326)	(0.0141)	(0.0295)
2000			0.1368***	0.0327**	0.0643**
			(0.0330)	(0.0151)	(0.0298)

Panel C: *Farm Outcomes*

	Log Farm Population	Log Farmland	Log Farm Revenue	Log Farm Rev. per Worker
Early Access ×				
1960	-0.0862***	-0.1106***	0.0076	0.1456***
	(0.0315)	(0.0229)	(0.0415)	(0.0419)
1970	-0.0625	-0.1407***	0.2033***	0.2997***
	(0.0390)	(0.0305)	(0.0542)	(0.0757)
1980	-0.0021	-0.1437***	0.0668	0.1102**
	(0.0430)	(0.0345)	(0.0543)	(0.0553)
1990	0.0572	-0.1354***	0.0524	0.0658
	(0.0447)	(0.0354)	(0.0626)	(0.0604)
2000		-0.1249***	0.0445	0.0337
		(0.0378)	(0.0688)	(0.0660)

Notes: The sample is restricted to counties that experienced above-median decreases in distance to the nearest power plant between 1930 and 1960. The variable *Early Access* is a dummy for counties that experienced the majority of the decrease prior to 1940. Each column reports the point estimates from a different regression. All models include the full set of controls. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 7: Long-run effects of early electricity access: Suburbanization

	Pop. and Emp.		Property Values			Farm Outcomes		
	Log Population	Log Employment	Log Med. Dwell. Value (Owner-Occ)	Log Med. Dwell. Rent (Renter-Occ)	Log Value Farmland and Farm Buildings	Log Farm Population	Log Farmland	Log Farm Revenue per Worker
Early Access × I(Near MSA) ×								
1960	0.0693**	0.0767**	0.0304	0.0608**	0.0811**	-0.1630***	-0.1684***	0.1374**
	(0.0346)	(0.0386)	(0.0294)	(0.0262)	(0.0365)	(0.0456)	(0.0304)	(0.0569)
1970	0.1448***	0.1608***	0.0866**	0.0997***	0.1523***	-0.1569***	-0.2247***	0.2757**
	(0.0460)	(0.0507)	(0.0345)	(0.0260)	(0.0353)	(0.0566)	(0.0455)	(0.1094)
1980	0.2003***	0.2162***	0.1256***	0.1044***	0.1225***	-0.0827	-0.2325***	-0.0847
	(0.0555)	(0.0617)	(0.0388)	(0.0275)	(0.0351)	(0.0631)	(0.0517)	(0.0785)
1990	0.2639***	0.2986***	0.1724***	0.1369***	0.1627***	-0.0118	-0.2199***	-0.1629*
	(0.0653)	(0.0729)	(0.0408)	(0.0302)	(0.0481)	(0.0655)	(0.0527)	(0.0936)
2000	0.3209***	0.3627***			0.1958***		-0.2096***	-0.1140
	(0.0745)	(0.0813)			(0.0464)		(0.0553)	(0.0920)
Early Access × I(Far MSA) ×								
1960	-0.0115	-0.0318	0.0111	-0.0340	-0.0505	-0.0162	-0.0575**	0.1584***
	(0.0337)	(0.0330)	(0.0320)	(0.0272)	(0.0367)	(0.0361)	(0.0276)	(0.0564)
1970	0.0239	0.0027	0.0348	0.0023	0.0728**	0.0238	-0.0636*	0.3283***
	(0.0410)	(0.0404)	(0.0349)	(0.0281)	(0.0330)	(0.0461)	(0.0334)	(0.0975)
1980	0.0477	0.0413	0.0337	0.0004	0.0885**	0.0728	-0.0617*	0.2916***
	(0.0458)	(0.0491)	(0.0364)	(0.0277)	(0.0351)	(0.0492)	(0.0374)	(0.0639)
1990	0.0505	0.0538	0.0320	0.0027	0.0824**	0.1225**	-0.0564	0.2789***
	(0.0511)	(0.0549)	(0.0380)	(0.0291)	(0.0384)	(0.0522)	(0.0385)	(0.0652)
2000	0.0617	0.0795			0.0824**		-0.0451	0.1770**
	(0.0565)	(0.0605)			(0.0400)		(0.0427)	(0.0810)
Full controls	Y	Y	Y	Y	Y	Y	Y	Y

Notes: The sample is restricted to counties that experienced above-median decreases in distance to the nearest power plant between 1930 and 1960. The variable *Early Access* is a dummy for counties that experienced the majority of the decrease prior to 1940. Each column reports the point estimates from a different regression. All models include the full set of controls. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 8: Long-run effects of early electricity access: Suburbanization

	Income proxies			Sorting		Amenities	
	Log Retail Payroll per Worker	Log Mfg. Payroll per Worker	Log Income per Capita	% White	% 25+ with HS Diploma	% Housing Units Built in Prev. Decade	Log Retail Sales per Capita
Early Access × I(Near MSA) ×							
1960	0.0468***	0.1009***		0.9605	-2.6027	1.2054	0.0245
	(0.0152)	(0.0361)		(0.7687)	(3.0643)	(0.7990)	(0.0269)
1970	0.0444**	0.0713**	0.0276**	1.2698	1.9865	3.3926***	0.0575
	(0.0182)	(0.0343)	(0.0139)	(0.7975)	(1.2556)	(0.8770)	(0.0353)
1980	0.0407**	0.0643	0.0372***	1.5431**	2.5575***	2.8712***	0.0300
	(0.0187)	(0.0407)	(0.0131)	(0.7597)	(0.9412)	(0.7937)	(0.0375)
1990	0.0332*	0.1020***	0.0566***	1.4227*	3.3971***	2.6396***	0.0656
	(0.0192)	(0.0380)	(0.0156)	(0.7834)	(0.7041)	(0.7417)	(0.0432)
2000	0.0561***	0.1073***	0.0186	0.4303	2.5033***		0.0974*
	(0.0201)	(0.0373)	(0.0131)	(0.9088)	(0.7732)		(0.0499)
Early Access × I(Far MSA) ×							
1960	0.0222	-0.0165		-0.5877	-3.3882	0.3593	0.0212
	(0.0162)	(0.0343)		(0.4766)	(2.6903)	(0.7603)	(0.0321)
1970	0.0360*	0.0128	-0.0142	-0.9918**	0.9970	2.2629***	0.0487
	(0.0200)	(0.0357)	(0.0138)	(0.4978)	(1.8058)	(0.7709)	(0.0375)
1980	0.0391**	0.0178	-0.0069	-0.6287	1.0415	1.1058*	0.0385
	(0.0181)	(0.0350)	(0.0136)	(0.4695)	(1.0738)	(0.6320)	(0.0383)
1990	0.0248	0.0297	-0.0060	-0.9400*	0.4612	0.7095	0.0731*
	(0.0180)	(0.0390)	(0.0127)	(0.5198)	(0.5973)	(0.5785)	(0.0422)
2000	0.0113	0.0238	-0.0002	-1.1893*	-0.5340		0.0621
	(0.0194)	(0.0393)	(0.0118)	(0.6066)	(0.9740)		(0.0472)
Full controls	Y	Y	Y	Y	Y	Y	Y

Notes: The sample is restricted to counties that experienced above-median decreases in distance to the nearest power plant between 1930 and 1960. The variable *Early Access* is a dummy for counties that experienced the majority of the decrease prior to 1940. Each column reports the point estimates from a different regression. All models include the full set of controls. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 9: Long-run effects of early electricity access and highway access

	Pop. and Emp.		Property Values			Farm Outcomes	
	Log Population	Log Employment	Log Med. Dwell. Value (Owner-Occ)	Log Med. Dwell. Rent (Renter-Occ)	Log Value Farmland and Farm Buildings	Log Farm Population	Log Farm Revenue per Worker
Early Access to Electricity ×							
1960	0.0294	0.0226	0.0217	0.0117	0.0118	-0.0855***	0.1442***
	(0.0255)	(0.0270)	(0.0233)	(0.0207)	(0.0281)	(0.0314)	(0.0415)
1970	0.0845***	0.0813**	0.0608**	0.0495**	0.1107***	-0.0621	0.2994***
	(0.0323)	(0.0339)	(0.0264)	(0.0206)	(0.0262)	(0.0391)	(0.0757)
1980	0.1243***	0.1287***	0.0791***	0.0512**	0.1060***	-0.0015	0.1091**
	(0.0376)	(0.0411)	(0.0286)	(0.0211)	(0.0269)	(0.0431)	(0.0555)
1990	0.1562***	0.1748***	0.1004***	0.0679***	0.1213***	0.0575	0.0663
	(0.0433)	(0.0475)	(0.0305)	(0.0227)	(0.0325)	(0.0448)	(0.0599)
2000	0.1898***	0.2197***			0.1373***		0.0327
	(0.0487)	(0.0527)			(0.0330)		(0.0662)
1944 Interstate Highway Plan ×							
1960	0.1119***	0.1129***	0.0143	0.0184	0.0336	-0.0203	0.1027**
	(0.0275)	(0.0287)	(0.0229)	(0.0194)	(0.0263)	(0.0302)	(0.0444)
1970	0.1603***	0.1794***	0.0446*	0.0294	0.0664**	0.0300	-0.0024
	(0.0349)	(0.0364)	(0.0243)	(0.0188)	(0.0272)	(0.0352)	(0.0686)
1980	0.2069***	0.2374***	0.0391	0.0290	0.0256	0.0293	0.0533
	(0.0397)	(0.0430)	(0.0262)	(0.0188)	(0.0291)	(0.0379)	(0.0553)
1990	0.2591***	0.2995***	0.0679**	0.0472**	0.0777**	0.0582	-0.0958*
	(0.0454)	(0.0495)	(0.0273)	(0.0194)	(0.0322)	(0.0388)	(0.0578)
2000	0.3029***	0.3422***			0.0591*		0.0192
	(0.0496)	(0.0538)			(0.0352)		(0.0611)
Full controls	Y	Y	Y	Y	Y	Y	Y

Notes: The sample is restricted to counties that experienced above-median decreases in distance to the nearest power plant between 1930 and 1960. The variable *Early Access* is a dummy for counties that experienced the majority of the decrease prior to 1940. Each column reports the point estimates from a different regression. All models include the full set of controls. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

A Appendix

A.1 Tables

Table A.1: Farm Equipment – January 1, 1928

Farm	1	2	3	4	5	6	7	8
Farm Equipment								
Barn equipment							X	X
Brooder	X	X	X	X	X	X		
Corn sheller								X
Feed grinder		X	X					
Feed mill					X	X		
Grain elevator								X
Hay hoist		X						X
Husker-shredder						X		
Incubator		X	X	X	X	X		
Milking machine			X			X		X
Motors	X	X	X		X	X	X	X
Pump jack		X				X	X	X
Root cutter		X						
Silo tiller							X	
Threshing machine								X
Ventilating fans							X	X
Wagon box elevator					X			
Home Appliances								
Bathroom equipment	X		X			X		X
Cream separator	X		X	X		X	X	X
Fans	X	X						
Fireless cooker			X	X				
Frying pan				X				
Griddle				X				
Heater	X	X	X	X		X		
Hot plate	X							
Iron	X	X	X	X	X	X	X	X
Ironing machine			X	X	X			
Laundry trays	X	X	X	X	X		X	
Milk warmer							X	
Oven				X				
Range	X	X	X		X	X	X	X
Refrigerator	X		X	X	X	X	X	
Sewing machine		X	X		X	X		X
Toaster				X			X	
Vacuum cleaner		X	X		X		X	
Washing machine	X	X	X	X	X	X	X	X
Water heater	X				X		X	X
Water softener								X
Basic Equipment								
Lighting	X	X	X	X	X	X	X	X
Water pump	X	X	X	X	X	X	X	X

Source: Authors' compilation based on Stewart, Larson, and Romness (1927).

A.2 A Two-Sector Rosen-Roback Model of Rural Electrification

To study the effects of rural electrification on local economies in the U.S., we outline a Rosen-Roback style model with two production sectors (Roback, 1982): rural production (agriculture), $s = R$, and urban production (manufacturing), $s = U$. We consider a setting with a large number of counties, each with a fixed supply of land. Workers are fully mobile across counties, but must work in their county of residence. Local labour mobility implies that urban and rural wages will equalize within each county,[22] whereas differences in housing amenities across urban and rural areas can lead to intra-county differences in land prices.

Workers are assumed to have identical preferences over a consumption commodity, x, residential land, l^s, and housing quality, h^s. The local wage and rental rate are denoted by w and q^s, where the latter may differ across urban and rural areas. The worker's indirect utility function, V, depends on prices, w and q^s, and housing quality, h^s. The equilibrium condition for workers is given by:

$$V\left(w, q^s, h^s\right) = v \quad \text{for} \quad s \in \{R, U\} \tag{A.1}$$

where v denotes the reservation utility of moving to another county. This condition states that wages and rental costs must equalize utility across counties and across sectors. Despite perfect labour mobility, wages need not equalize across counties, due to differences in housing quality and costs.

In both sectors, firms are assumed to produce a consumption commodity, X^s, which is sold to the world market at a price normalized to one. We assume that X^s is produced according to a constant-returns-to-scale production function, $X^s = f(l^s, N^s, A^s)$, where l^s denotes land used in production, N^s denotes the workers employed in sector, s, and A^s is a sector-specific technology.[23] In equilibrium, firm profits must equal zero in all sectors and counties, otherwise firms have an incentive to relocate. Under the constant-returns-to-scale assumption, the equilibrium condition implies that the unit cost must be equal to the output price:

$$C(w, q^s, A^s) = 1 \quad \text{for} \quad s \in \{R, U\}. \tag{A.2}$$

Equilibrium prices, $\left(w, q^R, q^U\right)$, are determined by the local housing amenities, h^R and h^U, sector technologies, A^R and A^U, and the worker's outside option, v.

A.2.1 The impact of rural electrification on the rural and urban sectors

This simple framework can be used to evaluate the effects of electrification on employment and population outcomes. Denote e as a measure of local electricity access (e.g. the fraction of farms with electricity). We assume that rural electrification can potentially affect the rural sector through increases in agricultural productivity, $A^{R\prime}(e) > 0$, and improvements in rural housing quality, $h^{R\prime}(e) > 0$. On the other hand, urban sector productivity and housing quality are not directly affected by rural electrification.

[22] The assumption of common wages can be relaxed to allow for heterogeneous worker productivity across sectors. In this case, rural electrification has a common effect on local wages, despite the fact that initial wage levels may differ across sectors.

[23] Since capital is fully mobile it can be 'optimized out' of the location problem.

Figure 3 depicts the rural equilibrium at an initial level of electricity access, e_0. To simplify notation, the sector superscripts are omitted. The downward-sloping curve $C\big(w, q, A(e_0)\big)$ displays the combinations of q and w that satisfy condition (2) – equating the producer's unit cost function to the output price – given agricultural technology, $A\left(e_0\right)$. The upward-sloping curve, $V\big(w, q, h(e_0)\big)$, depicts the combinations of q and w that satisfy the worker's equilibrium condition at housing quality $h(e_0)$, in which indirect utility is equal to the reservation value of moving.[24] Initial equilibrium prices are determined by the intersection of these curves at $\big(w_0, q_0\big)$.

Consider an expansion in rural electricity access to e_1. If electricity improves agricultural productivity but has no impact on the quality of rural housing – e.g. $A(e_1) > A(e_0)$ and $h(e_1) = h(e_0)$ – then an expansion in access will lead to an influx of agricultural producers driving up the price of rural land, q.[25] Because rural workers derive no direct benefits from this technology, they must be compensated for the increased cost of housing with a higher wage. This situation is depicted by the upward shift in the firm's unit cost function to $C\big(w, q, A(e_1)\big)$. Equilibrium is restored at the point where the new cost curve intersects the original indirect utility function. In this scenario, rural electrification leads to increases in local wages and land values. Overall, the rural sector will expand, as will agricultural land and employment.[26]

If electricity access affects rural housing quality but has no impact on agricultural productivity, rural workers must compensate producers for the rise in land costs. This situation is captured by the leftward shift in the indirect utility function to $V\big(w, q, h(e_1)\big)$, in which rural electrification leads to increases in rural land prices and decreases in wages. Employment in the rural sector should rise, although it will be somewhat mitigated by increased demand for land for rural housing.

When electricity access increases both rural housing quality and agricultural productivity, we should observe large increases in local land prices but ambiguous effects on wages. In Figure 3, this situation is captured by a shift in both the cost function and the indirect utility curve. Improvements in housing quality will attract rural workers and improvements in agricultural technology will attract rural producers, which will drive up local land values. The net effect on the wage is ambiguous, and depends on the relative size of these two shifts. Overall, the rural sector should expand, as should agricultural land and employment.

Although changes in rural electrification do not directly impact urban residents or producers, they can have indirect effects on the urban economy through local factor prices. Given a fixed supply of land in each county, an increase in the demand for agricultural land will drive up the urban land price, q^U. Local mobility also requires that the urban wage move in tandem with the rural sector. In urban areas, the rise in housing costs caused by

[24] The curvature of these functions depends on the degree of complementarity in production (between labour and land) and utility (between consumption and land).

[25] The effects on agricultural land price and land use will depend on the elasticity of demand for land in the urban sector.

[26] In principle, electricity could lead to a reduction in agricultural employment if it is a "strongly labour-saving" technology which lowers the marginal product of rural labour (Acemoglu, 2010). Even if electricity is a capital-augmenting technology (rather than factor neutral), we require both decreasing returns to scale and a high elasticity of substitution between capital and labour for this situation to arise. Intuitively, given that electricity increases the total amount of land in farming, strong substitution forces are needed to overwhelm the upward pressure on employment.

rural electrification will not be offset by improvements in housing quality or fully compensated by higher wages. As a result, rural electrification should lead to a relative decline in the local urban population. Moreover, the rise in land and labour costs should lead to a decrease in urban production. Over time outmigration will offset the upward pressure on housing prices, restoring equilibrium at lower levels of urban population, employment, and production.

A.2.2 Calculating the value of electricity to rural producers and rural residents

The previous results can be used to evaluate the amenity and production values associated with rural electrification. Define $p_e^* \equiv V_e/V_w$ as the amount of income required to compensate an individual for a change in electricity access. This variable captures the amenity value of rural electricity associated with improvements housing quality. Differentiating equations (1) and (2) and solving for dw/de and dq/de it can be shown that:

$$\frac{p_e^*}{w} = k_l \cdot \frac{d\log q}{de} - \frac{d\log w}{de} \tag{A.3}$$

where k_l denotes the fraction of the households budget spent on land. Equation (3) states that the amenity value of electricity can be calculated based on the relative change in local land prices and wages. Intuitively, when electricity access leads to large increases in housing prices relative to wages, workers must directly benefit from this technology. Specifically, p_e^*/w denotes the percent of income that households would be willing to forgo for access to electricity. Since k_l, $\frac{d\log q}{de}$, and $\frac{d\log w}{de}$ are observable, this expression can be used to derive the amenity value of electricity.

Turning to the benefits of electricity for rural productivity, the marginal impact of electricity on producers' unit costs, C_e, is given by:

$$C_e = -\left(\theta_w \frac{d\log w}{de} + \theta_q \frac{d\log q}{de}\right), \tag{A.4}$$

where θ_w and θ_q are the shares of labour and land in the cost of production. Since all right-hand-side variables are observable, we can estimate the productivity benefits associated with rural electrification.

Finally, the aggregate benefit of electricity to the rural sector can be constructed as the summation of the willingness-to-pay across the rural population, N^R, plus the cost-savings across all agricultural goods, X^R, as follows:

$$p_e^* N^R + \left[-C_e X^R\right] = \frac{dq}{de} L^R. \tag{A.5}$$

The aggregate willingness-to-pay for electricity is given by the change in rural land prices times the total land in the rural sector. Because the wage effects on rural workers and producers exactly offset, this measure does not depend on wages.