# The Value of Rural Electricity: Evidence from the Rollout of the U.S. Power Grid [*]

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July 2016

## Abstract

This paper exploits the historical rollout of the U.S. power grid between 1930 and 1960 to study the impact of rural electrification on local economies. We find that rural electrification led to increases in agricultural employment and farm populations. This expansion was offset by a contraction in urban industries, as increased demand for rural land drove up local housing costs and crowded-out non-agricultural sectors. The growth in the rural sector was due both to advances in agricultural productivity and improvements in housing quality. Applying a standard Rosen–Roback style model to our reduced form estimates, we derive estimates of the implied value of electricity for agricultural productivity, and the amenity value of residential electricity access. We find that farm access to electricity raised productivity by 35%, and that families were willing to forgo 32% of annual income to live in an electrified home. These findings are consistent with newly assembled data from a small-scale experiment in Minnesota, that suggests that a high level of rural demand for electricity, particularly for uses within the household The results suggest that the benefits of rural electrification far exceeded the historical costs of extending the grid, and imply that there is large scope to expand rural access in the developing world today.

## 1 Introduction

In 2009, 1.3 billion people worldwide lacked access to electricity, over 80 percent of whom resided in rural areas (IEA, 2011). In response, the World Bank has allocated more than 20 percent of its loans to electricity infrastructure projects, most of which target rural

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[*] We thank Karen Clay and seminar participants at the University of Montreal and the CNEH meetings for valuable comments and suggestions.
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electrification.[1] These loans are motivated by a widely held view that electricity offers a wide range of welfare gains to rural communities, including both market benefits – such as improvements in agricultural productivity, and non-market benefits – such as household access to better lighting and labour-saving consumer durables.

There is a growing body of research that examines the effects of electrification on a variety of rural outcomes including agricultural output (Fishback and Kitchens, 2014), economic activity (Lipscomb, Mobarak, and Bahram, 2012), female employment (Dinkelman, 2012; Lewis, 2014a), and health (Lewis, 2014b). Despite this research, we lack a comprehensive assessment of the value of electricity infrastructure. Researchers attempting evaluate the benefits of rural electrification face several challenges. First, electricity offers a range of benefits that cannot be easily quantified. For example, labour-saving electric appliances may change the composition of home production activities or reduce the physical hardship of housework without having observable effects on the total amount of time spent in home production (Schwartz Cowan, 1983). Similarly, given the large capital investments required to take advantage of this new technology, it may take several decades for the full impact on agricultural productivity to be observed.[2] Since access to electrical services is not typically allocated on the basis of a pricing mechanism, the value of this technology cannot be ascertained from the household's willingness-to-pay. A second challenge is that rural electrification may have broad effects on the local economy. For example, an expansion of the agricultural sector could crowd out non-agricultural production (Hornbeck and Keskin, 2013; Foster and Rosenzweig, 2004) or it might stimulate local development (Nunn and Qian, 2011). A comprehensive assessment must also take into account these local spillover effects.

This paper exploits the historical rollout of the U.S. power grid between 1930 and 1960 to study the impact of rural electrification. We exploit the non-uniform expansion of electrical

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

[2] Hornbeck and Keskin (2013) shows that it took several decades for farmers to adapt to access to groundwater under the Ogallala aquifer.

services to estimate fixed effects models of the reduced form effects of rural electricity access on a range of local outcomes. These estimates provide evidence of the broad impacts of local electrification on both the rural and urban sector. Because urban electrification was essentially universal by 1930, we are able to disentangle local spillovers from the agricultural sector from the direct effects of expanding urban access.

Second, we apply a standard Rosen–Roback style model (Rosen, 1979; Roback, 1982) to interpret the main empirical results. The model assumes that electricity can benefit rural populations through both advances in agricultural productivity and improvements in housing quality. The model delivers three equations which can be used to quantify the value of rural electrification to 1) rural producers (in terms of improved agricultural productivity), 2) rural residents (in terms of improved housing quality), and 3) overall rural welfare. These three objects can be calculated directly from the reduced-form estimates for local land prices and wages, allowing us to derive implicit estimates of the amenity and productivity values of rural electricity.

A key challenge for the empirical analysis concerns possible endogeneity in the rollout of the electric grid. If infrastructure was targeted at developing communities, basic fixed effects models would overstate the economic impact of rural electrification.[3] To address this concern, we rely on the timing of power plant openings between 1930 and 1960 as a plausibly exogenous source of variation in the cost of providing power to different communities based on their location. This identification strategy is supported by historical limitations on transmission technology and historical evidence on how power plant sites were chosen.

The main empirical results suggest that rural electrification led to an expansion in the agricultural sector, with increases in the number of farms, agricultural employment, and farm values. Meanwhile, rural electrification led to a contraction in the local urban economy: rural electricity access is associated with higher urban home prices, decreases in urban population, and decreases in the number of manufacturing, wholesale, and service

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[3] This issue is particularly salient given that the federal decision of whether to approve application of farming cooperatives under the REA was heavily influenced by the ability to repay the loans (Fishback and Kitchens, 2014).

establishments. Overall, rural electrification led to relative declines in local population and employment levels. These results are consistent with a setting in which increased demand for farmland drove up local housing prices, slowing the pace of suburban growth.

Electrification led to large gains in rural welfare. We estimate that electricity access increased individual farm values by roughly \$50,000 (1990 USD). Given historical costs of extending the grid, which ranged from \$7,200 to \$16,000 per mile (Beall, 1940), our results imply that line extensions were justified even at very low population densities. These benefits were driven by improvements in agricultural productivity and housing quality: Electricity increased farm productivity by 35% and rural families were willing to forgo 32% of annual income to live in a home equipped with electrical services. While previous research on rural electrification has focused on productivity and output, our results highlight the importance of residential electricity access. Omitting the amenity value of residential electrification seriously understates the welfare gains.

Finally, we show that these findings are consistent with results from a small-scale experiment of rural electrification in Minnesota in the 1920s. Analysis based on newly digitized data on farm-level electricity consumption by use, we find that overall electricity consumption was concentrated within the home. As a result, overall consumption was relatively stable throughout the year, despite the fact that farm consumption displayed a high degree of seasonality. This stability mitigated the challenges to electricity providers of meeting variable loads. Moreover, rural demand for electricity was high, exceeding the carrying costs even at low population densities.

## 2 Historical background

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

During the 1930s, the federal government introduced several programs to promote rural electrification. In 1933, the Roosevelt administration created the Tennessee Valley Authority (TVA), which offered local rural residents access to low cost electricity, and by 1952 the TVA was supplying electricity to 175 counties in seven states (Kitchens, 2014). In 1935, the Rural Electrification Administration (REA) was established. This agency provided low-interest loans for the construction of power lines into rural areas and to wire farms for electricity. Over the next 25 years, the REA funded over 1.4 million miles of distribution lines, and serviced over 4.8 million rural customers (U.S. Historical Statistics, 1976).[4] These programs, combined with the gradual expansion of rural services provided by the private sector, led to large increases in the proportion of farms that were electrified.

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

Electricity offered a range of positive effects on farm productivity. By 1960, more than 100 different types of farm machines driven by electric motors were in use on American

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

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

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

# 3 A Case Study of Rural Electrification: The Red Wing Project

## 3.1 Background

In the winter of 1923, the first experimental farm power line was built in Red Wing, Minnesota. The stated goal of the project was to "determine the optimum economic uses of electricity in agriculture and to study the value of electricity in improved living condition on the farm." In particular, the project was designed to examine (i) whether farmers could profitably use electricity, (ii) how much they would use, and (iii) which equipment they would need. The project ran from late 1923 to early 1928, and was backed by the local power company, farm bureau federation officials, leading farmers, the state university department of agriculture, and manufactures of electrical equipment and farm machinery.

Under the Red Wing Project, six miles of distribution lines were built to provide eleven farms electricity access. Participants received free access to a variety of household appliances and electrical farm equipment that were loaned from electrical-equipment manufacturers for a three year period (see Table A.1 for a description of the various equipment provided to each farm). The Minnesota Power Company set a service charge of $6.90 per month plus 5 cents per Kwh for the first 30 Kwh, and 3 cents per Kwh for additional use. These rates were set to cover overhead and all variable costs based on an average of three customers per mile.

The project was widely considered a success. It was initially projected that the average farm would consume 200 Kwh per month. By the final year of the project, average monthly electricity consumption was over 300 Kwh. Within three years of its inception, farmers were using electric motors to cut silage, grind feed, hoist hay, pump water, separate cream, mix concrete and thresh grain. Household access to labor-saving devises was also considered a key benefit. The enduring quality of the observations and data collected by the Red Wing Project and the policy recommendations arising from it were fundamental to the expansion of rural electrification in the U.S. For instance, the creation of the Rural Electrification Administration (REA) in 1935 is partially credited to the Red Wing findings.

## 3.2 Electricity Consumption on the Farm

The Red Wing Project installed electric meters in most of the equipment loaned by the manufactures, and collected information on monthly consumption. We digitize monthly data on electricity consumption by each piece of electrical equipment by farm for the period 1925 to 1927. As shown in Table A.1, not all farms had all kinds of equipment even by the end of the experiment, although virtually all had access to major household appliances and basic electrical farm equipment. Electricity consumption rose over the course of the Red Wing Project. Table 1 reports average monthly consumption for 8 of the participating farms for the period 1924 to 1927. During this four year period, average consumption rose from 120 Kwh per month to 307 Kwh per month. All but one farm experienced a significant increase in electricity consumption, although there were large differences in average consumption across farms driven primarily by differences in farming activities.

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

Because farm households faced a common price for electricity independent of its use, we can use the expenditure shares across each category of consumption to derive estimates of the value associated of electricity for farm, home, and basic consumption. Let $e$ denote a farm's electricity consumption, and $c$ denote consumption for all other goods. Suppose that electricity is used for farm machinery $x$, home appliances, $y$, and basic lighting and pumping, $z$. We assume the following Cobb-Douglas utility, and write the farm's problem as follows:

$$\text{Max} \quad \left(x^{\alpha} y^{\beta} z^{1-\alpha-\beta}\right)^{\theta} c^{(1-\theta)} \quad \text{s.t} \quad p(x+y+z)+c=M$$

The solution yields the following expenditure shares for each of the uses of electricity:

$$\alpha = \frac{px}{\theta M}, \quad ,\beta = \frac{py}{\theta M}, \quad (1-\alpha-\beta) = \frac{pz}{\theta M}.$$

Information on total farm expenditure and electricity expenditure by category to uncover the parameters of the utility function. These parameters capture the relative value of electricity for the farm, the home, and basic lighting and pumping.

We estimate these expenditure shares in each month for each farm in the sample. Table 2 reports shares of electricity expenditure for each category: farm ($\alpha$), home ($\beta$), and lighting and water pumping ($1 - \alpha - \beta$). Household electricity use dominated use on the farm. Together home and basic electricity accounted for 71 percent of the benefits derived on the farm. The middle panel reports these shares separately by year. There is little evidence of a change in electricity use over time. Nevertheless, there were large differences in electricity use across farms. The bottom panel reports these shares across the different farms in the sample. The farm share range from 0.07 to 0.48, primarily due to of differences in the intensity of dairy production. Consistent with these results, we find evidence increased electricity use had positive effects on farm dairy revenue but had little impact on non-dairy revenue (see Table A.2). In particular, the estimates imply that each additional dollar spent on electricity raised dairy revenue by \$14 (1925 USD), or about one percent. On the other hand, basic electricity consumption is more comparable across farms, with expenditure shares ranging from 0.25 to 0.44.

Finally, we examine the elasticity of demand for farm, home, and basic electricity. We estimate farm level fixed effects regressions that control for season-year fixed effects. These models link changes in changes in monthly electricity prices to consumption of electricity for farm, home, and basic facilities. Table 3 reports the results. At a time when farmers were still adopting the new technology, it is not surprising that farm electricity consumption was highly elastic. Interestingly, the inelastic demand for lighting and water pumping is very similar to current estimates of national electricity own-price elasticity in the U.S. (Paul, Myers, Palmer, 2009). This inelastic demand could also reflect the fact that basic facilities were considered necessity goods, and did not respond to monthly price changes.

Together, these results suggest that electricity was highly valued on the farm. Overall electricity consumption was 50 percent higher than initially predicted. The bulk of the benefits appear to have occurred within the home, which accounted for more than two-thirds of total electricity expenditure. Importantly, these findings cast doubt on a widely held view that it was unprofitable to provide rural electricity access, since electricity consumption more than covered carry costs. Moreover, the fact that consumption was concentrated within the home implied that overall electricity use remained relatively stable throughout the year. As a result, challenges to electricity providers in meeting variable loads were mitigated.

# 4 Theoretical framework

## 4.1 A two-sector model with internationally traded goods

Having examined a small scale study of rural electrification, we next turn to its broader impact across the U.S. To study the effects of rural electrification on local economies, 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,[5] 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:

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

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

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[5] 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.

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.[6] 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:

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

Equilibrium prices, $\big(w, q^R, q^U\big)$, 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, $v$.

## 4.2 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, ${A^R}'(e) > 0$, and improvements in rural housing quality, ${h^R}'(e) > 0$. On the other hand, urban sector productivity and housing quality are not directly affected by rural electrification.

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, $A\,(e_0)$. 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

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

equal to the reservation value of moving.[7] 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, $q$.[8] 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.[9]

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.

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

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

[9] 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.

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 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.

## 4.3 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:

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

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:

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

where $\theta_w$ and $\theta_q$ 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:

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

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.

## 5 Data

Historical county-level data from 1930 to 1960 are drawn from Censuses of Agriculture and Population (Haines and ICPSR, 2010; DOC and ICPSR, 2012). The main variables of interest include measures of population (total, rural farm, rural non-farm, and urban); employment (total and by sector), establishment counts, farm characteristics (total farmland, number of farms, farm size, and farm revenue), housing costs (median dwelling value, median dwelling rent, and value of farmland and farm buildings), and proxies for income (retail sales per capita, and payroll per worker in manufacturing, wholesale, retail, and service sectors).

Our preferred measure of electricity access is constructed as the county-centroid distance to the nearest power plant with at least 30 megawatts of nameplate capacity. Prior to the expansion of high-voltage transmission in the mid-1950s, historical limitations in transmission technology created an incentive to consume power near the source of generation, as did the direct cost of power line construction, which accounted for 15% of industry capital expenditure in the 1930s (*Electrical World,*, 1940). Consistent with this historical evidence, we document a strong empirical relationship between county-centroid distance to power plants and the fraction of farms with electrical services.

To construct the measure of electricity access, we rely on a set of seven maps produced by the Federal Power Commission in 1962. These maps identify the location of all power plants in the U.S., along with various plant characteristics. Using GIS software, we digitize this information, and combine it with historical information on the timing of plant openings to construct a panel of plants for the period 1930 to 1960. As the power grid expanded in the U.S. during the mid-twentieth century, more plants were built, and, consequently, distances reduced considerably.

Figure 4 documents the expansion of power plants between 1930 and 1960. There was differential growth in the Midwest and South whereas electricity infrastructure was already well-established in the Northeast and California by 1930. In part, the geographic pattern of this expansion was a result of advances in transmission technology, which allowed sites to be chosen primarily on the basis of local cost factors, such as hydroelectric potential or access to coal. With increasing interconnectedness, plants joined into the existing distribution network, rather than acting as sole providers to one local population. Both of these changes led new plants to be built further from urban centres.

# 6 Empirical strategy

In this section, we introduce our main empirical specification. We regress each outcome variable $Y$ in county $c$ and time $t$ on distance to the nearest power plant of 30 megawatts or more of nameplate capacity, time-varying county characteristics X (10-year moving average of precipation, temperature, degree days between $10^{o}$C and $29^{o}$C, and degree days above $29^{o}$C), time-constant county attributes $Z$ (latitude and longitude) interacted with time, county fixed effects $\eta$, and state-year fixed effects $\theta$. Our estimating equation can be expressed as

$$Y_{ct} = \alpha + \beta DistPP30_{ct} + \gamma X_{ct} + \delta_t Z_c + \eta_c + \epsilon_{ct}. \tag{6}$$

We measure $DistPP30$ as the negative of distance in tens of miles, so the estimated $\beta$s reflect the impact of moving ten miles closer to a power plant with at least 30 megawatts of capacity. For statistical inference, standard errors are clustered at the county level to adjust for heteroskedasticity and within-county correlation over time.

This empirical research design exploits the spatial and temporal variation in distances to the nearest power plant to explain changes in the main variables of interest. This identification strategy requires that decisions over the location of these large power plants were made independently of contemporeneous economic activity. One potential concern is that electricity infrastructure was targetted to particular communities, based on trends in local economic activity. For example, if REA loans were directed towards communities hit hardest by the Depression, our estimates might understate the benefits of rural electrification. If the empirical analysis relied on the rollout of electrical services to farms or access to transmission lines, this type of selection bias would be a concern. However, the vast majority of REA loans were spent on laying distribution lines and wiring homes rather than for the construction of power plants. In fact, cooperatively owned plants account for just 2% of our sample.

Roughly three quarters of the power plants in our sample were privately owned. Since private companies had little interest in supplying power to rural customers, the site choices for these plants should have been made indepently of rural demand for electricity. The remaining one quarter of plants in our sample were either municipally, state, or federally operated. While these agencies may have been interested in expanding access to rural communities, it was far cheaper to build lines than to construct a new plant. For example, between 40,000 and 70,000 miles of transmission line could have been constructed for the same cost as the average power plant built under the Tennessee Valley Authority. As a result, the location of power plant should be independent of rural demand for electricity.

The estimating equation does not control for measures of local economic activity. In the Rosen–Roback framework, all outcome variables, including those associated with the state of the economy, are endogenously determined by the spatial equilibrium. Hence, the right-hand side of equation (8) should include only the shock we are studying – access to electricity through the expansion of the power grid –, and other arguably exogenous covariates.

# 7 Results

## 7.1 Estimated impacts on the agricultural sector

Table 4 reports estimates of the direct effect of rural electricity access on the agricultural sector. Columns (2) – (5) report the estimates of $DistPP30$ from the estimating equation (8) across several different specifications. Column (2) includes only county and year fixed effects; in column (3) we add controls for a linear state trend to allow for different long-run trends across states; in column (4) we add controls for county geographical characteristics, to allow for differential trends based on geography; and in column (5) we replace the linear state trends with a full vector of state-by-year fixed effects.

The top two panels report the estimates for rural population and agricultural employment. Across a range of specifications, access to electricity is associated with large increases in farm population and agricultural employment. The preferred estimates imply that a 100 mile decrease in county-distance to a power plant is associated with an increase of 12% in the rural farm population and an 8% increase in agricultural employment.

Despite the large increases in rural electrification rates, the average rural farm population fell from 10,353 to 3,000 between 1930 and 1960. Our results suggest that in the absence of this technology, these declines would have been even more severe. Holding electricity infrastructure at the 1930 level, we calculate that the rural farm population would have fallen by an additional 4% by 1960, and an additional 400,000 workers nationwide would have left agricultural employment.

Panel C reports estimates for farm output. Access to electricity is associated with significant increases in the number of farms and total farm revenue. Interestingly, we find no evidence of an increase in farmland or average farm size, and electricity access is associated with declines in farmland per person. Many of the technological advantages of electricity were associated with capital-intensive production – such as dairy and poultry – rather than land-intensive production. Thus, electricity may have increased average farm productivity, while having little effect on productivity per acre of farmland. We do find much larger (albeit imprecisely estimated) effects in Western states where access to irrigation was beneficial for land-intensive production. In Western states, the point estimates for the logarithm of farmland is 0.0065 (compared to 0.0017 nationwide) and 30.9 for farm size (compared to 10.7 nationwide). A second explanation for this finding is that the relative increase in farm population was primarily driven by the amenity value of household electricity rather than by productivity effects. Consistent with this possibility we find some evidence of a decline in farm revenue per person.

### 7.2 Estimated impacts on housing costs and income proxies

The positive effects on rural population and employment found in Table 4 could reflect several different factors. Household access to electricity improved the quality of rural life, which may have slowed the pace of migration to urban areas. The findings could also reflect increased demand for rural labour 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 5 reports the estimated effects on proxies for housing costs and income. Access to electricity is associated with increases in median dwelling values, housing rents, and agricultural land values.[10] The point estimates are highly significant, and imply that a 100 mile decrease in county distance to a power plant would raise local housing and land prices by 5 to 8 percent. The bottom portion of Table 5 reports the results for various income proxies. We find no systematic evidence that rural electrification is associated with changes in local wages. The preferred point estimates range from -0.0005 to 0.003, and all are statistically insignificant.[11]

The large housing market response and limited wage impact is consistent with a setting in which rural electricity offered both productivity advantages to rural producers and amenity benefits to rural residents. Electricity brought a range of new technologies to rural residents including pumped water, washing machines, and better lighting. To the extent that these technologies improved the quality of rural life, the rollout of electrical services should drive a gap between housing prices and wages. Similarly, rural producers were willing to incur higher uncompensated land costs if electricity brought new technological advances to the farm.

Importantly, the increases in land and housing costs were accompanied by relative increases in the rural farm population and the number of farms. If, for example, electricity offered benefits to agricultural producers who were unwilling to compensate workers, we might still observe a wedge between housing costs and wages. Over time, however, this situation should lead to an outmigration of workers from the rural sector. The fact that electricity is associated with increases in the number of both rural producers and workers – despite the rise in land and housing costs – provides strong evidence against this type of short-run adjustment.

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[10] 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.

[11] Unfortunately, we lack direct evidence on the salaries of agricultural workers. To the extent that workers are mobile within each county, however, the wage effects across agricultural and non-agricultural sectors should be similar.

### 7.3 Estimated spillover effects onto non-agricultural sectors

In Table 6, we consider the broader effects of rural electrification on non-agricultural sectors. Panel A reports the estimates for local population. Rural electrification is associated with large relative declines in urban and overall population. Between 1930 and 1960, the average urban population rose by more than 50%. Nevertheless, we estimate that rural electrification slowed the pace of this expansion by 17%. Given that much of the mid-20th century urban population growth occurred in suburban areas (Baum-Snow, 2007), our estimates suggest that increased demand for farmland drove up local real estate prices, slowing the pace of suburban expansion.

Rural electrification also had local spillovers effects onto non-farm industries. We estimate a contraction in non-agricultural employment in counties that acquired rural access to electricity. The effect on overall employment is negative, wich implies that the gains to agricultural employment did not offest the declines in other industries. We also find that rural electrification led to significant decreases in the number of non-farm establishments, and some evidence of a decline in non-agricultural output and sales.

To the extent that urban areas were not directly affected by changes in electricity access, these results capture spillover effects from agricultural sector through common local factor prices.[12] Specifically, increased demand for agricultural land drove up local urban housing costs. Since non-farm industries were unwilling to offer higher wages to compensate workers for these costs, rural electrification leads to a net outmigration from local urban areas. Over time, the decline in urban population should offset the upward pressure on housing prices, which will restore equilibrium.

### 7.4 Sensitivity analysis

In Table 7, we examine the robustness of the main estimates to several alternative specifications. Column (1) reports the baseline estimates. In column (2) we report the

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[12] If urban areas did also benefit from local electricity access (for example, through more reliable services), our results would understate the contraction in non-agricultural sectors.

results from models that rely on variation from all power plants with at least 10mw of nameplate capacity (as opposed to plants with at least 30mw). Locational choices of these plants were more likely influenced by local demand characteristics, so if endogenous site location were a concern, we would expect the estimates in column (2) to be upwards biased relative to thes baseline results. Instead, we find the results to be consistent across the two estimation strategies, with very little difference between the two sets of point estimates.

In column (3) we examine the sensitivity of the results to controlling for the number of tractors per farm in 1930 interacted with the year fixed effects.[13] This specification controls for the diffusion of another key determinant of agricultural productivity during this time period (Olmstead and Rhode, 2001; Steckel and White, 2012). The estimates are virtually unchanged when these covariates are included. To control for the availability of transportation infrastructure, column (4) adds a covariate for the fraction of farms with access to a hard surface road in 1930 interacted with year. In these models, the point estimates for urban population and employment are roughly one quarter the size of the baseline findings and statistically insignificant. Meanwhile, the results for housing prices, rural population and employment are all similar in magnitude to the original results. Taken together, these findings support the baseline results that rural electrification led to an expansion in the rural sector and drove up local home values.

### 7.5 The value of electricity to rural producers and rural residents

To conclude the analysis, we apply the previous results to derive estimates of value of electricity for a) rural residents, b) rural producers, and c) overall rural welfare. These estimates can be derived directly from the reduced form price effects found in Table 5. Consider first, the amenity value associated with household access to electricity. Since the reduced form are expressed in terms of distance to power plants rather than electrification per se, we re-write equation (5) as follows:

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[13] Since the decision to adopt a tractor may have been influenced by electricity availability, we cannot control directly for decennial changes in tractor adoption between 1930 and 1960.

$$\frac{p_e^*}{w} = k_l \cdot \left( \frac{d \log q}{d(DistPP30)} \Big/ \frac{de}{d(DistPP30)} \right) - \left( \frac{d \log w}{d(DistPP30)} \Big/ \frac{de}{d(DistPP30)} \right).$$

The term $\frac{d \log w}{d(DistPP30)}$ is the reduced form effect of power plant distance on local wages, which is set equal to zero given the small and statistically insignificant wage effects found in Table 2. The term $\frac{d \log q}{d(DistPP30)}$ captures the effect of distance on housing costs, which we set equal to 0.0085 based on the preferred estimated for median dwelling value.[14] The term $\frac{de}{d(DistPP30)}$ denotes the relationship between county distance to power plants and the share of farm homes with electricity. Using data for the period 1930 to 1950, we estimate this value to be 0.0048, implying that a 100 mile decrease in distance would raise rural electrification rates by roughly 5 percentage points. Finally, we require information on expenditure share for housing, $k_l$. We calculate $k_l$ as the fraction of household income spent on rent in the sample in 1950 and find $k_l = 0.18$. Applying these estimates we can derive the willingness-to-pay for household electrical services. Since the analysis is conducted at the county-level, these results are equivalent to increasing the proportion of farms with electrical services from 0 to 100%. In particular we calculate: $\frac{p_e^*}{w} = 0.18 \cdot 0.0085/0.0048 = 32\%$. This estimate implies that a family would be willing to forgo 32% of total annual income (more tha \$3,600 in 1990 USD) to reside in a home with electricity.

Next, we examine the value of electricity for agricultural production. Again, we rescale the reduced form estimates by first stage relationship between power plant distance and the fraction of farms with electrical services. We set $\frac{d \log q}{d(DistPP30)} = 0.0051$ based on the preferred estimate for farm value in Table 5, and set the wage effect equal to zero. We also require information on $\theta_q$, the share of land in the cost of agricultural production. We rely on historical payments from sharecroppers to land owners and set $\theta_q = 0.33$ (Alston and Kauffman, 1997; Conrad, 1965; Grubb, 1971). Applying these estimates we find that

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[14] Alternatively, we could use the estimate for rental costs, which is 0.0052 and highly significant. The gap between the rental price and housing value effects likely reflects the fact that anticipated future benefits of electricity (such as future consumer durable acquisitions) are also capitalized into home values.

$C_e = -0.33 \times (0.0051/0.0048) = -35\%$, which implies that access to electricity on the farm lowers the unit cost of agricultural production by 35%.[15]

Finally, we can estimate the total willingness-to-pay for electricity within a county. Implicity, this calculation reflects the value of providing electricity to all rural producers and customers. We rewrite equation (7) as follows: $p_e^* N^R + \big[-C_e X^R\big] = q \cdot \left(\frac{d \log q}{d(DistPP30)} \Big/ \frac{de}{d(DistPP30)}\right) \cdot L^R$, where $L^R = 289,766$ is average acres in farmland in 1930, and $q = \$359.30$ is the average value of farmland and farm buildings per acre in 1930. Applying these estimates, we calculate the average net benefit of rural electrification to a county as $p_e^* N^R + \big[-C_e X^R\big] = \$359.30 \times (0.0051/0.0048) \times 289,766 = \$110,619,982$ (1990 USD), or \$50,860 per farm.

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. To assess the feasibility of this option, we compare these benefits with the historical costs of these diesel generators. In a 1922 industry manual, the prices quoted for a 1 megawatt diesel generator range from \$44,000 to \$86,000 (1990 USD) (Electrical World, 1922). Even without factoring in fuel costs, these costs would have been prohibitively expensive for the overwhelming majority of farmers.[16] 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 a population densities of just 2 or 3 farms per mile, these line extensions could easily

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[15] Notice that the calculation of $C_e$ can be intepreted as a Wald Estimate, which is calculated by dividing the reduced form impact of power plant distance on land prices by the first stage relationship between distance and electricity access. Even if the location of power plants was randomly assigned, the exclusion restriction might not hold, if proximity to plants improved agricultural productivity independently of its effects on household electrification. For example, greater access to electricity infrastructure may have spurred other types of local infrastructure investment, such as roads. In this case, rescaling the reduced form estimates would exaggerate the cost-savings associated with individual farm electrication. Nevertheless, we can still calculate the production value of operating near a source of generation. Consider, for example, the value of a 200 mile decrease in distance to a power plant. This change would lower production costs by $C_e = 0.33 \times (0.0051 \times 20) = 3.4\%$.

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

have been justified based on the value of this technology for the rural population.

## 8 Conclusion

This paper makes two main contributions to our understanding of benefits of rural electrification. First, we exploit the non-uniform rollout of the U.S. power grid to evaluate the impact of electricity access on a range local outcomes in both farm and non-farm sectors. The empirical results suggest that electrification generated an expansion in the agricultural sector, but that these gains were offset by contractions in non-agricultural sectors. Whether the outmigration from urban areas stimulated economic development in other regions remains an area for future research.

Our second contribution is provide a quantitative assessment of the value of rural electrification for agricultural productivity and improved household amenities. We estimate large welfare gains to farm households, driven both by improved productivity and the amenity value of household electrification. We calculate that households would be willing to forgo 32% of annual income to reside in a home equipped with electricity. To our knowledge, these results offer the first empirical evidence on the willingness-to-pay for household electricity access.

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

# References

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

Beal, R. (1940). "Rural Electrification," *Yearbook of Agriculture*: 790-809.

Conrad, D. (1965). *The Forgotten Farmers: The Story of Sharecroppers in the New Deal.* Urbana: University of Illinois Press.

*Electrical World*, November 27, 1922, vol. 80.

Haines, M. (2010). *Historical, Demographic, Economic, and Social Data: The United States, 1790-2000* [Computer file]. ICPSR02896-v2. Hamilton, NY: Colgate University/Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor].

*General Electric Digest*, April, 1925.

Grubbs, D. (1971). *Cry from the Cotton: The Southern Tenant Farmers' Union and the New Deal.* Chapel Hill, NC: University of North Carolina Press.

Hornbeck, R. and P. Keskin (2012). "Does Agriculture Generate Local Economic Spillovers? Short-run and Long-run Evidence from the Ogallala Aquifier." *NBER Working Paper 18416.*

International Energy Agency (2011). World Energy Outlook. http://www.worldenergyoutlook.org/publications/weo-2011/.

Kitchens, C. (2013). "The Role of Publicly Provided Electricty in Economic Development: The Experience of the Tennessee Valley Authority 1929-1955."

Kitchens, C., and P. Fishback (2014). "Flip the Switch: The Spatial Impact of the Rural Electrification Administration 1935-1940." *NBER Working Paper 19743.*

Lebergott, S. (1976). *The American Economy*, Princeton NJ: Princeton University Press.

Lee, K., et al (2014). "Barriers to Electrification for "Under Grid" Households in Rural Kenya", *NBER Working Paper 20327.*

Lewis, J. (2014a). "Short Run and Long Run Effects of Household Electrification," *University of Montreal Working Paper.*

Lewis, J. (2014b). "Fertility, Child Health, and the Diffusion of Electricity into the Home," *University of Montreal Working Paper.*

Lovell, A. (1941). *Generating stations, economic elements of electrical design.* New York NY, McGraw-Hill Book Company, Inc.

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

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

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

Schwartz Cowan, R. (1983). *More Work for Mother*, New York: Basic Books.

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.

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 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.

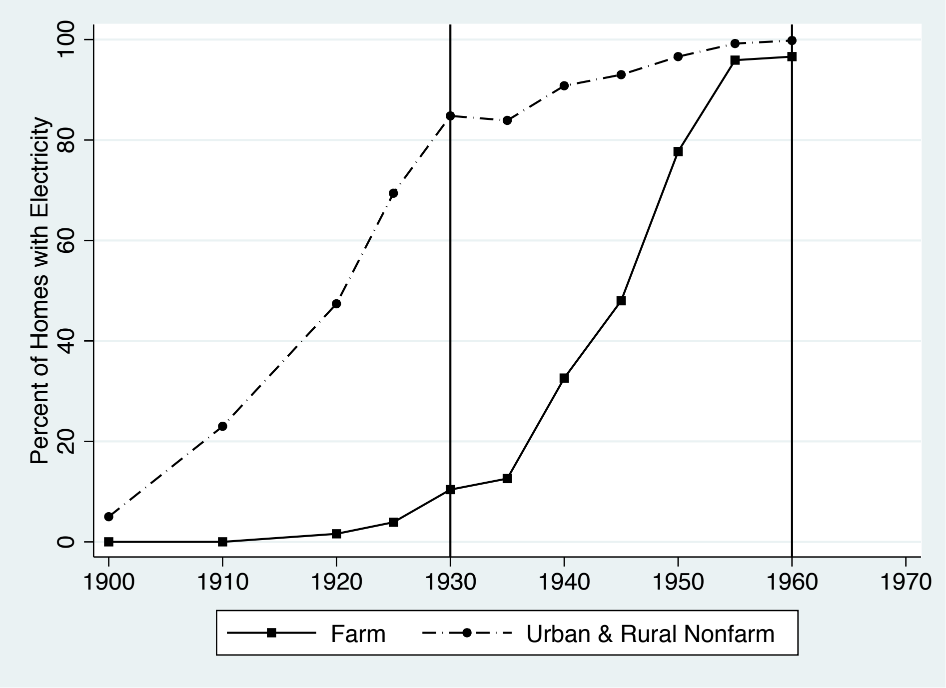
U.S. Federal Power Commission (1963). *Principal electric power facilities in the United States (map)*, Washington DC: U.S. Federal Power Commission.

World Bank (2008). “The welfare impact of rural electrification: A reassessment of costs and benefits,” *World Bank Independent Evaluations Group.*

World Bank (2013). “Global Tracking Framework: Sustainable Energy for All”.

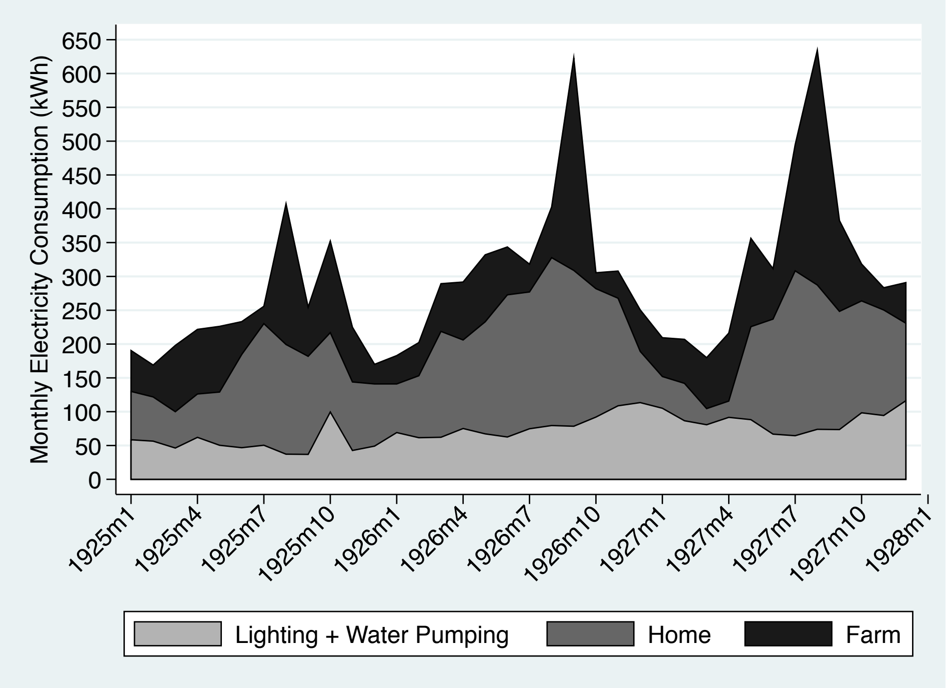
# 9 Figures and Tables

Figure 1: % farm and nonfarm households with electrical facilities



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

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



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

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

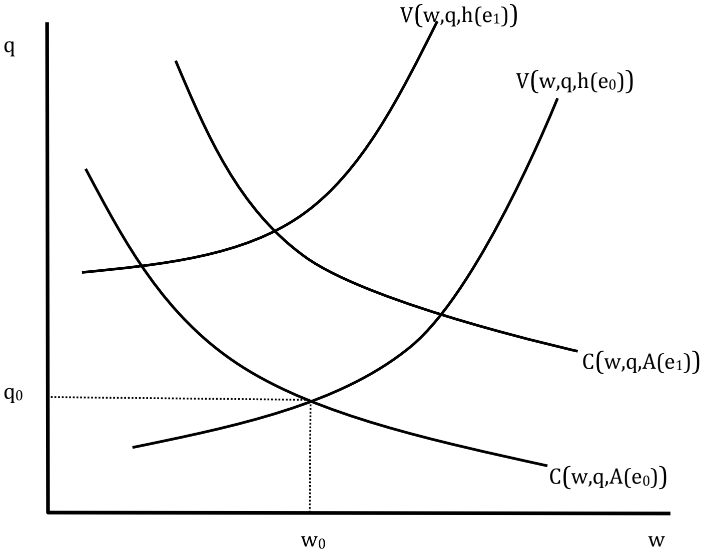
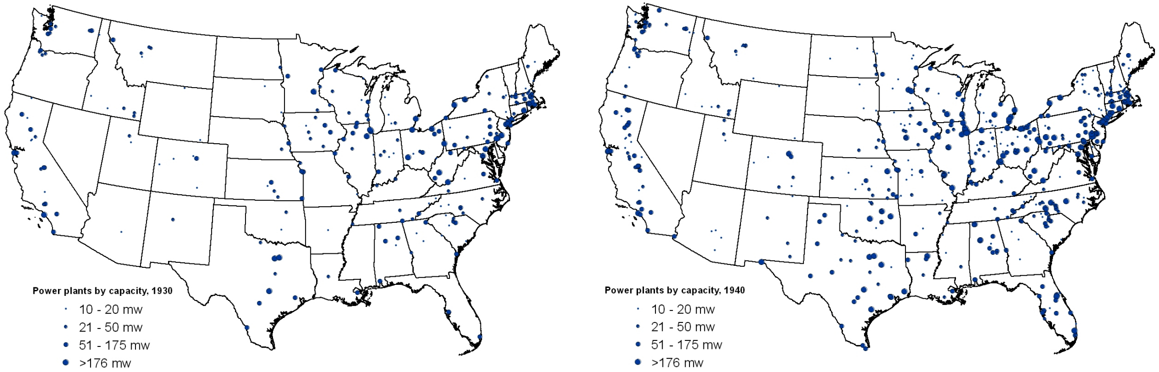
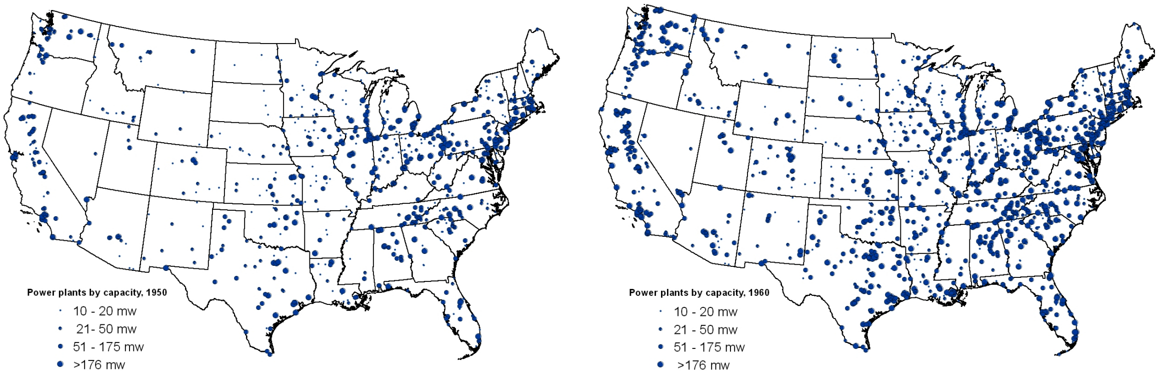


Figure 4: U.S. Power Plants: 1930 to 1960



(a) 1930

(b) 1940



(c) 1950

(d) 1960

Table 1: Average Monthly Electricity Consumption – Red Wing Project (1924-1927)

| Farm | 1924 | 1925 | 1926 | 1927 | Average |
|---|---|---|---|---|---|
| 1 | 53 | 178 | 243 | 251 | 181 |
| 2 | 224 | 239 | 225 | 316 | 251 |
| 3 | 240 | 308 | 310 | 379 | 309 |
| 4 | 42 | 161 | 206 | 223 | 158 |
| 5 | - | - | 837 | 577 | 707 |
| 6 | 113 | 175 | 158 | 197 | 161 |
| 7 | 84 | 327 | 309 | 201 | 230 |
| 8 | 86 | 219 | 249 | 309 | 216 |
| Average | 120 | 230 | 317 | 307 | 243 |

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

Table 2: Share of Electricity Consumption by Farm – Red Wing Project

| Farm | Farm Share ($\alpha$) | Home Share ($\beta$) | Light & Pumping ($1-\alpha-\beta$) |
|---|---|---|---|
| 1 | 0.1 | 0.66 | 0.23 |
| | [0.10] | [0.26] | [0.21] |
| 2 | 0.48 | 0.16 | 0.36 |
| | [0.19] | [0.18] | [0.17] |
| 3 | 0.25 | 0.45 | 0.3 |
| | [0.25] | [0.18] | [0.15] |
| 4 | 0.36 | 0.2 | 0.44 |
| | [0.36] | [0.19] | [0.28] |
| 5 | 0.07 | 0.63 | 0.3 |
| | [0.05] | [0.25] | [0.20] |
| 6 | 0.41 | 0.16 | 0.43 |
| | [0.22] | [0.16] | [0.19] |
| 7 | 0.2 | 0.5 | 0.3 |
| | [0.15] | [0.28] | [0.26] |
| 8 | 0.36 | 0.39 | 0.25 |
| | [0.21] | [0.19] | [0.16] |
| Average | 0.29 | 0.38 | 0.33 |
| | [0.25] | [0.29] | [0.22] |

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

Table 3: Share of Electricity Consumption by Farm – Red Wing Project

| **Dep Var** | **Ln(Farm Electricity Consumption)** | | |
|---|---|---|---|
| ln(Electricity Price ) | -2.0551***<br>[0.5447] | -2.0218***<br>[0.5213] | -2.0409***<br>[0.5209] |
| ln(Electricity Price)t-1 | | | 0.0867<br>[0.1371] |
| R-squared | 0.4052 | 0.4842 | 0.4845 |
| **Dep Var** | **Ln(Home Electricity Consumption)** | | |
| ln(Electricity Price)t | -1.2985**<br>[0.5069] | -1.1692*<br>[0.5116] | -1.1318*<br>[0.5337] |
| ln(Electricity Price)t-1 | | | -0.1695<br>[0.2611] |
| R-squared | 0.6862 | 0.7627 | 0.7637 |
| **Dep Var** | **Ln(Basic Electricity Consumption)** | | |
| ln(Electricity Price)t | -0.0052<br>[0.1356] | -0.2210**<br>[0.0919] | -0.1999*<br>[0.1052] |
| ln(Electricity Price)t-1 | | | -0.0956<br>[0.0979] |
| R-squared | 0.5575 | 0.8196 | 0.8207 |
| Farm FE | Yes | Yes | Yes |
| Season-by-Year FE | Yes | Yes | Yes |
| Farm Quadratic Time Trend | No | Yes | Yes |
| Observations | 248 | 248 | 248 |

Notes: Coefficients with *** are significant at 1%, ** at 5%, and * at 10%. Standard errors in parentheses are clustered at the farm level. Monthly electricity consumption is aggregated at the farm, home, or basics category level based on electricity usage by each piece of electrical equipment. Electricity prices are calculated by applying the Red Wing nonlinear pricing scheme for overall consumption.

Table 4: The effect of rural electricity access on farm outcomes

| | County Mean | Coefficient on *DistPP30*: Effect of a 10 mile decrease in power plant distance | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| **A: Population** | | | | | |
| Rural Farm | 7,725 | 137.4***<br>(22.3) | 118.3***<br>(21.6) | 99.4***<br>(22.0) | 85.5***<br>(22.8) |
| Log(Rural Farm) | 8.54 | 0.0132***<br>(0.0034) | 0.0155***<br>(0.0034) | 0.0119***<br>(0.0035) | 0.0105***<br>(0.0037) |
| Log(Rural Farm Share) | -1.28 | 0.0112***<br>(0.0028) | 0.0125***<br>(0.0026) | 0.0085***<br>(0.0026) | 0.0082***<br>(0.0027) |
| **B. Employment** | | | | | |
| Agriculture | 2,492 | 32.1***<br>(6.8) | 30.9***<br>(5.9) | 29.1***<br>(6.2) | 29.9***<br>(6.5) |
| Log(Agriculture) | 7.47 | 0.0078***<br>(0.0024) | 0.0086***<br>(0.0023) | 0.0071***<br>(0.0023) | 0.0062***<br>(0.0024) |
| Log(Agriculture Share) | -1.41 | 0.0159***<br>(0.0025) | 0.0113***<br>(0.0024) | 0.0092***<br>(0.0024) | 0.0092***<br>(0.0025) |
| **C. Output** | | | | | |
| Farms | 1,812 | 15.0***<br>(3.6) | 18.9***<br>(3.3) | 14.1***<br>(3.4) | 13.8***<br>(3.5) |
| Log(Farmland) | 12.4 | 0.0168***<br>(0.0024) | 0.0040*<br>(0.0022) | 0.0015<br>(0.0022) | 0.0017<br>(0.0022) |
| Log(Farmland Per Farm Population) | 3.89 | 0.0045<br>(0.0038) | -0.0109***<br>(0.0036) | -0.0099***<br>(0.0037) | -0.0084**<br>(0.0039) |
| Farm Size | 422 | 22.41**<br>(9.23) | 9.36<br>(11.27) | 6.93<br>(10.26) | 10.71<br>(11.17) |
| Log(Farm Revenue) | 9.44 | 0.0051<br>(0.0035) | 0.0051<br>(0.0034) | 0.0070**<br>(0.0034) | 0.0063*<br>(0.0035) |
| Log(Farm Revenue Per Farm Population) | 0.92 | -0.0073<br>(0.0044) | -0.0101**<br>(0.0042) | -0.0046<br>(0.0041) | -0.0039<br>(0.0044) |
| Linear state trend | | N | Y | Y | N |
| Geographic covariates | | N | N | Y | Y |
| State×year fixed effects | | N | N | N | Y |

Notes: All regressions include controls for county and year fixed effects. Each cell reports the point estimate from a different regression. Geographic covariates include time-varying controls for 10-year moving averages for temperature and precipitation, degree days between $10^{o}$C and $29^{o}$C and degree days above $29^{o}$C, and latitude and longitude interacted with year. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 5: The effect of rural electricity access on income and housing values

| | County Mean | Coefficient on *DistPP30*: Effect of a 10 mile decrease in power plant distance | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| **A. Housing costs** | | | | | |
| Log Median Dwelling Value (Owner-Occupied) | 9.98 | 0.0125*** | 0.0087*** | 0.0086*** | 0.0085*** |
| | | (0.0018) | (0.0017) | (0.0017) | (0.0017) |
| Log Median Dwelling Rent (Renter-Occupied) | 4.95 | 0.0102*** | 0.0066*** | 0.0053*** | 0.0052*** |
| | | (0.0017) | (0.0015) | (0.0015) | (0.0015) |
| Log Value of Farmland and Farm Buildings | 5.45 | 0.0021 | 0.0059*** | 0.0067*** | 0.0051*** |
| | | (0.0020) | (0.0019) | (0.0020) | (0.0020) |
| **B. Income proxies** | | | | | |
| Log(Retail Sales Per Capita) | 0.97 | 0.0034* | 0.0013 | 0.0011 | 0.0018 |
| | | (0.0017) | (0.0016) | (0.0017) | (0.0017) |
| Log(Manufacturing Payroll Per Worker) | 2.40 | 0.0040* | 0.0017 | 0.0009 | 0.0018 |
| | | (0.0021) | (0.0020) | (0.0020) | (0.0020) |
| Log(Wholesale Payroll Per Worker) | 2.57 | -0.0033 | 0.0036 | 0.0046* | 0.0025 |
| | | (0.0023) | (0.0025) | (0.0024) | (0.0025) |
| Log(Retail Payroll Per Worker) | 2.28 | 0.0008 | 0.0009 | 0.0011 | 0.0009 |
| | | (0.0009) | (0.0010) | (0.0010) | (0.0009) |
| Log(Service Payroll Per Worker) | 2.14 | 0.0023 | 0.0029 | -0.0004 | -0.0005 |
| | | (0.0025) | (0.0026) | (0.0026) | (0.0026) |
| Linear state trend | | N | Y | Y | N |
| Geographic covariates | | N | N | Y | Y |
| State×year fixed effects | | N | N | N | Y |

Notes: All regressions include controls for county and year fixed effects. Each cell reports the point estimate from a different regression. Geographic covariates include time-varying controls for 10-year moving averages for temperature and precipitation, degree days between $10^{o}$C and $29^{o}$C and degree days above $29^{o}$C, and latitude and longitude interacted with year. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 6: The effect of rural electricity access on non-farm outcomes

| | County Mean | Coefficient on *DistPP30*:<br>Effect of a 10 mile decrease in power plant distance | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| **A: Population** | | | | | |
| Total | 50,820 | -1,608.8*** | -998.1*** | -942.7*** | -1,037.8*** |
| | | (327.7) | (267.4) | (260.8) | (280.3) |
| Rural Non-Farm | 10,995 | -227.4*** | -61.7 | -36.4 | -34.7 |
| | | (49.1) | (40.6) | (42.1) | (44.8) |
| Urban | 32,099 | -1,518.7*** | -1,054.7*** | -1,005.7*** | -1,088.7*** |
| | | (330.1) | (264.5) | (257.1) | (277.3) |
| **B. Employment** | | | | | |
| Total | 18,673 | -574.2*** | -355.2*** | -316.7*** | -346.8*** |
| | | (116.3) | (93.8) | (90.9) | (97.5) |
| Manufacturing | 4,707 | -248.7*** | -141.1*** | -125.4*** | -136.3*** |
| | | (40.6) | (25.8) | (24.3) | (26.4) |
| Construction | 1,090 | 0.41 | -12.01 | -8.20 | -8.87 |
| | | (9.51) | (7.89) | (7.90) | (8.72) |
| Trade | 3,217 | -103.7*** | -67.9*** | -62.3*** | -71.3*** |
| | | (23.5) | (21.0) | (20.5) | (21.9) |
| Other | 7,167 | -254.2*** | -165.1*** | -149.9*** | -160.3*** |
| | | (55.4) | (47.0) | (46.3) | (49.1) |
| **C. Establishments** | | | | | |
| Manufacturing Establishments | 89 | -3.72*** | -2.28*** | -1.82*** | -2.12*** |
| | | (0.81) | (0.53) | (0.53) | (0.57) |
| Wholesale Establishments | 80 | -4.24*** | -2.52*** | -2.31*** | -2.64*** |
| | | (0.87) | (0.70) | (0.69) | (0.75) |
| Retail Establishments | 590 | 4.34 | 1.78 | 1.26 | 0.49 |
| | | (2.88) | (2.18) | (2.04) | (2.16) |
| Service Establishments | 283 | -8.50*** | -6.70*** | -6.45*** | -6.48*** |
| | | (1.97) | (2.19) | (2.16) | (2.26) |
| **D. Establishment output** | | | | | |
| Log(Manufacturing Value Added) | 3.18 | -0.0087 | -0.0095 | -0.0086 | -0.0101 |
| | | (0.0058) | (0.0063) | (0.0064) | (0.0067) |
| Log(Wholesale Sales) | 10.39 | -0.0142*** | -0.0031 | -0.0027 | -0.0036 |
| | | (0.0047) | (0.0047) | (0.0048) | (0.0049) |
| Log(Retail Sales) | 10.94 | -0.0045* | -0.0017 | -0.0015 | -0.0017 |
| | | (0.0026) | (0.0025) | (0.0026) | (0.0026) |
| Log(Service Receipts) | 8.35 | -0.0044 | -0.0063 | -0.0042 | -0.0046 |
| | | (0.0044) | (0.0044) | (0.0044) | (0.0045) |
| Linear state trend | | N | Y | Y | N |
| Geographic covariates | | N | N | Y | Y |
| State×year fixed effects | | N | N | N | Y |

Notes: All regressions include controls for county and year fixed effects. Each cell reports the point estimate from a different regression. Geographic covariates include time-varying controls for 10-year moving averages for temperature and precipitation, degree days between 10$^{o}$C and 29$^{o}$C and degree days above 29$^{o}$C, and latitude and longitude interacted with year. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

Table 7: Robustness exercises

| | Coefficient on *DistPP30*: Effect of a 10 mile decrease in power plant distance | | | |
|---|---|---|---|---|
| | (1) Baseline estimates | (2) Alternative measure of power plant distance (plants $\geq$ 10mw) | (3) Add controls for tractor diffusion | (4) Add controls for road access |
| **A. Housing and Wages** | | | | |
| Log Median Dwelling Value (Owner-Occupied) | 0.0085***<br>(0.0017) | 0.0090***<br>(0.0020) | 0.0086***<br>(0.0017) | 0.0069***<br>(0.0017) |
| Log Median Dwelling Rent (Renter-Occupied) | 0.0052***<br>(0.0015) | 0.0045***<br>(0.0017) | 0.0049***<br>(0.0015) | 0.0028**<br>(0.0014) |
| Log Value of Farmland and Farm Buildings | 0.0051***<br>(0.0020) | 0.0115***<br>(0.0023) | 0.0052***<br>(0.0019) | 0.0050**<br>(0.0020) |
| Log(Manufacturing Payroll Per Worker) | 0.0018<br>(0.0020) | -0.0013<br>(0.0021) | 0.0018<br>(0.0020) | 0.0017<br>(0.0020) |
| **B. Farm Outcomes** | | | | |
| Rural Farm Population | 85.54***<br>(22.85) | 53.93**<br>(24.29) | 87.40***<br>(22.80) | 66.40***<br>(22.6) |
| Log(Rural Farm Population) | 0.0105***<br>(0.0037) | 0.0086**<br>(0.0035) | 0.0106***<br>(0.0037) | 0.0035*<br>(0.0034) |
| Agricultural Employment | 29.95***<br>(6.51) | 16.48**<br>(7.13) | 30.21***<br>(6.48) | 27.38**<br>(6.48) |
| Log(Agricultural Employment) | 0.0062***<br>(0.0024) | 0.0039<br>(0.0028) | 0.0064***<br>(0.0024) | 0.0074***<br>(0.0024) |
| Farms | 13.76***<br>(3.49) | 7.29**<br>(3.67) | 14.06***<br>(3.47) | 12.52***<br>(3.49) |
| **C. Non-farm Outcomes** | | | | |
| Total Population | -1,037.8***<br>(280.3) | -909.7***<br>(251.4) | -1,026.3***<br>(282.2) | -228.5<br>(269.8) |
| Urban Population | -1,088.7***<br>(277.3) | -928.5***<br>(247.3) | -1,082.6***<br>(279.5) | -273.1<br>(271.4) |
| Total Employment | -346.7***<br>(97.5) | -308.6***<br>(87.8) | -348.2****<br>(98.3) | -78.6<br>(96.7) |
| Manufacturing Employment | -136.1***<br>(26.4) | -123.1***<br>(26.9) | -133.5***<br>(26.8) | -42.1<br>(30.5) |

Notes: All regressions include the full set of controls for county and year fixed effects, geographic characteristics, and a state-by-year fixed effect. Column (2) reports estimates using $DistPP10$: distance to the nearest power plant with at least 10mw of nameplate capacity. Column (3) reports estimates from regressions that control for the number of tractors per farm in 1930 interacted with year. Column (4) reports estimates from regressions that control for the fraction of farms with access to a hard surface road in 1930 interacted with year. Standard errors are clustered at the county-level. ***,**,* denote significance at the 1%, 5%, and 10% level, respectively.

# A Appendix

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

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

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

Table A.2: Share of Electricity Consumption by Farm – Red Wing Project

| **Dep Var** | **Dairy Revenue ($)** | | **Ln(Dairy Revenue)** | |
|---|---|---|---|---|
| Electricity Expenditure | 9.0823***<br>[2.46] | 14.1050**<br>[6.29] | 0.0070***<br>[0.0018] | 0.0098**<br>[0.0041] |
| R-squared | 0.4193 | 0.7558 | 0.4382 | 0.7824 |
| **Dep Var** | **Non-Dairy Revenue ($)** | | **Ln(Non-Dairy Revenue)** | |
| Electricity Expenditure | 7.52<br>[4.99] | -14.8927<br>[10.53] | 0.0032<br>[0.0022] | -0.0067<br>[0.0039] |
| R-squared | 0.112 | 0.8005 | 0.1007 | 0.8721 |
| Farm FE and Year FE | No | Yes | No | Yes |
| Observations | 20 | 20 | 20 | 20 |

Coefficients with *** are significant at 1%, ** at 5%, and * at 10%. Robust standard errors in parentheses. The analysis is based on five farms with annual information for the period 1924-1927.