# The Labor Market Consequences of Technology Adoption: Concrete Evidence from the Great Depression<sup>\*</sup>

#### Miguel Morin

Do labor-saving technologies cause employment to fall or output to increase in the medium-run? This paper estimates the effects of cheaper electricity using the share of coal power as an instrument and the labor market outcomes from the non-traded industry of concrete. Electricity caused electric capital intensity to increase, conditional and unconditional labor demand to decrease, and had no effect on output. The effects are stronger in counties where the Depression was more severe. A structural estimation finds that the elasticity of substitution between electric capital and dexterity tasks at 2.2.

**Keywords**: electricity, technical change, labor demand, Great Depression, employment, labor productivity, labor share of income.

**JEL codes**: J23, N12, O33.

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### 1 Introduction

A long-standing question in economics is whether labor-saving technology affects firms in the medium-term by increasing output, decreasing employment, or both. The debate on labor displacement seems to revive from each new wave of technology adoption: the Jacquard textile loom, the steam engine, electricity, and computers. On the one hand, proponents argue that either firms do not pass on lower production costs as lower prices, or that demand adjusts slowly to lower output prices. Labor-saving innovations improve labor productivity faster than demand for products and are bound to displace some types of workers in the medium-term (i.e., over a 5-10 year horizon).<sup>1</sup> This view of unemployment caused by adoption of technologies came to be known as "technological unemployment." On the other hand, critics argue that firms do pass on lower production costs as cheaper prices and that demand for products adjusts quickly to those prices. The effect of productivity-enhancing technologies should occur at the output margin with firms increasing production instead of destroying jobs.<sup>2</sup> This view labels technological unemployment as the "Luddite fallacy." The debate has again resurfaced in the context of computers, e.g. with computers leading firms to create more narrow job opportunities by skill and permanently increasing unemployment and the skill premium (Acemoglu, 1999), and especially with the high unemployment since the Great Recession of 2007 (Jaimovich and Siu 2012; Krugman, 2013; Frey and Osborne 2013). Despite the length of the debate and the relevance of occupational displacement for policymakers since the financial crisis of 2007, there is little empirical work supporting either side of the discussion.<sup>3</sup>

This paper uses Instrumental Variables methods to measure the net effect of technology adoption on employment in the medium-run. Focusing on the adoption of electricity in the concrete industry during the 1930s for its unique source of variation and data availability, it finds that the net effect

<sup>&</sup>lt;sup>1</sup>See Ricardo (1821), Mill (1871), Keynes (1933), and Samuelson (1988).

<sup>&</sup>lt;sup>2</sup>See McCulloch (1821), Say (1924), and Woirol (1996, pages 17-18).

<sup>&</sup>lt;sup>3</sup>Lubin (1929) surveyed over 700 recently laid off workers in Baltimore, Chicago, and Worcester and documented their difficulty in finding a new job. Jaimovich and Siu (2012) show descriptive statistics that occupations susceptible to replacement by computers suffer more after recent recessions.

of electrification was a decrease in employment. The first contribution of this paper is a novel identification strategy—the coal share of power as an instrument for the change in the price of electricity in the United States in the 1930s. To maximize the chances that the exclusion restriction holds, the paper uses the concrete industry because it is a local, non-traded industry whose location decisions are driven by proximity to customers and in principle orthogonal to the geographic instrument.<sup>4</sup> The second contribution is to use this identification strategy and the very detailed plant-level measurements to trace the transmission channel of cheaper electricity with the following logic: (a) falling electricity prices lead to electric capital accumulation; (b) if the elasticity of substitution  $\sigma$  between electric capital and certain types of tasks (called *dexterity* tasks) is sufficiently high, the labor share of income decreases; (c) conditional on output and with a high elasticity of substitution, electric capital substitutes dexterity tasks and decreases employment; (d) this effect on employment can be muted or overturned if output prices decrease and cause an increase in the demand for concrete (depending on the elasticity of product demand). This paper finds evidence for (a)-(c) but not for (d) and thus documents the transmission mechanism of technology adoption at the plant level. These results are robust to including a range of geographic and plant-level controls.

The paper also finds that the effects of cheaper electricity are stronger in counties where the Depression hit hardest, consistent with the "pit-stop view of recessions," where establishments use a recession as an opportunity to upgrade the production structure (Aghion and Saint-Paul, 1998, Field, 2003). Finally, the paper estimates a structural equation for the labor share of income and finds an elasticity of substitution between electric capital and labor at 2.2, which is similar to Krusell et al. (2000) for the more recent period.

Studying the adoption of electricity in the concrete industry in the 1930s provides unique features to examine the margin of adjustment to a laborsaving technology. Two challenges arise in this context: the source of variation determining technology adoption and the available data on productivity, capital intensity, employment, and output. The 20th century witnessed

 $<sup>{}^{4}</sup>$ See Syverson (2004) and other papers cited in Section 2.

two main General Purpose Technologies: computers and electricity (Field, 2011). Computers have limited price variation within a country and it is inherently difficult to control for all idiosyncrasies at the national level in a comparison across countries. On the other hand, electricity before 1950 not only has price variation across regions but also offers an instrument with the generating technology (hydroelectric power or coal power). The plant-level dataset that survived over this period, the Census of Manufactures from 1929 to 1935,<sup>5</sup> is unique in that it contains information on employment, wages, output by quantity and value, and the horsepower of electric motors. This context warrants a test of the transmission mechanism of cheaper electricity and its effects on output and employment.

To guide empirical work, the paper proposes a simple model of technology adoption where establishments can substitute dexterity tasks with electrical machinery. (Gray (2013) found that electricity replaced dexterity tasks in a similar way as computer technology is replacing routine tasks.) If the elasticity of substitution between dexterity tasks and electric capital is greater than one, the model predicts that cheaper electricity increases electric capital intensity and labor productivity, and decreases the labor share of income. An increase in labor productivity is equivalent to a decrease in labor demand conditional on output. The paper then estimates the effect of cheaper electricity on prices, output, and employment (i.e. unconditional labor demand).

To address endogeneity bias, this paper uses the coal share of power as an instrument for the change in the price of electricity. A natural concern would be that a positive aggregate demand shock can simultaneously increase the price of electricity and the demand for concrete products. The resulting correlation between electricity and output is not due to the channel of technology adoption in question. To avoid bias from demand shocks and other omitted variables, this paper uses the coal share of power as an

<sup>&</sup>lt;sup>5</sup>Bresnahan and Raff (1991) was the first paper to use this dataset at the micro-level to describe how the automobile industry weathered the Great Depression. Ziebarth (2011), Ziebarth, Chicu and Vickers (2013), Ziebarth and Mathy (2014) renewed interest in this dataset and digitized other industries to answer questions on the dispersion of Total Factor Productivity across plants, collusion agreements during the National Recovery Act, and the employment effects of political uncertainty under Huey Long. See Appendix B.2 for details on the Census of Manufactures in other years.

instrument for supply-side changes in the price of electricity. Electricity came from two main sources in the 1930s: hydroelectric power and coal power. Hydroelectric power was relatively efficient from the start and extracted 90% of the potential energy of falling water, leaving no margin for progress. Coal power was relatively inefficient, it extracted 25% of the thermal energy of coal, and this technology improved for exogenous reasons (an increase in steam pressure and the addition of a second steam circuit). States with coal power, such as New Jersey, need to pay initially more for electricity, but the price of electricity falls faster than states with hydroelectric power, such as California. The first stage of the regression consists of instrumenting the change in the price of electricity over 1927-1937 with the initial level of coal reliance in 1927.

The second stage of the 2SLS approach consists of running regressions with the labor market outcomes from the non-traded industry of concrete, digitized for the first time for this project. Given the geographical variation in electricity prices, it could still be a problem if establishments could endogenously choose where to locate their business. The concrete industry, being a non-traded industry with high transport costs, provides a close approximation to a random allocation of plants across regions. (The concrete industry is the 6th most dispersed industry according to a Gini concentration index.) The second stage of the regression uses as outcome variables the plant-level measurements of the labor share of revenue, labor productivity, electric capital intensity, employment, and output.

The baseline results in Instrumental Variables confirm that cheaper electricity led to an increase in electric capital intensity, a decrease in the labor share of income, and an increase in labor productivity—which implies a fall in conditional labor demand. Unconditional labor demand also fell: cheaper electricity had no statistically significant effect on output, either in quantity or value, and explains 15% of the decrease in employment, which is larger than the housing boom in the 1920s. These results are consistent with the view that the adoption of labor-saving technology causes job loss in the adopting sector. These results are robust to controlling for the share of agricultural population, the housing boom in the 1920s, proximity to dam construction, and using all establishments (instead of continuing establishments).

The effects of cheaper electricity are heterogeneous depending on the depth of the Depression, as measured by the change in farm output at the countylevel between 1930 and 1935. The causal effect of cheaper electricity is larger for the labor share of income, labor productivity and employment in counties where the Depression was more severe. These results are consistent with the "pit-stop view of recessions" where a temporary downturn forces establishments to adopt labor-saving technologies that increase productivity and reduce labor input.

A final contribution is the structural estimation of the elasticity of substitution between electric capital and dexterity tasks from the labor share of income in OLS. The non-linear equation for the labor share requires using the level of electricity prices at the beginning and end of the period and precludes IV estimation with only one instrument. The estimate of  $\sigma = 2.2$ is plausible and within a third of the standard error of the estimate of Krusell et al. (2000) for the elasticity of substitution between equipment and unskilled labor for the more recent period.

**Related literature.** This paper relates to two main strands of the literature: the theoretical and empirical effects of General Purpose Technologies and electrification during the 1930s.

From the large literature on the effects of General Purpose Technologies, this paper is closely related to Acemoglu (1999), who suggests theoretically that Information Technologies change the process of job creation for firms: instead of creating jobs in a common pool aimed at both skilled an unskilled workers, they design jobs specifically for skilled and unskilled workers. The narrower scope of job vacancies permanently increases unemployment. This paper is also related to Jaimovich and Siu (2012), who find in sectoral data that the long process of routine-biased technical change led to the disappearance of middle-skill jobs during recent recessions. Autor, Levy and Murnane (2003) find that computerization substitutes for workers performing routine, cognitive tasks and complements workers performing non-dexterity tasks (using the Dictionary of Occupational Titles, the Census of Population and the Current Population Survey). Perhaps closest in spirit to this paper, Hornbeck and Naidu (2014) use the Great Mississippi flood of 1927 as a natural experiment to estimate the effect of cheap labor on the mechanization of the agricultural sector. Massive out-migration and labor scarcity in flooded counties induced faster mechanization compared to similar nearby non-flooded counties. Compared to this literature on the effects of input prices on the demand for factors, this paper provides causal evidence by exploring the idiosyncrasies of historical electricity prices and asks whether establishments adjust to cheaper technology at the output or employment margin, which is more difficult to assess with the confounding shifts in labor supply due to migration of workers.

On electrification in the 1930s, several studies have used aggregate-level data or Ordinary Least Squares to assess the effects of electrification on the labor market. Gray (2013) studied worker-level evidence from the first half of the 20th century and found that electrification was correlated with a shift away from occupations intensive in dexterity skills, similar to the findings of Autor, Levy and Murnane (2003) for computerization in the late 20th century. Field (2003) used aggregate-level growth accounting and argued that the 1930s had an unprecedented increase in TFP and were the "most technologically progressive decade of the century" because of electricity. Woolf (1984) used industry-level data from the Census of Manufactures between 1909 and 1929 and found that "firms sought laborsaving and capital-using techniques in response to cheaper energy ... [and reduced] labor's share of income." The evidence from previous studies is consistent with the thesis of this paper, whose contribution is to use plantlevel data, to propose a new instrument for the adoption of electricity, and to fully test the implications of technology adoption on the labor share of income, employment, productivity, and capital intensity. Also on electrification, Severnini (2012) uses a related but distinct instrument: among all counties in the US with high hydroelectric potential, he compares counties that received dam construction to those that did not. He finds strong and persistent effects of dam construction: a dam built before the 1950 causes an increase in the county's population density of 51% after 30 years. The instruments are different in that he uses dam construction within high hydroelectric potential counties and this paper uses a comparison between hydroelectric power and coal power. The papers are also different in that he looks at the long-run effects on population density over the 20th century while this paper looks at mechanization, labor share, productivity, and employment within the establishment.

The remainder of the paper is organized as follows. Section 2 discusses the data sources. Section 3 presents a simple model of technology adoption. Section 4 presents the identification strategy and the results on labor-saving technology and the margin of adjustment. Section 5 concludes.

### 2 Data

This section presents the reasons for focusing on the concrete industry, describes the industry background and the micro-data, and details the production of electricity as well as the data sources for the price of electricity.

#### 2.1 Motivation for the concrete industry

Similar to previous literature, this paper uses the concrete industry as an empirical laboratory for the wider economy: for example, Hortaçsu and Syverson (2007) used it to study the effect of vertical mergers on market power. The concrete industry is often confused with the cement industry but the Census Bureau distinguished them: concrete is downstream of cement. (Appendix B.2 provides more details for the concrete industry and its mode of production.)

The main reason to choose the concrete industry is non-tradability and spatial dispersion (Syverson, 2004): downstream of the cement industry, it produces heavy products with high transport costs or a limited time to reach its destination (e.g., ready-mix concrete has to be delivered in a few hours before it hardens). Accordingly, concrete is among the most spatially dispersed industries with a Gini concentration coefficient of 29% in 1929.<sup>6</sup>

 $<sup>^{6}</sup>$ This coefficient (Holmes and Stevens, 2004, page 2810) measures the difference between the distribution of economic activity compared to population. The most dispersed of all industries is Beverages with a Gini concentration coefficient of 16%.

The non-traded quality of concrete products ensure that this industry locates near its customers, as opposed to industries selling traded goods and able to choose their location (concrete products bear the risk of un-mixing if carried for a long distance (Tennessee Valley Authority, 1947)). Concrete plants locate in New Jersey or California to be close to their customers which strengthens the exclusion restriction of the identification strategy in Instrumental Variables.

A second reason to consider the concrete industry is the analysis of the transition from manual power to electricity powered by the grid. The concrete industry has the advantage of consisting of small plants that buy all of their electricity from the grid. With around 13 employees, concrete plants may not afford to have steam engines or electric generators on site. In contrast, the manufacturing industry is four times larger with 48 employees per plant<sup>7</sup> and was more suited to afford the fixed costs of on-site electric generators, using 35% of its electric horsepower with electricity generated in the plant. This paper focuses on the transition from manual labor to electric-powered machinery and avoids the switch from one type of power technology to another. The concrete industry provides a clean setting: 99.99% of electric horsepower and 90% of all horsepower is driven by electricity purchased from the grid—the highest of all non-traded industries.<sup>8</sup>

For these reasons, a detailed case study of the concrete industry is a clean setting to estimate the effects of electricity adoption on establishments' labor decisions. The broader economy is more complex and identification is not as clean because of geographical sorting, the endogenous choice of the generation of power, and strategic adoption. But anecdotal evidence on the wider adoption of labor-saving machinery in the 1930s suggests that the effects of cheaper electricity could be more general than what can be found in the concrete industry: Jerome (1934) compiled an extensive list of labor-saving innovations in other industries and the House of Representatives suggested in 1936 that "mechanical and other labor-saving devices are the chief cause of the growing number of unemployed."<sup>9</sup> Furthermore, the time

<sup>&</sup>lt;sup>7</sup>Census of Manufactures, 1929, Table 3, page 16.

 $<sup>^{8}</sup>$  Industries with a spatial concentration coefficient in 1929 below 30%.

<sup>&</sup>lt;sup>9</sup>Committee on labor (1936, page 118)

series plot of the labor share of value added in the concrete industry and manufacturing in Figure 1 suggests that they are relatively similar.

#### [FIGURE 1 HERE]

#### 2.2 Plant-level data for the concrete industry

The dataset used in the analysis is the Census of Manufactures in 1929 and 1935, which covers the universe of manufacturing plants with sales above \$5,000.<sup>10</sup> This dataset is at the National Archives and Records Administration in Washington D.C. Two barriers prevent the wider use of this dataset: the schedules are in paper or microfilm format and the National Archives protect them with in-house access only. The concrete industry was digitized for the first time for this project.

I scanned all the microfilm schedules (around 2,500 for 1929 and 1,100 for 1935). The archivists marked as lost one microfilm roll with 300 plants in 1935 for states Alabama to Iowa but I was able to locate a backup copy in a different location.<sup>11</sup> A professional data entry firm tabulated these schedules into electronic format. I verified the tabulations and corrected outliers, such as missing commas in the separation of cents and dollars. I also cleaned the names of states, counties and cities. The Census Bureau had no unique plant identifier and I matched the plants across years based on their name, location and ownership (see Appendix B.2). From the 3,500 plants present in both 1929 and 1935, I obtained a panel of 630 continuing plants.

The dataset also has information on employment, wage-bill, revenue, the quantity of concrete tons, and the horsepower of electric motors, which

<sup>&</sup>lt;sup>10</sup>This threshold in 1929 corresponds to around \$66 thousand today and is high above the average sales for the concrete industry of \$38 thousand in 1929 prices.

<sup>&</sup>lt;sup>11</sup>Despite scanning all the records I could find at the National Archives, some discrepancies remain between my sample and the state-level aggregation from the books published by the Census of Manufactures: some establishments are missing from California in 1935, and the total value of products is sometimes different.

serve as outcomes in the investigation of the effects of cheaper electricity. Table 1 shows summary statistics for continuing concrete plants in 1929 and between 1929 and 1935. The typical continuing concrete plant employs 13 workers with an average revenue productivity of \$3,500 and wages of \$1,445. The average worker produces 516 tons of concrete products per year, works 264 days per year, 51 hours and six days per week. From the Census of Population, the typical concrete worker is 37 years old and the most common occupation is laborer (37% of workers), i.e. a worker doing unskilled manual tasks. The second most common occupation is contractor (11%) and foreman (4%). Among the workers in concrete in 1930 whom I can follow<sup>12</sup> with their occupations in 1940, most of them changed occupations: 10% of laborers in 1930 remain laborers in 1940 (230 workers) while 90% change occupations: salesmen, truck drivers, farmers, and proprietors (652 workers). Appendix B.2 contains more details on the cyclical sensitivity of the concrete industry and the most common products.

This period covered is 1929 to 1935, the first half of the Great Depression. An important reason is that the plant schedules of the Census of Manufactures survived only for this period and the years before or after were destroyed.<sup>13</sup> Access to plant-level data is important in order to link plants across years and avoid compositional bias due to the turnover of plants. It also contains more information, such as output in tons of concrete, the price of concrete products, and the horsepower of electric motors, which is not otherwise available. Another reason to focus on this period is that to examine the heterogeneous effects depending on the depth of the Depression.

#### [TABLE 1 HERE]

 $<sup>^{12}</sup>$ I used the methodology in Abramitzky, Boustan and Eriksson (2012) to follow men by their name, ethnicity, birthplace, and age.

<sup>&</sup>lt;sup>13</sup>The National Recovery Act contained provisions for the ready-mix portion of the concrete industry. Approved near the end of the period in February 1934, it capped worktime at 40 hours and 6 days per week and set minimum wages. The provision on hours was not enforced: in 1935, plants operated on average at 45 hours per week. The National Recovery Act did not contain provisions with respect to firing workers. The impact of the NRA is therefore limited.

#### 2.3 Electric industry and electricity data

The electricity industry saw outstanding efficiency improvements over the 20th century. The two main sources of improvement were economies of scale in electricity generation and the increasing efficiency of coal in power generation (Hughes 1993, Warkentin-Glenn 2006). Economies of scale are not in the scope of this paper for concerns of endogeneity from the wave of consolidations in the electric industry. Coal power represented two thirds of electricity production and hydroelectricity represented one third, with oil and natural gas as marginal fuel sources. Coal power and hydropower are similar in that a fluid (water or steam) spins a turbine in a dynamo and converts mechanical energy into electric energy. They are different in three respects. First, hydroelectric plants require a larger initial investment and the availability of falling water while coal plants can be smaller and locate closer to the consumers (a validity test in the results section suggests that the coal share of power does not predict changes in demand prior to the period). Second, coal plants need to pay for the fuel but not hydroelectric plants.

The third difference between coal and hydroelectric plants, which is the focus of this paper, concerns the technical efficiency in energy extraction. Hydroelectric power had high efficiency in 1930, extracting 90% of the potential energy of falling water, and had few opportunities for cost savings. Coal power had low efficiency, extracting 25% of the thermal energy of coal, and had many opportunities for cost savings: "much of the heat is lost in the condensing water, some of it goes up the stack, and the remainder escapes by radiation from the pipe and steam apparatus."<sup>14</sup> Coal efficiency improved for technological reasons: an increase in the pressure and temperature of steam boilers and new thermodynamic cycles to extract energy (for example, adding a second circuit to capture the residual steam from the first circuit). Hunter (1991) summarizes these advances: "the general adoption of superheaters brought further advances in pressures, efficiency, and generating capacity ... made possible by improvements in the design and fabrication of piping and fittings and by the development of alloys ca-

<sup>&</sup>lt;sup>14</sup>National Electric Light Association (1931, page 43).

pable of standing up under these conditions of temperature and pressure. Automatic control of fuel supply and combustion gave great regularity in steam pressure and supply to the turbo-generating units. ... This remarkable improvement in the fuel economy of the steam-electric power plant in the early decades of the 20th century was the joint product of improvements in all three of its major components—the boiler room, the prime mover, and the generator—and the greater of these, although perhaps the least appreciated, were the improvements in the efficiency of the boiler room." Accordingly, in 1922, hydroelectric power was half as cheap as coal power (Census Bureau, 1922). By 1950, these differences had all but disappeared (Severnini, 2012).

The electric industry was regulated at the state-level, which limited its ability to transfer power across states and makes the state the relevant unit of analysis for the electricity treatment. Only 5% of power was bought from outside of the state Census Bureau, (1932, page 14). Most utilities were regulated at the state-level: Stigler and Friedland (1962) document that 42 out of 48 mainland states had a state-level regulator by 1929.<sup>15</sup>

The electric industry suffered little through the Great Depression, aside from the bankruptcy of the business conglomerate of Samuel Insull (in no small part due to his financial strategy of cross holding of companies). Nye (1992) details the performance of the electric industry during the 1930s: the business of utilities was "virtually immune to the Depression" (page 348), the "number of central stations increased from 3,838 in 1929 to 4,023 in 1935," and "in a period when incomes, employment, stocks, profits, and most other economic indicators fell, electrification increased. More homes were wired, more power stations were built, and per capita consumption shot up" (page 340).

The price of electricity had a spectacular fall in the first half of the 20th century. Figure 2 illustrates this declining trend for the price of electricity relative to wages on a log-scale. The price of electricity relative to unskilled

<sup>&</sup>lt;sup>15</sup>The six unregulated states are Arkansas, Florida, Kentucky, Louisiana, Mississippi, and New Mexico. These states have little importance in the concrete industry and represent only 20 plants in the sample.

wages fell by 7% per year between 1892 and 1950. Over the period 1929-1935 under consideration in this paper, the residential price of electricity fell by 4.2% per year and the industrial price of electricity fell by 1.3% per year. The decrease in the price of electricity from 1902 to 1950 was 6% relative to the consumer price index or to the wholesale price index.

#### [FIGURE 2 HERE]

This paper uses data at the state-level from the Census of Electric Light and Power Stations in 1927 and 1937, published by the Census Bureau. It uses total revenue divided by current sold to ultimate consumers as a proxy for the cost of electricity by state. The relevance of this proxy is supported by the state-level regulation of electric utilities. Notice also that the public electricity projects come at the end of the sample period and are less likely to have a strong effect: the Tennessee Valley Authority started delivering power in 1934 (Kitchens, 2012), compared to the time period of 1929-1935. The preferred measure of the change in the price of electricity in this paper is:  $\Delta \log (p_{E,k,t}) = \log (p_{E,k,1937}/p_{E,k,1927})/10$ , where  $p_{E,k,t}$  denotes the price of electricity for state k at time t, which is the average price of electricity for ultimate consumers from the Census of Electric Light and Power Stations in 1927 or 1937.

# 3 A partial equilibrium model of technology adoption

This section presents a simple production function with capital-labor substitution and its implications for electric capital intensity, the labor share of income, and labor productivity. It also translates these predictions into regression equations and adds further tests on the margin of adjustment whether establishments adjust to growing productivity by increasing output or firing workers.

#### 3.1 A simple model

Plants are indexed by i and produce output  $Y_{i,t}$ . Plants hire workers to perform two types of tasks, dexterity tasks  $L_{D,i,t}$  and non-dexterity tasks  $L_{ND,i,t}$ . Plants also rent two types of capital, non-electric capital  $K_{NE,i,t}$ and electric capital  $K_{E,i,t}$ . The production function is the most important part of the model.

**Assumption 1.** The production function for plant *i* is:

$$Y_{i,t} = A_{i,t} \ K_{NE,i,t}^{\alpha} \ L_{ND,i,t}^{\beta} \ M_{i,t}^{\gamma}, \ with \ M_{i,t} = \left( K_{E,i,t}^{\frac{\sigma-1}{\sigma}} + L_{D,i,t}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, \qquad (1)$$

where  $\alpha + \beta + \gamma = 1$ ,  $A_{i,t}$  is Total Factor productivity, and  $\sigma$  is the elasticity of substitution between dexterity tasks and electric capital.

This production function has Cobb-Douglas aggregation of three factors: non-electric capital  $K_{NE,i,t}$ , employment in non-dexterity tasks  $L_{ND,i,t}$ , and a third factor, which is a Constant-Elasticity-of-Substitution aggregate between electric capital  $K_{E,i,t}$  and employment in dexterity tasks  $L_{D,i,t}$ . Krusell et al. (2000) use this production function to explain the increase in income inequality with capital-skill complementarity. They estimate an elasticity of substitution between capital equipment and unskilled labor at 1.67. Then the increase in capital investment contributes to increasing the skill premium by raising the marginal product of skilled labor faster than that of unskilled labor. Autor and Dorn (2009, page 11) also use this function to explain the recent disappearance of middle-skill, routine occupations: as firms invest more in computer capital, they increase employment of middle-skill routine jobs slower than low-skill or high-skill nonroutine jobs.<sup>16</sup>

<sup>&</sup>lt;sup>16</sup>This production function is also related to the literature on directed technical change (Acemoglu, 2009, page 501): the ratio of marginal products of nonroutine and routine tasks is proportional to  $1+(K_{E,i,t}/L_{D,i,t})^{\rho}$  and rises with electric capital, so the adoption of electricity favors non-routine tasks more than routine tasks. Nevertheless, this paper looks at the response of factor intensities as a function of relative prices, while the directed technical change literature looks at endogenous technological progress in the productivity of those factors.

The establishment takes prices as given and maximizes intertemporal profits:  $^{17}$ 

Assumption 2. Plant *i* operates under perfect competition and maximizes the present value of profits, discounted with the market interest rate  $r_t$ . The profit flow of period *t* is:

$$profits_{i,t} = p_{i,t}Y_{i,t} - w_{ND,i,t}L_{ND,i,t} - w_{D,i,t}L_{D,i,t} - r_{NE,i,t}K_{NE,i,t} - r_{E,i,t}K_{E,i,t},$$

where  $p_{i,t}$  is the price of output,  $w_{ND,i,t}$  is the wage for non-dexterity tasks,  $w_{D,i,t}$  is the wage for dexterity tasks,  $r_{NE,i,t}$  is the rental rate of non-electric capital, and  $r_{E,i,t}$  is the rental rate of electric capital.

These assumptions on the production function and establishment behavior have precise implications for ratio variables: the labor share of income, labor productivity, and electric capital intensity. These ratios correspond to total employment and do not differentiate between dexterity and nondexterity tasks. The focus on variables aggregated for all occupations stems from the Census of Manufactures, which does not report employment or wages by occupation (see Appendix B.2). The following proposition derives the implications of the production function for ratio variables (see Appendix A for the proof).

**Proposition 3.** Profit maximization under perfect competition implies the following expressions for electric capital intensity, the labor share of income,

<sup>&</sup>lt;sup>17</sup>The assumption of perfect competition finds support in the concrete industry: in 1929, less than 5% of all concrete plants are in a state with fewer than five competitors, and less than 2% of plants with fewer than three competitors. Bresnahan and Reiss (1991) find that three to five competitors is sufficient to induce competitive behavior. The small scale of concrete diminishes the importance of strategic technology adoption, whereby an oligopolist may have an incentive to adopt a technology earlier to front-run a competitor or later to benefit from cheaper future prices (Tirole and Fudenberg, 2010, Reinganum, 2007).

and labor productivity:

$$\frac{K_{E,i,t}}{L_{i,t}} = \left(\frac{r_{E,i,t}}{w_{D,i,t}}\right)^{-1} \left(\frac{\beta}{\gamma} \frac{w_{D,i,t}}{w_{ND,i,t}} + \left(1 + \frac{\beta}{\gamma} \frac{w_{D,i,t}}{w_{ND,i,t}}\right) \left(\frac{r_{E,i,t}}{w_{D,i,t}}\right)^{\sigma-1}\right)^{-1},$$
(2)

$$\frac{w_{i,t}L_{i,t}}{p_{i,t}Y_{i,t}} = \beta + \gamma \left(1 + \left(\frac{r_{E,i,t}}{w_{D,i,t}}\right)^{1-\sigma}\right)^{-1},\tag{3}$$

$$\frac{Y_{i,t}}{L_{i,t}} = \frac{w_{i,t}}{p_{i,t}} \left( \beta + \gamma \left( 1 + \left( \frac{r_{E,i,t}}{w_{i,t}} \right)^{1-\sigma} \right)^{-1} \right)^{-1}, \tag{4}$$

where  $w_{i,t}L_{i,t} = w_{D,i,t}L_{D,i,t} + w_{ND,i,t}L_{ND,i,t}$  is the total wage bill.

The expression for the labor share of income provides a direct test of the substitutability between electric capital and dexterity tasks: if  $\sigma > 1$ , the labor share of income decreases as electric capital becomes cheaper; if  $\sigma = 1$ , the labor share is independent of the rental rate of electrical machinery; and if  $\sigma < 1$ , the labor share of income increases as electric capital becomes cheaper. The model also predicts that labor productivity and capital intensity increase as electric capital becomes cheaper.

For simplicity, this paper studies only the implications of the production function in partial equilibrium. Household preferences, labor supply, and the ensuing General Equilibrium properties do not alter equations (2-4). The interested reader is referred to Morin (2014).<sup>18</sup>

#### 3.2 Ratio regressions and conditional labor demand

To translate the predictions (2-2) into regression equations, I log-linearize the expressions. The linearization does not identify the parameter  $\sigma$  but can recover the sign of  $\sigma - 1$  with the expression for the labor share of

<sup>&</sup>lt;sup>18</sup>On the other hand, the implications for output or employment in General Equilibrium depend crucially on the household preferences and labor market structure. Without labor market frictions, employment is constant and output increases as a result of technology adoption. With labor market frictions, such as a retraining cost, the substitution of capital for labor reduces employment for the duration of retraining.

revenue. Two further difficulties arise in the context of electricity. First, the relative rental rate  $r_{E,j,t}/w_{j,t}$  of electrical machinery is unobserved and I use the price of electricity in cents per kilowatt-hour as a proxy. Second, the average price of electricity at the plant-level is far from the marginal price: several forms of fixed costs (see Appendix B.1) introduce measurement error in the price of electricity paid by small concrete plants. Fixed costs lose importance when considering a larger entity such as the state, whose average price of electricity should be closer to the marginal price. The preferred measure of the price of electricity is the state-level average price from the Census of Electric Light and Power Stations for 1927 and 1937.<sup>19</sup> This measure minimizes the importance of fixed costs, making the average price closer to marginal price, and is close to the price of electricity paid by industrial users, since power stations sold on average 69% of their current to industrial consumers.<sup>20</sup>

Plants or states may also have unobserved characteristics, such as managerial ability or skill endowment. To abstract from these effects, I difference out these fixed effects by using changes across time as dependent variables. The regression equations for the predictions on ratio variables are:

$$\Delta \log \frac{K_{E,i,t}}{L_{i,t}} = constant + a \Delta \log \left( p_{E,k,t} \right) + error, \tag{5}$$

$$\Delta \log \frac{w_{i,t}L_{i,t}}{p_{i,t}Y_{i,t}} = constant + b\Delta \log (p_{E,k,t}) + error,$$
(6)

$$\Delta \log \frac{Y_{i,t}}{L_{i,t}} = constant + c \Delta \log \left( p_{E,k,t} \right) + error, \tag{7}$$

where *i* indexes plants, *k* indexes states,  $w_{i,t}L_{i,t}$  is the aggregate wagebill at the plant-level,  $p_{i,t}Y_{i,t}$  is the output value at the plant-level,  $p_{E,k,t}$ is the change in the price of electricity at the state-level,  $Y_{i,t}/L_{i,t}$  is labor quantity productivity in tons of concrete,  $L_{i,t}$  is employment, and  $K_{E,i,t}/L_{i,t}$ is electrical intensity at the plant-level (the horsepower of electric motors per worker). If the elasticity of substitution  $\sigma$  is greater than 1, then

 $<sup>^{19}{\</sup>rm Stigler}$  and Friedland (1962) used this measure to assess the effect of regulation on electricity prices. I have been unable to find other sources for the price of electricity at the state-level during this period.

<sup>&</sup>lt;sup>20</sup>Census of Electric Light and Power Stations, 1927, page 51.

the model predicts a < -1, b > 0, and c < 0: a decrease in the price of electricity causes a decrease in the labor share of income, an increase in productivity, and an increase in electrical intensity.<sup>21</sup> Because the change in output  $\Delta \log Y$  is an outcome variable, it should not appear on the righthand side of regression equation 7 and prevents the direct estimation of the effect of electricity on conditional labor demand. Yet, a positive effect of electricity on labor productivity implies that conditional labor demand is lower, i.e. labor decreases while holding output constant. Therefore, these predictions test the steps (a)-(c) in the introduction: electric capital intensity, labor share, and conditional labor demand.

# 3.3 Net effect regressions and unconditional labor demand

To move from conditional to unconditional labor demand, this paper runs a further set of regressions with output and employment as separate dependent variables. The model is silent on this respect: establishments make zero profits, are indifferent about the scale of production, and it is the demand side of the market that determines the level of production and employment. If establishments pass cheaper input prices into cheaper output prices and the product demand elasticity if sufficiently elastic, consumers increase demand and plants produce more output for the same level of employment. Otherwise, establishments hold output constant and decrease employment.

The regression equations for measuring the net effects of cheaper electricity on employment through prices, output and revenue are:

$$\Delta \log p_{i,t} = constant + a' \Delta \log (p_{E,k,t}) + error$$
$$\Delta \log p_{i,t} Y_{i,t} = constant + c' \Delta \log (p_{E,k,t}) + error$$
$$\Delta \log Y_{i,t} = constant + b' \Delta \log (p_{E,k,t}) + error$$
$$\Delta \log L_{i,t} = constant + d' \Delta \log (p_{E,k,t}) + error$$

<sup>&</sup>lt;sup>21</sup>The regressions use a nominal price with no deflator—deflating prices by a nationwide price or wage index would affect the intercept of the regression and not the slope.

### 4 Empirics

This section presents the instrument for the electricity supply curve, measures the causal effect of cheaper electricity on ratio outcomes and net effects (including conditional and unconditional labor demand), argues for the validity of the instrument, presents the heterogeneous results depending on the depth of the Depression, and estimates the elasticity of substitution between electric capital and dexterity labor.

#### 4.1 Instrument for the electricity supply curve

Estimating a regression of quantities on prices as in equations (5-7) raises concerns about endogeneity and is a challenge to identification: it is unclear whether the regression estimates the demand or supply equation. This paper is interested in the demand for electricity and requires an instrument that shifts the electricity supply curve and not the demand curve. This endogeneity should bias the estimation of the downward-sloping electricity demand curve toward the upward-sloping electricity supply curve. The coefficients should be further away from zero in Instrumental Variables (IV) compared to Ordinary Least Squares (OLS). A similar argument suggests that endogeneity also biases the coefficient on the labor share of income toward zero because the labor share of income is decreasing in the electric capital-labor ratio in the model.<sup>22</sup>

The identification strategy to deal with the endogeneity bias consists of two parts: using geography as an instrument for the change in the price of electricity and choosing the non-traded industry of concrete. The ideal test of technological explanation for labor market changes would be a random assignment of electricity prices across regions and an analysis of the subsequent labor market decisions of establishments. It is impossible to achieve

<sup>&</sup>lt;sup>22</sup>Electric capital intensity is a strictly decreasing function of the relative rental rate of electrical machinery. By the implicit function theorem, the relative rental rate of electrical machinery is a decreasing function of electric capital intensity. The labor share of income is increasing in the relative rental rate of electrical machinery and therefore decreasing in electric capital intensity.

this random allocation but one can use natural variation in the price of electricity depending on geography and the source of power. Electricity at this time came either from hydroelectric power or coal power. Hydroelectric power had high efficiency in 1930, extracting 90% of the potential energy of falling water, and had few opportunities for cost savings. Coal power had low efficiency, extracting 25% of the thermal energy of coal, and had many opportunities for cost savings.<sup>23</sup> The price of electricity decreased in regions with coal power, such as New Jersey, but less in regions with hydroelectric power, such as California. A state's initial loading on coal power is an instrument for the supply-side change in the price of electricity. The top panel of Figure 3a shows the first-stage of the instrument at the state-level: states with initially larger dependence on coal power also had a decrease in the relative price of electricity. The F-statistic of the first-stage regression is high and above 20 in an unweighted regression that treats all states equally. The plant-level regressions put more weight on California than Arizona and consequently the F-statistic in the regressions decreases but is still above the usual confidence threshold of 10. One drawback from this identification strategy, shown in the bottom panel of Figure 3b, is that the instrument captures inland regions more than the coasts, which have the altitude differential for hydroelectric power. To ensure that the instrument is not capturing a systematic difference between regions with and without hydroelectric potential, a robustness check excludes counties near dam construction.

#### [TABLE 2 HERE]

To provide more support for the validity of the instrument, Table 2 suggests that the coal share instrument is orthogonal to plant-level characteristics and that the sample is balanced on 1929 establishment-level observables. Plants in coal states are initially similar to plants in hydroelectric states in many respects, such as initial productivity, employment, revenue, and labor share of income. The only statistical difference is in capital intensity: plants in coal states have less electric horsepower per worker than hydro states. These tables give confidence that the sample of continuing establishments is

 $<sup>^{23}</sup>$ National Electric Light Association (1931, page 43).

balanced on observables and that electricity is the main difference between them. Table 2 also reports the balance of the sample with respect to two state-level characteristics, initial GDP and the Herfindahl concentration index of the concrete industry. The geographic variables for which the sample is not balanced are included as controls in the regressions.

#### [FIGURE 3 HERE]

Given the natural variation in electricity prices, it could still be a problem if plants chose endogenously to locate in regions with cheaper electricity prices. The concrete industry provides a close approximation to the ideal random assignment of plants across regions because it is a local industry selling a non-traded good, as mentioned in Section 2. The location decision of concrete plants is orthogonal to the geography of the price of electricity, rules out geographical sorting, and strengthens the validity of the instrument. Measurements of labor market outcomes for the concrete industry provide a quasi-experiment to assess the causal effect of technical progress in electric utilities on downstream industries.

Three additional arguments support the validity of the geographical instrument. First, the narrow scope of the concrete industry suggests that the instrument should affect electric utilities on the supply side of the electricity market but not concrete plants on the demand side of the market. Second, the instrument is an initial level and the outcome variables are changes. Omitted variables in levels, such as the skill composition of the workforce or the density of the road network, would appear as a state or city fixed effect in a regression in levels and are differenced out in a regression in changes. Third, using ratios at the plant-level, such as labor productivity or the labor share of income, implies the absence of that plant-level shocks that affect the numerator and denominator similarly, such as TFP shocks, at least to a first-order approximation. The end of this section presents more empirical evidence supporting the validity of the instrument.

#### 4.2 Results on ratios and conditional labor demand

This section presents the results for ratio outcomes: electric capital intensity, the labor share of income, and labor productivity. The results imply that the elasticity of substitution  $\sigma$  is greater than 1 and that cheaper electricity causes a decrease in conditional labor demand. The results are robust to including geographic controls: farm share in 1920, housing boom in the 1920s, bank suspensions in the 1930s.

Table 3 shows the results for electric capital intensity, the labor share of income, and labor productivity, in Instrumental Variables and in OLS. The coefficients are economically and statistically significant. (The standard errors in all plant-level regressions are clustered at the state-level and all variables are "winsorized" at the 2% level.) The IV regression for electric capital intensity traces the demand curve and finds a negative coefficient: cheaper electricity induces more horsepower per worker. The instrument is relevant with F-statistics above the threshold of 10. The regression of the labor share of revenue supports the crucial assumption in the model. The coefficient for the labor share is proportional to  $\sigma - 1$ : it should be positive under the assumption  $\sigma > 1$  and zero under  $\sigma = 1$ . Furthermore,  $\sigma > 1$  implies that the coefficient on electric capital intensity should be greater than 1, which is supported by the data. The decrease in the price of electricity also caused an increase in labor quantity productivity (tons of concrete per worker) $^{24}$ . This implies that labor demand, conditional on output, decreased in reaction to cheaper electricity. These regressions in quantities suggest that the results are not due to deflation or other price channels.

#### [TABLE 3 HERE]

The coefficients appear large at first but several reasons support their plausibility. First and most foremost, these coefficients are not structural elasticities: the structural equations (2-2) are not log-linear and the linearized

<sup>&</sup>lt;sup>24</sup>Note that, while cheaper electricity causes an increase in productivity, the average productivity change in the sample is negative (see Table 1). The causal effect of electricity is relative to establishments in counties without coal power and does not account for aggregate shifts.

regression equations inform on the sign of the partial derivative of the outcome variables with respect to the price of electricity. A structural estimation of  $\sigma$  in Section 4.6 finds a plausible estimate of 2.2. Second, each line in the table has the *beta* coefficients in italics: a 1 standard deviation fall in the price of electricity predicts a fall in the labor share of 0.15 standard deviations, an increase in labor productivity of 0.25 standard deviations, and an increase in electric capital intensity of 0.28 standard deviations. The predictions from the regressions are of similar magnitude to the actual changes. Third, these results do not mask some observed variable that was excluded from the regressions: I have extensively included in robustness tests all the geographic variables available for this period to the best of my knowledge.<sup>25</sup> Fourth, they are consistent with the advertising in the trade journal Concrete and Constructional Engineering in 1929: "Little Giant mixer ... [from] 6 men to one man's job ... guaranteed to at least halve your labor costs." Fifth, they are also consistent with electricity being a General Purpose Technology similar to computers, where the literature has also found large effects from technology adoption (Gaggl and Wright, 2015). Finally these results are also consistent with the speed of adoption accelerating in cyclical downturns, e.g. during the Great Depression over 1929-1935, as evidenced in Section 4.5.

# 4.3 Results through prices and unconditional labor demand

Having measured the effect of cheaper electricity on conditional labor demand, the paper now turns to the price channel and unconditional labor demand. The top panel of Table 4 contains the results for prices, output (revenue and quantity), and employment. The F-statistics are close to or above 10. Cheaper electricity led to cheaper prices for concrete products: the elasticity is positive, statistically significant, and around 3. The next

<sup>&</sup>lt;sup>25</sup>Some examples include unionization from Fishback et al. (2011); the ratio of bank or deposit suspensions, for all banks, national banks, or federal banks, on average or over the year 1931, 1932, and 1933, with the county or aggregated with a 50-mile area of influence; using hours instead of number of workers; and housing construction within the county or with a 50-mile area of influence.

columns show the effect for revenue and quantity production: the estimated coefficients are not statistically significant, they are positive for revenue and negative for quantity. The demand for concrete products seems inelastic and cheaper concrete prices did not lead to an increase in demand.

If cheaper electricity led to an increase in productivity with no effect on output, the only remaining channel is employment. The top right columns confirm that concrete plants adjusted to cheaper electricity by decreasing employment. The coefficient is positive, statistically significant at the 1% level, and around 3. The *beta* coefficient implies that a fall in the price of electricity of 1 standard deviation causes a fall in employment of around 0.15 standard deviations, which is larger than the housing boom in the 1920s. Taken together, the available evidence from the concrete industry supports that cheaper electricity led to an increase in electric capital intensity and in labor productivity, a decrease in conditional and unconditional labor demand, and no effect on output.

#### [TABLE 4 HERE]

#### 4.4 Instrument validity

The bottom panel of Table 4 conducts robustness and falsification tests. If plants in the mountain regions are affected differently during the Depression, the differential treatment may invalidate the exclusion restriction of the Instrumental Variables approach. One possible violation of the exclusion restriction is that mountain regions have government programs for building dams, which would increase demand for concrete in regions with hydroelectric power compared to regions with coal power. This increase in demand may be met with the more adjustable factors, such as labor or materials. Nevertheless, the definition of the concrete industry excludes work done on site for dam construction and alleviates the concerns that concrete plants in hydroelectric regions are affected differentially. To be sure, the bottom panel of Table 4 runs a falsification test with the materials share of revenue: electricity prices have no statistically significant effect. Similarly, they have no statistically significant effect on plants' profits (defined

as revenue minus wages, cost of materials, and energy). Another concern with the identification strategy is that cheap electricity could affect other local establishments and increase the demand for concrete products. The absence of a statistically significant effect on quantity output and revenue in Table 4 allays these concerns.

The next check excludes plants within 50 miles of dams under construction: the point estimates for employment are similar with or without these counties. The first-stage *F*-statistic drops below the usual confidence threshold of 10—mainly because of California, the largest state with hydroelectric power. The last column accounts uses all establishments (instead of continuing ones) with the symmetric change in employment  $\tilde{\Delta}L_{i,t+1} = (L_{i,t+1} - L_{i,t}) / (0.5 \times (L_{I,t+1} - L_{i,t}))$ . This measure accommodates entrants and exiters, which are assigned +2 and -2 respectively. The results in this paper are robust to this alternative specification.

### 4.5 Heterogeneous effects by the depth of the Depression

This section inquires into the heterogeneous effects of electricity adoption depending on the depth of the Great Depression. This exercise is informative because it answers the question of whether concrete establishments used the Great Depression as an opportunity to fire workers, invest in electrical machinery, and increase productivity. It also informs on the source of the relatively large effects found in the previous section.

This section uses the change in farm crop value at the county-level between 1930 and 1935 (from Fishback et al., 2011) as a measure of the depth of the recession. It splits the sample in two sub-groups—either deep or shallow recession—and runs again the above regressions for the labor share, labor productivity, electric capital intensity, and employment.

Figure 4 summarizes the results and plot the estimated coefficients along with 95% confidence intervals. Each dependent variable labeled on the *y*-axis is regressed on the instrumented change in the price of electricity for

the half of counties where the Depression hit harder ("deep Depression") and the half where the Depression was softer ("shallow Depression"). The F-statistics and number of clusters for each regression are in a caption next to the regression. These results are robust to other measures of the Depression (change in housing construction, change in retail sales, change in manufacturing sales).

#### [FIGURE 4 HERE]

This figure suggests that the full range of effects of electricity adoption are stronger when establishments experienced a deep recession. The subsample with a deep recession has statistically significant coefficients for the five main outcome variables: labor share, productivity, electric capital intensity, output price, and employment. The subsample with a shallow recession has a statistically significant coefficient only for the change in electric capital intensity. Both the deep recession and the shallow recession subsamples see no statistically significant effect on value added or quantity output. Insufficient aggregate demand in a recession exacerbates the negative effects of cheaper electricity on conditional and unconditional labor demand.

These results suggest that concrete establishments used the recession as an opportunity to fire worker, invest in electrical machinery, and increase productivity. It supports the "pit-stop" view of recessions, where downturns are times of reorganization to increase productivity. This figure also suggests that the period of the Depression contributes to the relatively large size of the average coefficients: one would expect to find stronger effects of electricity adoption during a downturn than in normal times. The average coefficient can thus be seen as an upper bound on the average effect.

These results also provide an interesting look at the nature of innovation during the business cycle. The absence of an effect on output suggests that innovation in electrical equipment was not directed at gaining market share. One possible explanation is that a recession induces existential business risks and increases the bargaining power of capital owners. With more bargaining power, establishments may have an incentive to increase the capital share at the expense of the labor share. If innovation is irreversible, this incentive to innovate during a recession could lead to jobless recoveries—in fact, the New York Times invented the expression "jobless recoveries" in 1938 to describe the weak recovery from the Great Depression.<sup>26</sup> Unfortunately, the data does not contain variables such as unionization at the plant level, which would inform on bargaining power and would allow a more detailed test of this hypothesis.

# 4.6 Structural estimation of the elasticity of substitution $\sigma$

This subsection provides a structural estimation of  $\sigma$  from the equation of the labor share in 2. The elasticity of substitution between capital and labor has attracted considerable attention in the literature (Krusell et al., 2000, Karabarbounis and Neiman, 2014, Oberfield and Raval, 2014). Estimating  $\sigma$  is a contribution in its own right and the plausible final estimation of  $\sigma = 2.2$  supports the argument above that the reduced-form elasticities should not be interpreted as structural elasticities. The equation for the labor share is the best suited out of the four structural equations because it contains the same information as labor productivity but with a normalized quantity and it has the largest coverage as opposed to electric capital intensity, which is sometimes not reported, and (3) it has no unobserved variables such as TFP in the price equation.

Two adjustments are necessary to take the equation for the labor share to the data. First, the rental rate of electricity is assumed to be proportional to the price of electricity in kilowatt-hours:  $r_{E,i,t} = k p_{E,k,t}$ . Second, the estimation is in changes on the left-hand side but in levels on the right-hand side, making IV estimation unsuitable as it would require two instruments, one for each level of the price of electricity relative to wages. Therefore, this section considers the OLS estimation using the state-level price of electricity and establishment-level wages. Given the similar magnitude of

<sup>&</sup>lt;sup>26</sup>November 27, 1938, "Jobless recovery?"

the coefficients from the OLS and IV regressions in Table 3, this structural estimation is still be informative about the magnitude of  $\sigma$ .

The estimation uses Bayesian methods that are quite suited for non-linear, high-dimensional models with possibly multiple local maxima. The estimation model is:

$$\Delta \log \frac{w_{i,t} L_{i,t}}{p_{i,t} Y_{i,t}} = \Delta \log \left( 1 + \mu \left( 1 + \left( \frac{k r_{E,i,t}}{w_{D,i,t}} \right)^{1-\sigma} \right)^{-1} \right) + \epsilon_i, \quad \epsilon_i \sim \text{Laplace}\left(0, s\right),$$

where  $\mu = \gamma/\beta$  and the variance of the errors is  $2s^2$ . The fat tails of Laplace errors make them robust to outliers. The prior distribution for sis an inverse gamma  $\mathcal{IG}(2, sd_{LSI})$ , where  $sd_{LSI}$  is the standard deviation of the change in the labor share of income in the data, so the mean of the prior distribution of s coincides with the standard deviation of the data. The distributions for the remaining parameters are conditional on sand are independent and truncated normals:  $\mu$  is centered around 1 and constrained to be inside [0.5, 2] (since the parameters of the production function  $\gamma$  and  $\beta$  should be of similar magnitude), k is centered around 0 and constrained to be positive,<sup>27</sup> and  $\sigma$  is centered around 1.67, the estimate of Krusell et al. (2000) for the elasticity of substitution between equipment and unskilled labor, and constrained to be greater or equal than 1. The variance of these independent normals is the random variable s. Normal-inverse-gamma priors is common in Bayesian regression (Johannes and Polson, 2009). The estimation uses a Monte-Carlo, Markov-Chain with Metropolis-Hastings sampling on the conditional posteriors to sample from the posterior distribution of the parameters. The procedure was tested with simulated data and it is remarkably accurate and efficient, then run on real data for 2 million iterations with a burn-in period of 1 million.

Table 5 presents the point estimates, namely the plausible value of  $\sigma = 2.2$ , and also the 95% credibility intervals. This point estimate is within a third of the standard error of the elasticity of substitution between equipment

<sup>&</sup>lt;sup>27</sup>The likelihood is flat with respect to k and the posterior is influenced by the prior. In practice, the results are robust to constraining k to be "small" and the results presented here use this uninformative prior to assess robustness to different values of k.

and unskilled labor in Krusell et al. (2000).<sup>28</sup> Figure 5 shows the distribution of the samples for  $\sigma$  as well as the posterior distribution as a function of  $\sigma$  (holding the remaining parameters at their estimated means). Despite a small peak near  $\sigma = 1$ , the likelihood is highest for  $\sigma$  around 2.2. These results confirm that the reduced-form estimates are not to be interpreted as structural elasticities and the data are consistent with a reasonable estimate for  $\sigma$ .

# 5 Conclusion

This paper provides two contributions. First, it uses a novel identification strategy and estimates the causal effect of electricity using a new instrument—a state's initial loading on the coal technology—to isolate the exogenous shift in the electricity supply curve. Second, it documents the transmission mechanism of cheaper electricity prices with a detailed plantlevel dataset digitized for this project. Concrete establishments adjusted to cheaper electricity prices by increasing electric capital intensity, decreasing the labor share, and reducing conditional labor demand. They also reduced output prices but product demand did not react to this decrease, leading to no effect on output and a reduction in unconditional labor demand. Electricity can explain between 15 and 25 percent of the changes in the labor share of income, labor productivity, electrical intensity, and job loss. These results imply that the elasticity of substitution between electricity and dexterity tasks is greater than 1, and it is estimated at 2.2, which is remarkably similar to Krusell et al. (2000) for the elasticity of substitution between equipment and unskilled labor. The paper also finds heterogeneous effects depending on the depth of the Depression: the effects of cheaper electricity are stronger in counties where the Depression hit hardest. This finding supports the "pit-stop view of recessions," where temporary downturns allow establishments to take advantage of new laborsaving technologies, restructure production, and reduce labor input.

<sup>&</sup>lt;sup>28</sup>Table 1 reports a value for the equivalent of  $(\sigma - 1) / \sigma$  of 0.401 with a standard error of 0.234, while the estimate of  $\sigma = 2.2$  implies  $(\sigma - 1) / \sigma = 0.54$ .

How much can we generalize to the broader economy from this example? The concrete industry is representative of manufacturing as a whole with respect to the electricity share, in the sense that the industry has percentile 44 in the initial share of value added and its change between 1929 and 1935. The non-traded nature of concrete products secures identification and displays a definite example where technology adoption leads establishments to upgrade their machinery, increase productivity, and fire workers.

This paper also contributes to the recent debate on labor market changes since the 1980s: Berger (2012) attributed the emergence of jobless recoveries to the decline in unionization, whereas Jaimovich and Siu (2012) explained them with the adoption of Information and Communication Technologies, either directly with the substitution of computers for workers or indirectly with the ability to offshore jobs to developing countries. If we consider the similarities between computers and electricity (David, 1990) and bear in mind that offshoring was infeasible in the 1930s and unionization rates were increasing until the 1940s (Farber and Western, 2000), then this paper offers historical support for the channel of direct substitution of computers for workers in routine occupations.

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# Tables and Figures

Levels in	n 1929	Change	s 29-35
Mean	S.d.	Mean	S.d.
43,550	78,787	-0.10	0.16
0.02	0.04	0.06	0.15
0.04	0.06	0.04	0.14
0.48	0.21	-0.01	0.10
516	464	-0.04	0.14
43.81	71.57	0.01	0.13
4.48	5.35	0.07	0.16
2.88	0.81	-0.02	0.01
17.56	15.43	-0.02	0.10
12.66	21.07	-0.04	0.13
24,326	48,889	-0.09	0.21
	Levels in Mean 43,550 0.02 0.04 0.48 516 43.81 4.48 2.88 17.56 12.66 24,326	Levels in $1929$ MeanS.d.43,55078,7870.020.040.040.060.480.2151646443.8171.574.485.352.880.8117.5615.4312.6621.0724,32648,889	$\begin{array}{c c c c c c c c c c c c c c c c c c c $

Table 1: Summary statistics for the concrete industry.

**Notes:** see text for the definitions. The changes between 1929 and 1935 are annualized.



Figure 1: Labor share of value added in the concrete industry and in manufacturing.

**Notes:** The labor share of value added is the wage bill divided by revenue minus cost of materials every two years from 1909 to 1939, from the publication Census of Manufactures for the year 1939. Shaded areas are NBER recessions.





Notes: The price of electricity is in cents per kilowatt-hour from the Historical Statistics of the United States (Db234, Db235, and Db237), divided by "Money wages for unskilled labor" (Ba4218). The two vertical lines are the beginning and end of the sample period.

Table 2:	The sampl	le is ba	lanced of	n observab	oles, excep	t for e	lectricity	usage.
					/		•/	()

A. Firm-level vari	ables in 1929				
Dependent	labor	amanlarmaant		elec. capital	labor
variable:	productivity	employment	revenue	intensity	share
coal share $(1927)$	0.194	0.0612	0.116	-0.314**	-0.00619
	(0.0555)	(0.0140)	(0.0266)	(-0.0836)	(-0.00742)
Observations	561	628	630	563	630
R-squared	0.003	0.000	0.001	0.007	0.000

B. Geographic variables

	state-level	Herfindahl
	GDP	index
coal share $(1927)$	-0.00962	-0.0105
	(-0.00771)	(-0.0532)
Observations	630	630
<i>R</i> -squared	0.000	0.003

**Notes:** All dependent variables in logarithms, except for the labor share and the Herfindahl index. Constant omitted. Clustered standard errors in parentheses. Significance levels: \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.1



(a) First-stage regression: initially higher coal reliance causes a decrease in the price of electricity.



(b) Geography of coal power in 1927.

Figure 3: Identification strategy: first-stage regression and geography of coal power.

**Notes:** Top panel: Census of Electric Light and Power Stations (1927 and 1937). Larger circles represent states with more plants but the regression has the same weight for all states. Bottom panel: Census of Electric Light and Power Stations (1927).

productivity, and an increase in electric capital intensity, both in OLS and in IV. Table 3: The decrease in the price of electricity caused a decrease in the labor share of value added, an increase in labor

A. IV results on ratio vari	ables $\Delta$ elec. $\alpha$ 907***	cap. int. 1 119***	$\Delta$ labc	or share	$\Delta$ labor p
	$(1.761) \\ 0.286$	$(1.169) \\ 0.200$	(0.886) - $0.148$	(0.811) - $0.123$	$(2.195) \ 0.252$
housing boom in 1920s		$0.281^{**}$ (0.114)		0.00308 (0.0674)	
Farm share in 1920		-0.197 *** (0.0439) -0.191		0.0522* (0.0317) 0.0802	
Observations First-stage <i>F</i> -statistic	$475 \\ 12.01$	$\begin{array}{c} 464\\ 12.14 \end{array}$	$621 \\ 11.25$	$\begin{array}{c} 608\\ 11.27\end{array}$	448 10.80
Number of states/clusters R OLS results on ratio no.	39 riahles	38	42	41	40
	$\Delta$ elec.	cap. int.	$\Delta$ labe	or share	$\Delta$ labor p
fall in price of electricity	<b>1.801</b> (1.390) <i>0.0818</i>	<b>2.824***</b> (0.945) 0.128	-0.979* (0.571) -0.0707	<b>-1.174**</b> (0.566) -0.0840	<b>1.668*</b> (0.936) <i>0.0892</i>
housing boom in 1920s		$\begin{array}{c} 0.252^{**} \\ (0.118) \\ 0.101 \end{array}$		$\begin{array}{c} 0.0144 \\ (0.0708) \\ 0.00931 \end{array}$	
Farm share in 1920		-0.189*** (0.0424) -0.183		$egin{array}{c} 0.0492 \ (0.0316) \ 0.0756 \end{array}$	
Observations Number of states/clusters	$475 \\ 39$	$\frac{464}{38}$	$621 \\ 42$	608 41	448 40
Number of states/clusters	39	35	42	41	40

levels: \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.1and Snowden (2007), kindly provided by Kenneth Snowden. Constant omitted. Clustered standard errors in parentheses. Significance Notes: farm share of employment in 1920 from the Census of Population and county-level housing construction from Kimbrough

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$\Delta$ outp	ut price	$\Delta \mathrm{rev}$	venue	Δ 01	utput	$\Delta \ \mathrm{empl}$	oyment
-2.977**	$-2.511^{**}$	-1.758	-1.225	1.514	2.299	-3.082***	-2.489***
(1.246)	(1.086)	(1.292)	(1.120)	(2.372)	(2.096)	(1.067)	(0.842)
-0.239	-0.203	-0.0793	-0.0557	0.0688	0.105	-0.168	-0.137
	$-0.192^{***}$		$-0.391^{***}$		-0.0559		$-0.221^{**}$
	(0.0498)		(0.0842)		(0.0933)		(0.106)
	-0.142		-0.161		-0.0234		-0.110
	0.00114		-0.0284		0.0675		0.0363
	(0.0257)		(0.0417)		(0.0444)		(0.0322)
	0.00199		-0.0278		0.0668		0.0430
454	447	630	617	454	447	621	608
10.77	10.90	11.30	11.32	10.77	10.90	11.25	11.27
40	39	42	41	40	39	42	41
$\Delta$ p	$\operatorname{rofits}$	$\Delta$ materi	ials share	$\Delta \text{ emp.}$	no dams	$\tilde{\Delta}$ emp. (er	(try + exit)
-1.980	-1.436	-1.176	-1.099	$-2.759^{*}$	$-2.073^{**}$	$-3.123^{**}$	$-2.928^{**}$
(1.775)	(1.500)	(1.091)	(0.969)	(1.445)	(1.052)	(1.582)	(1.432)
-0.0670	-0.0486	-0.0711	-0.0660	-0.147	-0.111	-0.0918	-0.0865
	-0.408***		0.0679		-0.234**		-0.0964
	(0.136)		(0.0721)		(0.108)		(0.114)
	-0.126		0.0367		-0.119		-0.0238
	-0.0348		0.0512		0.0386		0.0693
	(0.0627)		(0.0384)		(0.0322)		(0.0426)
	-0.0252		0.0665		0.0461		0.0415
602	589	599	587	512	499	2,846	2,795
11.14	11.29	10.82	10.89	7.231	6.785	15.14	13.73
41	40	42	41	38	37	49	48
	$\begin{array}{c c} & \Delta \text{ outp} \\ \hline \textbf{-2.977**} \\ (1.246) \\ \textbf{-0.239} \\ -0$	$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{array}{c c c c c c c c c c c c c c c c c c c $	$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	$ \begin{array}{ c c c c c c c c } \hline $\Delta$ output price $$\Delta$ output price $$\Delta$ revenue $$\Delta$ output translow $$\Delta$ output price $$-1.758 $$-1.225 $$1.84$ $$2.599$ $$0.105$ $$0.105$ $$0.105$ $$0.105$ $$0.105$ $$0.105$ $$0.105$ $$0.105$ $$0.105$ $$0.105$ $$0.105$ $$0.105$ $$0.105$ $$0.105$ $$0.105$ $$0.102$ $$0.102$ $$0.102$ $$0.102$ $$0.00114 $$0.00114 $$0.00842$ $$0.005$ $$0.0075$ $$0.0075$ $$0.0075$ $$0.0075$ $$0.0075$ $$0.0075$ $$0.0075$ $$0.0075$ $$0.0075$ $$0.0075$ $$0.0075$ $$0.0075$ $$0.0075$ $$0.007441$ $$0.0075$ $$0.0075$ $$0.007441$ $$0.007441$ $$0.007441$ $$0.007441$ $$0.007441$ $$0.007441$ $$0.007441$ $$0.007441$ $$0.007441$ $$0.007441$ $$0.007441$ $$0.0075$ $$0.0075$ $$0.0075$ $$0.0075$ $$0.0075$ $$0.007441$ $$0.0075$ $$0.00461$ $$0.0055$ $$0.0055$ $$0.0055$ $$0.0065$ $$0.0055$ $$0.0065$ $$0.0055$ $$0.0055$ $$0.0055$ $$0.0055$ $$0.0055$ $$0.0055$ $$0.0055$ $$0.0065$ $$$0.0055$ $$0.0055$ $$0.0055$ $$0.0055$ $$$0.0055$ $$$0.0055$ $$$0.0055$ $$$0.0055$ $$$0.0055$ $$$0.0055$ $$$0.0055$ $$$0.0055$ $$$$0.0055$ $$$$0.0055$ $$$$0.0055$ $$$$0.0055$ $$$$$0.0055$ $$$$$$$$0.0055$ $$$$$$$$$$$	$\begin{array}{ c c c c c c c c c c c c c c c c c c c$

**Notes:** Constant omitted. Clustered standard errors in parentheses. Significance levels: \*\*\* p<0.01, \*\* p<0.05, \* p<0.1



Figure 4: Summary of regression estimates by deep and shallow Depression: the effects of electricity are stronger where the Depression hit harder.

**Notes:** The center of each box is the estimate of the baseline regressions conditioning on counties where the change in agricultural output is above the median (shallow Depression) or below the median (deep Depression). The whiskers at the end of each box represent the 95% confidence intervals of the estimate, with standard errors clustered at the state-level. The first-stage F-statistic is at the right, as well as the number of clusters / states in each regression.

Table 5: Structural, non-linear estimation of the labor share equation in OLS.

Parameter	$\mu = rac{\gamma}{eta}$	k	$\sigma$	s
Posterior mean	1.13	0.48	2.2	0.47
Credibility interval	[0.53, 1.91]	[0.01, 1.44]	[1.05, 3.23]	[0.43, 0.51]
Notes: author's calcu	lations (see	text).		



Figure 5: Structural, non-linear estimation of  $\sigma$ , the elasticity of substitution between electric capital and routine labor, from the labor share equation.

**Notes:** The histogram is the marginal distribution of the posterior for  $\sigma$  and the line is the posterior distribution function, conditional on the remaining parameters being equal to their posterior estimates.

# A Proofs

**Proof of equations (2-2).** This proof omits the plant index i. The firm maximizes intertemporal profits

$$\sum_{t=0}^{\infty} D_{0,t} \left( p_t A_t K_{NE,t}^{\alpha} L_{ND,t}^{\beta} \left( K_{E,t}^{\rho} + L_{D,t}^{\rho} \right)^{\frac{\gamma}{\rho}} - w_{ND,t} L_{ND,t} - w_{D,t} L_{D,t} - r_{NE,t} K_{NE,t} - r_{E,t} K_{E,t} \right),$$

where  $\rho = (\sigma - 1) / \sigma$  and  $D_{0,t}$  is the discount factor. The firm has no accumulation constraints on capital or labor and the intertemporal maximization problem collapses to a sequence of static maximization problems.

Taking prices as given, the first-order conditions for profit-maximization are:

$$MPK_{NE,t} = \frac{\alpha p_t Y_t}{K_{NE,t}} = r_{NE,t},$$
  

$$MPL_{ND,t} = \frac{\beta p_t Y_t}{L_{ND,t}} = w_{ND,t},$$
  

$$MPK_{E,t} = \gamma p_t Y_t L_{D,t}^{\rho-1} \left(K_{EI,t}^{\rho} + L_{D,t}^{\rho}\right)^{-1} = r_{E,t},$$
  

$$MPL_{D,t} = \gamma p_t Y_t L_{D,t}^{\rho-1} \left(K_{E,t}^{\rho} + L_{D,t}^{\rho}\right)^{-1} = w_{D,t},$$

where MPF is the marginal product of factor F. The ratio of electric capital to dexterity tasks is:

$$\frac{K_{E,t}}{L_{D,t}} = \left(\frac{r_{E,t}}{w_{D,t}}\right)^{-\sigma}$$

The labor share of income is increasing in the rental rate of electrical machinery:

$$\frac{w_t L_t}{p_t Y_t} = \frac{w_{ND,t} L_{ND,t}}{p_t Y_t} + \frac{w_{D,t} L_{D,t}}{p_t Y_t} = \beta + \gamma \left( 1 + \left(\frac{K_{E,t}}{L_{D,t}}\right)^{\rho} \right)^{-1} = \beta + \gamma \left( 1 + \left(\frac{r_{E,t}}{w_{D,t}}\right)^{1-\sigma} \right)^{-1}$$

Labor productivity is decreasing in the rental rate of electrical machinery:

$$\frac{Y_t}{L_t} = \frac{w_t}{p_t} \left( \beta + \gamma \left( 1 + \left( \frac{r_{E,t}}{w_{D,t}} \right)^{1-\sigma} \right)^{-1} \right)^{-1}$$

To compute electric capital intensity, first use the ratio of the marginal products to write the dexterity share of employment as:

$$\frac{L_{D,t}}{L_t} = \frac{L_{D,t}}{L_{ND,t} + L_{D,t}} = \left(1 + \frac{L_{ND,t}}{L_{D,t}}\right)^{-1} = \left(1 + \frac{\beta}{\gamma} \frac{w_{D,t}}{w_{ND,t}} + \frac{\beta}{\gamma} \frac{w_{D,t}}{w_{ND,t}} \left(\frac{r_{E,t}}{w_{D,t}}\right)^{1-\sigma}\right)^{-1}.$$

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Then use this ratio to write electric capital intensity as a decreasing func-

tion of the rental rate of electrical machinery:

$$\frac{K_{E,t}}{L_t} = \frac{K_{E,t}}{L_{D,t}} \frac{L_{D,t}}{L_t} = \left(\frac{r_{E,t}}{w_{D,t}}\right)^{-\sigma} \left(1 + \frac{\beta}{\gamma} \frac{w_{D,t}}{w_{ND,t}} + \frac{\beta}{\gamma} \frac{w_{D,t}}{w_{ND,t}} \left(\frac{r_{E,t}}{w_{D,t}}\right)^{1-\sigma}\right)^{-1},$$
$$= \left(\frac{r_{E,t}}{w_{D,t}}\right)^{-1} \left(\frac{\beta}{\gamma} \frac{w_{D,t}}{w_{ND,t}} + \left(1 + \frac{\beta}{\gamma} \frac{w_{D,t}}{w_{ND,t}}\right) \left(\frac{r_{E,t}}{w_{D,t}}\right)^{\sigma-1}\right)^{-1}$$

**Elasticity of labor share of income to the relative rental rate of electricity.** A tedious but straightforward calculation yields

$$\frac{\partial \log \frac{w_t L_t}{p_t Y_t}}{\partial \log \frac{r_{E_t}}{w_{D,t}}} = (\sigma - 1) \frac{\gamma \left(\frac{r_{E,t}}{w_{D,t}}\right)^{1-\sigma}}{\left(\beta + \gamma \left[1 + \left(\frac{r_{E,t}}{w_{D,t}}\right)^{1-\sigma}\right]^{-1}\right) \left(1 + \left(\frac{r_{E,t}}{w_{D,t}}\right)^{1-\sigma}\right)^2}$$

## **B** Online appendix (NOT FOR PUBLICATION)

#### **B.1** More details on electricity

**Other measures of the price of electricity:** Other measures of the price of electricity at the city-level or state-level exist during this period but they are inferior to the state-level price of electricity used in the baseline regressions.

At the state-level, the Census of Electric Light and Power Stations in 1927 and 1937 reports the price of electricity by municipal utilities but these concern a small market (5% of total kilowatt-hours).<sup>29</sup> The Census of Electric Light and Power Stations also published the price of electricity from both public and private utilities to industrial consumers, split by "small" (retail) and "large" (wholesale), but the "wholesale" numbers exist only half of the states to prevent disclosure of establishment information.

At the city-level, the price of electricity paid by ice plants (Ziebarth, 2011) covers cities that coincide with only 200 concrete plants. Another source, the city-level price of electricity for residential consumers for a typical bill of 25, 100, or 250 kilowatt-hours (Federal Power Commission, 1937) is a survey with measurement error due to retrospective questions asked in 1936, concerns residential consumers instead of industrial consumers, and

<sup>&</sup>lt;sup>29</sup>Census of Electric Light and Power Stations, 1927, page 71.

has a significantly lower amount than the average demand by concrete plants in 1929 (1400 kilowatt-hours per month for concrete plants versus 250 kilowatt-hours for residential consumers), and they are also on different rate schedules, detailed below. To the best of my knowledge, there are no other measures for the price of electricity that are disaggregated geographically over this period.

At the plant-level, the price of electricity is plagued with fixed costs: a Paasche index of the change in the price of electricity at the plant-level aggregated at the state-level is *negatively* related to the change in the state-level price of electricity, but it should be positively related.

**Pricing of electricity and rate schedules of electric utilities:** Electric utilities offered many rate schedules, detailed by the Federal Power Commission in a published glossary in 1936. All rates have a component of capacity, in kilowatts or horsepower, and of energy, in kilowatt-hours or Joules.

An electric bill consists of three types of charges: a customer charge to connect to the grid, a demand charge for the right to use a given capacity from the grid, and an energy charge for consumption of electricity. Most rate schedules also define "maximum demand," which is often the aggregate capacity of electric appliances commonly used. For example, a plant may have a primary motor and a stand-by motor, each with a capacity of 100 kW. The plant may normally use only the primary motor and contracts for a maximum demand of 100 kW. If the plant happens to use both motors at the same time, it will have to pay a higher price for using more capacity than the maximum demand.

Electric utilities offered up to eight different schedules depending on the use of fixed costs. Some examples are the flat rate, the straight line meter rate, the flat demand rate. See the glossary by the Federal Power Commission for more details.

#### B.2 More details on the concrete industry

**Production process:** Concrete production uses cement, water, a coarse aggregate such as crushed stone, and a fine aggregate such as sand. Note that the cement industry is upstream of concrete and burns limestone to produce cement powder, which is lighter and can be transported more easily. The thorough mix of all elements is poured on a mold, and compact with vibrators to make durable and heavy products such as pipes, slabs, and bricks. Plants may crush the stone to make the coarse aggregate.

They may also include steel bars, in which case the product is "reinforced concrete," performs better under stress but is also less durable because of rusting of steel. After the concrete hardens and is delivered, it is "cured" with water or water spraying to ensure that the cement has the moist environment for hardening further and gluing the aggregate.

Main technology: The main technology of the concrete industry is the mixer, which represents half of advertisements for equipment of the trade journal "Concrete and constructional engineering" from 1925 to 1937, and where new mixers were hailed as "labor-savers" and "profit-earners." Mixers directly replace manual mixing but also improve the efficiency of mixing: Orchard (1962, page 404) mentions that "on all but very small jobs concrete is now mixed by machines because of the labour saved and the much more homogenous mix produced." Jerome (1934, page 137) mentions that "the power-driven concrete mixer has practically displaced hand mixing." Before 1929, the start of the period under consideration in this paper, the industry used machines to crush stones and produce blocks, pipes, or bricks. Several other machines were invented during the period: the steel-bender for reinforced concrete, a washer and grader for gravel, and an electric vibrator to compact the mixture. Plants can also use the conveyor belts to move material around the factory and electric hammers for drilling. If plants convey the concrete product over a long distance to the delivery location, the product bears the risk of un-mixing (see Tennessee Valley Authority, 1947).

Matching across years: I matched plants between years 1929 and 1935 according to a similar procedure as Bresnahan and Raff (1991). Some plants sent two schedules to the Census Bureau, such as one by the plant and another by the general office; on two occasions, I aggregated them into a new plant by either averaging their responses if the two schedules covered the same period of operation, or by summing their results if they covered different periods.

I considered that two plants were a match if: (1) one plant is from 1929 and the other from 1935, (2) the two plants are located in the same state, county, and city,<sup>30</sup> (3) one of the following conditions hold: (3a) the name fields coincide (name of plant, name of owner, or their change) and the location fields coincide (same street location in both years, or the street location in a year coincides with the general office location in another year),<sup>31</sup> (3b) the

<sup>&</sup>lt;sup>30</sup>I consider small cities included in larger cities to be the same, such as Flushing and New York. I also considered nearby cities to be the same, such as Edina and Minneapolis, since concrete plants sometimes reported the location of the plant and sometimes the post office address of the general office.

 $<sup>^{31}\</sup>mathrm{For}$  example, this condition holds between a plant in 1935 with name "Gehirs" and

name fields coincide, one of the plants did not report a street location, and they are the only plants in that state, county, and city, and (4) no other plants match criteria (1-3).<sup>32</sup>

This procedure produces 630 plants merged between 1929 and 1935. Out of the 2,435 concrete plants operating in 1929, 74% exited the market, representing 54% of value and 58% of employment. Out of the 1,108 concrete plants operating in 1935, a third entered the market.

The schedules changed slightly across plants. Some concrete plants in 1929 filled a schedule for the Census of Mines and Quarries, which omitted questions about electricity consumption and the quantity of output. For the quantity of output, I only considered products reported with a unit of tons, converting ready-mix concrete from cubic yards to tons with a factor of 2.02817. I set quantity output to a missing value if it represented less than 50% of the value of products. To compute the price of concrete, I aggregate the value and quantity of products that report both and define the price as the ratio.

**Data for the Census of Manufactures in other years:** The schedules from the Census of Manufactures before 1929 and after 1935 did not survive. The Census Bureau used them to compile information for the Statistical Abstracts and other publications of the manufacturing industry. Page 88 of Preliminary Inventory 161<sup>33</sup> mentions that "Most of the manufacturing schedules—but not those described immediately below and in entries 321, 322, and 324—have been disposed of by authorization of Congress." The surviving years for the Census of Manufactures are 1810-1885 and 1929-1935.

**Categories of employment:** The Census asked about two categories of employment, wage-earners and salaried workers, described in detail below. Wage-earners are present in all years and represent around 90% of employment. Officers of the corporation were sometimes reported on a special administrative schedule that is absent from the Census of Manufactures.

In 1929, the Census seems to have included engineers and other technical employees as wage-earners. In 1935, technical employees had a separate

address "23 Conklin St," and a plant in 1929 with owner "Gehirs" and address "Conklin street and Liberty Avenue."

<sup>&</sup>lt;sup>32</sup>If two plants in Rockford, Illinois, share the name "Rockford plant" in 1929, then none is matched to the "Rockford plant" in 1935.

<sup>&</sup>lt;sup>33</sup>This document is unpublished and exists physically at the National Archives and Records Administration. It serves as a reference tool for researchers to know the location of the records to request. It was compiled by Katherine H. Davidson and Charlotte M. Ashby.

category. This paper considers all categories of employment, excluding proprietors (who had no salary) and salaried officers (who were sometimes reported on a different form).

The definition of wage-earners includes "skilled and unskilled workers of all classes" and implies that the two types of employment are different from skilled/unskilled and from dexterity/non-dexterity occupations.

Cyclical sensitivity: The concrete industry was cyclically sensitive and suffered through the Great Depression: the construction trades are the main buyers of concrete and therefore the housing bubble of the 1920s impacted on the industry. Over 70% of concrete firms, representing 50% of value added, exited the market between 1929 and 1935. The main determinant of exit of concrete firms during the Great Depression was the size, productivity, housing bust, and bank suspensions. The housing bubble, as measured by the increase in housing construction at the county-level, is correlated with firm exit, as well as bank suspensions from the FDIC. Furthermore, smaller and unproductive firms also exited the market. This margin of adjustment is unrelated to electricity: the initial level of electricity adoption is uncorrelated with firm exit. The results in this paper are more precise using the sample of continuing firms but are qualitatively similar when using all firms and including entry and exit (using symmetric changes instead of growth rates). Continuing concrete plants had a decrease in output, the labor share, employment, the price of electricity, and an *increase* in the horsepower of electric motors.

**Common products:** The most common products in the sample of continuing concrete plants are building materials, which represent 48% of value in 1929 (especially "Block and tile," which represent 24% of value) and "Conduits and pipes", which represent 23% of value (especially reinforced sewer pipe, which represents 11% of value). These most common products suggest that the construction sector and the population at large are the main customers of the concrete industry. The population's location decisions are slow-moving and likely to be unrelated to the geography of electricity prices, avoiding co-location problems between the customers of the concrete industry and cheap electricity.