Human Capital, Female Employment, and Electricity: Evidence from the Early 20th-Century United States*

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Abstract

This paper revisits the link between electrification and the rise in female labor force participation (LFP), and presents theoretical and empirical evidence showing that electrification triggered a rise in female LFP by increasing market opportunities for skilled women. I formalize my theory in an overlapping generations model and find that my mechanism explains one quarter of the rise in female LFP during the rollout of electricity in the United States (1880–1940), and matches the slow decline in female home-production hours during this period. I then present micro-evidence supporting my theory using newly digitized data on the early electrification of the United States.

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Improving access to electricity has received considerable attention in academic and policy circles recently, and has long been a primary goal of international development programs. This avid interest stems from the belief, widely held by economists and policy makers, that electrification is a precondition for development. According to this view, having access to electricity is not only necessary for modern production, but can also alleviate poverty by fundamentally changing the time-use patterns and organization of households. The increase in opportunities for women following electrification is frequently singled out as one of the main drivers of such changes and thus of the aggregate prosperity that results from expanded access to the grid. Gordon (2016) argues, for instance, that the economic revolution fueled by electricity is unrepeatable, because new technologies are unlikely to have such profound effects on so many people. The main mechanism fueling the effects of electricity on women explored in the literature to date is the reduction in the time burden of housework and consequent rise in female labor force participation (LFP). In a notable paper, Greenwood et al. (2005) formalize this intuition by arguing that the adoption of time-saving appliances following electrification enabled women to be liberated from housework and was one of the main factors leading to the steady increase in female labor supply in the United States during the 20th century. Other work argues, however, that trends in female time spent in home production do not match this intuition. For instance, after closely examining several time-use studies, Ramey (2009) finds that the time spent on housework by women fell only minimally between 1900 and 1965, even though the prevalence of electricity and the use of time-saving appliances increased significantly during the same period.

In this paper, I revisit the link between electricity and female LFP, and present theoretical and empirical evidence supporting a new channel that focuses on the increase in market production opportunities for women and the role of complementary human capital accumulation. I build an overlapping generations (OLG) model where electricity is skill biased and human capital investments are made early in life. The novel insight of my model is showing that electricity complements work tasks that favor women and that these productive benefits require complementary human capital investments. In particular, electricity raises the relative productivity of skilled labor, which is less brawn intensive than unskilled labor and thus more favorable toward women's employment. These gains can only be capitalized on by women with a high level of schooling, however, since they involve work in skilled tasks. Given that schooling investments are put forward early in life, young women experience a unique advantage relative to older women as they can coordinate human capital decisions to maximize the benefits from electrification. This generational divide, in turn, causes the effects of electrification on female LFP to accrue through generational change, as new generations replace old ones and human capital accumulates. The skill and youth bias of electrification also creates a direct link between the effects of electrification on the LFP of young skilled women and the aggregate changes in female LFP in the model. This motivates the use of the estimates on the effects of electrification on the employment decisions of young women derived in the empirical section of the paper to discipline the model and quantify the aggregate effects of electrification.

In order to quantify the importance of this human capital channel of electricity in explaining female LFP trends, I calibrate a quantitative version of the model to the 1880–1940 United States and simulate the effects of the rollout of electricity. I use my empirical analysis, and in particular the estimate on the effect of electrification on the LFP of highly educated young women, to discipline the model parameters. I find that the human capital channel explains approximately one quarter of the rise in female LFP during this period. Moreover, this channel decouples the rise in female labor supply from a decrease in home production hours and helps explain the slow decline in female home production hours that occurred in the first half of the 20th century. In addition, I find that the human capital channel is complementary to the home production channel of electrification suggested by Greenwood et al. (2005). This stems from the fact that, as suggested by Lewis (2014), home electrification allows mothers to take over some of the domestic duties of teenage daughters, in turn enabling the latter to focus more on their studies and take advantage of the productive returns of electrification highlighted in the human capital channel.

I then present empirical evidence supporting the main predictions of my theory and underlying the estimates on the effects of electrification used to calibrate the model. I use microdata from the early 20th-century United States, and focus in particular on the effects of electrification investments made during the 1910s, an interesting and seldom-examined period in the history of electrification. During this era, the proportion of households with electricity rose from 15% to 35% and electrification efforts concentrated in "Middle America," midsize urban areas that were electrified after large cities, but still early in the expansion of the electric grid across the United States (Rieder (1989), Nye (1992)). I build a new dataset with the universe of utilities and central generating stations in 1911 and 1919 by digitizing historical documents containing information on 5409 and 5631 generators, respectively.[1] Using this information, I construct measures of the electric capacity generated within each county in the United States. I then combine this data with an individual-level panel dataset built from the full-count 1910–1940 decennial census waves, using the record-linking algorithm proposed by Abramitzky et al. (2012, 2014).[2]

[1]The specific sources I use are two editions of "Central station directory: a complete list of electric light and power companies with data" (McGraw Publishing Company (1911, 1919)).

[2]All record-linking algorithms rely heavily on between-wave name comparisons to form matches and thus

Using these combined data sources, I study the effects of electrification in the 1910s on the lifetime outcomes of women of different cohorts. To identify the effect of electrification, I use a triple difference (DDD) approach, focusing on the heterogeneity of the effects of electrification by educational level and cohort. This follows from my model's predictions that a high level of education was critical for taking advantage of the new market opportunities electrification opened up for women, and that age at the arrival of electricity was key due to the existence of "formative years" when human capital investments are made. Since education decisions are affected by electrification and are thus endogenous in my setting, I use a proxy for years of schooling that follows the data and approach of Clay et al. (2021) and thus exploits changes in required years of schooling arising from geographic and temporal variation in compulsory attendance, continuation school, and child labor laws. I provide empirical and anecdotal evidence in support of my identification strategy, along with pre-treatment trend tests. In particular, I show that electrification investments during the 1910s were driven primarily by static cost considerations and continued well into the 1920s. This provides a control group comprising counties of similar characteristics that gained access to electricity at different times. Moreover, my specification includes a rich set of controls comprising demographic, income, and wealth variables, along with individual, year, state-by-year fixed effects, and county fixed effects.

I find that higher levels of required educational attainment increased the employment response of young women to electrification, particularly for those with 8 or more years of required schooling, for all years considered. Specifically, I find that the increase in employment triggered by electrification for women who were 15–20 years old upon electrification was 8 percentage points larger in 1920 (relative to 1910) for those with a required schooling level of 8 years or more years, compared to those with a required schooling level of less than 8 years. This estimate grounds my calibration and is consistent with the prediction in the model that the effects of electrification on female LFP concentrate among educated women who have the required skills to capitalize on the skill bias of electrification. Moreover, I find that the enhancing effect of education on electricity-driven employment is mostly absent among older women. This matches the generational differences in the effects of electrification predicted by my model, stemming from the ability of young women to coordinate key lifecycle decisions.

have difficulties in matching women due to maiden-to-married name changes. As a result, women who reported being married in the first census wave (1910) are overrepresented in my data. Another group that is overrepresented in this data are women who never married and prioritized career over family. In Appendix M I study whether the baseline results differ for women who were married in 1910, women who ever married, or women who ever had children.

In addition, I find that the effects of electrification on female employment vary with women's fertility and marital choices. I find that electrification did not differentially increase the employment of young and skilled women who were married in 1910, but did differentially increase the employment of young and skilled women who married or had children in later years. This suggests that women who had competing responsibilities that limited their ability to coordinate key human capital decisions when young were unable to take advantage of the productive returns brought about by electrification. However, women who later married and had families did see an increase in their LFP due to electrification when young, suggesting that the effects of electrification on female LFP are not limited to women who prioritized career over family.

Relatedly, I also find that the changes in female LFP induced by electrification were accompanied by changes in fertility and marriage rates. I find that electrification decreased the fertility and delayed the timing of childbearing of young women (particularly those born in areas with high levels of required schooling), but increased their lifetime marriage rates. These results match the evidence presented by Goldin (2020), who shows that at the turn of the 20th century, women moved from a regime of having to choose between career or family to a regime where they could pursue a career when young and a family afterwards. Taken jointly, my results suggest that electrification fueled deep changes in female work, fertility, and marriage patterns.

The rest of the paper is organized as follows: Section 1 situates this paper and its contributions in the literature. Section 2 presents the simplified benchmark model, which contains the intuitions driving the main results and the discussion of the link between the effects of electrification on the LFP of young skilled women and the aggregate changes in female LFP in the model. Section 3 embeds the main mechanism in a quantitative framework and presents the calibration and quantitative results. Section 4 delineates the data and methods used for the empirical assessment of the mechanisms predicted by the model in the early 20th-century United States and discusses the results of the effects of electrification used to calibrate the model. Section 5 concludes.[3]

1 Related Literature

My theory combines intuitions from two different literatures. First, through the emphasis on the link between new technologies and female LFP, my model is rooted in the time-

[3]In addition, Appendix A provides a brief history of electrification in the United States from 1880 to 1960 and its link to the rise in female LFP, while providing evidence of the paper's mechanism by exploring the rise in skilled female occupations concomitant with the rise in female LFP and electrification.

use models originally proposed by Becker (1960, 1965) and related to the home production and durable adoption model of Greenwood et al. (2005), as well as recent papers focusing on technological progress and the movement between home and market production, such as Ngai and Pissarides (2008), Buera and Kaboski (2012), and Moro et al. (2017). Second, through its focus on the complementarities between electricity and skilled labor, my paper relates to the literature that links technological change to the rise in skilled wages (Acemoglu (1998), Acemoglu (2002), Autor et al. (2003), Acemoglu and Autor (2011)), and specifically to the literature that explores the role of specific technologies and mechanisms driving skill-biased technical change and the rise of the skill-wage gap (Krusell et al. (2000), Atkeson and Kehoe (2007), Acemoglu and Restrepo (2020), Adão et al. (2019)). Moreover, the advantage faced by young households in coordinating their human capital decisions highlighted in my paper relates to Goldin and Katz (2008), who suggest that technological change in the 20th century has increasingly required the employment of higher-skilled workers and thus the catching up by workers and educational institutions to fully exploit the productive possibilities of the economy.

My paper also relates to the literature studying female LFP and time-use trends in the United States. In particular, the human capital channel of electrification helps reconcile the increase in female labor supply documented during the first half of the 20th century with the absence of a decline in the time devoted to housework documented by several studies and labeled by Mokyr (2000) the "Cowan Paradox," following the work of Cowan (1983). For instance, Ramey (2009) finds that the time spent in housework by prime-age women fell by only 6 hours between 1900 and 1965, and that much of that change could be accounted for by the number and age of children and the increased education levels of housewives. Moreover, my paper relates to studies investigating the sources of the rise in female LFP during the 20th century, particularly those that highlight the contribution of productive opportunities for women (Galor and Weil (1996), Costa (2000)) and the gender wage gap (Goldin (1990), Jones et al. (2015), Gayle and Golan (2012)).[4]

This paper relates to studies that empirically quantify the effects of electrification in two distinct ways. First, by focusing on the US context, this paper is related to the literature examining the effects of electrification in the United States (Lewis (2018), Gray (2013), Kitchens and Fishback (2015), Lewis and Severnini (2017), Kitchens (2014), and Gaggl et al. (2016, 2021)). Most papers in this literature have focused on rural electrification. My paper,

[4]Other explanations for the rise of female LFP during the 20th century include cultural change and learning (Fogli and Veldkamp (2011), Fernández (2013)), the introduction of the contraceptive pill and fertility changes (Goldin and Katz (2002), Bailey (2006), Knowles (2009)), medical advances (Albanesi and Olivetti (2016)), and reductions in the cost of childcare (Attanasio et al. (2008)).

in contrast, focuses on the effects of electrification in "Middle America," with a particular emphasis on female labor supply and heterogeneity of the effects by cohort and educational level. Within this literature, and by emphasizing the importance of skill bias and human capital, my paper is particularly related to the work of Gray (2013), who shows that electrification changed the demand for skill in manufacturing in the pre-World War II United States, increasing the demand for clerical, numerical, and planning jobs while reducing the demand for manual and dexterity-intensive jobs.

Second, my paper relates to studies in the development literature quantifying the effects of electrification. In particular, the importance of electrifying market production and complementary human capital investments predicted by my theory helps reconcile the large effects found by medium- and long-run studies in the developing world (Lipscomb et al. (2013), Lewis and Severnini (2017), Rud (2012), Kassem (2018), and Dinkelman (2011)) with the sparse effects found in recent short-run studies (Lee et al. (2020), and Burlig and Preonas (2016)). My theory suggests that electrification programs targeting households exclusively or focusing in areas with low human capital will have limited short-run impacts. In this sense, my paper also contributes to the empirical literature exploring the factors mediating the responses to electrification.[5]

2 An Analytical Model of Electrification and Human Capital

In this section I present an analytical version of the model. This benchmark framework focuses on the main mechanisms mediating the scope of the productive and skill dimensions of electrification to alter female work patterns. In Section 3, I embed these mechanisms in a quantitative framework and quantify the importance of the human capital channel of electrification in explaining empirical trends in female LFP. The results from this section will motivate the empirical exercises in Section 4.

2.1 Households

The model economy is populated by a continuum of size 1 of married couples $i \in [0, 1]$, whose adult life spans two periods: a "young period", and an "old period". Men and women

[5] Some of these factors include the frequent blackouts and general unreliability of grid connections documented in developing settings (Steinbuks and Foster (2010), Lee et al. (2020), Allcott et al. (2016), Lagakos and Fried (2020)), liquidity constraints hindering the purchase of connections or complementary goods (Hanna and Oliva (2015)), and "Keeping up with the Joneses" and information effects to grid connections (Bernard and Torero (2015).

are endowed with 1 unit of time each period, which they use to work in one of three sectors: the unskilled market sector, the skilled market sector, or the home sector. During the first period of their lives, men and women must also decide on schooling investments. I assume that the schooling choice is discrete. In particular, men and women can choose to become skilled at a cost of ρ_i^m and ρ_i^f units of time, respectively, or remain unskilled. These costs differ across individuals and households and are drawn randomly at the beginning of the household's life from a given distribution F. I allow women and men to differ in the relative productivity with which they perform each task, in order to capture, for instance, the relative importance of brawn across these. For expositional purposes, in what follows I ignore the household index in most expressions.

The lifetime utility of a household is given by the sum of consumption when old and young:

$$U = c_y + c_o.$$

Households use the income derived from female and male labor to acquire consumption goods in each period:

$$c_j = \mathrm{I}_j^m + \mathrm{I}_j^f \quad \text{for } j = \{y, o\}.$$

The incomes of males and females in turn are determined by their choice of work. Women and men can choose to work in the unskilled or skilled market sectors, which pay competitive wages, or engage in home production. I assume all three types of production and wages yield the same consumption good.[6] To work in the skilled sector, individuals must put forward schooling investments when young. These schooling investments entail a cost of ρ^i units of time, limiting the time available to work when young.[7]

I also assume that men and women differ in the productivity with which they perform each of these three tasks. In particular, women are more inefficient at unskilled labor relative to men, but relatively less so in skilled production. This stems from the relative importance of brawn in unskilled production, which disfavors women. In addition, men face a sharp disadvantage in home production relative to women. These differences in productivity are presented in Table 2.1:

[6] In the quantitative model, I assume consumption and home goods are distinct and thus not perfectly substitutable.

[7] In the quantitative model, I assume that individuals live with their parents when young and thus schooling decisions are made by their mother and father. With this, I allow for indirect investments in daughters by mothers, which may be an alternative mechanism through which household electrification could encourage female LFP (Lewis (2014)).

Table 2.1: Endowed Productivity per Type of Work for Men and Women

	Unskilled Market	Skilled Market	Home
Men	1	1	0
Women	0	μ	1

with $0 < \mu < 1$.

These differences in endowed productivity and the schooling time cost required for skilled labor shape the income households derive from engaging in each type of work, as shown in Table 2.2 and Table 2.3:

Table 2.2: Men's Income

	Unskilled Market	Skilled Market	Home
Young (I_y^m)	w_u	$w_s(1-\rho_i^m)$	0
Old (I_o^m)	w_u	w_s	0

Table 2.3: Women's Income

	Unskilled Market	Skilled Market	Home
Young (I_y^f)	0	$\mu_s w_s(1-\rho_i^f)$	A_h
Old (I_o^f)	0	$\mu_s w_s$	A_h

where A_h denotes the productivity of home production and w_u and w_s denote unskilled and skilled wages, respectively. Because utility follows solely from consumption goods, which can be produced using any technology, women's and men's choices can be separated and both women and men will aim to maximize their respective lifetime incomes.

2.2 Production Functions

Consumption goods can be produced using three production technologies: unskilled market production, skilled market production, and home production.

In the market, the unskilled production technology captures a traditional mode of production that uses unskilled labor only, while the skilled production technology captures a modern mode of production:

$$Y_u = A_u L_u \qquad\qquad Y_s = A_s L_s$$

where L_u and L_s denote effective unskilled and skilled labor inputs, respectively, and A_u and A_s denote Total Factor Productivity (TFP) terms for unskilled and skilled production, respectively. Wages in the skilled and unskilled sectors are thus given by

$$w_u = A_u \qquad\qquad w_s = A_s.$$

The home production technology, on the other hand, captures the possibility individuals have of producing goods at home, and is given by

$$Y_h = A_h L_h$$

where L_h denotes effective hours of home production and A_h the productivity term. Each of these production technologies yields the same consumption good, so that the total production of consumption goods is given by $Y = Y_u + Y_s + Y_h$.

2.3 Electricity

Electricity maps directly onto the labor productivity of skilled production.[8] With electrification, machines that enhance the productivity of skilled labor can be used in skilled production. This captures the skill-biased nature of electric technological change:

$$A_s = \begin{cases} A_l & \text{prior to electrification} \\ A_h & \text{after electrification.} \end{cases}$$

I assume that the decision on electrification and thus the efficiency of electricity technology is exogenous and determined by the government. This matches up with the experience in most settings, where the high fixed costs and natural monopoly features of electrification projects make it unfeasible for firms or individuals to take them on.

2.4 Equilibrium and Results

Since unskilled labor is very unproductive for them, women focus on choosing between skilled and home production, depending on their value of ρ_i^f and wages. Analogously, men focus on choosing between unskilled and skilled market production. These features match the nature of unskilled labor, which is brawn intensive and disfavors women, and the fact that men traditionally focus on market rather than home production. In what follows, I focus on the effects on women, since they and home-to-market movements are the main focus of my theory.

First, since the cost of skill monotonically increases with ρ_i^f, while its benefits and the value of home work remain constant, there is a unique cutoff in the cost of skill for women denoted

[8] In the quantitative version, I assume electrification changes the productivity of electrical power production, and that purchases of electricity are an input of skilled production.

by $\bar{\rho}^f$, which determines the proportion of women who decide to get schooling and engage in skilled production rather than home production. This cutoff is given by

$$\bar{\rho}^f = 2\left(1 - \frac{A_h}{\mu_s w_s}\right).$$

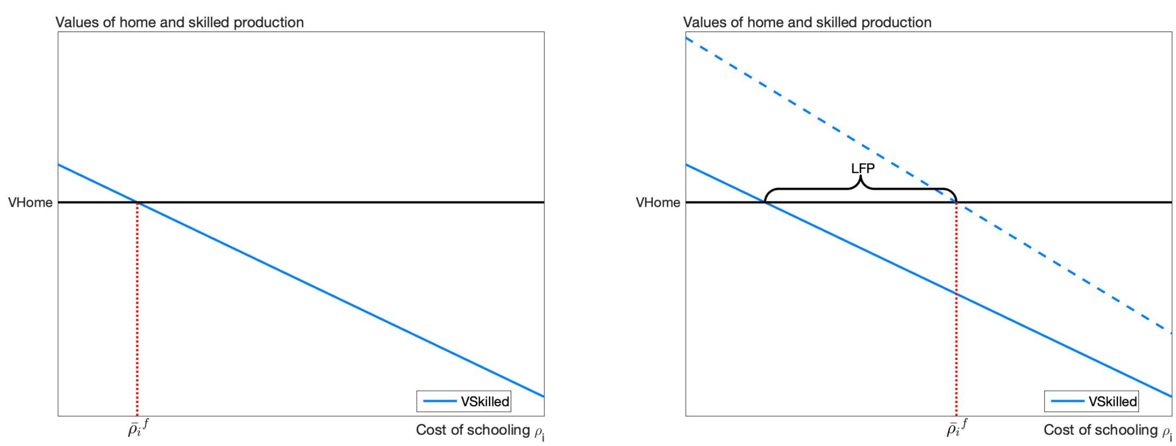
The proportion of women participating in the labor market is fully characterized by this cutoff and the schooling cost distribution: the portion of women whose schooling cost is lower than the schooling cutoff acquire schooling and participate in the labor market. Given this setup, we can characterize female LFP in every period t as the sum of the mass of old and young women participating in the labor market:

$$\text{Female LFP}_t = \frac{1}{2}F(\bar{\rho}^f_{t-1}) + \frac{1}{2}F(\bar{\rho}^f_t), \tag{1}$$

where F denotes the cdf of the schooling cost distribution, $\bar{\rho}^f_{t-1}$ denotes the schooling cutoff prevalent in period $t-1$ when old women were young and made their schooling decisions, and $\bar{\rho}^f_t$ denotes the schooling cutoff prevalent in period t, which guides the schooling decisions of young women.

Figure 2.1: Change in Women's Schooling Cost Cutoff due to Electrification

(a) Pre-electrification (b) Post-electrification



The schooling cutoff prevalent in any period and thus the proportion of women who acquire schooling and engage in skilled market work depend positively on the skilled wage w_s of that period. Therefore, by raising the productivity and wage of skilled market tasks, electrification encourages female LFP. In Figure 2.1, I illustrate this process in action. Prior to electrification, the schooling cutoff and proportion of women in the labor force are low, since the returns to skilled labor are smaller than those for home production for the majority of women. In other words, the only women engaging in market production are those with very low schooling cost levels. After electrification, the cutoff and the proportion of women engaging in the labor market rise.

A key consequence of the importance of skill in my theory is the fact that women who were old upon electrification will have no change in their labor force participation rates. This result follows from two facts: (i) the market returns to electrification can only be capitalized on by skilled women and (ii) the decisions regarding these are concentrated early in life.[9] Since old women are not able to coordinate their human capital decisions to fully maximize the new market opportunities generated by electrification, they exhibit lower levels of schooling and female LFP, relative to young women, upon electrification. Thus, the prevalence of older women dampens the increase in female labor supply in the short run. This generational wedge in turn generates a dynamic effect of electrification on female LFP, which accrues through generational change and human capital accumulation (see Appendix B.1 for a more detailed discussion and description of this result).

Notice also that since new market opportunities concentrate among skilled labor, the productive return from electrification is perceived only by women who invest in acquiring skill. This translates into higher schooling incentives for young generations.[10]

Using Equation (1), we can write the change in female LFP in period t that follows from a concurrent rise in skilled wages due to electrification as follows:

$$\Delta\text{Female LFP}_t = \frac{1}{2}\left[F(\bar{\rho}_t^f) - F(\bar{\rho}_{t-1}^f)\right] = \frac{1}{2}\int_{\bar{\rho}_{t-1}^f}^{\bar{\rho}_t^f} f(\rho_i)d\rho_i, \tag{2}$$

where $\bar{\rho}_t^f$ is the schooling cost cutoff prevalent in period t and $\bar{\rho}_{t-1}^f$ is the schooling cost preva-

[9]I assume that when individuals are making their schooling investments, they forecast that their current electricity status will be held constant for the rest of their lives. Thus, unelectrified households cannot forecast when electricity will be available for them. This assumption is important in terms of understanding conceptually why older households face a disadvantage relative to younger households: they cannot coordinate their human capital decisions to take advantage of the new technological regime. In practice, however, imperfect forecasting would still yield an underinvestment in human capital for older households, because for them electrification would arrive later in life and would thus imply fewer periods to enjoy the higher returns from skill stemming from electrification.

[10]This positive correlation between electrification and schooling is of empirical interest. In particular, the fact that electrification increases schooling in the model suggests that the early electrification efforts of the 1910–1940 period in the United States might help explain the emergence of the high school movement during this time period and in particular the marked gains for women (Goldin and Katz (1999)). Moreover, my framework ties this increase in schooling to the subsequent gains in female LFP during the middle and latter parts of the 20th century.

lent in period $t-1$ (the pre-electrification regime).[11] This equation highlights two different forces shaping the increase in female labor force participation due to the electrification of production processes.

The first force stems from the increase in the proportion of women becoming skilled, $\bar{\rho^f}$. This increase will be given by $\Delta\bar{\rho}^f = \frac{2A_h}{\mu_s}\left(\frac{1}{w_{s,t-1}} - \frac{1}{w_{s,t}}\right)$. The term in parentheses captures the increase in the skilled wage after electrification, which will directly impact the rise in the schooling cost cutoff and thus the response of female LFP. The term $\frac{2A_h}{\mu_s}$ captures the attractiveness of skilled work relative to home production. Note in particular that low levels of endowed productivity in skilled production μ_s undermine the ability of electrification to stimulate female LFP, because the attractiveness of this sector will be diminished in comparison to home production. This therefore suggests the importance of the relative content of brawn and brain in skilled tasks in determining the aggregate effect of electrification on female LFP. In particular, higher relative female productivity in skilled labor, driven, for instance, by the use of brain rather than brawn capacity in skilled tasks, will enhance the scope of electrification to change the productive opportunities for women and in turn enhance its capacity to drive aggregate growth patterns (see Appendix B.2 for a more detailed discussion and description of this result). The second force shaping the increase in female labor force participation in the human capital channel follows from the distribution of schooling costs across women. In particular, if there is a large density of women with schooling costs between $\bar{\rho}^f_{t-1}$ and $\bar{\rho}^f_t$ per the distribution F, the scope of electrification to encourage female LFP will be larger. As a consequence, the response of female LFP to electrification is partially determined by the shape of the schooling distribution.

2.5 Link between Effect of Electrification on Young Skilled Women and Aggregate Effects

There is a direct connection between the effect of electrification on the LFP of young skilled women I estimate in the empirical section and the aggregate rise in female LFP. With some algebraic manipulations, the change in female LFP due to electrification summarized in Equation (2) can be written as

$$\begin{aligned}\Delta\text{Female LFP}_t =& \frac{1}{2}Prop.Skilled_{Coh_t,el}\left[DDD\right] \\ &+\frac{1}{2}\left[\Delta Prop.Skilled_{Coh_t} DD^{skill}_{Coh_t,unel} + DD_{Coh_t,unsk}\right],\end{aligned} \tag{3}$$

[11] The expression for the change in skilled wages due to electrification in $t+1$ after the economy reaches the new steady state is symmetric and given by Female $\text{LFP}_{t+1} = \frac{1}{2}\left[F(\bar{\rho}^f_t) - F(\bar{\rho}^f_{t-1})\right]$.

where the subscripts Coh_t, el/unel, and sk/unsk denote the cohort of women born in period t, whether they are electrified or not in period t, and whether they are skilled or unskilled, respectively. In addition, DDD denotes the triple difference estimated in the empirical section, capturing the effects of electrification on the LFP of young skilled women: $DDD = DD^{skill}_{Coh_t,el} - DD^{skill}_{Coh_t,unel}$, and

$$DD^{skill}_{Coh_t,el} = (LFP_{Coh_t,t,el,sk} - LFP_{Coh_t,t-1,el,sk}) - (LFP_{Coh_t,t,el,unsk} - LFP_{Coh_t,t-1,el,unsk})$$

$$DD^{skill}_{Coh_t,unel} = (LFP_{Coh_t,t,unel,sk} - LFP_{Coh_t,t-1,unel,sk}) - (LFP_{Coh_t,t,unel,unsk} - LFP_{Coh_t,t-1,unel,unsk})$$

$$DD_{Coh_t,unsk} = (LFP_{Coh_t,t,el,unsk} - LFP_{Coh_t,t-1,el,unsk}) - (LFP_{Coh_t,t,unel,unsk} - LFP_{Coh_t,t-1,unel,unsk})$$

(see Appendix B.3 for details on this derivation).

This equation showcases the direct connection between the effects of electrification on the LFP of young skilled women (DDD) in the model, which is calibrated to match that of the empirical section, and the aggregate effects in this framework. A larger DDD value will correspond to a larger rise in female LFP due to electrification. This stems from the fact that the DDD captures the change in incentives to engage in market work after electrification for skilled young women, who are precisely the drivers of female LFP in the model.[12]

However, the DDD has some limitations for determining the aggregate change in female LFP due to electrification. First, if the proportion of skilled women after electrification $Prop.Skilled_{Coh_t,el}$ is small, the scope of the DDD to alter the aggregate change in female LFP due to electrification will be smaller. This is because in this case the DDD effect applies to very few women, so its importance in the aggregate is diminished.

Second, if the second line in this equation is large, it will primarily drive the aggregate effect of female LFP in the model, dwarfing the role of the DDD. The first term in the second line corresponds to the product of the change in the proportion of skilled women after electrification and the skill-based difference-in-differences term DD^{skill} within unelectrified areas. If this is large, the rise in female LFP of skilled relative to unskilled women in

[12]In the empirical section, the specific measure of electrification considered is the county-level change in generating capacity between 1911 and 1919, in 100s of megawatts. As such, the empirical estimate of the DDD corresponds to the increase in the employment of young and skilled women in areas where the generating capacity increased by 100 megawatts in the 1910s relative to those in areas where the generating capacity did not increase. I choose the generating threshold of 100 megawatts to construct the DDD and calibrate the model based on technological and institutional facts of this era. The 100-megawatts generation threshold is equivalent to 3 to 4 large generating plants. Since my measures of electrification are built 50 miles around each county's boundaries, and the average county area is 1200 square miles, this capacity threshold guarantees that most households and businesses in the county are located within a 50-mile radius of one of these large plants, and thus have access to electricity.

unelectrified areas is a predominant force, indicating that the process of electrification is not a primary driver of female LFP changes. The second term corresponds to the difference-in-differences coefficient of the effect of electrification within unskilled women. If this is large, the rise in female LFP for unskilled electrified women relative to their non-electrified counterparts is a predominant force, indicating that skill acquisition is not a primary driver of female LFP changes. As a consequence, in both of these cases the role of the DDD, which captures the relative impact of electrification on skilled women, is second order.

3 A Model of Electrification and Human Capital: Quantitative Assessment

In order to quantify the importance of the human capital channel of electrification, I now embed these mechanisms in a quantitative framework. I calibrate the model to match the United States economy in the 1880–1940 period, simulate the effects stemming from the rollout of the electricity grid, and quantify the importance of this channel in explaining female LFP trends during this period.

3.1 Quantitative Model Setup

As before, the model economy is populated by a continuum of size 1 of men and women. Women and men live for J periods and are endowed with 1 unit of time each period, which they use for work, home production, and leisure. During the first period of their lives, men and women live at home with their parents, who in turn must choose their children's schooling investments. We assume that each couple has a daughter and son of the same age, and that this initial life period for children occurs when parents are of age $K < J$.[13] In particular, parents in family i can choose that each of their children become skilled at a cost of ρ_i units of time or remain unskilled.[14] These costs differ across families and are drawn randomly at the beginning of the daughter and son's lives life from a beta distribution,[15] $\rho_i \sim Beta(\alpha_H, \rho_H)$. After this initial period, women and men get married and live as a couple for their remaining lifetimes. Furthermore —and similar to the benchmark model— I allow women and men to differ in the relative productivity with which they perform each task, in order to capture, for instance, the relative importance of brawn across these. For expositional purposes, in what

[13] Here I abstract of the fertility decision for households. In Vidart (2022), I explicitly examine the effects of electrification on fertility.

[14] This assumption implies that the daughter and son of each family have the same cost of schooling. This is consistent with the similarity between siblings arising from shared nature and nurture.

[15] I choose a beta distribution in order to have values bounded by 0 and 1 and thus consistent with a time cost interpretation.

follows I ignore the household index i in most expressions.

3.1.1 Tastes

We assume that couples only have control over their utility and choices after they leave their childhood home and get married (after the first period of their lives). Couples care about their children's utility in the periods after making their schooling decisions. Thus, the period utility function of a couple of age j is given by

$$U_j = \begin{cases} \log c_j + \sigma_l \left(0.5 \log l_j^m + 0.5 \log l_j^f\right) & \text{if } 1 < j \leq K \\ \log c_j + \sigma_l \left(0.5 \log l_j^m + 0.5 \log l_j^f\right) + U_j^s + U_j^d & \text{if } j > K, \end{cases}$$

where c denotes consumption and l^f and l^m denote female and male leisure, respectively. σ_l denotes the value of leisure relative to consumption and $\sigma_l > 0$. U^s and U^d denote the utility of the couple formed by the son and daughter, respectively, after leaving the family home during the period when their parents are of age j. I assume that at the beginning of period K, the daughter and son of each family get betrothed to their respective partners, who in turn are the son and daughter from a different family. The two families then jointly maximize the sum of their utilities.[16]

Consumption is a CES composite of home and market consumption,

$$c = \left(\nu {c_y}^{\frac{\theta-1}{\theta}} + (1-\nu) {c_h}^{\frac{\theta-1}{\theta}}\right)^{\frac{\theta}{\theta-1}},$$

where c_y denotes market consumption and c_h home production. ν denotes the share of market goods in total consumption, while θ denotes the elasticity of substitution between market and home goods.

3.1.2 Time constraints

The time endowment of women and men is allocated to work, leisure, home production, and schooling. For simplicity, I assume that during the first period of their lives and while living with their parents, women only spend time in schooling or home production, while men only

[16] I assume that these matches occur across women and men with the same familial background. This implies that parental educational levels, children's schooling costs, and location (which determines electrification status) are symmetric across betrothed families and matches the literature showing significant homogamy patterns across parents of husbands and wives, particularly in the late 19th and early 20th centuries (Charles et al. (2013) and Craig et al. (2021)).

spend time in schooling or work.[17] I also assume that men and women only have τ^m and τ^f units of time during the first period of their lives to allocate to each of their corresponding activities, respectively. With this, and given that I assume that younger individuals spend no time in leisure, I can match the fact that young women and men spend less time in home production and work, respectively, relative to older individuals.

The time constraints of women and men are therefore given by

$$h^f_{t,j} = \begin{cases} \tau^f(1 - s^f\rho) & \text{if } j = 1 \\ 1 - n^f_{t,j} - l^f_{t,j} & \text{if } j > 1 \end{cases} \qquad n^m_{t,j} = \begin{cases} \tau^m(1 - s^m\rho) & \text{if } j = 1 \\ 1 - h^m_{t,j} - l^m_{t,j} & \text{if } j > 1, \end{cases}$$

respectively, where $n^f_{t,j}$ and $n^m_{t,j}$ denote the labor supply of women and men, respectively, at time t, while $h^f_{t,j}$ and $h^m_{t,j}$ denote the time dedicated to home production by women and men. The terms s^m and s^f denote endogenous indicators that capture the binary schooling decisions for men and women:[18]

$$s^f = \begin{cases} 1 & \text{if woman becomes skilled at } j = 1 \\ 0 & \text{otherwise} \end{cases} \qquad s^m = \begin{cases} 1 & \text{if man becomes skilled at } j = 1 \\ 0 & \text{otherwise.} \end{cases}$$

3.1.3 Income and Consumption

Men and women are endowed with differing levels of productivity for each skill level, summarized by

	Unskilled Market	Skilled Market	Home
Men	1	1	1
Women	μ_u	μ_s	1

with $0 < \mu_u < \mu_s < 1$ reflecting the disadvantage women face in brawn activities and the gender wage gaps in both unskilled and skilled labor.[19]

[17] This is equivalent to assuming parents only care about schooling and home production for their young daughters and schooling and work for their sons. This matches up with the historical evidence of this period, which suggests that young males spent almost no time in home production (less than 4 hours a week), while young women spent almost no time at work (3–12 hours a week) (Ramey and Francis (2009)).

[18] Notice that unlike the benchmark model, in this setup there are no unique cutoffs in the cost of schooling for men and women determining their choices. This arises from the interaction between siblings in the family. Given that daughter and son from the same family share a common cost of schooling, shifts in the cost of schooling trigger both direct and indirect changes in the education cost of each child, where the latter stem from the change in the sibling's position. The interaction between these direct and indirect changes may lead to multiple cutoffs in the cost of schooling for both sons and daughters.

[19] Note that in what follows, I denote the labor supply and home production of men and women when $j = 1$ differently, in order to distinguish it from those of their parents. Specifically, superscripts f and d denote women at ages $j > 1$ (main female in household) and $j = 1$ (daughter), respectively, and the superscripts m and s denote men at ages $j > 1$ (main male in household) and $j = 1$ (son), respectively.

The household budget constraint is therefore given by

$$c_{t,j}^{y}+p_{t}^{E}E_{j}=\begin{cases}w_{t}^{m}n_{t,j}^{m}+\mu_{sf}w_{t}^{f}n_{t,j}^{f} \text{ if } j>1 \text{ and } j\neq K\\ w_{t}^{m}n_{t,j}^{m}+\mu_{sf}w_{t}^{f}n_{t,j}^{f}+w_{t}^{s}n_{t,j}^{s} \text{ if } j=K,\end{cases}$$

where w_t^m, w_t^f, and w_t^s capture the efficiency unit wages faced by men, women, and sons, respectively. For women and men, these wages depend on their schooling choices. Since young men (sons) are still potentially in the process of acquiring skills, we assume they work in the unskilled sector and thus face the unskilled wage. $n_{t,j}^s$ captures the labor supply of the couple's son. $E_{t,j}$ denotes the purchases of electricity of the household at price p_t^E

The production of home goods c_h, on the other hand, is limited by the total home production men, women, and daughters can accomplish when they dedicate h^m, h^f, and h^d units of time to home production, respectively, and purchase electricity level E. Thus, the level of home goods is given by

$$c_{ht,j}=\begin{cases}[\omega E_{t,j}^{\frac{\phi-1}{\phi}}+(1-\omega)\left(h_{t,j}^{f}+h_{t,j}^{m}\right)^{\frac{\phi-1}{\phi}}]^{\frac{\phi}{\phi-1}} \quad \text{if } j>1 \text{ and } j\neq K\\ [\omega E_{t,j}^{\frac{\phi-1}{\phi}}+(1-\omega)\left(h_{t,j}^{f}+h_{t,j}^{m}+h_{t,j}^{d}\right)^{\frac{\phi-1}{\phi}}]^{\frac{\phi}{\phi-1}} \text{ if } j=K.\end{cases}$$

I choose this specific CES function for home production, which considers a role for electricity in home production, for three main reasons. First, I want to allow for the mechanisms driving the home production savings channel in order to compare its predictions to the human capital channel.[20] Second, I want to allow for the possibility that this channel, and in particular the higher wages triggered by electrification, enable some households to acquire more electricity even if prices remain constant.

Third, by assuming that daughters' home production time enters into this function, I allow for an alternative mechanism through which household electrification could encourage female LFP: indirect investments in daughters by mothers. As suggested by Lewis (2014), household technological change led mothers to take over some of the domestic duties that had been the responsibility of teenage daughters, in turn enabling the latter to focus more on their studies. Therefore, this mechanism also introduces a complementarity between the home production and human capital channels, where young women are more able to coordinate their human

[20]This specification resembles that presented by Greenwood et al. (2005), but differs from it by abstracting from the durable appliance adoption decision. This simplification is not important for the main results in my model, since home production time savings will be generated by reductions in the price of electricity analogous to reductions in the price of durables. Moreover, this setup matches the fact that appliance adoption followed closely after electrification in the United States and was in many cases facilitated by utility companies looking to induce households to use more electricity (Nye (1992)).

capital decisions and invest in skills that are now more in demand in the labor market, because their mothers are relieving them from household duties they would otherwise have.

3.1.4 Production of Consumption Goods

Consumption goods are produced competitively using two production technologies. The first production technology captures a traditional (unskilled) mode of production that uses unskilled labor only:

$$Y_u = A_u L_u,$$

where L_u denotes effective unskilled labor and A_u the TFP term for unskilled production. The second production technology captures a modern (skilled) mode of production, and follows a CES production technology that combines skilled labor and electricity:

$$Y_s = A_s \left[\zeta E_s^{\frac{\gamma-1}{\gamma}} + (1-\zeta)\, L_s^{\frac{\gamma-1}{\gamma}} \right]^{\frac{\gamma}{\gamma-1}} \quad \text{with } \gamma < 1,$$

where L_s denotes effective skilled labor and E_s the level of electricity used, while A_s denotes a TFP term. γ is the elasticity of substitution between electrical goods and skilled labor. Since electricity complements skilled labor, $\gamma < 1$. The goods produced by traditional and modern (or unskilled and skilled) production technologies are combined in a CES production function, so that the total production of consumption goods is given by

$$Y = \left[\lambda Y_u^{\frac{\eta-1}{\eta}} + (1-\lambda) Y_s^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \quad \text{with } \eta > 1.$$

3.1.5 Production of Electricity

Electricity is produced competitively using a technology with a binary and exogenous productivity level. Prior to gaining access to the power grid (electrification), electricity is produced with an old and inefficient technology (small generators). With electrification, electricity production is produced at central generating stations with higher efficiency. I assume that the decision of the type of technology available to produce electricity is determined exogenously. The production of electricity therefore follows:

$$E = \begin{cases} A_{E,L} X & \text{prior to electrification} \\ A_{E,H} X & \text{after electrification,} \end{cases}$$

where X denotes inputs in terms of the consumption good and $A_{E,L} < A_{E,H}$. In Appendix C, I present the aggregation and equilibrium results of this model.

3.1.6 Effects of Electrification: The Human Capital Channel

Electrification increases the productivity of electricity production, reducing the price of electricity. This price reduction affects both households and firms. The reduction in household-level electricity prices corresponds to the channel highlighted by Greenwood et al. (2005) (home production channel), and leads to time savings in home production. The reduction in firm-level electricity prices corresponds to the human capital channel, and leads to increases in skilled wages.

In the human capital channel, by raising the productivity and wage of skilled market tasks, electrification encourages female LFP. This effect is shaped by the endowed productivities of women in skilled and unskilled labor and the shape of the schooling cost distribution. Note that because new market opportunities concentrate among skilled labor, the productive return from electrification is perceived only by women who are skilled. This translates into higher schooling incentives for young generations and muted labor force participation effects for older generations, who were old upon electrification and had already made their schooling decisions.[21]

Also note that since daughters can contribute to home production when young, the reduction in the burden of domestic tasks triggered by electrification may allow mothers to take over some of the household duties of daughters, allowing the latter to decrease their home production hours and engage in schooling instead. This feature has two effects. First, it opens an additional channel through which the home production channel could encourage female LFP. Second, it creates the potential for a key complementarity between the human capital channel and the home production channel, because maternal investments and the increase in the return to skills in the labor market jointly encourage female skill acquisition and ultimately female LFP.

3.2 Calibration

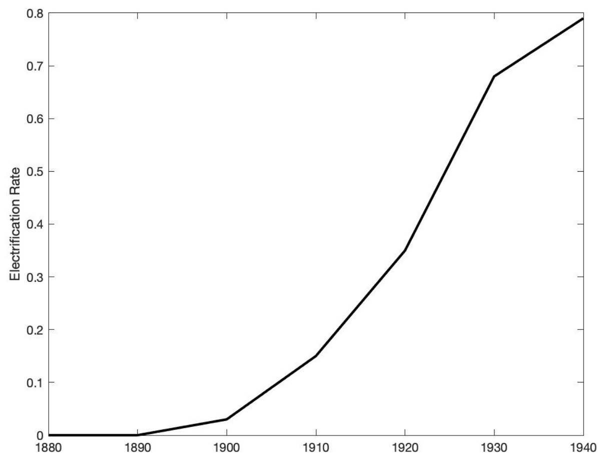
I calibrate the above framework to the United States in the 1880–1940 period, which comprises the era when the majority of areas in the United States became electrified.[22] I simulate

[21] Similar to the benchmark model, I assume that when parents are making their children's schooling investments, they forecast that their current electricity status will be held constant for the rest of their and their children's lives. Note that imperfect forecasting would still yield an underinvestment in human capital and thus similar results.

[22] Although the process of electrification expanded into rural and isolated areas after 1940 and until 1960 as shown in Appendix A, I focus on the period preceding 1940 for two main reasons. First, my empirical

the effects that stem from the rollout of electricity during this period (as shown in Figure 3.1) and, particularly in the human capital channel, from the progressive electrification of production processes. Calibrated values appear in Table 3.1. There are three sources for parameter values: the literature, closed-form expressions matching data moments, and the method of moments.

Figure 3.1: Rollout of Electricity Grid



Source: Lebergott (1976).

I choose some of the parameters of the market, composite consumption, and home production functions from the literature. In particular, I choose the elasticity of substitution between electricity and labor γ following the work of Hassler et al. (2012), who found that the short-term elasticity of substitution between energy and a labor-capital composite that matches postwar aggregate United States data was close to zero (around 0.02), but can be approximated by unity in the long term. Since each period in my model is 5 years long, I take an intermediate value of 0.2. Furthermore, I choose both the share and elasticity parameters entering the CES production function that combines skilled and unskilled production from Goldin and Katz (2008). I take the elasticity of substitution between home and market consumption in total consumption, θ, to match the estimates found for married couples by Rupert et al. (1995) using the Panel Study of Income Dynamics (PSID). Finally, the share of electricity in home production, ω, is taken from Greenwood et al. (2005).

analysis, which generates estimates on the effects of electrification used to calibrate the model, focuses on the 1900–1940 period. Second, after 1940 the US economy and particularly female labor faced dramatic changes due to the advent of World War II, the post-war economic boom, and the baby boom.

Table 3.1: Model Parameters

Parameter	Value	Source
Literature		
Substit. in skilled prod. γ	0.2	Hassler et al. (2012)
Share of Y_u in total prod. λ	0.5	Goldin and Katz (2008)
Substit. in total prod. η	1.64	Goldin and Katz (2008)
Substit. in cons. composite θ	1.57	Rupert et al. (1995)
Share of E in home prod. ω	0.3	Greenwood et al. (2005)
Discount factor β	0.82	4% annualized return
Pinned Down from Model Expressions		
Share of E in skilled prod. ζ	0.017	Share of energy in manufacturing in 1900
Female productivity in unskilled labor μ_u	0.46	Ratio of unskilled female and male LIDO occ. scores in 1900
Female productivity in skilled labor μ_s	0.57	Ratio of skilled female and male LIDO occ. scores in 1900
Skilled TFP A_s	1.17	Ratio of skilled and unskilled male LIDO occ. scores in 1900
Electricity prod. after electrification $A_{E,H}$	1.85	Price from small generators vs. grid
Time availability of young women τ^f	0.4	Ratio of home prod. hrs. for 14–17 to 55–64 unsk women in 1900
Time availability of young men τ^m	0.8	Ratio of work hrs. for 14–17 to 55–64 unsk men in 1900
Method of Moments		
Substit. in home prod. ϕ	1.74	Female work hours in 1900
Electricity prod. before electrification $A_{E,L}$	0.37	Female LFP in 1900
Relative value of leisure σ_l	0.43	Female home prod. hours in 1900
Share of market cons. in cons. composite ν	0.75	Prop. of skilled women in 1900
2nd shape parameter of sch. cost distribution ρ_H	0.98	*DDD* coefficient
Normalized		
First shape parameter of sch. cost distribution α_H	1	Normalized
Unskilled TFP A_u	1	Normalized
Length of life J	10	Each period 5 years; 50 years total life (15–65)
Age of parents when children are age 1 K	7	Age when children are 15–20 = 45–50

I choose the values of the share of electricity in skilled production, endowed efficiency, unskilled and skilled productivity, and post-electrification electricity productivity to match select data moments, given closed-form share, wage, and price expressions. I choose the share of electricity in skilled production, ζ, to match the share of energy expenditures in manufacturing in 1900 documented by Haines and ICPSR (2010).[23] I calibrate women's endowed efficiency in skilled and unskilled labor to match the ratio of average unskilled and skilled male and female occupational scores in 1900.[24] To compute these ratios, I use the occupation information available in the 1900 census, in conjunction with the Lasso-adjusted industry, demographic, and occupation (LIDO) occupational score approach proposed by Saavedra and Twinam (2020), which adjusts occupation scores by race, sex, age, industry, and geography,

[23] Although the skilled sector does not map directly onto manufacturing, I use information from this sector to calibrate the share of electricity in skilled production, ζ, because manufacturing is one of the most energy-intensive sectors in the economy and there is little information about the share of energy in skilled labor or GDP historically.

[24] Since educational attainment variables are not available in the 1900 census, I consider unskilled labor to correspond to the following occupations: farmers, operatives, service workers (in and outside private households), farm laborers, and laborers. Skilled labor, on the other hand, corresponds to the following occupations: professional and technical, managers, officials and proprietors, clerical and kindred, sales workers, and craftsmen.

and reduces the attenuation bias in gender earnings gaps. I calibrate the TFP of skilled labor A_s to match the ratio of skilled and unskilled male LIDO occupational scores in 1900 from the census.[25] Finally, I choose the efficiency of electricity production after electrification, $A_{E,H}$, to match the relative price charged for electricity produced by a small generator rather than a large-scale plant, as documented by Institute for Energy Research (2019).[26] In addition, I choose the time availability of young women and men to match the ratio of home production between young and old unskilled women, and the ratio of work hours between young and old unskilled men, respectively.[27]

I choose the rest of parameters using the method of moments in order to minimize the distance between model and data moments.[28] In particular, I choose the elasticity of substitution in home production, ϕ, the efficiency of electricity production prior to electrification, $A_{E,L}$, the relative weight of leisure in utility, σ_l, the share of market consumption in the consumption composite, ν, and the second shape parameter of the schooling distribution[29], ρ_H, to minimize the distance between the moments generated by the model and the following moments in the data: female LFP in 1890, work hours and home hours in 1900, the proportion of women with completed high school in 1900, and the DDD coefficient capturing the rise in female LFP due to electrification for highly educated young women in 1920 (with post-secondary education) estimated in my data.[30] Details on these moments can be found in Appendix D.6.

3.3 Effects of the Rollout of Electricity: The Human Capital Channel

I now present the effects of the rollout of electricity from 1880 to 1940 on female LFP and other variables predicted by the human capital channel and stemming from the increase in market opportunities for women. This follows from assuming a rollout of electrification in the market production sector, through which a progressively larger portion of households

[25] I thank an anonymous referee for the suggestion of using the data in Haines and ICPSR (2010) to calibrate the share of energy in skilled production and the LIDO occupational scores to calibrate wage-related parameters.

[26] This calibration follows from comparing the average price of electricity in 1902, when privately run small generators were the primary source of energy, to that in 1930, when central stations provided most of the power (Casazza (2004), Hunter and Lynwood (1991)).

[27] See Appendix D for details on the calibration of these parameters.

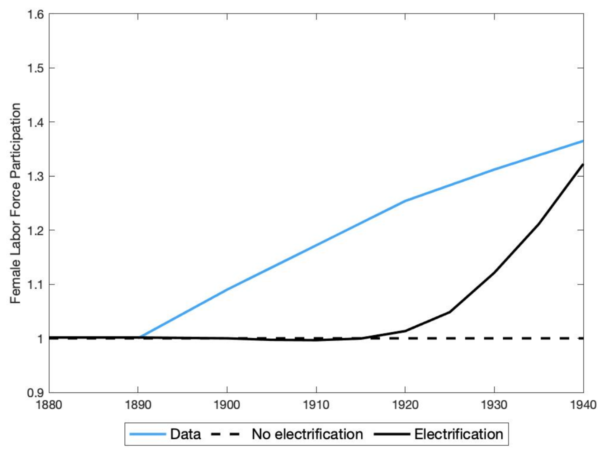
[28] See Table D.1 for a comparison of the data and model moments targeted in the method of moments.

[29] In order to solve the model, I discretize the schooling time cost distribution into 10 bins, each containing 10% of families according to the schooling cost distribution.

[30] In the empirical section, the specific measure of electrification considered is the county-level change in generating capacity between 1911 and 1919, in 100s of megawatts. As such, the empirical estimate of the DDD corresponds to the increase in the employment of young and skilled women in areas where the generating capacity increased by 100 megawatts in the 1910s relative to the employment of those in areas where the generating capacity did not increase. See Section 4 for further details on my empirical analysis.

has access to higher electrification-driven wages.[31] I then present evidence comparing the effects of electrification across cohorts, in order to capture differences that arise from young women's ability to coordinate their human capital decisions to take advantage of the returns brought about by electrification. In Section 3.4, I examine the role of different parameters in shaping the aggregate rise in female LFP stemming from the human capital channel. In Section 3.5, I allow for home production savings and examine how the effects of the human capital channel change.

Figure 3.2: Female LFP: Model and Data



Data Source: Goldin (1990) Normalized 1890=1.[32]

In Figure 3.2 I contrast the effects of electrification on female LFP predicted by the human capital channel in the model and the data. The results for men are summarized in Figure E.3.[33] I find that the human capital channel explains 25.21% of the rise in female LFP in the 1900–1940 period. This increase is generated by the relative enhancement of market opportunities stemming from electrification, and particularly the fact that electricity complements skilled tasks that favor female labor. Complementary human capital investments are needed to take full advantage of these returns. This importance of human capital causes the effects of electrification to be more marked among new generations, who make their human capital decisions based on the new technological regime. This causes the effects of electrification to accrue through generational change and thus slows down the rise

[31]Specifically, in the context of my model, I assume home and market production are served by two distinct sets of electricity technologies, each of which can use either the efficient or inefficient technology.

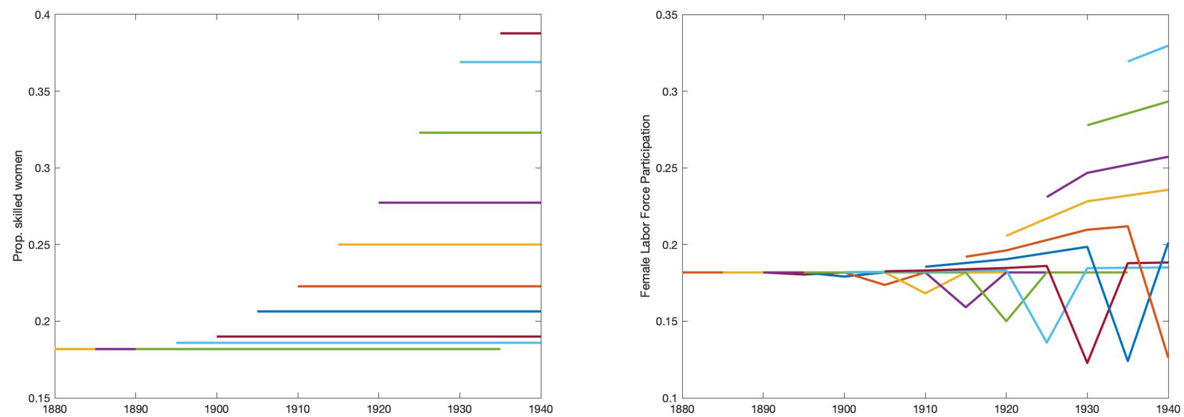
[32]Values of female LFP in 1910, which are omitted in Table 2.1 of Goldin (1990) due to an overcount of agricultural labor force in that year, are imputed here as the average between the values in 1900 and 1920. The values in intercensal years are also imputed using the average in neighboring years. This applies to all figures where female LFP data is presented.

[33]The model predicts a slight increase in men's work hours during the period considered, while male labor force participation remains universal. The increase in men's work hours is driven by the increase in skilled wages, and the proportion of skilled men.

in female LFP predicted by the human capital channel.[34] In what follows, I further explore the importance of human capital acquisition by examining the effects of electrification across women of different cohorts.

Figure 3.3: Proportion of Skilled Women and Female LFP by Cohort

(a) Proportion of Skilled Women (b) Female LFP



Notes: Ages 2 to J plotted for every cohort.

In Figure 3.3, I plot the paths of schooling and female LFP across different cohorts through time. Panel (a) suggests that cohorts accumulate progressively more schooling as the electricity grid is rolled out, and furthermore, that within each period there is a wedge between the skill of young and old women. Panel (b), on the other hand, shows that the labor force participation of each cohort increases over time. This is driven by both the buildup in electrification that occurred during this era and by the process of human capital accumulation depicted in Panel (a).[35] In particular, women born after gaining access to electricity can coordinate their schooling decisions to maximize the productive returns of electrification and thus exhibit higher level of participation in the labor market. This is particularly evidenced in the fact that within each period, when all cohorts exhibit the same electrification rates, younger cohorts exhibit higher levels of LFP, driven by the fact that new cohorts have acquired schooling that complements the new work environment. In addition, this plot indicates that the LFP of each cohort of women declines at age K when daughters and sons are engaging in school. This decline follows from the increased financial support provided by sons, but also from the fact that mothers relieve daughters from their domestic duties in order to enable the latter to attend school.[36]

[34] For the effects on all female variables, see Figure E.1.

[35] For the effects on all female variables by cohort, please see Figure E.2.

[36] In particular, Figure E.2 indicates that the time spent in home production declines at age K due to the home production help women receive from daughters in this period. However, the time spent in home production at age K does not decline among newer cohorts unlike at all other ages, indicating mothers

3.4 Discussion of Key Parameters and Sensitivity Results

I now examine the role of different parameters in shaping the aggregate rise in female LFP stemming from the human capital channel. Motivated by the discussion of Section 2.4, and specifically the forces shaping the aggregate rise in female LFP due to the progressive electrification of production processes highlighted in the benchmark model, I focus on the following parameters: (1) the productivity of electricity production after electrification $A_{E,H}$, (2) the elasticity of substitution between electricity and labor in skilled production γ, (3) female productivity in skilled labor μ_s, and (4) the second shape parameter of the schooling cost distribution ρ_H. The results from this exercise are discussed in detail in Appendix F and summarized below.

I find that larger values of the productivity of electricity production after electrification $A_{E,H}$, higher complementarity between electricity and labor in skilled production captured by lower values of γ, and larger values of female productivity in skilled labor μ_s increase both the rise of female LFP and the decline in female home production hours in the human capital channel. This stems from the fact that these parameters jointly determine the increase in skilled wages perceived by women after electrification. $A_{E,H}$ determines the size of the decline in the price of electricity that occurs after electrification and thus the increase in the demand for electricity in skilled firms. γ, in turn, dictates by how much the demand for skilled labor, and consequently skilled wages, increase after this rise in the demand for electricity. Finally, μ_s shapes how much of this increase in skilled wages is reflected in women's compensation.

In addition, I find that larger values of the second shape parameter of the schooling cost distribution ρ_H generally also increase both the rise of female LFP and the decline in female home production hours in the human capital channel. ρ_H dictates the density of the schooling cost distribution and thus governs the response of female employment to the rise in the skilled wage by determining the number of women whose schooling cost is low enough that they will be encouraged to gain skills and join the workforce in response to electrification. Larger values of ρ_H imply a larger mass accumulates at lower values of the schooling distribution, which in turn raises the response of female labor to electrification. In particular, the fraction of this rise the human capital channel can explain increases to about 32% when ρ_H is 150% of its baseline value. This suggests that my quantitative results are quite sensitive to the value of ρ_H and motivates the use of the well-identified empirical estimates of Section 4 to calibrate this parameter and quantify the importance of electrification in the model.[37]

refrain from further reducing their time spent in home production at age K in order to help daughters with their domestic duties as electrification occurs and the returns to education increase.

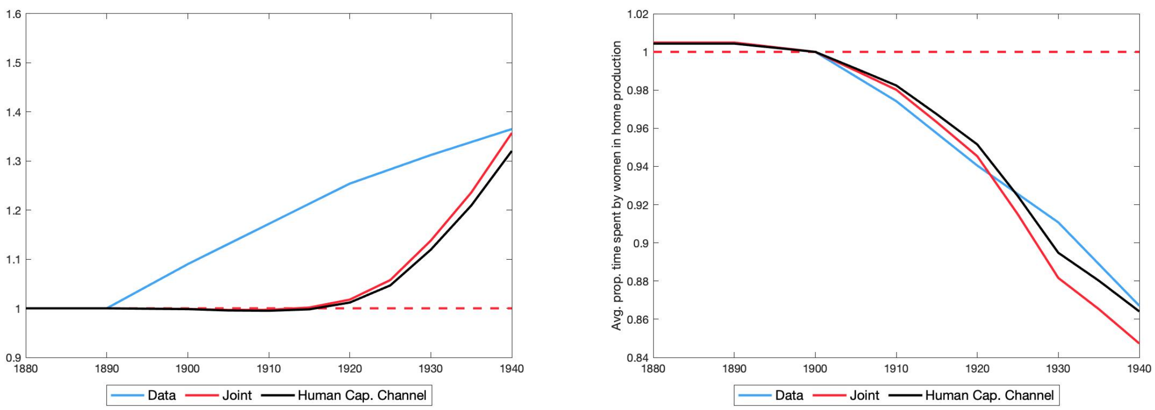
[37] In Section 2.5, I provided a discussion of how the DDD shapes the aggregate response of female LFP to electrification, which motivates its use as the calibration target. Note that although the same intuition

3.5 The Joint Effect of the Human Capital and Home Production Channels

I now examine how the effects of the human capital channel change when I allow for home production savings. To do this, I consider the case when both market and home production are electrified. The calibration for this exercise targets the same moments as before and follows the same structure.[38] In Appendix H, I examine the case when electrification occurs only within the household (home production channel only).[39]

Figure 3.4: Female LFP and Home Production Hours, Joint Channels

(a) Female LFP (b) Female Home Production Hours



Data Source: Goldin (1990) and Ramey and Francis (2009). Normalized 1890=1 and 1900=1.

I present the effects of electrification on female LFP that follow from the human capital channel and the joint model featuring both channels in Panel (a) of Figure 3.4 and contrast them to the data. I find that the joint model explains 29.22% of the rise in female LFP in 1900–1940, which is 3.9 percentage points higher than the human capital channel alone and thus implies that the human capital and home production channels are complementary. This complementarity stems partly from an increase in the indirect investments in daughters by mothers due to the availability of electricity in the household. As a consequence of home

linking the DDD to the rise in female LFP due to electrification is present in the quantitative model, other forces such as familial background, and the economic prospects of husbands, sons and daughters also play a role here.

[38]Since all the moments targeted are set in 1900 or 1890, when only 3% of households were electrified, the parameter values used for this exercise are the same as the ones used before. The only parameter not set in 1900 is the DDD coefficient, which nevertheless is well approximated in the joint model (see Table G.1 for details on the fit of this channel to the data.).

[39]Note that the exercise of Appendix H is not directly comparable to that of Greenwood et al. (2005), due to the introduction of human capital accumulation and investments in daughters by mothers in my model, which change the incomes and intra-household allocation of men and women. These two mechanisms imply that women's decisions of home production do not follow from household technology alone, but also change in response to daughters' current and future prospects.

electrification, young women are more able to invest in skills that are now more in demand in the labor market due to the electrification of production processes, because their mothers relieved them from household duties they would otherwise have. This matches the intuition in Lewis (2014), who shows that household electrification in 1930–1960 was associated with increased school attendance, particularly among teenage daughters.

I also find that the human capital channel and the joint model predict declines in home production hours that are very close to the data, as evidenced in Panel (b) of Figure 3.4. The decline in the joint model is slightly faster, however, due to the introduction of the home production channel, which triggers a further decline in home production hours after electrification due to the substitutability between hours and electric goods in home production.[40,41] My human capital channel can match the slow decline in home production hours evidenced in the data while explaining a large fraction of the rise in female LFP for two main reasons. First, the human capital channel does not trigger gains in home productivity and thus decouples the rise in female labor supply from a decline in home production hours. Second, because complementary human capital investments are needed to take full advantage of the productive returns from electrification, the effect generated by the human capital channel and the transition from home to market become more marked as new generations who make their human capital decisions under the new technological regime replace the old ones.

4 Evidence from the Early Electrification of the US

I now present evidence supporting the theoretical predictions of my model and underlying the estimates on the effects of electrification used to calibrate the model. I use data from the first half of the 20th century in the United States and focus, in particular, on the effects of electrification efforts put forward during the 1910s on the outcomes of individuals in the period from 1920 to 1940. I employ a triple difference (DDD) approach, focusing on the heterogeneity of the effects of electrification by educational level and cohort, given my model's predictions that (1) a high level of education was critical to taking advantage of the new market opportunities electrification opened for women and (2) the age at the arrival of electricity was key, due to the existence of "formative years" when human capital capital investments are made. Since readily available electrification data does not exist for this period, I build a dataset with the universe of utilities and central generating stations in 1911

[40] A full description of the effects predicted by the joint model on all variables can be found in Figure G.1.

[41] Appendix H shows that although the overall decline in home production hours in the home production channel is small due to the introduction of human capital accumulation and investments in daughters by mothers in my model, this decline is actually quite large relative to the size of the increase in female LFP predicted in that case.

and 1919 by digitizing historical sources to construct county-level measures of electrification. I then combine this electrification data with an individual-level panel dataset built from the full-count 1910–1940 decennial census waves, using the record-linking algorithm proposed by Abramitzky et al. (2012, 2014). In addition, since education decisions are affected by electrification and are thus endogenous in my setting, I use a proxy for years of schooling that follows the data and approach of Clay et al. (2021) and thus exploits changes in required years of schooling arising from geographic and temporal variation in compulsory attendance, continuation school, and child labor laws.[42]

By focusing on the 1910s, I am able to study the effects of electrification in "Middle America," smaller urban areas that were electrified after the large cities, but still early in the expansion of the electric grid (Rieder (1989), Nye (1992)). This contrasts with previous studies, which primarily focus on rural electrification and thus rely on much later data sources to study the effects of electrification (Kitchens and Fishback (2015), Kitchens (2014), Gaggl et al. (2016) and Lewis and Severnini (2017)). Please see Appendix I for further details on the rapid expansion of electricity generation in the 1910s in "Middle America", and the changes to women's economic situations fueled by this.

4.1 Electricity Data

I build an electrification dataset from power plant generation and location data found in the 1911 and 1919 editions of "Central station directory: a complete list of electric light and power companies with data" published by McGraw. Each edition contains a list of all the electric power plants owned by electric and power companies in the United States and is organized as a list of all the cities where power utilities operate. Each city entry contains information on all the utilities operating in the city area and includes their generation capacity and other information. Using the location and generation-capacity information, I am able to construct measures of the electrical capacity within and around each county in the United States.[43] My preferred treatment definition follows from this, and is given by the change in the total electrical capacity within and 50 miles around each county's boundaries between 1911 and 1919, in 100s of megawatts.[44] For details on the McGraw publications and construction of

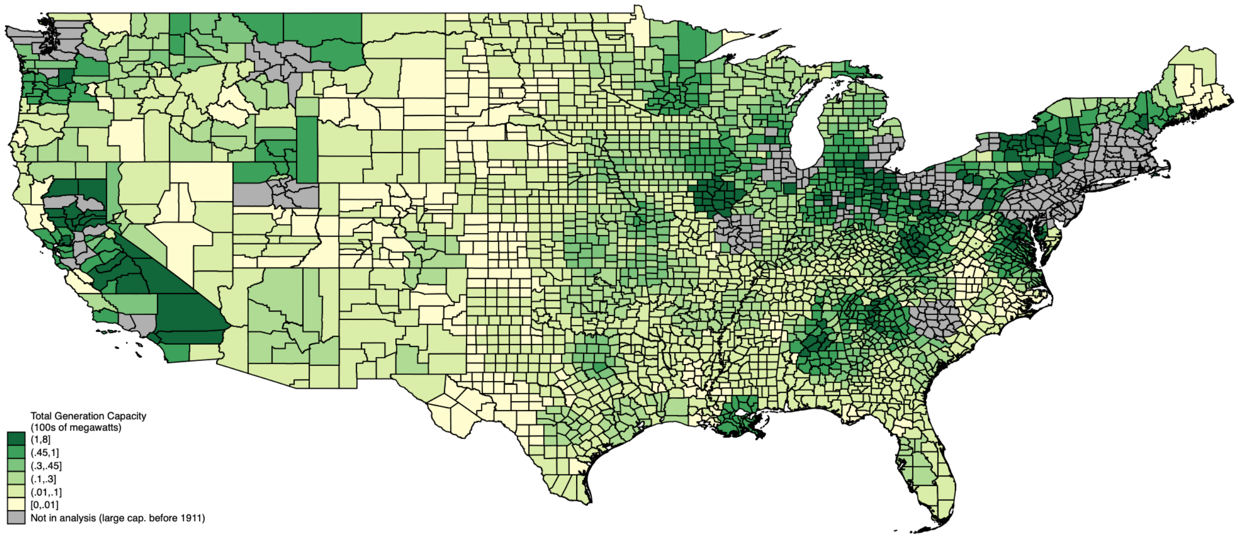
[42] I thank an anonymous referee for this suggestion.

[43] County boundaries have changed throughout time in the United States. In order to maintain consistent county-boundary definitions, I use the county definitions from 1910 and link these back to other years using the crosswalk built by Eckert et al. (2020).

[44] Historical constraints in transmission technology made it unfeasible to consume power far from the generation site prior to the expansion of high-voltage AC transmission lines beginning in the late 1920s (Casazza (2004)). Thus, my treatment definition of the change in the total electrical capacity within and 50 miles around each county's boundaries between 1911 and 1919 approximates the change in the extent of electrification in each county during the 1910s.

the electrification measures please see Appendix J.1.

Figure 4.1: Map of County-Level Intensity of Electrification Treatment in the United States



Notes: Electricity-generation capacity within and 50 miles around each county.

In Figure 4.1, I present county-level maps of my preferred electrification measure: the change in the total capacity within and 50 miles around county boundaries between 1911 and 1919. In this treatment definition, I exclude counties that were already widely electrified before 1911 (above the 90th percentile of generation capacity), in order to focus on areas that gained access to electricity during the 1910s.[45] A visualization of this measure for Alaska and Hawaii is available in Figure J.3.

4.2 Construction of Panel Data

I combine the electrification data with an individual-level panel dataset built from the full-count 1910–1940 decennial census waves using the record-linking algorithm proposed by Abramitzky et al. (2012, 2014). I rely on name, birth year, and state or country of birth matches to link records across waves. For details on the construction of this panel data, please see Appendix J.2.

In my analysis, I focus on individuals who during 1910 lived in areas that gained access to electricity during the 1910s, as defined by my treatment variable above. The total number of individuals in the matched panel sample in this category equal 670,352 men and 507,292

[45] The excluded areas correspond to large cities such as New York, Washington, DC, Los Angeles, Chicago, Seattle, and Detroit, and areas with substantial generating resources, such as some areas in Montana (hydroelectric resources) and West Virginia (coal resources). My treatment, nevertheless, encompasses most of the United States (in terms of both population and land mass) and has substantial regional variation.

women. In Table 4.1, I report average values for select variables of interest in this panel sample, along with the full repeated cross-section data (encompassing all individuals in each census wave), for individuals born in the contiguous United States in my cohorts and treatment areas of interest. I find that both specifications are fairly similar along all dimensions considered, except for the proportion of married women, and related female outcomes like fertility and school attendance. This follows from the fact that due to maiden-to-married name changes, women who were married in the the first census wave (1910) are overrepresented in my data.[46] Appendix J.2.1 presents summary tables for 1920–1940, characterized by broadly the same patterns.

Table 4.1: Summary Statistics in Panel and Full Repeated Cross-Section Data in 1910

	Panel		Repeated Cross-Section	
	Men	Women	Men	Women
Prop. employed	0.87	0.15	0.77	0.22
Prop. attending school	0.18	0.09	0.16	0.16
Avg. Years of Required Schooling	3.97	3.42	2.95	3.06
Prop. with 8+ Years of Req. Sch.	0.12	0.08	0.07	0.07
Avg. children born per woman		2.01		1.75
Prop. married	0.37	0.74	0.38	0.53
Prop. urban	0.30	0.33	0.31	0.35
Avg. socioeconomic index	19.24	4.68	15.77	6.04
Prop. white	0.94	0.94	0.84	0.85
Total obs.	670,352	507,292	10,113,632	9,462,431

Notes: The sample for this table consists of individuals who were 15–35 years of age in 1910, were born in the contiguous US, and who lived in areas that gained access to electrification in the 1910s in 1910.

4.3 Strategy and Identification

My main analysis follows a triple difference (or DDD) strategy with continuous treatment intensity and examines the heterogeneity in the effects of electrification on employment across educational levels and cohorts. With this analysis, I study whether living in counties with a large extent of electrification in the 1910s differentially changes the employment rates[47] of women and men of different cohorts and education levels in 1920, 1930, and 1940 relative to those in 1910 and to their counterparts living in areas with a small extent of electrification.[48]

[46] Given these name changes, another group that is overrepresented in this data are women who never married and prioritized career over family. In Appendix M I study whether the baseline results differ for women who were married in 1910, women who ever married, or women who ever had children.

[47] The US Census considered individuals to be in the labor force if they reported steady, gainful employment for the 1850–1930 censuses. From 1940 onwards the census used a different concept of LFP. For consistency across censuses, I focus on the gainful occupation definition.

[48] It has been documented that the 1910 census overcounted unpaid female farm laborers (Goldin (1990)). I correct for this by excluding all women reported as unpaid female farm laborers in 1910 from the analysis.

By focusing on the heterogeneity in the effect of treatment by educational attainment levels, I attempt to test the model prediction regarding the role of skill in mediating the effects of electrification for different cohorts.

Since education decisions are affected by electrification and are thus endogenous in my setting, I proxy for educational attainment using the data and methodology proposed by Clay et al. (2021), who construct a measure of required years of schooling using geographic and temporal variation in state compulsory attendance, continuation school, and child labor laws. Clay et al. (2021) construct this measure for each state-year birth cohort through an iterative process that calculates whether attendance was required at each year of life for each cohort in each state, based on the state-specific age limits and exemptions in place in that year. Given that in my model the skill decision is binary (skilled or unskilled), I focus on a binary level of required school attendance, capturing 8 years or more of required schooling.[49] The oldest cohorts with information on required schooling in the Clay et al. (2021) data were born in 1875 and were thus 35 years of age in my baseline period of 1910. As such, I focus on four cohorts: individuals who were 15–20 years old in 1910, individuals who were 21–25 years old in 1910, individuals who were 26–30 years old in 1910, and individuals who were 31–35 years old in 1910. Note also that because the required years of schooling data is built at the state of birth by cohort-level, this analysis is limited to individuals born in the contiguous United States.[50]

I estimate the following regression for each cohort:

$$\begin{aligned} Employed_{i,h,c,t} &= \alpha + \beta_t \Delta Cap_c \times Post_t + \beta^{Skill} \Delta Cap_c \times ReqSch_{i,h,c} \\ &+ \beta_t^{Skill} Post_t \times ReqSch_{i,h,c} + \beta_t^{CapxSkill} \Delta Cap_c \times Post_t \times ReqSch_{i,h,c} \\ &+ \alpha_i + \alpha_t + \alpha_{s,t} + \alpha_c + \beta_{X,t} X_{i,h,c,1910} \times Post_t + \beta_{Z,t} Z_{h,c,1910} \times Post_t + \epsilon_{i,h,c,t}, \end{aligned} \tag{4}$$

where *Employed* refers to the gainful employment definition, that is, employment in a job with steady work and payment. i, h, c, and t denote the individual, cohort, county of residence, and year, respectively. ΔCap_c corresponds to my preferred measure of electrification: change in generating capacity between 1911 and 1919 (in 100s of megawatts), excluding counties that were already widely electrified before 1911 (above the 90th percentile of generation capacity). $Post_t$ denotes a set of three binary variables indicating post-treatment periods

[49] In Appendix L.2, I follow the approach of Clay et al. (2021) more closely, and use several binary variables denoting different levels of years of required attendance, namely 1 to 5, 6, 7, and 8 or more.

[50] In Appendix L.1, I show the results when I do not proxy for educational level. This allows for the inclusion of older cohorts, several educational attainment levels, and individuals born abroad and in excluded territories. These results are not as clean as the baseline ones, however, since education is an endogenous variable to electrification.

after 1910: 1920, 1930, and 1940. $ReqSch_{i,h,c}$ denotes a binary variable capturing whether the years of required school attendance were equal to or larger than 8 for individual i. My coefficients of interest are thus $\beta_t^{CapxSkill}$, which capture the heterogeneity in the effect of treatment by required educational attainment. α_i, α_t, $\alpha_{s,t}$, and α_c denote individual, year, state-by-year, and county fixed effects, respectively. $X_{i,h,c,1910}$ denotes individual-level controls in 1910 (urban status, marital status, and school attendance), while $Z_{h,c,t}$ denotes cohort by county-level controls in 1910 (total population and socioeconomic index).[51] I cluster these results at the 100-mile radius-by-year level following the method proposed by Colella et al. (2019) in order to account for serial correlation stemming from the location of electricity plants. I choose the distance threshold of 100 miles based on the technological constraints associated to the transmission of electricity prevalent during 1910–1935, which prevented the consumption of electricity far from the generation site (Casazza (2004)).[52,53]

Identification relies on the assumption that absent change in electrical capacity, individuals with the same required education level and from the same cohort living in counties experiencing a large change in generation capacity would have trended similarly to their counterparts in counties with a small change. Two main concerns threaten this assumption. First, areas with higher electrification investments may also exhibit other related characteristics exerting a time-varying effect on employment rates or education during my period of study. Second, the early 20th century was a period of rapid change driven by key transformative events like World War I, the Great Depression, and the development and expansion of technologies like railroads and telephones, raising the concern that unobservable characteristics or concurrent shocks occurring in areas with high levels of electrification are driving the effects. In what follows, I put forth three pieces of evidence supporting the identification assumption and

[51] I include the baseline (1910) level of these controls interacted with post-treatment indicators rather than contemporaneous levels to avoid post-treatment bias, since some of the controls might be affected by treatment. Given that I consider a long period of 30 years and that the existence of concurrent shocks or omitted variables biasing the results might be relevant, in Appendix L.4 I repeat this exercise, considering contemporaneous controls and find very similar results.

[52] I thank an anonymous referee for the suggestion of using the method developed by Colella et al. (2019) to cluster standard errors at different radii. In Appendix L.5 I consider the robustness of these results to other clustering levels.

[53] This analysis proxies for educational attainment using required years of schooling. Therefore, this framework is equivalent to estimating the reduced-form differential effect of electrification by required years of schooling. I employ this reduced-form approach rather than an instrumental strategy where required schooling is used to predict educational level, like Clay et al. (2021), for two main reasons. First, my setting features far fewer cohorts than those studied by Clay et al. (2021), which greatly reduces the variation in required years of schooling and thus thwarts the predictive strength (or relevance) of the first-stage. This difficulty is compounded in my setting, because my DDD requires first stages for each of the variables that include an interaction with educational attainment (Wooldridge (2010), Chapter 8). Second, and most importantly, the required-years-of-schooling binary variable I employ at baseline, which denotes individuals who were required to attend school for a minimum of 8 years, captures individuals who were considered relatively skilled during this time period.

addressing these concerns.

The first concern is addressed through my data and historical accounts of the process of electrification, which indicate that in "Middle America" the process was primarily driven by static cost considerations and extended beyond my period of interest (1910s) into the 1920s, providing a natural control group of counties with similar characteristics that were electrified a few years later. This is evidenced in Figure K.1, which shows that although most of the electrification during the 1910s focused on medium-sized counties, many of these also experienced small to no change in generation capacity during this period, indicating the staggered nature of this process. This figure also shows that most of the counties that were electrified prior to the period under study had large populations. In Table K.1, I present the averages for individuals aged 15–35 for counties above and below the 50th percentile of treatment, respectively, along with counties that had a large generating capacity prior to 1911 and are thus excluded from my analysis.[54] Counties electrified to a significant extent prior to 1911 are substantially different from those in my analysis. However, the differences between counties above and below the median treatment included in my analysis are much less marked. Moreover, any remaining differences in levels are controlled with the difference-in-differences framework; and the inclusion of a rich set of controls, including individual, county, and state-by-year fixed effects, along with county- and person-level controls, further assures that the results are not driven by omitted characteristics.

To address the second concern, I perform pre-treatment trend tests by examining the effects of an expansion in generation capacity in the 1910s on female and male employment in 1900, the pre-treatment period.[55] I plot the results for each cohort in Figure K.2, and find the effects of electrification on these variables to be nonsignificant and substantially smaller than those found in the results section, suggesting parallel trends in the 1900–1910 pre-treatment period and thus the absence of confounders driving the outcomes of interest in highly treated counties during the pre-period.

[54] For summary statistics for individuals aged 15–35 in the rest of the years, see Appendix K.1.

[55] These results are performed at the aggregated county-level rather than using the matched sample, because I limited my record linking to the 1910–1940 period in order to maximize the number of matches, and especially because much of the younger cohorts would be missed in this period. In addition, because the youngest cohort would be aged 5–10 in 1900 and thus have no occupational or labor force information, I limit this analysis to the three older cohorts. Also, I do not use data from 1890, because census records from this wave were largely lost to fire. The equation I estimate follows:

$$Employed_{h,c,t} = \alpha + \beta_t \Delta Cap_c \times Pre_t + \alpha_t + \alpha_{s,t} + \alpha_c + \beta_{X,t} X_{h,c,1910} \times Pre_t + \beta_{Z,t} Z_{c,1910} \times Pre_t + \epsilon_{h,c,t}, \quad (5)$$

where h, c, and t denote cohort, county, and year, respectively, and Pre_t denotes a binary variable indicating the pre-treatment period of 1900. $X_{h,c,1910}$ denotes cohort by county-level controls in 1910 (proportion urban, proportion married, racial composition, total population, and socioeconomic index). The rest of the notation follows Equation (4).

Finally, given that the bulk of my analysis relies on the heterogeneity in the effects of treatment across cohorts and predicted education levels, some of the concerns regarding identification are alleviated, because for bias to arise, young women who were born in states and eras with a large number of years of required school attendance need to be differentially different from young women who were born in states and eras with a low number of years of required school attendance in treatment relative to control counties. This approach follows from my model, where the complementary influence of skill and the possibility of coordinating schooling decisions enables young cohorts to maximize the returns of electrification on female employment.

In Figure K.3, I present evidence of this in action by plotting the rates of female employment by birth-year cohort in 1940 in more-treated (above-median) and less-treated (below-median) counties to explore heterogeneity in employment across cohorts in 1940, the final period I consider. The graph shows that the differences in employment rates across more- and less-treated counties are muted for cohorts who were past the age at which key schooling and family decisions are set when electricity arrived. This pattern is substantially different for men, who display consistently lower employment rates for all cohorts in more-treated relative to less-treated counties, except for the youngest cohorts. Taken jointly, these data follow the main insight of my model regarding the importance of timing in the effects of new technologies (which I further explore in my results section) and reassure that potential confounding shocks or omitted characteristics are not driving the results, since the effects of these would likely affect all cohorts.

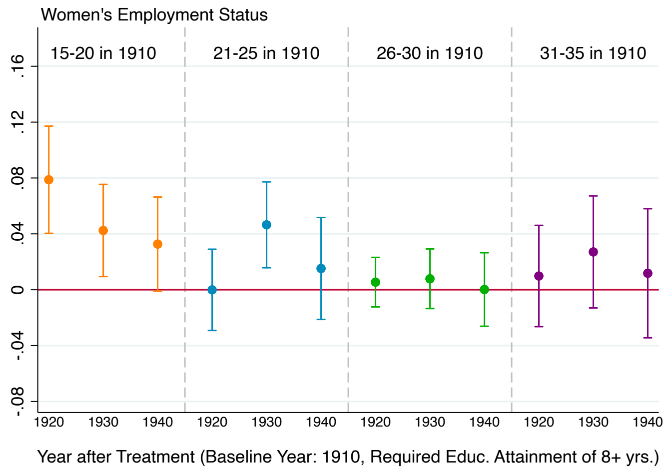
4.4 Effects of Electrification

In this section, I first study whether the response to electrification of female and male employment varies with required years of educational attainment across different cohorts.[56] At the end of this section, I (1) discuss the robustness of these main results to different specifications, (2) discuss how these effects vary with women's fertility and marital choices, and (3) show evidence suggesting that these changes in female LFP due to electrification were accompanied by changes in fertility, timing of childbearing, and marriage rates.

I present the results on the heterogeneous effects of electrification on the employment status of women and men of different cohorts by required educational attainment. Doing this

[56] In Appendix O, I also explore the effects of electrification on male and female employment per se without the heterogeneity/triple difference component. In addition, in Appendix P, I employ a difference-in-differences strategy and study the effects of electrification on schooling by comparing the county-level changes in school attendance for individuals ages 6 to 24 between 1910 and 1940. This analysis relies on aggregated county-level data (not panel) and is thus more suggestive.

Figure 4.2: Heterogeneity in the Effects of Electrification on Women's Employment by Required Educational Attainment of 8 or More Years, For Different Cohorts



Notes: The coefficients plotted correspond to $\beta_t^{CapxSkill}$ in Equation (4), estimated for each cohort separately. These coefficients capture the heterogeneity in difference-in-differences effects by required educational attainment of 8 or more years for each of the post-treatment periods (1920, 1930, and 1940, with baseline 1910). The analyses encompass women in the panel sample who were 15–20, 21–25, 26–30, and 31–35 years of age in 1910, respectively, and were born in the contiguous US. 95% confidence intervals built from standard errors clustered at the 100-mile Radius x Year level are plotted.

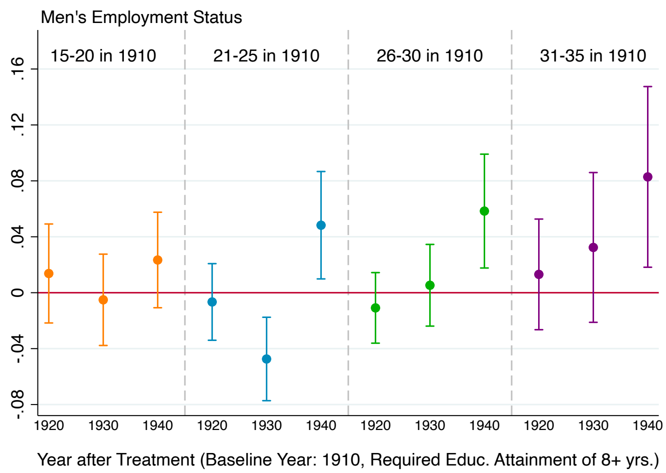
allows me to test the prediction in my model that the new work opportunities triggered by electrification require complementary schooling investments and thus favor young and skilled women.

I find that young women born in areas with a required level of schooling of 8 years or above experienced a significantly higher increase in employment after electrification, relative to their counterparts with lower required levels of schooling, for all years considered (see Figure 4.2).[57] In particular, the increase in employment among young women with a required schooling level of 8 years or more was approximately 8 percentage points higher on average in 1920 (relative to 1910) than that of young women with a required level of schooling level of less than 8 years in areas with an increase in generating capacity of 100 megawatts in the 1910s. This magnitude of this effect decreases to about 4.5% in 1930 and 3% in 1940, but remains significant at the 5% and 10% levels, respectively. This positive interaction between required education and electrification is consistent with the idea that electricity complements skilled tasks and occupations, and these, in turn, favor women, particularly those who have the necessary education to carry out these jobs. More generally, this effect is suggestive of production-side considerations entailing a role for skill in the response of women's employment to electrification, which would be absent if the returns from electrification were driven purely by home production savings and skill neutral. This effect is absent for older women. This

[57] The last column of Table Q.1 contains tabulates of these results for the young cohort. Tabulates of these results for older cohorts are available upon request.

suggests that young women were more able to coordinate key decisions, such as the length and type of education they pursued or their marital status and fertility, enabling them to capitalize on the market opportunities favoring women generated by electrification to a greater extent than older cohorts.

Figure 4.3: Heterogeneity in the Effects of Electrification on Men's Employment by Required Educational Attainment of 8 or More Years, For Different Cohorts



Notes: The coefficients plotted correspond to $\beta_t^{CapxSkill}$ in Equation (4), estimated for each cohort separately. The coefficients capture the heterogeneity in difference-in-differences coefficients by required educational attainment of 8 or more years for each of the post-treatment periods (1920, 1930, and 1940, with baseline 1910). The analyses encompass men in the panel sample who were 15–20, 21–25, 26–30, and 31–35 years of age in 1910, respectively, and were born in the contiguous US. 95% confidence intervals built from standard errors clustered at the 100-mile Radius x Year level are plotted.

These intuitions are further hinted at by the results for men presented in Figure 4.3. In particular, a higher level of required educational attainment raised the effect of electrification on male employment only in 1940, particularly for older cohorts.[58] This contrasts with the results for women and indicates that for these it is more critical to be young and thus able to coordinate key decisions to take advantage of the market returns of electrification. Moreover, when we decompose these results along several levels of required schooling in Appendix L.2, we find that the positive effects of required schooling are more heavily concentrated within the highest required schooling category (8 or more years of required schooling) for women compared to men. This suggests that the shift in the female work environment triggered by electricity focused on more highly skilled jobs, where women face a particular advantage.

Jointly, the results for men and women are also consistent with the argument outlined in Goldin and Katz (2008), who contend that over the last century, technological change has increasingly required the employment of high-skilled workers, and the evidence presented in

[58] The last column of Table Q.2 contains tabulates of these results for the young cohort. Tabulates of these results for older cohorts are available upon request.

Gray (2013), who shows that electrification changed the demand for skill in manufacturing by raising the demand for clerical, numerical, and planning jobs and reducing the demand for manual and dexterity-intensive jobs.

In Appendix L I consider the robustness of my results to different specifications, and find broadly the same results. In particular, I consider robustness to (1) not proxying for educational level, (2) following the approach of Clay et al. (2021) more closely and using several binary variables denoting different levels of years of required attendance, (3) including different fixed effects and controls, (4) using contemporaneous controls instead of baseline-level controls, (5) clustering at the 100-mile radius and county-by-year levels, (6) excluding counties in the South, (7) excluding counties in the West, and (8) considering an alternate treatment definition based on the proximity to large electricity-generating plants. I also provide a discussion of the relationship between World War I and my results.

In addition, and given that women who never married and thus prioritized career over family are overrepresented in my panel sample together with women who were already married in 1910, in Appendix M I study whether the baseline results differ for women who were married in 1910, women who ever married, or women who ever had children. I find that electrification did not differentially increase the employment of young and skilled women who were married in 1910, but did differentially increase the employment of young and skilled women who married or had children in later years (particularly in 1920). This suggests that women who had competing responsibilities that limited their ability to coordinate key human capital decisions when young were unable to take advantage of the productive returns brought about by electrification. However, women who later married and had families did see an increase in their LFP due to electrification when young, suggesting that the effects of electrification on female LFP were not limited to women who prioritized career over family.

Given this intimate link between female LFP, educational choices, and fertility, in Appendix N I explore the impacts of electrification on fertility. With this, I shed light on the role of electrification in driving the significant changes in both women's careers and family lives in the first half of the 20th century.[59] I first explore the effects of electrification on the fertility of women of different cohorts. I find that electrification reduced the fertility of women of all cohorts considered and that this effect is especially marked among younger women. In addition, I find that electrification altered the timing of fertility, with women in electrified areas waiting longer to have children. These results are consistent with the findings showing electrification encouraged the female LFP of young and skilled women and suggest that electrification increased the opportunity cost of childcare by creating work opportunities for

[59] These key historical changes are documented in detail in Appendix A.

women. This link between human capital, work, and fertility is further supported when I explore the differential impacts of electrification on fertility by required schooling. I find that young women born in areas with a required level of schooling of 8 years or above experienced a significantly lower increase in fertility after electrification, relative to their counterparts with lower required levels of schooling, for all years considered. Similar to the baseline results on female LFP, these effects are muted for older women.

I then explore the impacts of electrification on women's ever-married status. Because there is no change in this variable within individuals, I conduct this analysis at the age-group level, and thus compare the county-level trends in the proportion of ever-married individuals of ages 36–55 from 1910 to 1940 in counties that were electrified versus those that were not.[60] I find that the proportion of ever-married women in the 36–55 years of age range rises from 1910 to 1940 as a consequence of electrification. Although this may seem at odds with the decline in fertility mentioned above, this pattern matches the evidence presented in Goldin (2020), and suggests that electrification fueled deep changes in the societal role of women during the early 20th century. In particular, the advent of electricity changed the productive landscape for women, encouraging them to further their educations and pursue careers during their youth, and pursue marriage and a family in later years.

5 Conclusions

In this paper, I proposed a new channel linking electrification and female LFP that focuses on market production opportunities and the role of human capital accumulation. I formalized my intuitions in an overlapping generations (OLG) model where electricity is skill biased and households make decisions about human capital early in life. Using this framework, I showed that electricity raises the productivity of skilled labor, which is less brawn intensive than unskilled labor and thus more favorable toward women's employment, encouraging female LFP. However, complementary human capital investments are required to take advantage of these returns, because they involve work in skilled tasks. Since human capital choices are made early in life, young households experience a unique advantage relative to older households, because they can coordinate these decisions to maximize the benefits from electrification. This generational divide causes the effects of electrification on female LFP to accrue through generational change, as old generations who made their decisions prior to electrification are replaced.

[60] I choose the age group of 36–55 because (1) by this age most marriages have happened and (2) these individuals correspond to those who were 15–35 in 1910 (my cohorts of interest in the main analysis) in the mid-post-treatment period in 1930.

I calibrated my model to the 1880–1940 United States and used my empirical analysis, in particular the estimate on the effect of electrification on the LFP of highly educated young women, to quantify the aggregate effects of electrification. The human capital channel of electrification I propose explains approximately one quarter of the rise in female LFP in the 1890–1940 period and matches the slow decline in home production hours in the first half of the 20th century by decoupling the rise in female labor supply from a decline in home production hours. I then presented empirical evidence supporting the main predictions of my theory and underlying the estimates on the effects of electrification used to calibrate the model. I linked individual-level panel data from the full-count 1910–1940 censuses to a new dataset of the universe of central generating stations in 1911 and 1919 in the United States, built by digitizing historical sources. I found that high levels of required educational attainment enhanced the increase in female employment of young cohorts after electrification. This matches the prediction of my model regarding the importance of being young and able to make complementary human capital investments to reap the market gains generated by electrification. I then showed evidence that these changes in female LFP due to electrification were accompanied by changes in fertility and marriage. Taken jointly, these results suggest that electrification fueled deep changes in female work, education, marriage, and fertility patterns.

The above theoretical and empirical results have policy implications for current electrification interventions targeted to the developing world. In particular, this paper suggests that the effectiveness of electrification interventions relies partly on electrifying production processes and can be boosted through schooling programs, particularly if targeted to women and girls. Moreover, since sparse firm-level electrification and low levels of human capital dampen the effects of electrification in the short run, my paper also helps reconcile the large effects found by medium- and long- run studies in the developing world (Lipscomb et al. (2013), Lewis and Severnini (2017), Rud (2012), Kassem (2018), and Dinkelman (2011)), with the modest effects found in recent short-run studies (Lee et al. (2020) and Burlig and Preonas (2016)).

More broadly, this paper brings attention to a new feature of electrification that has been previously overlooked: the rise in female LFP stemming from new market opportunities and the accumulation of human capital. This paper focuses on documenting theoretically and empirically the importance of this channel within the context of the United States. However, the implications of the rise in women's opportunities may matter for several other key questions of economic development. For example, the rise in women's opportunities stemming from electrification may impact gender wage gaps, women's bargaining power within the household, children's outcomes, and declining male work hours.

6 Data Availability Statement

The data and code underlying this article are available on Zenodo at https://doi.org/10.5281/zenodo.7544448.

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