Short- and Long-Run Impacts of Rural Electrification: Evidence from the Historical Rollout of the U.S. Power Grid*

Joshua Lewis (University of Montreal)
Edson Severnini (Carnegie Mellon University and IZA)

February 2017

Abstract

Investment in large scale infrastructure projects has long been considered a transformative force for the economy. Historically and today, electrification has figured prominently among these projects, but its estimated short-run impacts have been mixed, and its long-run effects have yet to be evaluated. In this study, we exploit the historical rollout of the U.S. power grid between 1930 and 1960 to examine the evolving impacts of rural electrification on the local economy. We have two main findings. First, rural electrification led to an immediate increase in farmland value and an expansion in the rural sector, but had no impact on local wages or nonagricultural sectors. These estimates imply large short-run gains to rural welfare that exceeded the historical cost of extending the grid, and were driven by improvements in agricultural productivity and rural housing quality. Second, rural counties that gained early access to electricity experienced economic growth that lasted decades after the country was fully electrified. Although the relative expansion in the agricultural sector was short-lived, growth in property values, income, and nonagricultural employment persisted. This long-run expansion was particularly large in rural counties located near metropolitan areas, suggesting that rural electrification helped fuel suburban growth. These historically evolving impacts demonstrate how rural electrification can foster broader local development, and highlight the importance of accounting for long-run responses when making electricity infrastructure investment decisions.

JEL Codes: N72, N92, N52, N32, O13, O18, Q48, H54

*We thank Karen Clay, Michael Greenstone, Rick Hornbeck, Carl Kitchens, Brian Kovak, Lowell Taylor and seminar participants at Carnegie Mellon, University of Chicago – EPIC, University of Illinois at Urbana-Champaign, University of Montreal, and conference participants at the 2016 NBER Summer Institute (Development of the American Economy), the 2016 Economic History Association Annual Meeting, and the 2015 CNEH Meetings for valuable comments and suggestions.
Joshua Lewis: Mailing address: Université de Montréal, 3150, rue Jean-Brillant, Montréal, QC, H3T 1N8, Phone: (514) 240-4972, Email: joshua.lewis@umontreal.ca.
Edson Severnini: Mailing address: Carnegie Mellon University, 4800 Forbes Ave, Pittsburgh, PA 15213, Phone: (510) 860-1808, Email: erseverni@gmail.com.

1 Introduction

Investment in large scale infrastructure has long been considered a transformative force for the economy (e.g., Rostow, 1960; Rosenstein-Rodan, 1961; Murphy, Shleifer, and Vishny, 1989). Currently, one third of international development lending is devoted to major infrastructure projects. Electrification figures prominently among these projects because 1.2 billion people worldwide still lack access to electricity (IEA, 2016). Historically, expansions in the power grid also played a key role in bringing electricity to rural America during the mid-20th century. Economists have begun studying the impacts of electrification on various economic outcomes but the evidence has been mixed, in part because electricity offers a range of benefits that are difficult to quantify and not captured by standard economic indicators.[1] Moreover, as with many large scale infrastructure projects, short-run evaluations may fail to capture the transformative effects of electrification that could take several decades to emerge (Devine Jr., 1983; David, 1990).

This paper proposes a new approach to assess the short-run benefits of electricity access taking into account non-market amenities, and provides the first estimates of the long-run impacts of rural electrification on the local economy. Our approach combines a standard spatial equilibrium model (Rosen, 1979; Roback, 1982) with reduced-form effects on farmland values, housing prices, incomes, and a range of other local outcomes characterizing the immediate effects of electricity access on the rural sector. These estimates are obtained by exploiting the historical rollout of the U.S. power grid between 1930 and 1960. To track the evolving long-run impacts of rural electrification, we use a difference-in-differences strategy relying on detailed data on a range of outcomes for the period 1930 to 2000, and the timing of electricity access over those three decades of the power grid expansion.

The historical U.S. context provides an exceptional opportunity to study the effects of rural electrification. While urban areas were almost fully electrified by 1930, more than 90 percent of rural households gained access to electricity between 1930 and 1960, and there

[1] For example, Cowan (1976) famously observed that the diffusion of modern household technologies reduced the drudgery and physical hardship of housework, but did not affect hours worked in the home or in the labor market.

were sharp differences in the timing of rural electrification driven by plausibly exogenous factors related to the cost of extending services. Moreover, these expansions occurred at a time when even poor households had access to credit for purchasing electric appliances and home retrofitting, allowing us to evaluate the benefits of electrification in a setting in which households can take full advantage of the technology.[2] In addition, the historical U.S. censuses provide information on a rich set of county-level outcomes, which combined with the 70-year historical time horizon, allow us to identify adjustments that occurred gradually over an extended period of time.

The empirical analysis combines a panel dataset 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. We use county-centroid distance to the nearest power plant as our measure of electricity access. Proximity to plants played an important role in determining which rural communities electrified.[3] Our identification assumption – that rural counties would have evolved similarly in the absence of changes in power plant distance – is supported by three pieces of evidence. First, the historical record indicating that siting decisions were driven primarily by cost considerations and urban electricity demand.[4] Second, the amount of electricity generated by these plants relative to rural demand.[5] Third, the fact that baseline rural population characteristics are generally unrelated to subsequent power plant openings.

We have two main findings. First, using county fixed effect regressions that control for differential trends based on initial demographic and economic conditions, we show that a reduction in distance to a large power plant led to short-run increases in farmland values

[2] In 1934, the Roosevelt administration established the Electric Home and Farm Authority (EHFA) and the Federal Housing Administration (FHA). These programs provided low interest loans to households for purchasing modern household appliances and retrofitting homes for electrical services.

[3] In part, this relationship was driven by the fact that the Rural Electrification Administration (REA) loan approval process hinged on the cooperative's ability to secure low wholesale electricity rates.

[4] Electric utilities faced severe constraints on where plants could be built. Hydroelectric plants were ideally located at narrow points along a river that had consistent water flow throughout the year and a sufficient gradient. Meanwhile, coal-fired power plants needed to locate near a source of coal and a large body of water for coolant (Lovell, 1941; Rushmore and Lof, 1923).

[5] Given the limits of electricity transmission and low rural electricity consumption, we calculate that less than 10 percent of total power plant generation could have been used by rural customers.

and an expansion in the rural sector, but had little impact on various income proxies and did not generate spillovers onto nonagricultural sectors. These results are robust to a range of specifications and samples. In a standard spatial equilibrium model, these reduced-form estimates imply that rural electrification led to large gains in rural welfare driven by both improvements in agricultural productivity and the non-market amenity of improved rural housing.[6] We calculate that the average rural family would have been willing to forgo 21 percent of annual income to live in a home equipped with electrical services. Given the large upfront and operating costs of home generators, these gains were likely not large enough to justify individual farm electrification.[7] Nevertheless, we calculate that the benefits exceeded the historical costs of extending the grid even at population densities of less than three farms per mile of distribution line.

Second, adopting a difference-in-differences approach that compares relative outcomes across early versus late electrifying rural counties with similar observable characteristics in 1930, we show that these two groups of counties diverged in the post-1960 period, when the U.S. was fully electrified. Although those counties were similar along baseline outcomes and pre-1930 trends, early electrifying counties experienced persistent relative growth in population and employment in the period 1960 to 2000. By 2000, early electrifying counties were 16 percent more populous than observationally similar late electrifying counties. This expansion was not driven by the agricultural sector. Instead, employment growth was concentrated in construction, services, and trade sectors, suggesting that the temporary local advantage of early electrification spurred broader local development. Relative growth in local property values and income proxies in early electrifying counties is also consistent with this interpretation.

Why did early electrifying rural areas experience persistent growth even after the country was fully electrified? We find that the effects on population, employment, and property

[6] Intuitively, farmers might have been willing to pay more for agricultural land because electricity access might have increased farm productivity, and because it might have been more pleasant to live in the countryside after electricity became available. On the other hand, although electricity may have increased labor productivity in the farm, leading to increased wages, farmers might have been willing to earn less to live in an electrified farm due to the non-market amenities associated with electricity access.

[7] Less than 4 percent of farms owned generators in 1930 (Nye, 1990).

values were concentrated in rural counties located relatively near metropolitan areas (within 60 miles). The temporary local advantage of early electrification may have solved a residential coordination problem, concentrating mid-20th century suburbanization into particular rural areas which subsequently spurred long-term local development. Workers who moved to these rural counties had higher levels of education, were disproportionately white, earned higher incomes, and consumed more local amenities, suggesting that residential segregation may have reinforced these migration patterns. Together, these results suggest that suburban growth was an important channel through which early electrification influenced the long-run population distribution.[8]

This paper makes two important contributions to the literature. First, it provides a new approach to evaluate the short-run benefits of electricity access incorporating non-market amenities, which might reconcile the mixed evidence on the impact of rural electrification in both the historical and the developing country context. Some previous studies have estimated positive effects of rural electrification on agricultural output (Kitchens and Fishback, 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)[9], while others have shown modest or potentially negative impact on the local economy (Burlig and Preonas, 2016; Lee, Miguel, and Wolfram, 2016). Our hedonic results suggest that expansions in electricity access brought large benefits to the rural economy, but a sizeable share of these gains occurred through improvements in the quality of rural housing, unlikely to be fully captured by standard economic indicators.

Second, our study highlights the importance of long-run evaluations of rural electrification infrastructure investments. Because adjustments occur over a period of decades, short-run assessments are unlikely to capture the full responses to these investments. We

[8]The results are robust to controls for the interstate highway system (Baum-Snow, 2007). In particular, we find that that both early rural electrification and planned interstate highway expansions had *distinctive* effects on population and employment growth.

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

add 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 ultimately led to persistent differences in long-run outcomes even after the technology was universally adopted. These findings also 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). This study adds electrification to a list of large scale infrastructure projects that have a transformative impact on the local economy such as major railways (e.g., Haines and Margo, 2008; Atack et al., 2010; Atack, Haines, and Margo, 2011; Atack and Margo, 2011; Banerjee, Duflo, and Qian, 2012; Donaldson, 2013; Faber, 2014; Donaldson and Hornbeck, 2016), highways (e.g., Baum-Snow, 2007; Michaels, 2008; Duranton, Morrow, and Turner, 2014), and dams (e.g., Duflo and Pande, 2007; Strobl and Strobl, 2011; Lipscomb, Mobarak, and Barham, 2013; Severnini, 2014).

This paper also suggests a new determinant of U.S. suburbanization: rural electrification. Baum-Snow (2007) provides evidence that the construction of the interstate highway system caused suburbanization. Boustan (2010) shows that the postwar suburbanization was a "white flight". Here, the availability of electricity far from city centers reduced the cost of living in the suburbs. Rural electrification may have solved a coordination problem on where to extend the urban sprawl in a period of high geographic mobility.[10]

The paper proceeds as follows: Section 2 provides a historical background about the rural electrification in the U.S. Section 3 introduces a conceptual framework to highlight potential effects of rural electrification on 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. Section 7 offers concluding remarks.

[10]Interestingly, in 1984 a New York Times article reflects on the long-run impact of federal subsidies to rural electrification cooperatives by stating that "While the county still has wide expanses of farmland, many of the co-ops' newer customers live among the subdivisions and the tract home developments that have grown up over the past decade in rural Johnson County, marking the southern reach of Indianapolis's suburban sprawl" (Schmidt, 1984).

2 Historical Background

In this section, we describe the increase in rural electricity access between 1930 and 1960. We also document the expansion of the U.S. power grid during this period, and discuss its impact on rural electrification rates. Finally, we draw on a unique historical case study of rural electrification to discuss the potential uses of electricity on the farm.

2.1 Rural Electrification in the U.S.

In the U.S., electrification in urban and rural areas occurred in distinctive periods. 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. Meanwhile, 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 view of high infrastructure costs per customer.[11]

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. Census Bureau, 1976).[12] These programs, combined with the gradual expansion of rural services provided by the private

[11] 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, 1925).

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

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 only 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.

2.2 Expansion in the U.S. Power Grid and Rural Electricity Access

In the early 20th century, electricity was produced and consumed locally. Limitation on transmission technology meant that power plants had to be built near urban areas and there was virtually no interconnection of the power grid across markets. As transmission technology improved, electric utilities were less constrained in the siting of power plants.[13] In the years after World War I, electric utilities began integrating power plants into a grid that supplied multiple markets, allowing them to smooth across local peaks in electricity demand and increase overall reliability of services (Hughes, 1993; p.324). With this shift, new power plants were increasingly built outside of urban areas in an effort to provide electricity to a broader network.[14]

Advances in transmission technology also allowed power plants to be sited increasingly on the basis of cost considerations. In a summary of numerous technical reports from the 1920s, Hughes (1993, p.370) argues that a key objective for large power plants was "massing the generating units near economical sources of energy and near cooling water" and "transmitting electricity to load centers" using high voltage transmission lines. Local characteristics were a key determinant of the construction costs and ongoing operating costs of power plants. Coal-fired plants accounted for three-quarters of electricity generation

[13] Maximum transmission voltages increased from less than 50 kilovolts in 1900 to over 150 kilovolts in the 1920s (Casazza, 2004; p.10).

[14] See Figure A.1, which reports the distribution of electricity capacity around the 50 largest U.S. cities in 1930 and 1960.

during this period (Historical Statistics, 1976, p.820). In 1930, roughly 1.6 pounds of coal was burned for each kilowatt-hour of electricity generation (Historical Statistics, 1976, p.826). Thus, a 30 MW coal-fired power plant operating at full capacity would have burned over 500 tons of coal per day. Plant operating costs depended on the distance coal had to be shipped, since freight costs typically accounted for two-thirds of the total cost of shipped coal (*Electrical World, 1938*). Access to a large supply of water for coolant was also essential to coal-fired power plant efficiency.[15] There were even greater constraints on the siting of large hydroelectric power plants. These plants needed to be located at a narrow point along a river that had a consistent water flow throughout the year and a a sufficient gradient.

Figure 2 reports the map of power plants that opened before 1930 and power plants that opened between 1930 and 1960. There were strong regional patterns in power plant construction. In 1930, there had already been substantial development in the Northeast and in California, although few plants had been built in the Midwest or South. Over the next 30 years, there was dramatic growth in the number of new power plants built. Plants continued to open along the west coast throughout the Northeast. There was also significant development throughout the South and Midwest, and by 1960, there was wide coverage throughout the country.

The non-uniform expansion of the power grid led to differential changes in the cost of extending rural electricity access. Although rural demand for electricity was far too small to have influenced the siting decisions of these large plants – the typical power plant would have produced roughly 10 times the amount of electricity that could have been consumed by all potential rural customers.[16] Once built, however, distance to the grid was an important determinant of rural electricity access. In particular, electric utilities were responsable for the construction and maintenace of transmission lines, and power losses are a function

[15] For every pound of coal, 400 pounds of cooling water were used, and water temperature played a crucial role in the performance of steam turbines (Hughes, 1993, p.306).

[16] This calculation is based on an average household electricity consumption of 3,854 Kwh per year (Historical Statistics, 1976, p.828), and the assumption that each power plant serviced all rural customers within a 100 km radius.

of transmission distance. Moreover, proximity to the electric was a key determinant of REA loan approval, which hinged on the cooperative's ability to secure low cost wholesale electricity rates (Fishback and Kitchens, 2014).

2.3 Uses of Electricity on the Farm and in the Home

Electricity offered a range of benefits to farm production. 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 percent, and milk production per cow rose by almost 60 percent (U.S. Census Bureau, 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 of irrigation led to large increases in average farm size in those states.

Electricity also brought many benefits to rural households. Electric lighting extended the day and reduced exposure to smoke from kerosene lamps. Electricity provided access to a range of labor-saving appliances, which dramatically reduced the time of home production. Evidence from historical time use studies suggest that 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 (USDA, 1944; Wilson, 193-).[17]

Federal programs that provided widespread consumer credit allowed virtually all American households, including low income households, to take advantage of this new technology. In 1934, the federal government established the Electric Home and Farm Authority (EHFA), and the Federal Housing Administration (FHA). The EHFA provided low-cost and long-term financing services to consumers who bought tested and labeled appliances, and purchased electricity from utilities whose rates were approved by the Authority. The goal of

[17]Despite major changes in household technologies, time spent in home production remained roughly constant between 1920 and 1960 (Ramey, 2009), and that time savings was reallocated towards investment in child health (Lewis, 2016b).

the EHFA was to overcome the "four main obstacles to widespread utilitization of electric power: high electric rates, high appliance costs, high finance charges, and the 'public's lack of information relative to the use of electricity and electrical appliances'" (Coppock, 1940, p.11). Approximately 3 million rural customers were eligible for loans under the EHFA.[18] The FHA also provided home rehabilitation loans under Title I of the National Housing Act, that could be used for electric wiring upgrade, retrofit, and the purchase of modern appliances. Historians have emphasized the importance of this program in allowing low income households to take full advantage of the benefits associated with electrical modernization (Tobey, 1996)). Between 1934 and 1937, the FHA insured about 1,450,000 modernization loans (Coppock, 1940).[19] Roughly two-fifths of the loaned funds were used for the purchase and installation of equipment and machinery, while three-fifths went for home additions, alterations, or repairs.

The "Red Wing Project". To provide case study evidence on the potential uses of electricity on the farm, we collected data from the Red Wing rural electrification project (Stewart, Larson, and Romness, 1927). The Red Wing Project ran from late 1923 to early 1928 in Red Wing, Minnesota. Nine participating farms received electrical services along with free access to a variety of household appliances and electrical farm equipment (see Table A.1 for the list of appliances and equipment).[20] We collected monthly data on electricity consumption by specific appliance and farm machinery for Red Wing participants.

Figure 3 shows the monthly pattern for farm, home, and basic (lighting and pumping) electricity consumption. Together home and basic electricity accounted for over 70 percent of consumption on the farm.[21] Household electricity consumption was relatively stable throughout the year, except for modest seasonality in refrigerator use. Farm consumption

[18]The typical down payment for appliance purchases was 15 percent of the average cash selling price. The average length of the contract was 30 months, and the average monthly payment represented less than 5 percent of the monthly income for the majority of the beneficiaries (Coppock, 1940).

[19]Although insured loans could run as long as 5 years, the average duration was 30 months.

[20]The project was run by the University of Minnesota in collaboration with the local power company and manufacturers of electrical equipment and appliances. The local 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.

[21]There were large differences in electricity use across farms. The farm share ranged from 0.07 to 0.48, primarily because of differences in the intensity of dairy production.

displayed the greatest variability, peaking during the harvesting season for barley, corn, oats, and wheat, around August-September in Minnesota (USDA, 1997).

Total electricity consumption among Red Wing participants was 50 percent higher than initially predicted, exceeding the national average of 35 kWh per month (U.S. Census Bureau, 1976).[22] Electricity consumption was concentrated in the home and remained fairly stable throughout the year, mitigating the challenges of providing electricity to meet variable loads. The results of the Red Wing Project were influential in the federal government's decision to support rural electrification, by suggesting that electricity was highly valued on the farm, and casting doubt on the long-held view that it was uneconomical to expand rural access.

3 Conceptual Framework

We outline a conceptual framework to guide our interpretation of the local impacts of rural electrification. In the short run, prices respond immediately to electricity access, even though cross-county mobility may be limited. In the long run, all factors adjust to the new technology, and worker sorting may have first-order implications for welfare.

Short-Run Effects of Rural Electrification. The standard Rosen-Roback spatial equilibrium model (see details in Appendix A.2) can be used to evaluate the effects of electrification on property values, wages, employment and population outcomes (Rosen, 1979; Roback, 1982). The model delivers equations that identify the local gains associated with electrification driven by both the non-market amenity of improved rural housing and increases 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

[22]The large gap can likely be attributed to the fact that households in the Red Wing Project were provided free access to a range of appliances. Meawhile, prior to widespread credit under EHFA and FHA, the median electrified American home owned only a single major appliance.

and counties, and land values and wages are set such that all markets clear.

Rural electrification 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. These two mechanisms will increase demand for farmland and attract workers and producers to the rural sector. The relative impacts of rural electrification on land prices and total farmland depends on the supply elasticity of rural land.[23]

The relative impact of electricity access on land values and wages can be used to identify the benefits to rural communities driven by increases in agricultural productivity and improvements in the quality of rural housing. An increase in agricultural productivity will drive up local land values and the cost of rural housing. In the absence of improvements in rural housing quality, workers must be compensated for these costs with a higher wage. Similarly, improvements in the quality of rural housing will drive up local land prices. Without improvements in agricultural productivity, producers must be compensated for the increase in costs through lower wages, which workers will be willing to accept given the improvements in local rural housing quality.

Figure 4 provides a graphical representation of the predicted local impact of rural electrification. The downward-sloping curve denotes combinations of wages w and rental rates q that equalize unit costs C at a level of electricity access e. The upward-sloping curve denotes the combinations of w and q for a level of electricity access, e, for which worker's indirect utility is constant and equal to the outside option of moving to another county, V^*. The initial spatial equilibrium occurs at the intersection of these two curves at prices w_0 and q_0. Improvements in agricultural productivity associated with electrification will lead to a rightward shift of the unit cost curve. If workers do not benefits from improvements in housing quality, they must be compensated for the increase in housing costs with higher wages, and the new equilibrium is characteristized by the intersection between the original indirect utility curve and the new unit cost curve with higher land prices and higher wages. Conversely, improvements in housing quality will lead to a leftward shift the the indirect

[23] If the supply of rural land in inelastic, rural electrification can lead to large increases in land prices without having effects on total farmland.

utility curve, and equilibrium will be restored at higher land prices and lower wages. The model delivers two simple equations based on reduced form impacts of rural electrification on local land prices and wages that allow us to decompose the benefits to rural communities driven by increases in agricultural productivity and improvements in rural housing quality.

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.

Long-Run Impact of Early Rural Electrification. In the short-run, rural counties that gained early acces to electricity are predicted to have experienced a relative expansion. It is theoretically ambiguous, however, whether these initial advantages persisted in the post-1960 period, after the country was fully electrified.

In spatial equilbrium models that feature local congestion costs, early and late electrifying rural counties should return to their initial population distributions after the technology becomes widely available and the temporary local advantage is eliminated. This situation is likely to arise in settings with homogeneous preferences over neighbors and local amenities, and weak economies of density. The speed of adjustment back to the long-run equilibrium will depend on whether early electricity spurred endogenous local investments. Historians have emphasized the importance of electrification for broader investments in housing quality. For example, Tobey (1996, p.138-139) argues that "electrical modernization was not piecemeal; it led to the whole renovation of the home to bring the quality of living in it up to the electrical standard." The initial spatial equilbrium will not be restored until these sunk investments are fully depreciated. Nevertheless, in the long-run the relative distribution of population across rural counties should eventually be restored to the pre-1930 equilibrium.[24]

[24]This static model does not account for the long-run trends in rural-urban migration. The baseline prediction should be unaffected, however, since in the long-run, early and late electrifying rural counties

Alternatively, the short-term local advantage of early electrification may have persisted and even magnified in the post-1960 period, when electricity was universally adopted. This situation could arise if there were coordination problems, heterogeneous preferences over neighbor characteristics and local amenities, or strong economies of density. Early access to electricity may have helped resolve a residential coordination failure about where the co-locate (Bleakley and Lin, 2012). The expansion in rural electrification occurred during a period of high geographic mobility and rapid suburbanization.[25] The temporary local advantage associated with early electrification may have concentrated mid-20th century suburbanization of rural counties. Assuming there were fixed costs associated with establishing new suburban communities and provided that congestion costs were not too large, locations that electrified early may have continued to attract suburban residents and experienced persistent economic growth even after the country was fully electrified.

Preferences to sort across communities on the basis of socioeconomic characteristics such as a race and education levels may have reinforced the incentive to co-locate across rural counties (Behrens, Duranton, Robert-Nicoud, 2014; Behrens and Robert-Nicoud, 2015).[26] This sorting channel likely played an important role in determining the long-run spatial equilbrium, since the mid-20th century geographic mobility featured an important demographic component, as predominantly white populations moved to suburban areas (Boustan, 2010). Moreover, recent evidence suggest that individual preferences for local amenities vary by socioeconomic status (Diamond, 2015). Endogenous investment in local infrastructure could magnify the sorting response, as individuals select into communities on the basis of their desired levels of local amenity.[27]

---

should be affected similarly by this trend and thus should maintain stable relative populations.

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

[26] There is growing evidence that temporary historical determinants can lead to persistent sorting across neighborhoods (see Lee and Lin, 2013; Villarreal, 2014; Brooks and Lutz, 2016; Heblich, Trew, and Zylberber, 2016).

[27] There is a large literature documenting Tiebout sorting on the basis of local amenities such as public school quality (Black, 1999; Bayer, Ferreira, and McMillan, 2007), and environmental air quality (Banzhaf and Walsh, 2008; Heblich, Trew, and Zylberberg, 2016).

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, and farm size), 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 (FPC, 1963). 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 latitude, 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.[28]

Figure 4 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 counties that were at least 50 percent rural and within 200 miles of a power plant in 1930.[29] 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.

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

[29] 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, and state-by-year fixed effects, λ_{st}. 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

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

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 10 mile decrease in power plant distance on contemporaneous decadal changes in the outcome variable across counties in the same state that trended similarly according to observable baseline characteristics.

To study the longer term adjustments to rural electrification, 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.[30] We focus on the sample of rural counties that experienced above-median decreases in power plant distance between 1930 to 1960, and compare relative changes across early and late access counties for the period 1960 to 2000.[31] For-

[30] Quantitatively similar estimates are found when "late access" is calculate for the period 1950 to 1960 (reported in Table A.2).

[31] Similar estimates are found when the full sample of rural counties are included (see Table A.2).

mally, outcome Y_{ct} is differenced from its value in 1930 and regressed on a county indicator for early access, $EarlyAccess_c$, state-by-year fixed effects, λ_{st}, 1930 county characteristics, $X_{c,1930}$, interacted with year fixed effects, and an error term, ϵ_{ct}:

$$Y_{ct} - Y_{c,1930} = \beta_t EarlyAccess_c + \lambda_{st} + \theta_t X_{c,1930} + \epsilon_{ct}. \quad (2)$$

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, in the same state that trended similarly according to baseline observable characteristics.[32] Because both early and late access counties were fully electrified by 1960, the estimates in equation (2) allow us to assess whether the timing of rural electrification had persistent effects on the local economy, where $\beta_t > 0$ implies amplification over time, $\beta_t < 0$ implies reversal, and $\beta_t = 0$ implies constant effects over time.[33] For statistical inference, standard errors are clustered at the county level to adjust for heteroskedasticity and within-county correlation over time.[34]

The identifying assumption for the empirical analysis is that outcomes in rural counties in the same state would have trended similarly in the absence of changes in electricity access.[35] This assumption is supported by three main pieces of evidence. First, the historical narrative that indicates that the siting decisions of large power plants were made primarily on the basis of local geographic and topological conditions that influenced construction and

[32]For this class of regression, in which the sample is balanced and the regressors are fully interacted with each time period, differencing the data and including county fixed effects yield numerically identical coefficients (as in the case of two time periods). Differencing is more efficient when the untransformed error term is closer to a random walk, the differenced coefficients are easier to interpret, and differencing is computationally faster (see Hornbeck, 2012).

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

[34]Conley (1999) standard errors were also estimated for changes in key outcomes from 1930 to 1960, and were similar to standard errors clustered at the county level. The Conley method allows for outcomes to be correlated among nearby counties, with the degree of correlation declining linearly until some cutoff distance. We examined the following outcomes: rural farm population, agriculture employment, log value of farmland and farm buildings, log median dwelling value (owner-occupied), and log median dwelling rent (renter-occupied). Relative to county-clustered standard errors, the increase in Conley standard errors for changes in $DistPP30$ ranged from -4 to 23 percent for a 100-mile cutoff.

[35]In practice, this assumption must hold only after controlling for differential trends according to baseline county socioeconomic characteristics.

operating costs, and a desire to develop an interconnected power grid across multiple urban areas , rather than a desire to serve sparsely population rural areas (Hughes, 1993; Casazza, 2004).[36]

Second, given typical electricity consumption on the farm and in the home, and low rural population densities, rural demand accounted for only a small fraction of the total electricity produced by these large power plants. Among the power plants used in the empirical analysis, rural consumption would have accounted for less than 10 percent of total electricity generation. Thus, it is highly unlikely that these large power plants would have been built in response to changes in rural demand for electricity.

Third, neither the timing nor the magnitude of changes in county distance to power plants between 1930 and 1960 were related to the baseline population and economic conditions of rural counties. Table 1 reports mean county characteristics in 1930 (column 1) and the logarithm of within-state differences in baseline characteristics for rural counties that experienced above-median relative to below-median decreases in distance to power plants from 1930 to 1960.[37] We report these estimated differences separately for rural counties that gained early access (column 2) and late access (column 3). Panel A shows that future expansions in electricity access were generally unrelated to baseline farm outcomes. Counties that experienced large decreases in power plant distance tended to have larger average farm size, consistent with expansion of the power grid into less densely populated areas. Panel B reports baseline differences in rural population and employment characteristics. Again, there were few systematic differences across rural counties according to the magnitude of future decreases in power plant distance. If anything, counties that experienced large decreases in distance were somewhat less populous, had less manufacturing employment, and were more non-white. Column 4 reports the difference in the estimates across early access (column 2) and late access (column 3) rural counties. There were no signifi-

[36] In fact, Morton (2000, p.29) notes that "private utilities insisted that extending service to these rural customers would be unprofitable." Moreover, at a cost of $7,200 per mile (Beall, 1940), it was far cheaper to extend rural lines than to build power plants to meet rural demand.

[37] Notice that this test of baseline characteristics in levels is more stringent than the identifying assumption that rural counties would have trended similarly in the absence of rural electrification.

cant differences in the baseline characteristics according to the *timing* of rural electricity access. Importantly, any baseline differences across rural counties are controlled for in the fixed-effects specification, and the inclusion of the term, $\theta_t X_{c,1930}$, allows rural counties to trend differentially according to observable population and economic characteristics.

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.[38] 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.

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,

[38] 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.

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:

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

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 samples 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 households with electricity, $\frac{de}{ddistPP30} = 0.0025$. The resulting calculations reflect the rural benefits of an increase in the fraction of farms with electrical services from 0 percent to 100 percent.[39] These estimates are combined with 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).[40] We calculate the following annual willingness-to-pay for electricity access: $p_e^* N^R + \left[- C_e X^R \right] = (0.0052/0.0025) \times 12.85 \times 306,245 = \$7,870,497$ per county. This estimate implies that a typical farm household would have been willing to forgo $4,063 per year to gain access to electricity, roughly 41 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):

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

[39] These willingness-to-pay calculations might overestimate the benefits of farm electrification, if power plant distance affected agricultural productivity independently of farm household electrification. For example, if increased access to electricity infrastructure spurred investment in other local infrastructure.

[40] 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.

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.[41] 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.[42] The value associated with household amenities is given by: $p_e^* N^R = 0.18 \times (0.0050/0.0025) \times 4,393 \times 2,605 = \$4,119,755$. The estimates imply that rural residents were willing to forgo 21 percent of annual revenue to reside in an electrified home, and that roughly one half of the benefits from rural electrification occurred through the 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 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.[43] 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.

[41] The rural wage is calculated by multiply a labor share of 0.6 by the mean farm revenue per agricultural worker (REF).

[42] 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.

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

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 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.[44] Panel A graphs the estimates for population and employment, panel B graphs the estimates 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 insignificant 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

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

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 productivities, 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.

Panel 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, Mobarak, and Szerman, 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 metropoli-

tan 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.[45] 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).[46] This increased investment in housing amenities may have reinforced the upward pressure on local property values.

The previous results suggest that early electricity access played a significant role in suburban growth during the second half of the 20th century. We assess the sensitivity of these results to another source of suburban growth: the mid-20th century construction of the interstate highway system (Baum-Snow, 2007). In particular, we re-estimate equation (2), including controls for a dummy variable indicating whether the 1944 planned interstate route intersected the rural county (Michaels, 2008) interacted with year fixed effects.[47] Table 9 reports these results. The bottom panel reports the estimates for the planned interstate. The estimates suggest that highway construction led to increases in population and employment, but had little impact on local property values or farm outcomes. Importantly, the inclusion of these covariates has little impact on the main estimates. Together the

[45] 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.

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

[47] Because early electrification may have influenced future investment in transportation infrastructure, we do not directly control for the actual highway network.

estimates suggest that both transportation and electricity infrastructure had independent effects on long-run population growth in these rural counties.

7 Conclusion

This paper exploited the historical rollout of the U.S. power grid between 1930 and 1960 to study the evolving impact of rural electrification on local economies. Our empirical analysis provided evidence that rural electrification led to short-run increases in agricultural employment, farm population, and property values, but had limited impacts on nonagricultural sectors. The short-run local benefits were driven by both improvements in agricultural productivity and non-market amenities associated with improved rural housing, and were estimated to have exceeded the historical cost of extending the grid, even at low population densities.

In addition to those short-run effects, rural counties that gained early access to electricity experienced long-run economic growth that persisted long after the country was fully electrified. This long-run expansion was concentrated in nonagricultural sectors and occurred primarily in rural counties located near metropolitan areas (within 60 miles of an MSA), suggesting that rural electrification facilitated the mid-20th century suburbanization. Early electricity access may have helped solving a coordination problem on where to suburbanize, which might have led to further agglomeration economies and sorting. Our results demonstrate how gradual local adjustments to rural electrification can either reinforce or reverse short-run effects, and highlight the importance of accounting for these long-run responses when making electricity infrastructure investment decisions.

Our findings have relevance for current policy in the developing world. Recent evidence from Kenya, for instance, suggests that even in rural communities with high population density, electrification rates remain very low, and households appear to be unable or unwilling to pay the connection cost individually (Lee et al., 2016). Our willingness-to-pay estimates suggest that credit constraint might be a key barrier, and that government loans

or subsidies for rural electrification to rural populations may offer large welfare gains. 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. Our findings also suggest that investment in rural electrification may be a key catalyst for sub-urban growth. To the extent that policy-makers in developing countries seek to accelerate the pace of the rural-urban transition, increased investment in electric grid infrastructure help achieve this objective.

References

Assuncao, Juliano, Molly Lipscomb, A. Mushfiq Mobarak, and Dimitri Szerman. (2016). "Agricultural Productivity and Deforestation in Brazil," *Mimeo.*

Atack, Jeremy, Fred Bateman, Michael Haines, and Robert A. Margo. (2010). "Did Railroads Induce or Follow Economic Growth? Urbanization and Population Growth in the American Midwest, 18501860," *Social Science History*, 34: 171-197.

Atack, Jeremy, Michael Haines, and Robert A. Margo. (2011). "Railroads and the Rise of the Factory: Evidence for the United States, 18501870, in *Economic Evolution and Revolutions in Historical Time*, P. Rhode, J. Rosenbloom, and D. Weiman, eds. (Palo Alto, CA: Stanford University Press).

Atack, Jeremy, and Robert A. Margo. (2011). "The Impact of Access to Rail Transportation on Agricultural Improvement: The American Midwest as a Test Case, 18501860," *Journal of Transport and Land Use*, 4: 5-18.

Banerjee, Abhijit, Esther Duflo, and Nancy Qian. (2012). "On the Road: Access to Transportation Infrastructure and Economic Growth in China," *NBER Working Paper* #17897.

Baum-Snow, Nathaniel. (2007). "Did Highways Cause Suburbanization?" *Quarterly Journal of Economics* 122(2): 775-805.

Beall, Robert T. (1940). "Rural Electrification," *Yearbook of Agriculture*: 790-809.

Behrens, Kristian, Gilles Duranton, and Frederic Robert-Nicoud. (2014). "Productive Cities: Sorting, Selection, and Agglomeration", *Journal of Political Economy* 122(3): 507-553.

Behrens, Kristian, and Frederic Robert-Nicoud. (2015). "Agglomeration Theory with Heterogeneous Agents". In: Gilles Duranton, J. Vernon Henderson and William C. Strange (eds.) *Handbook of Regional and Urban Economics*, vol. 5, chapter 4, Elsevier: North-Holland, pp. 171-245.

Bleakley, Hoyt, and Jeffrey Lin. (2012). "Portage and Path Dependence", *Quarterly Journal of Economics* 127(2): 587-644.

Boustan, Leah Platt. (2010). "Was Postwar Suburbanization 'White Flight'? Evidence from the Black Migration," *Quarterly Journal of Economics* 125(1): 417-443.

Burlig, Fiona, and Louis Preonas. (2016). "Out of the Darkness and Into the Light? Development Effects of Rural Electrification," *Mimeo.*

Chakravorty, Ujjayant, Martino Pelli, and Beyza Ural Marchand. (2014). "Does the Quality of Electricity Matter? Evidence from Rural India," *Journal of Economic Behavior & Organization* 107(A): 228-247.

Chakravorty, Ujjayant, Kyle Emerick, and Majah Leah-Ravago. (2016). "Lighting Up the Last Mile: The Benefits and Costs of Extending Electricity to the Rural Poor," *Mimeo.*

Clay, Karen, Joshua Lewis, and Edson Severnini. (2016). "Canary in a Coal Mine: Infant Mortality, Property Values, and Tradeoffs Associated with Mid-20th Century Air Pollution", *NBER Working Paper* #22155.

Conley, Timothy G. (1999). "GMM Estimation with Cross-Sectional Dependence, *Journal of Econometrics* 92(1): 1-45.

Coppock, Joseph D. (1940). *Government Agencies of Consumer Instalment Credit*, NBER Books.

Cowan, Ruth Schwartz. (1976). "The 'Industrial Revolution' in the Home: Household Technology and Social Change in the 20th Century", *Technology and Culture* 17(1): 1-23.

David, Paul A. (1990). "The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox", *American Economic Review: Papers and Proceedings* 80(2):355-361.

Davis, Donald R., and David E. Weinstein. (2002). "Bones, Bombs, and Break Points: The Geography of Economic Activity," *American Economic Review* 92(5): 1269-1289.

Devine, Warren D. (1983). "From Shafts to Wires: Historical Perspective on Electrification," *Journal of Economic History*, 43(2): 347-372.

Diamond, Rebecca. (2016). "The Determinants and Welfare Implications of US Workers' Diverging Location Choices by Skill: 1980-2000", *American Economic Review* 106(3): 479-524.

Dinkelman, Taryn. (2011). "The Effects of Rural Electrification on Employment: New Evidence from South Africa," *American Economic Review* 101(7): 3078-3108.

Donaldson, Dave. (2013). "Railroads of the Raj: Estimating the Impact of Transportation Infrastructure," *American Economic Review*.

Donaldson, Dave, and Richard Hornbeck. (2016). "Railroads and American Economic Growth: A 'Market Access' Approach", *Quarterly Journal of Economics* 131(2): 799-858.

Duflo, Esther, and Rohini Pande. (2007). "Dams," *Quarterly Journal of Economics* 122(2): 601-646.

Duranton, Gilles, and Diego Puga. (2004). "Micro-Foundations of Urban Agglomeration Economies". In: J. Vernon Henderson and Jacques-Francois Thisse (eds.) *Handbook of Regional and Urban Economics*, vol. 4, chapter 48, Elsevier: North-Holland, pp. 2063-2117.

Duranton, Giles, Peter M. Morrow, and Matthew A. Turner. (2014). "Roads and Trade: Evidence from the US", *Review of Economic Studies* 81(2): 681-724.

Faber, Benjamin. (2014). "Trade Integration, Market Size, and Industrialization: Evidence from China's National Trunk Highway System", *Review of Economic Studies* 81(3): 1046-1070.

General Electric Digest, April 1925.

Haines, Michael R., and Inter-university Consortium for Political and Social Research (ICPSR). (2010). *Historical, Demographic, Economic, and Social Data: The United States, 1790-2002*. Ann Arbor, MI: Inter-university Consortium for Political and Social Research, icpsr.org.

Haines, Michael, and Robert A. Margo. (2008). "Railroads and Local Development: The United States in the 1850s," in *Quantitative Economic History: The Good of Counting*, J. Rosenbloom, ed. (London: Routledge), 78-99.

Hornbeck, Richard. (2012). "The Enduring Impact of the American Dust Bowl: Short- and Long-Run Adjustments to Environmental Catastrophe," *American Economic Review* 102(4): 1477-1507.

International Energy Agency (IEA). (2016). *World Energy Outlook*, available at worldenergyoutlook.org/publications/weo-2016/.

Kitchens, Carl. (2014). "The Role of Publicly Provided Electricity in Economic Development: The Experience of the Tennessee Valley Authority," *Journal of Economic History* 74(2): 389-419.

Kitchens, Carl, and Price Fishback. (2015). "Flip the Switch: The Impact of the Rural Electrification Administration 19351940," *Journal of Economic History* 75(4): 1161-1195.

Kline, Patrick, and Enrico Moretti. (2014). "Local Economic Development, Agglomeration Economies, and the Big Push: 100 Years of Evidence from the Tennessee Valley Authority," *Quarterly Journal of Economics* 129(1): 275-331.

Lebergott, Stanley. (1976). *The American Economy: Income, Wealth and Want*. Princeton NJ: Princeton University Press.

Lee, Kenneth, Eric Brewer, Carson Christiano, Francis Meyo, Edward Miguel, Matthew Podolsky, Javier Rosa, Catherine Wolfram. (2016). "Electrification for 'Under Grid' Households in Rural Kenya," *Development Engineering* 1: 26-35.

Lee, Kenneth, Edward Miguel, and Catherine Wolfram. (2016). "Experimental Evidence on the Demand for and Costs of Rural Electrification," *Mimeo*.

Lewis, Joshua. (2016a). "Short-run and Long-run Effects of Household Electrification, *Mimeo*.

Lewis, Joshua. (2016b). "Fertility, Child Health, and the Diffusion of Electricity into the Home, *Mimeo*.

Lipscomb, Molly, A. Mushfiq Mobarak, and Tania Barham. (2013). "Development Effects of Electrification: Evidence from the Topographic Placement of Hydropower Plants in Brazil," *American Economic Journal: Applied Economics* 5(2): 200-231.

Michaels, Guy. (2008). "The Effect of Trade on the Demand for Skill: Evidence from the Interstate Highway System," *Review of Economics and Statistics* 90(4): 683-701.

Morton, David. (2000). *Power: A Survey History of Electric Power Technology Since 1945.* New York: IEEE Press.

Murphy, Kevin M., Andrei Shleifer, and Robert W. Vishny. (1989). "Industrialization and the Big Push," *Journal of Political Economy* 97(5): 1003-1026.

National Electric Light Assocation (NELA). (1925). *Proceedings, Forty-Eighth Convention.*

Nye, David E. (1990). *Electrifying America: Social Meanings of a New Technology: 1880-1940.* Cambridge, MA: The MIT Press.

Ramey, Valerie A. (2009). "Time Spent in Home Production in the Twentieth-Century United States: New Estimates from Old Data, *Journal of Economic History* 69(1): 1-47.

Redding, Stephen J., and Daniel M. Sturm. (2008). "The Costs of Remoteness: Evidence from German Division and Reunification," *American Economic Review* 98(5): 1766-97.

Roback, Jennifer. (1982). "Wages, Rents, and the Quality of Life," *Journal of Political Economy* 90(6): 1257-1278.

Rosen, Sherwin. (1979). "Wages-Based Indexes of Urban Quality of Life. In *Current Issues in Urban Economics*, edited by Peter Mieszkowski and Mahlon Straszheim, 74-104. Baltimore: John Hopkins University Press.

Rosenstein-Rodan, Paul N. (1961). "Notes on the Theory of the 'Big Push'. In *Economic Development for Latin America*, edited by Howard S. Ellis and Henry C. Wallich. New York: St. Martin's, 57-81.

Rostow, Walt W. (1960). *The Stages of Economic Growth: A Non-Communist Manifesto.* Cambridge: Cambridge University Press.

Ryan, Nicholas. (2014). "The Competitive Effects of Transmission Infrastructure in the Indian Electricity Market," *Mimeo.*

Schmidt, William E. (1984). "Rural Electric Co-Ops Fight to Keep Subsidy," *New York Times.*

Severnini, Edson. (2014). "The Power of Hydroelectric Dams: Agglomeration Spillovers," *IZA Discussion Paper* #8082.

Stewart, E.A., J.M. Larson, and J. Romness. (1927). *The Red Wing Project on Utilization of Electricity in Agriculture.* University of Minnesota Agricultural Experiment Station, Division of Agricultural Engineering.

Strobl, Eric, and Robert O. Strobl. (2011). "The Distributional Impact of Large Dams: Evidence from Cropland Productivity in Africa", *Journal of Development Economics* 96(2): 432-450.

Tobey, Ronald C. (1996). *Technology as Freedom: The New Deal and the Electrical Modernization of the American Home.* Berkeley, CA: University of California Press.

U.S. Census Bureau. (1976). *Historical Statistics of the United States, Colonial times to present*. Washington D.C.: U.S. Census Bureau.

U.S. Department of Agriculture (USDA). (1944). *The Time Costs of Homemaking – A Study of 1,500 Rural and Urban Households*. Agricultural Research Administration, Bureau of Human Nutrition and Home Economics.

U.S. Department of Agriculture (USDA). (1997). *Usual Planting and Harvesting Dates for U.S. Field Crops*. Washington D.C.: USDA.

U.S. Department of Commerce, Bureau of the Census. (1943). *Sixteenth Census of the United States: 1940. Housing, Volume II: General Characteristics*. Washington, DC: Government Printing Office.

U.S. Department of Commerce, Bureau of the Census. (1953). *Census of Housing, 1950. Volume I: General Characteristics*. Washington, DC: Government Printing Office.

U.S. Department of Commerce, Bureau of the Census. (1963). *Census of Housing, 1960. Volume I: States and Small Areas*. Washington, DC: Government Printing Office.

U.S. Department of Commerce (DOC), Bureau of the Census, and Inter-university Consortium for Political and Social Research (ICPSR). (2012). *County and City Data Book (United States) Consolidated File: County Data, 1947-1977*. Ann Arbor, MI: Inter-university Consortium for Political and Social Research, icpsr.org.

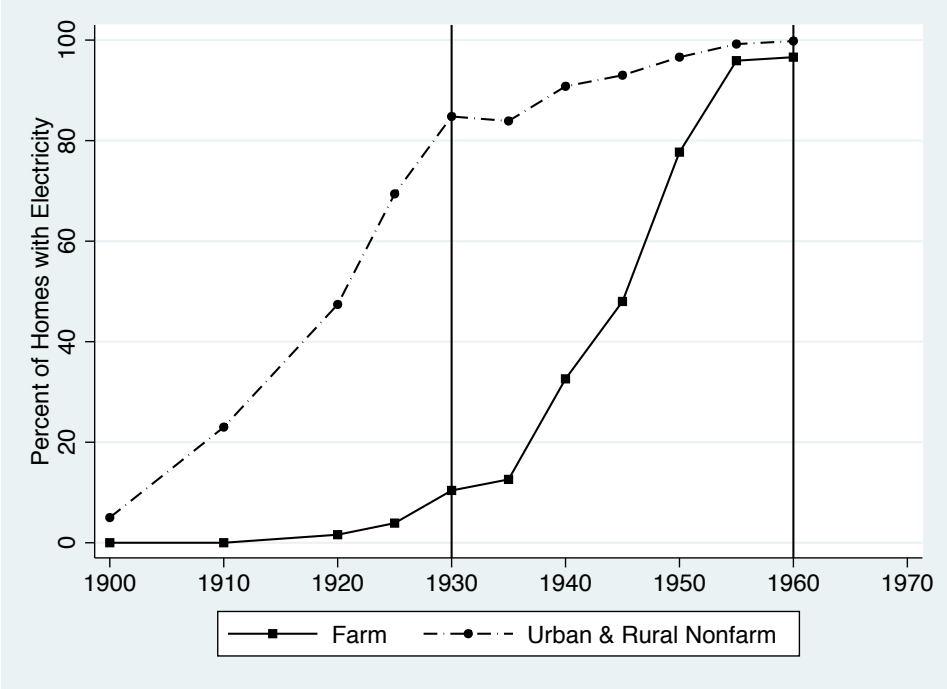
U.S. Federal Power Commission (FPC). (1963). *Principal Electric Power Facilities in the United States (Map)*. Washington DC: U.S. Federal Power Commission.

Wilson, Maud. (193-). *Present Use of Time in Households and by Homemakers: Complete Report of Purnell Study*, Oregon State Agricultural Experiment Station.

World Bank. (2013). *Global Tracking Framework*, available at trackingenergy4all.worldbank.org/˜/media/GIAWB/GTF/Documents/GTF-2013-Full-Report.pdf.

8 Figures and Tables

Figure 1: % farm and nonfarm households with electrical facilities



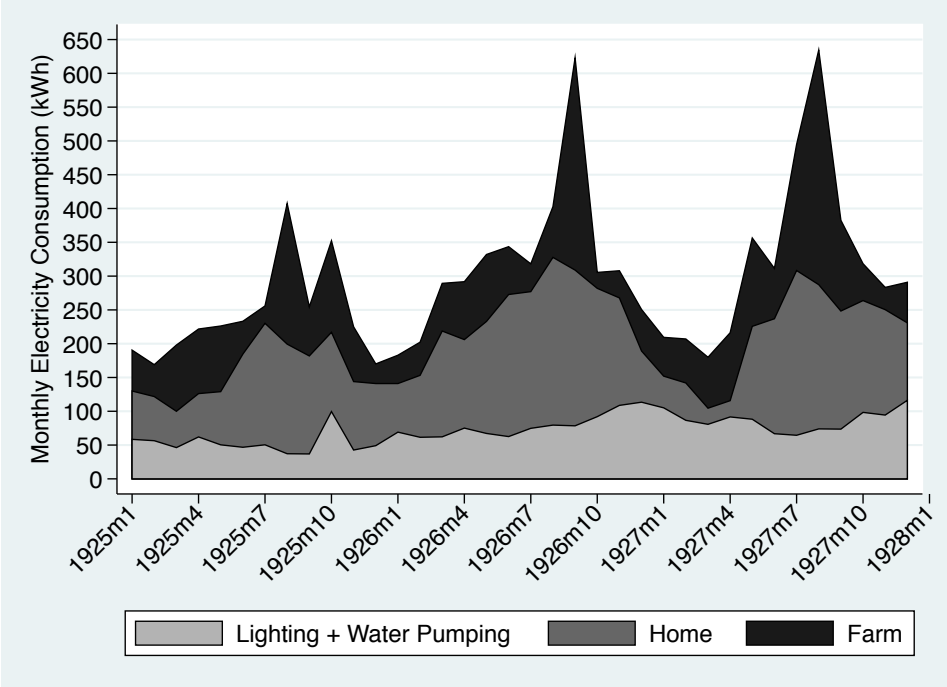
Source: Lebergott (1976); 1940, 1950, 1960 Census of Housing.

Figure 2: Large Power Plant Openings, 1930-1960



Note: The figure reports the location of large power plants (>30MW of nameplate capacity). Red triangles identify power plants in operation in 1930. Blue circle identify power plants that opened between 1930 and 1960. Source: Federal Power Commission (1962).

Figure 3: Electricity Consumption by Category – Red Wing Project (1924-1927)



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

Figure 4: The impact of increase in electricity access on the rural sector

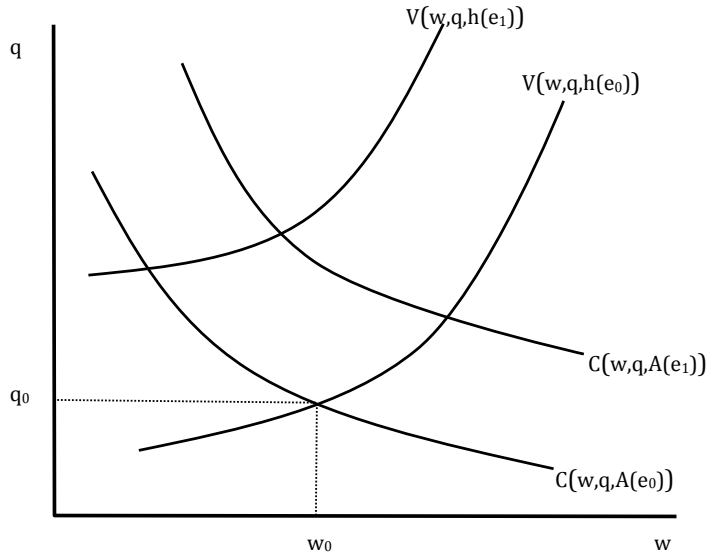
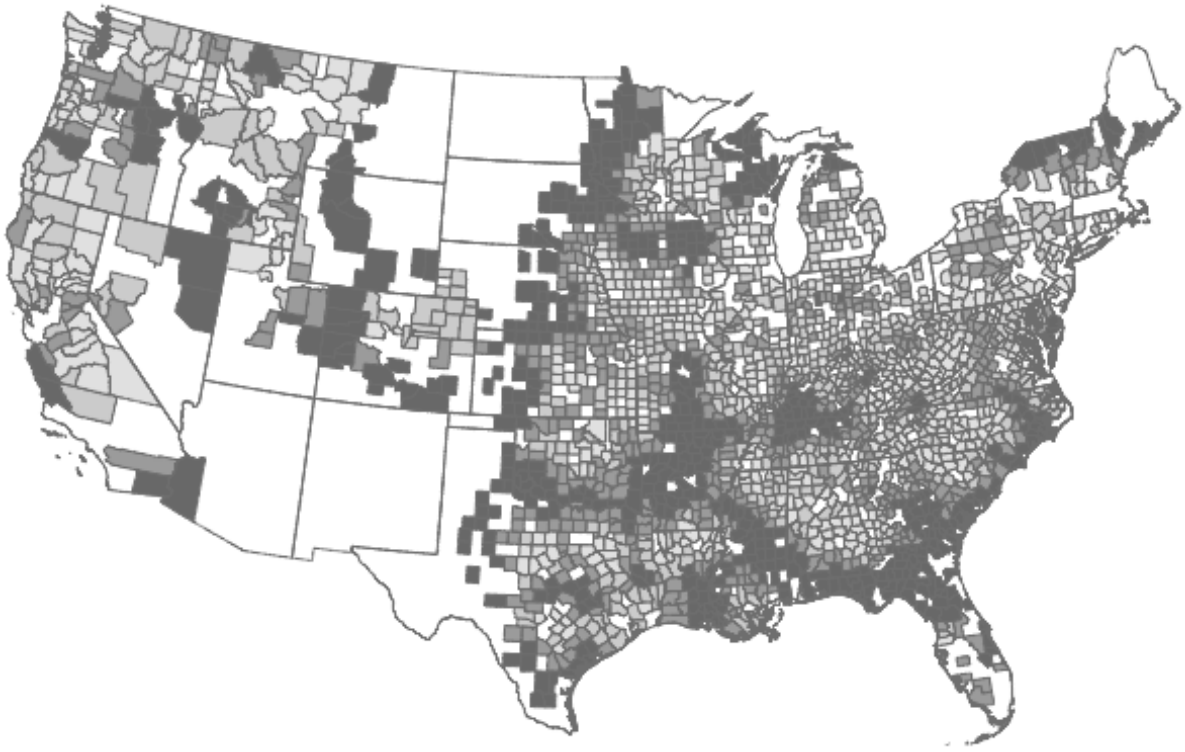


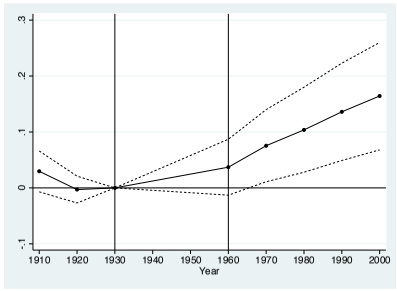
Figure 5: Sample counties and power plant openings



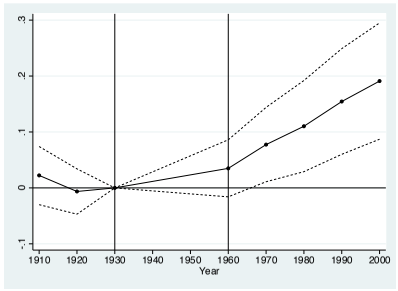
Notes: The figure reports the 2,162 sample. Counties are shaded by quartile of change in power plant distance between 1930 and 1960, with darker shades indicating larger decreases in distance.

Figure 6: Estimated differences in log outcomes between early electricity access and late electricity access rural counties

Panel A: Population and Employment

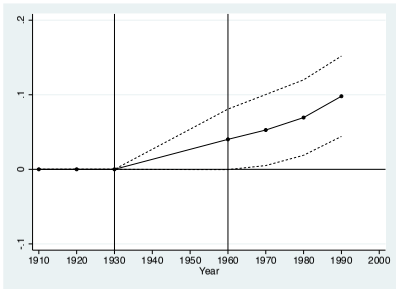


Population

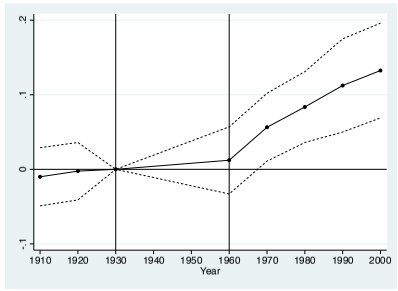


Employment

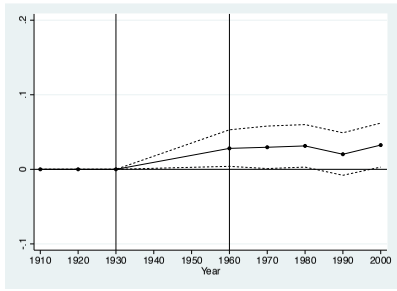
Panel B: Property Values and Income



Median Dwelling Value



Farmland Value

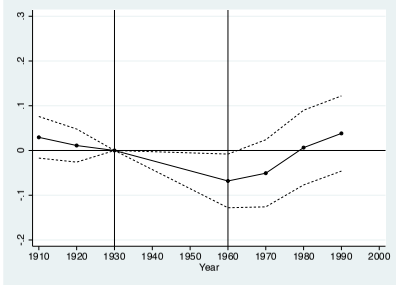


Retail Payroll per Worker

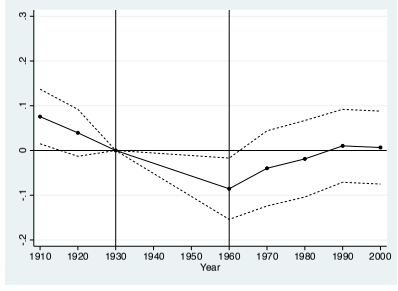


Manuf. Payroll Per Worker

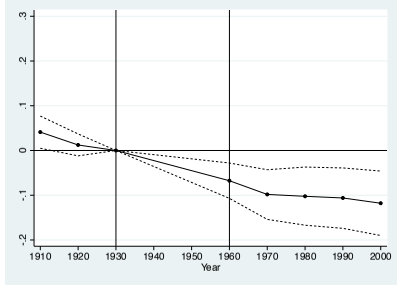
Panel C: Rural Outcomes



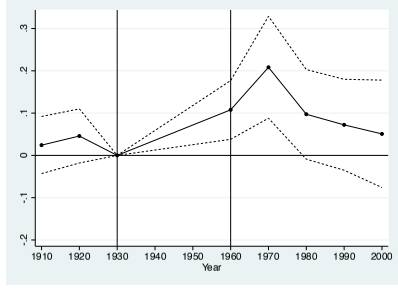
Rural Population



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 means in 1930, by changes in electricity access 1930-1960 ($\Delta DistPP30$)

		Above median relative to below median change in p.p. distance, $\Delta DistPP30$ 1930-1960		
	Sample mean (1)	Early Access (2)	Late Acess (3)	Difference (2)-(3) (4)
Panel A. Farm Outcomes				
Agriculture Employment	3,574	-0.017	0.021	-0.038
Rural Farm Population	11,022	0.001	0.010	-0.008
Number of farms	2,283	-0.023	-0.002	-0.021
Farmland, per 100 county acres	66.74	0.047*	0.018	0.030
Farm Size	180.76	0.091**	0.082**	0.009
Panel B. Population and Employment				
Total Population	22,485	-0.054	-0.041	-0.013
Rural Non-Farm	6,882	-0.038	-0.102**	0.064
Urban	4,582	-0.057	-0.095	0.038
White	19,024	-0.027	-0.069*	0.042
Total Employment	7,832	-0.083**	-0.039	-0.044
% Manufacturing	10.12	0.006	-0.092*	0.099
% Retail	8.35	-0.021	0.013	-0.035
% Construction	4.39	-0.063	-0.010	-0.053
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% and 5% 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 p.p. distance			
		(1)	(2)	(3)	(4)
Dependent Variables					
A. Population and Employment					
Agr. Employment	2,606	34.2**	27.5**	23.4**	22.7**
		(6.4)	(5.3)	(3.8)	(4.1)
Rural Farm Pop.	8,488	68.6**	38.8**	36.8**	26.8*
		(21.7)	(14.2)	(11.3)	(12.2)
B. Agricultural Output					
Log Farm Revenue	9.43	0.0070*	0.0059*	0.0060*	0.0071*
		(0.0029)	(0.0029)	(0.0029)	(0.0030)
Number of Farms	1,937	12.92**	10.29**	9.56**	8.96**
		(3.55)	(2.91)	(2.26)	(2.36)
Farmland	306,245	889.8	948.9	953.2	1,016.9
		(584.7)	(588.1)	(589.6)	(626.5)
Farm Size	252	5.08	4.42	4.40	4.57
		(3.12)	(3.07)	(3.08)	(3.40)
County & Year FE		Y	Y	Y	Y
Linear State Trend		Y	Y	Y	
Geographic Covariates		Y	Y	Y	Y
Demographic Covariates			Y	Y	Y
Economic Covariates				Y	Y
State-Year FE					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% and 5% level, respectively.

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

	Mean Dep. Var.	Coefficient on *DistPP30*: Effect of a 10 mile decrease in p.p. distance			
		(1)	(2)	(3)	(4)
Dependent Variables					
A. Employment					
Agriculture	2,606	34.2**	27.5**	23.4**	22.7**
		(6.4)	(5.3)	(3.8)	(4.1)
Manufacturing	1,526	-41.6**	-18.3**	-17.8**	-18.3**
		(7.8)	(6.8)	(6.3)	(6.8)
Retail	1,138	-12.69*	3.11	3.22	3.84
		(5.32)	(4.45)	(4.39)	(4.77)
Construction	464	-4.06	0.52	0.60	0.99
		(2.52)	(2.41)	(2.40)	(2.53)
Total	8,439	-26.2	32.0	30.4	29.7
		(28.2)	(27.4)	(26.6)	(27.0)
B. Population					
Rural Farm	8,488	68.6**	38.8**	36.8**	26.8*
		(21.7)	(14.2)	(11.3)	(12.2)
Rural Non-Farm	9,335	-33.7	-4.4	5.5	1.4
		(30.0)	(27.2)	(27.4)	(29.6)
Urban Population	7,345	-116.2	44.5	41.4	48.2
		(61.7)	(55.2)	(52.8)	(57.7)
Total	25,168	-81.3	78.9	83.6	76.4
		(69.9)	(68.6)	(65.4)	(70.9)
C. Sorting and Amenities					
% White	86.9	-0.050	-0.061	-0.06 3	-0.046
		(0.072)	(0.071)	(0.071)	(0.077)
% of 25+ with	26.2	0.224	0.243	0.247	0.457
High School		(0.346)	(0.365)	(0.369)	(0.570)
Log Retail Sales	0.86	0.0002	-0.0001	-0.0002	0.0012
per Capita		(0.0017)	(0.0016)	(0.0016)	(0.0016)
County & Year FE		Y	Y	Y	Y
Linear State Trend		Y	Y	Y	
Geographic Covariates		Y	Y	Y	Y
Demographic Covariates			Y	Y	Y
Economic Covariates				Y	Y
State-Year FE					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% and 5% level, respectively.

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

	Mean Dep. Var.	Coefficient on *DistPP30*: Effect of a 10 mile decrease in p.p. distance			
		(1)	(2)	(3)	(4)
Dependent Variables					
A. Property Values					
Log Value of Farmland and Farm Buildings	5.41	0.0060** (0.0019)	0.0056** (0.0020)	0.0057** (0.0020)	0.0050* (0.0020)
Log Median Dwelling Value (Owner-Occupied)	9.87	0.0061** (0.0018)	0.0052** (0.0017)	0.0050** (0.0017)	0.0054** (0.0017)
Log Median Dwelling Rent (Renter-Occupied)	4.83	0.0049** (0.0013)	0.0038** (0.0013)	0.0039** (0.0013)	0.0038** (0.0013)
B. Income Proxies					
Log Farm Revenue Per Worker	1.86	-0.0034 (0.0026)	-0.0045 (0.0026)	-0.0043 (0.0026)	-0.0018 (0.0026)
Log Retail Payroll Per Worker	2.24	0.0015 (0.0010)	0.0012 (0.0010)	0.0012 (0.0009)	0.0016 (0.0009)
Log Manufacturing Payroll Per Worker	2.31 (Obs=7,465)	0.0012 (0.0022)	0.0016 (0.0022)	0.0016 (0.0022)	0.0022 (0.0023)
County & Year FE		Y	Y	Y	Y
Linear State Trend		Y	Y	Y	
Geographic Covariates		Y	Y	Y	Y
Demographic Covariates			Y	Y	Y
Economic Covariates				Y	Y
State-Year FE					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% and 5% level, respectively.

Table 5: Robustness tests

	Coefficient on *DistPP30*: Effect of a 10 mile decrease in p.p. distance							
			Alternate samples				Restrict power plants	
	Baseline estimates	Add controls for 1930 infrastructure	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 $\geq$ 50 MW	Use only private power plants
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A. Population and Employment								
Agr. Employment	22.7076**	24.4870**	17.0657**	19.3853**	20.2283**	27.3497**	13.4782**	10.9433*
	(4.1184)	(4.0284)	(5.2710)	(4.0278)	(4.3491)	(4.4344)	(3.9060)	(5.2482)
Rural Farm Population	26.8413*	32.5008**	14.9720	10.0904	23.7598	38.0519**	12.7069	16.7046
	(12.1712)	(12.1045)	(13.4170)	(14.2642)	(12.6318)	(12.4572)	(11.9894)	(14.8910)
B. Farm Output								
Log Farm Revenue	0.0071*	0.0081**	0.0107**	0.0019	0.0080*	0.0097**	0.0013	0.0007
	(0.0030)	(0.0030)	(0.0041)	(0.0031)	(0.0032)	(0.0032)	(0.0026)	(0.0038)
Number of Farms	8.9599**	10.1828**	4.3414	9.0720**	8.7754**	12.4230**	7.2668**	6.6134*
	(2.3604)	(2.3305)	(2.8975)	(2.7120)	(2.4994)	(2.4368)	(2.4902)	(3.1706)
Farmland	1,016.9455	1,024.6771	1,842.0883	-33.4770	969.4113	1,222.3428	351.3138	-564.8965
	(626.4724)	(622.9241)	(1,041.2982)	(449.9609)	(616.4170)	(685.8791)	(357.1411)	(730.2476)
Farm size	4.5698	3.8088	12.9303*	0.6505	2.2902	5.2688	1.7871	-3.9987
	(3.3963)	(3.3800)	(5.7156)	(3.5298)	(3.6857)	(3.7880)	(2.0086)	(3.5265)
C. Property Values								
Log Value of Farmland	0.0050*	0.0048*	0.0052	0.0071**	0.0053*	0.0057**	0.0029	0.0090**
and Farm Buildings	(0.0020)	(0.0020)	(0.0028)	(0.0021)	(0.0021)	(0.0021)	(0.0015)	(0.0024)
Log Median Dwelling Value	0.0054**	0.0049**	0.0053*	0.0082**	0.0061**	0.0050**	0.0055**	0.0093**
(Owner-Occupied)	(0.0017)	(0.0017)	(0.0022)	(0.0019)	(0.0018)	(0.0018)	(0.0016)	(0.0022)
Log Median Dwelling Rent	0.0038**	0.0033*	0.0023	0.0056**	0.0038**	0.0042**	0.0036**	0.0056**
(Renter-Occupied)	(0.0013)	(0.0013)	(0.0016)	(0.0015)	(0.0014)	(0.0014)	(0.0012)	(0.0018)
D. Income Proxies								
Log Farm Revenue	-0.0018	-0.0021	0.0037	-0.0060*	-0.0015	-0.0003	-0.0064**	-0.0051
Per Worker	(0.0026)	(0.0026)	(0.0036)	(0.0028)	(0.0027)	(0.0028)	(0.0021)	(0.0033)
Log Retail Payroll	0.0016	0.0015	0.0004	0.0031**	0.0015	0.0009	0.0025*	0.0020*
Per Worker	(0.0009)	(0.0009)	(0.0013)	(0.0011)	(0.0010)	(0.0010)	(0.0012)	(0.0009)
Log Manuf. Payroll	0.0022	0.0023	0.0004	0.0041	0.0032	0.0024	0.0020	0.0044
Per Worker	(0.0023)	(0.0023)	(0.0036)	(0.0022)	(0.0025)	(0.0024)	(0.0026)	(0.0025)
Full controls	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% and 5% 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	0.0370	0.0349	-0.0856**	0.1199	0.0749	0.1030
	(0.0239)	(0.0245)	(0.0328)	(0.0622)	(0.0493)	(0.0639)
1970	0.0754*	0.0774*	-0.0398	0.0826	0.1037	0.1712*
	(0.0308)	(0.0318)	(0.0401)	(0.0667)	(0.0535)	(0.0671)
1980	0.1013**	0.1102**	-0.0188	0.0532	0.1650**	0.1803**
	(0.0363)	(0.0389)	(0.0407)	(0.0685)	(0.0585)	(0.0692)
1990	0.1360**	0.1544**	0.0103	0.0897	0.2130**	0.2416**
	(0.0412)	(0.0449)	(0.0389)	(0.0717)	(0.0634)	(0.0754)
2000	0.1643**	0.1910**	0.0067	0.1317	0.2365**	0.2593**
	(0.0457)	(0.0494)	(0.0387)	(0.0748)	(0.0664)	(0.0782)
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	0.0402	0.0202	0.0122	0.0281*	0.0399
	(0.0207)	(0.0187)	(0.0214)	(0.0114)	(0.0259)
1970	0.0527*	0.0458*	0.0572**	0.0296*	0.0469
	(0.0243)	(0.0195)	(0.0217)	(0.0133)	(0.0250)
1980	0.0694**	0.0521**	0.0830**	0.0314*	0.0487
	(0.0258)	(0.0192)	(0.0228)	(0.0133)	(0.0272)
1990	0.0980**	0.0572**	0.1116**	0.0202	0.0567*
	(0.0275)	(0.0201)	(0.0297)	(0.0132)	(0.0286)
2000			0.1325**	0.0323*	0.0638*
			(0.0300)	(0.0138)	(0.0286)

Panel C: *Farm Outcomes*

	Log Farm Population	Log Farmland	Log Farm Revenue	Log Farm Rev. per Worker
Early Access ×				
1960	-0.0681*	-0.0676**	0.0223	0.1078**
	(0.0282)	(0.0227)	(0.0206)	(0.0331)
1970	-0.0508	-0.0966**	0.1661**	0.2082**
	(0.0353)	(0.0298)	(0.0291)	(0.0575)
1980	0.0065	-0.1024**	0.0822	0.0988
	(0.0395)	(0.0337)	(0.0339)	(0.0504)
1990	0.0371	-0.1061**	0.0773	0.0739
	(0.0397)	(0.0347)	(0.0352)	(0.0512)
2000		-0.1178**	0.0575	0.0508
		(0.0372)	(0.0376)	(0.0604)

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% and 5% 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	0.0806*	0.0822*	0.0469	0.0604*	0.0285	-0.1464**	-0.1125**	0.1565**
	(0.0329)	(0.0361)	(0.0269)	(0.0245)	(0.0277)	(0.0407)	(0.0290)	(0.0451)
1970	0.1469**	0.1538**	0.0805*	0.0908**	0.0715*	-0.1354**	-0.1833**	0.3093**
	(0.0440)	(0.0477)	(0.0314)	(0.0243)	(0.0288)	(0.0510)	(0.0438)	(0.0818)
1980	0.2043**	0.2202**	0.1239**	0.1134**	0.0933**	-0.0884	-0.1975**	-0.1238
	(0.0529)	(0.0582)	(0.0350)	(0.0253)	(0.0313)	(0.0581)	(0.0513)	(0.0738)
1990	0.2680**	0.2978**	0.1786**	0.1330**	0.1503**	-0.0112	-0.1953**	-0.0987
	(0.0616)	(0.0681)	(0.0367)	(0.0271)	(0.0443)	(0.0587)	(0.0528)	(0.0833)
2000	0.3216**	0.3639**			0.1864**		-0.2105**	-0.1349
	(0.0690)	(0.0755)			(0.0422)		(0.0571)	(0.0859)
Early Access × I(Far MSA) ×								
1960	0.0067	0.0048	0.0280	-0.0080	-0.0099	-0.0056	-0.0357	0.0720
	(0.0298)	(0.0284)	(0.0263)	(0.0241)	(0.0278)	(0.0333)	(0.0248)	(0.0424)
1970	0.0302	0.0323	0.0346	0.0152	0.0395	0.0246	-0.0305	0.1291
	(0.0374)	(0.0368)	(0.0312)	(0.0260)	(0.0279)	(0.0424)	(0.0331)	(0.0706)
1980	0.0385	0.0440	0.0283	0.0064	0.0706*	0.0961*	-0.0333	0.2735**
	(0.0429)	(0.0451)	(0.0318)	(0.0251)	(0.0281)	(0.0463)	(0.0382)	(0.0575)
1990	0.0543	0.0677	0.0394	0.0036	0.0848*	0.1073*	-0.0414	0.2002**
	(0.0474)	(0.0512)	(0.0340)	(0.0259)	(0.0344)	(0.0465)	(0.0396)	(0.0530)
2000	0.0686	0.0865			0.1009**		-0.0522	0.1863*
	(0.0521)	(0.0557)			(0.0367)		(0.0420)	(0.0740)
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% and 5% 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	0.0342*	0.0865*		1.5293*	-2.1439	1.5217	-0.0072
	(0.0145)	(0.0343)		(0.6762)	(2.5549)	(0.7957)	(0.0243)
1970	0.0254	0.0855**	0.0286*	1.7708*	1.4736*	2.8315**	-0.0015
	(0.0164)	(0.0306)	(0.0139)	(0.7170)	(0.7293)	(0.8997)	(0.0296)
1980	0.0336	0.0671	0.0390**	1.7846*	2.3994**	3.0449**	0.0142
	(0.0175)	(0.0395)	(0.0134)	(0.7165)	(0.7774)	(0.8183)	(0.0342)
1990	0.0315	0.0897*	0.0499**	1.4795*	3.4168**	2.7109**	0.0601
	(0.0181)	(0.0371)	(0.0151)	(0.7349)	(0.7098)	(0.7266)	(0.0401)
2000	0.0527**	0.1154**	0.0225	0.5929	2.6958**		0.0875
	(0.0181)	(0.0341)	(0.0134)	(0.8301)	(0.6170)		(0.0458)
Early Access × I(Far MSA) ×							
1960	0.0268	0.0059		-0.1613	-1.7028	0.8412	0.0228
	(0.0154)	(0.0337)		(0.4669)	(1.5348)	(0.7670)	(0.0294)
1970	0.0359*	0.0177	-0.0093	-0.4824	-0.6426	1.6680*	0.0289
	(0.0180)	(0.0348)	(0.0138)	(0.4705)	(0.7081)	(0.7730)	(0.0328)
1980	0.0358*	0.0366	-0.0172	-0.4724	0.1043	0.8501	0.0335
	(0.0169)	(0.0329)	(0.0132)	(0.4632)	(0.6697)	(0.6535)	(0.0344)
1990	0.0159	0.0366	-0.0003	-0.8152	0.5125	1.0783	0.0762
	(0.0167)	(0.0373)	(0.0133)	(0.4869)	(0.6147)	(0.5711)	(0.0393)
2000	0.0201	0.0245	-0.0006	-1.1096*	0.3060		0.0614
	(0.0178)	(0.0377)	(0.0118)	(0.5651)	(0.5345)		(0.0436)
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% and 5% level, respectively.

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

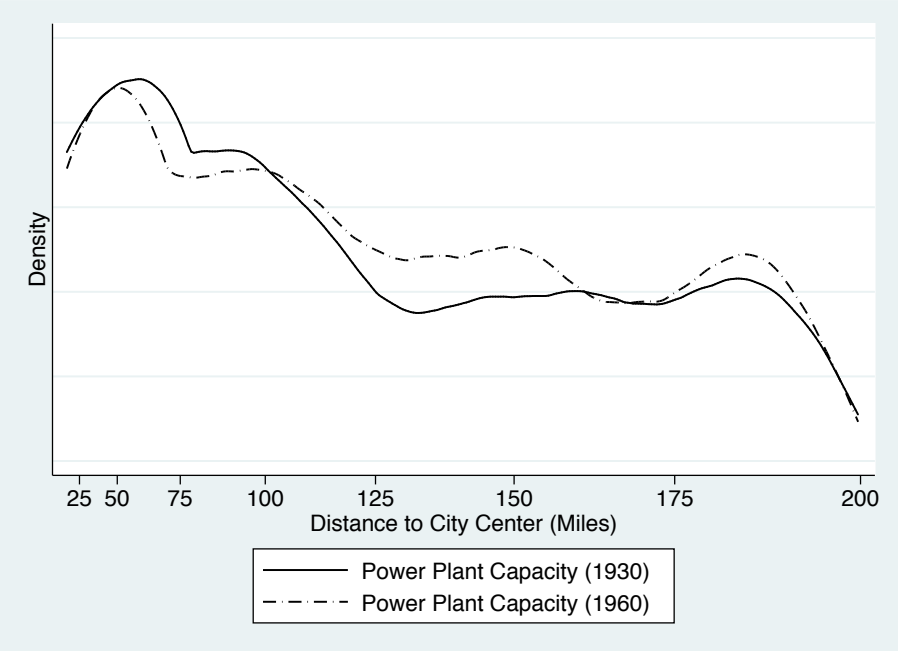
	Pop. and Emp.		Property Values			Farm Outcomes		
	Log Population	Log Employment	Log Med. Dwell. Value (Owner-Occ)	Log Med. Dwell. Rent (Renter-Occ)	Log Value Farmland and Farm Buildings	Log Farm Population	Log Farmland	Log Farm Revenue per Worker
Early Access to Electricity ×								
1960	0.0392	0.0370	0.0403	0.0205	0.0131	-0.0681*	-0.0792*	0.1090**
	(0.0235)	(0.0241)	(0.0208)	(0.0187)	(0.0214)	(0.0283)	(0.0351)	(0.0330)
1970	0.0784**	0.0806**	0.0533*	0.0462*	0.0583**	-0.0502	-0.1155**	0.2073**
	(0.0303)	(0.0312)	(0.0243)	(0.0195)	(0.0219)	(0.0354)	(0.0408)	(0.0576)
1980	0.1060**	0.1144**	0.0700**	0.0526**	0.0835**	0.0071	-0.1138*	0.0995*
	(0.0357)	(0.0380)	(0.0259)	(0.0192)	(0.0229)	(0.0398)	(0.0452)	(0.0506)
1990	0.1406**	0.1595**	0.0992**	0.0579**	0.1128**	0.0380	-0.1174*	0.0726
	(0.0403)	(0.0439)	(0.0275)	(0.0201)	(0.0298)	(0.0399)	(0.0461)	(0.0510)
2000	0.1695**	0.1969**			0.1335**		-0.1293**	0.0514
	(0.0446)	(0.0480)			(0.0301)		(0.0485)	(0.0606)
1944 Interstate Highway Plan ×								
1960	0.1170**	0.1149**	0.0075	0.0157	0.0465*	-0.0016	0.0128	0.0657
	(0.0251)	(0.0257)	(0.0208)	(0.0174)	(0.0215)	(0.0271)	(0.0339)	(0.0394)
1970	0.1595**	0.1743**	0.0345	0.0235	0.0693**	0.0348	0.0230	-0.0581
	(0.0319)	(0.0328)	(0.0216)	(0.0168)	(0.0231)	(0.0311)	(0.0373)	(0.0555)
1980	0.1946**	0.2253**	0.0327	0.0228	0.0310	0.0339	-0.0062	0.0371
	(0.0368)	(0.0394)	(0.0234)	(0.0170)	(0.0256)	(0.0345)	(0.0410)	(0.0511)
1990	0.2444**	0.2803**	0.0606*	0.0406*	0.0697*	0.0530	-0.0005	-0.0788
	(0.0417)	(0.0451)	(0.0246)	(0.0174)	(0.0300)	(0.0344)	(0.0416)	(0.0497)
2000	0.2839**	0.3211**			0.0558		0.0085	0.0325
	(0.0450)	(0.0486)			(0.0325)		(0.0431)	(0.0564)
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% and 5% level, respectively.

A Appendix

A.1 Figures and Tables

Figure A.1: Density of Electricity Capacity Around 50 Largest U.S. Cities in 1930 and 1960



Notes: This figure reports the distribution of generated capacity around the 50 largest U.S. cities in 1930 and 1960. For ease of interpretation, the x-axis is scaled such that a uniform density will appear as a horizontal line in the figure.

Table A.1: Farm Equipment and Home Appliances – 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).

Table A.2: Robustness: Long-run effects of early electricity 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 Agr. Employment	Log Farm Revenue per Worker
Panel A: *Compare 'Early Access' (1930-1940) to 'Late Access' (1950-1960)*								
Early Access ×								
1960	0.0230	0.0280	0.0605*	0.0231	-0.0163	-0.0061	-0.0063	0.0832*
	(0.0269)	(0.0264)	(0.0261)	(0.0245)	(0.0252)	(0.0313)	(0.0405)	(0.0379)
1970	0.0594	0.0609	0.0878**	0.0400	0.0198	0.0304	0.0621	0.0421
	(0.0351)	(0.0352)	(0.0320)	(0.0259)	(0.0255)	(0.0381)	(0.0523)	(0.0704)
1980	0.0840*	0.0923*	0.1029**	0.0496*	0.0461	0.1233**	0.0176	0.1077
	(0.0418)	(0.0442)	(0.0346)	(0.0251)	(0.0251)	(0.0455)	(0.0506)	(0.0605)
1990	0.1046*	0.1224*	0.1303**	0.0407	0.0361	0.1280**	0.0788	0.0324
	(0.0478)	(0.0521)	(0.0371)	(0.0253)	(0.0326)	(0.0418)	(0.0494)	(0.0586)
2000	0.1273*	0.1576**			0.0756*		0.0234	0.0449
	(0.0537)	(0.0581)			(0.0338)		(0.0475)	(0.0726)
Panel B: *Diff-in-diff including rural counties with below-median decreases in distance ($\Delta DistPP30$ 1930-1960)*								
DID: Early Access × Above-median decrease ×								
1960	0.0491	0.0433	0.0573*	0.0451*	0.0168	-0.0339	-0.0135	0.0688
	(0.0306)	(0.0340)	(0.0258)	(0.0227)	(0.0267)	(0.0341)	(0.0441)	(0.0409)
1970	0.1011*	0.0893*	0.0787**	0.0720**	0.0864**	0.0135	0.0402	0.0964
	(0.0395)	(0.0431)	(0.0295)	(0.0232)	(0.0288)	(0.0484)	(0.0514)	(0.0748)
1980	0.1200**	0.1244*	0.0780*	0.0697**	0.0922**	0.0249	0.0033	0.1049
	(0.0455)	(0.0508)	(0.0322)	(0.0238)	(0.0306)	(0.0530)	(0.0499)	(0.0718)
1990	0.1665**	0.1809**	0.1000**	0.0765**	0.1222**	0.0921	0.1079*	-0.0086
	(0.0521)	(0.0583)	(0.0344)	(0.0249)	(0.0375)	(0.0518)	(0.0512)	(0.0639)
2000	0.1981**	0.2189**			0.1474**		0.0732	0.0107
	(0.0577)	(0.0635)			(0.0391)		(0.0477)	(0.0823)

Notes: 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% and 5% level, respectively.

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,[48] 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.[49] 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.

[48] 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.

[49] 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.[50] 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.[51] 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.[52]

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

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

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

[52] 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.