Directed Technical Change: Evidence from U.S. Rural Electrification

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Motivation

- Technical progress is a key force in the process of growth and structural change
  - Economic history can shed light on the nature of technological progress
  - One key dimension is directed technical change—the responsiveness of innovation to economic incentives, e.g. factor prices
  - Active area of research with key recent contributions, but still a lot to learn
- This paper: directed technical change in response to rural electrification
  - Interesting context to assess whether innovation is responsive to *local* conditions
    - Agricultural innovations were local, most agricultural patents came from rural counties
  - We shed some light on the nature of technological progress
    - Link a general-purpose technology (electricity) to induced innovation and embodied technical change (in farm machinery)
    - Explore the scope and conditions of induced innovation

Related Literature and Contributions

- Directed technological change (Olmstead and Rhode, 1993; Newell et al, 1999; Popp, 2002; Finkelstein; 2004; Acemoglu and Linn, 2004 Acemoglu et al 2012; Hanlon 2015; San, 2021)
  - We add to previous evidence by studying a different context
    - We study innovations induced by new energy source, instead of factor availability
    - Key role of local conditions (spatial variation in electricity access and product mix)
- Electrification
  - Impacts on economic growth, productivity, labor markets, structural change (e.g., David, 1990; World Bank, 2008; Olanrele, 2020; Fiszbein et al., 2020; Vidart, 2024)
  - Effects on the rural sector (Kitchens and Fishback, 2015; Lewis and Severnini, 2020)
  - Developing countries (Burlig and Preonas, 2021; Dinkelman, 2011; Lee et al., 2020)
  - We directly examine the effects of electricity on innovation (implicitly an important mechanism in previous studies)
- Agricultural innovation
  - We add to previous evidence of remarkable dynamism (Olmstead and Rhode, 2008)

What we do

- We study how access to electricity affected the direction of the technical change
  - We address endogeneity of local conditions using cross-county and cross-product variation in diff-in-diff approach (Rajan & Zingales, 1998; Ciccone & Papaioannou, 2023)
- We identify the impacts of local access to electricity on agricultural innovation
  - New GPT created wide array of potential applications across farm products $\longrightarrow$ great context to study the scope and conditions of induced innovation
  - Direct evidence on a key mechanism underlying the widespread economic effects of electricity documented in previous studies
- We find heterogeneous effects, consistent with literature on induced innovation
  - Impacts were stronger where market access was larger and where labor costs were higher

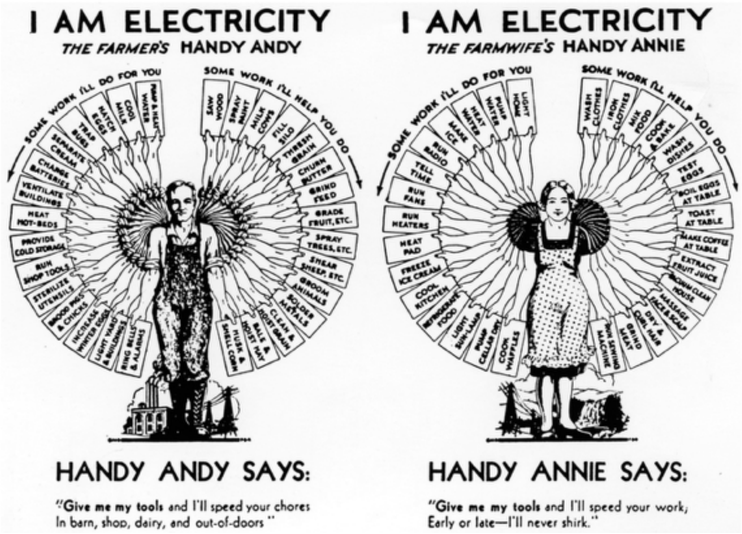
Roadmap

- **Background**
- Empirical Strategy and Data
- Main Results
- Output Results
- Further Analysis

Historical Background: Electricity on Farms

- A lot of emphasis on the role of electrification within the household (Greenwood et al. 2005; Bailey and Collins, 2011; Lewis, 2018)
- Electricity improved farm productivity (Kitchens and Fishback, 2015; Lewis and Severnini, 2020; Hirsh, 2022)
  - electric milking and cooled storage
  - electric heaters and lights for hens and eggs
  - grain elevators
  - irrigation
- Wide array of potential applications across farm products in response to new GPT were publicized by electricity companies and REA
- Innovations in electric farm machinery started early; most attempts did not materialize, but many did
  - 30 profitable uses of electricity on farms in 1913 emphasized by NELA
  - 200+ profitable uses documented in 1930 (NELA-CREA)

Historical Background: Electricity on Farms



Source: Idaho Power Company 1933 advertisement, reproduced in Hirsh (2022).

Conceptual Background: Directed Technical Change

- Key idea: innovations depend on their profitability
- Captured in a simple model adapted from Acemoglu (2002)
  - Two types of machines: complementary with labor or with energy
  - "**Weak induced-bias hypothesis**": energy abundance (access to electricity) leads to more energy-intensive innovations... as net effect from two forces:
    - *Price effect*: more invention in machines that complement the scarce factor
    - *Market size effect*: more invention in machines that complement the abundant factor
  - Heterogeneous effects: scope and limits of induced innovation
    - Smaller effects if expanding production reduces prices, which is less likely if agricultural products are commodities
    - Incentives stronger when labor is scarcer or more expensive

Roadmap

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- **Empirical Strategy and Data**
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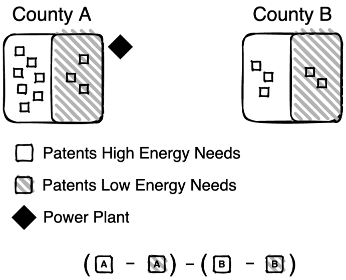
Empirical Strategy (I): Basic Idea

- We want to understand whether access to cheap electricity directed innovation towards electricity in agricultural activities that would get larger benefits from it
  - We cannot just compare counties with and without cheaper electricity because the location of power plants may have been demand-driven
  - We leverage cross-county cross-product variation, as in cross-country cross-industry approaches (Rajan and Zingales, 1998; Ciccone and Papaioannou, 2023)



Empirical Strategy (II): Difference-in-differences

Effect on total and electric patents

$$\Delta(y)_{ict} = \gamma_t \cdot \text{Energy intensity}_{i,0} \cdot Prox_c + \theta_{it} + \theta_{ct} + \epsilon_{ict} \quad (1)$$

- i denotes a crop and c a county.
- $\Delta(y)_{ict}$ is the difference in the total number of patents (or electric patents) between a given 5-year period relative to 1890–1895
- Energy intensity$_{i,0}$ measures the crop-specific initial share of patents that required energy in 1850-1905
- $Prox_c$ is dummy variable if the county is less than 70 km away from the nearest power plant
- γ_t measures the differential impact of access to electricity on agricultural innovation for a specific crop given its location
- θ_{it} and θ_{ct} are crop and county FE

Empirical Strategy (III): Triple difference

Differential effect on electric patents

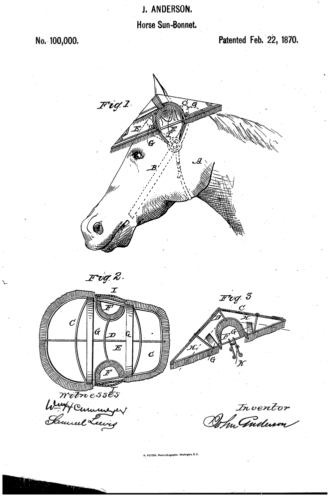
$$\Delta(y)_{icet} = \gamma_t \cdot \text{Energy intensity}_{i,0} \cdot Prox_c \cdot Electric_e + \theta_{it} + \theta_{ct} + \theta_{et} + \epsilon_{icet} \qquad (2)$$

- where $Electric_e$ is a dummy that denotes if the patents are electric or not.
- θ_e are electric patents fixed effects.
- $\Delta(y)_{icet}$ corresponds to the change in the total number of electric/non-electric patents' applications between each 5-years period relative to 1890-1895 in each country and for each crop.
- γ_t measures the differential impact of the access of electricity on the electric agricultural innovation compared to non-electric innovations for a specific crop given its location.

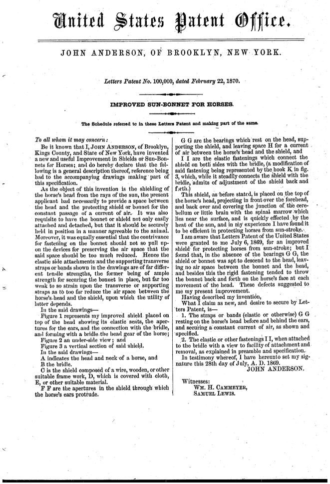
Measuring Agricultural Innovation

- Data from the United States Patent and Trademark Office (USPTO) through Google Patents
- Focus on innovations related to agriculture
  CPC classes A01B, A01C, A01G, A01H, A01K, and A01J (restricted to milk)
- We identify electrical patents and specific crops with a text search algorithm (with random manual checks for verification)
- Links with HistPat dataset (Petralia et al, 2016) to obtain geographical locations
- In our analysis, we use citations as a proxy for quality and distinguish between new and old innovators

Examples (I): Horse Sun-Bonnet



(a) Image



United States Patent Office.

JOHN ANDERSON, OF BROOKLYN, NEW YORK.

Letters Patent No. 100,000, *dated February* 22, 1870.

IMPROVED SUN-BONNET FOR HORSES.

The Schedule referred to in these Letters Patent and making part of the same.

To all whom it may concern:

Be it known that I, John Anderson, of Brooklyn, Kings County, and State of New York, have invented a new and useful Improvement in Shields or Sun-Bonnets for Horses; and do hereby declare that the following is a general description thereof, reference being had to the accompanying drawings making part of this specification.

As the object of this invention is the shielding of the horse's head from the rays of the sun, the present applicant had necessarily to provide a space between the head and the protecting shield or bonnet for the constant passage of a current of air. It was also requisite to have the bonnet or shield not only easily attached and detached, but that it should be securely held in position in a manner agreeable to the animal. Moreover, it was equally essential that the contrivance for fastening on the bonnet should not so pull upon the devices for preserving the air space that the said space should be too much reduced. Hence the elastic side attachments and the supporting transverse straps or bands shown in the drawings are of far different tensile strengths, the former being of ample strength for securing the bonnet in place, but far too weak to so strain upon the transverse or supporting straps as to too far reduce the air space between the horse's head and the shield, upon which the utility of latter depends.

In the said drawings—

Figure 1 represents my improved shield placed on top of the head showing its elastic seats, the apertures for the ears, and the connection with the bridle, and forming with a bridle the head gear of the horse;

Figure 2 an under-side view; and

Figure 3 a vertical section of said shield.

In the said drawings—

A indicates the head and neck of a horse, and

B the bridle.

C is the shield composed of a wire, wooden, or other suitable frame work, D, which is covered with cloth, E, or other suitable material.

F F are the apertures in the shield through which the horse's ears protrude.

G G are the bearings which rest on the head, supporting the shield, and leaving space H for a current of air between the horse's head and the shield, and

I I are the elastic fastenings which connect the shield on both sides with the bridle, (a modification of said fastening being represented by the hook K in fig. 3, which, while it steadily connects the shield with the bridle, admits of adjustment of the shield back and forth.)

This shield, as before stated, is placed on the top of the horse's head, projecting in front over the forehead, and back over and covering the junction of the cerebellum or little brain with the spinal marrow which lies near the surface, and is quickly effected by the heat of the sun, and in my experience I have found it to be efficient in protecting horses from sun-stroke.

I am aware that Letters Patent of the United States were granted to me July 6, 1869, for an improved shield for protecting horses from sun-stroke; but I found that, in the absence of the bearings G G, the shield or bonnet was apt to descend to the head, leaving no air space between the bonnet and the head, and besides this the rigid fastening tended to throw the bonnet back and forth on the horse's face at each movement of the head. These defects suggested to me my present improvement.

Having described my invention,

What I claim as new, and desire to secure by Letters Patent, is—

1. The straps or bands (elastic or otherwise) G G resting on the horse's head before and behind the ears, and securing a constant current of air, as shown and specified.

2. The elastic or other fastenings I I, when attached to the bridle with a view to facility of attachment and removal, as explained in preamble and specification.

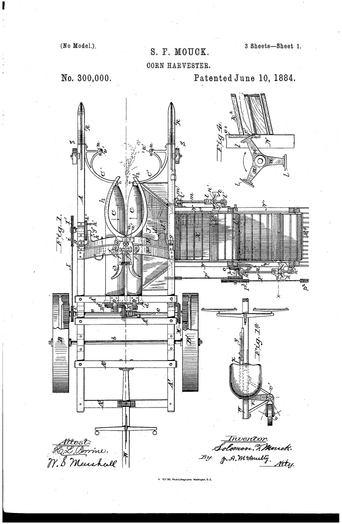
In testimony whereof, I have hereunto set my signature this 28th day of July, A. D. 1869.

JOHN ANDERSON.

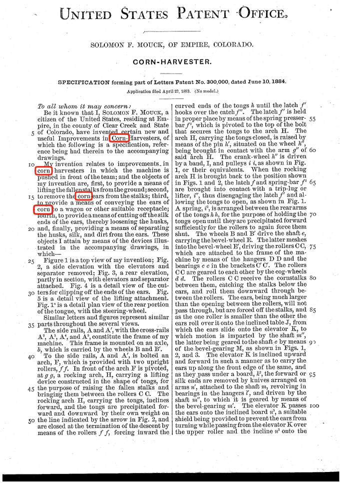
Witnesses:
Wm. H. Cammeyer,
Samuel Lewis.

(b) Text

Examples (II): Corn Harvester



(c) Image



UNITED STATES PATENT OFFICE.

SOLOMON F. MOUCK, OF EMPIRE, COLORADO.

CORN-HARVESTER.

SPECIFICATION forming part of Letters Patent No. 300,000, dated June 10, 1884.

Application filed April 27, 1883. (No model.)

To all whom it may concern:

Be it known that I, SOLOMON F. MOUCK, a citizen of the United States, residing at Empire, in the county of Clear Creek and State of Colorado, have invented certain new and useful Improvements in Corn-Harvesters, of which the following is a specification, reference being had therein to the accompanying drawings.

My invention relates to improvements in corn harvesters in which the machine is pushed in front of the team; and the objects of my invention are, first, to provide a means of lifting the fallen stalks from the ground; second, to remove the corn ears from the stalks; third, to provide a means of conveying the ears of corn to a wagon or other suitable receptacle; fourth, to provide a means of cutting off the silk ends of the ears, thereby loosening the husks, and, finally, providing a means of separating the husks, silk, and dirt from the ears. These objects I attain by means of the devices illustrated in the accompanying drawings, in which—

Figure 1 is a top view of my invention; Fig. 2, a side elevation with the elevators and separator removed; Fig. 3, a rear elevation, partly in section, with elevators and separator attached. Fig. 4 is a detail view of the cutters for clipping off the ends of the ears. Fig. 5 is a detail view of the lifting attachment. Fig. 1^a is a detail plan view of the rear portion of the tongue, with the steering-wheel.

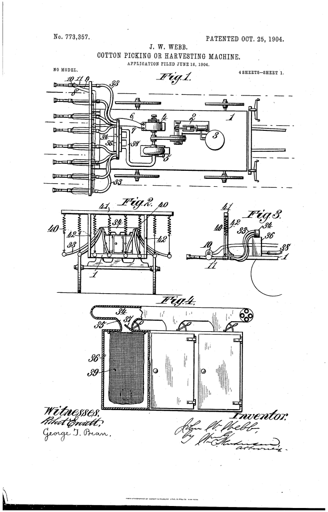
Similar letters and figures represent similar parts throughout the several views.

The side rails, A and A′, with the cross-rails A^2, A^3, A^4, and A^5, constitute the frame of my machine. This frame is mounted on an axle, *b*, which is carried by the wheels B and B′.

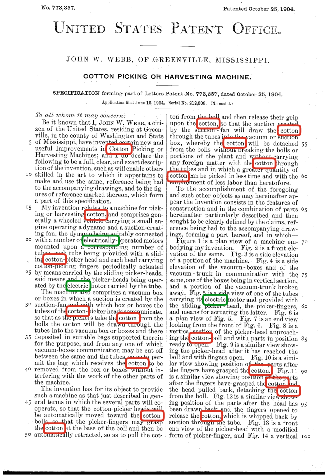
To the side rails, A and A′, is bolted an arch, F, which is provided with two upright rollers, *f f*. In front of the arch F is pivoted, at *g g*, a rocking arch, H, carrying a lifting device constructed in the shape of tongs, for the purpose of raising the fallen stalks and bringing them between the rollers C C. The rocking arch H, carrying the tongs, inclines forward, and the tongs are precipitated forward and downward by their own weight on the line indicated by the arrow in Fig. 2, and are closed at the termination of the descent by means of the rollers *f f*, forcing inward the curved ends of the tongs *h* until the latch *f′* hooks over the catch *f″*. The latch *f′* is held in proper place by means of the spring presser-bar f^2, which is pivoted to the top of the bolt that secures the tongs to the arch H. The arch H, carrying the tongs closed, is raised by means of the pin *h′*, situated on the wheel *h″*, being brought in contact with the arm *g′* of said arch H. The crank-wheel *h″* is driven by a band, I, and pulleys *i i*, as shown in Fig. 1, or their equivalents. When the rocking arch H is brought back to the position shown in Figs. 1 and 2, the latch *f* and spring-bar f^2 are brought into contact with a trip-lug or lifter, *i″*, thus disengaging the latch *f′* and allowing the tongs to open, as shown in Fig. 1. A spring, i^3, is arranged between the rear arms of the tongs *h h*, for the purpose of holding the tongs open until they are precipitated forward sufficiently for the rollers to again force them shut. The wheels B and B′ drive the shaft *e*, carrying the bevel-wheel E. The latter meshes into the bevel-wheel E′, driving the rollers C C, which are attached to the frame of the machine by means of the hangers D D and the bearings *c c* in the brackets C′ C′. The rollers C C are geared to each other by the cog-wheels *d d*. The rollers C C receive the cornstalks between them, catching the stalks below the ears, and roll them downward through between the rollers. The ears, being much larger than the opening between the rollers, will not pass through, but are forced off the stalks, and as the one roller is smaller than the other the ears roll over it onto the inclined table J, from which the ears slide onto the elevator K, to which motion is imparted by the shaft *m″*, the latter being geared to the shaft *e* by means of the bevel-gearing M, as shown in Figs. 1, 2, and 3. The elevator K is inclined upward and forward in such a manner as to carry the ears up along the front edge of the same, and as they pass under a board, k^2, the forward or silk ends are removed by knives arranged on arms *n′*, attached to the shaft *m*, revolving in bearings in the hangers *l′*, and driven by the shaft *m″*, to which it is geared by means of the bevel-gearing *m′*. The elevator K passes the ears onto the inclined board n^3, a suitable shield being provided to prevent the ears from turning while passing from the elevator K over the upper roller and the incline n^3 onto the

(d) Text

Examples (III): Cotton Picker



(e) Image



No. 773,357. Patented October 25, 1904.

UNITED STATES PATENT OFFICE.

JOHN W. WEBB, OF GREENVILLE, MISSISSIPPI.

COTTON PICKING OR HARVESTING MACHINE.

SPECIFICATION forming part of Letters Patent No. 773,357, dated October 25, 1904.

Application filed June 16, 1904. Serial No. 212,808. (No model.)

To all whom it may concern:

Be it known that I, JOHN W. WEBB, a citizen of the United States, residing at Greenville, in the county of Washington and State of Mississippi, have invented certain new and useful Improvements in Cotton Picking or Harvesting Machines; and I do declare the following to be a full, clear, and exact description of the invention, such as will enable others skilled in the art to which it appertains to make and use the same, reference being had to the accompanying drawings, and to the figures of reference marked thereon, which form a part of this specification.

My invention relates to a machine for picking or harvesting cotton, and comprises generally a wheeled vehicle carrying a small engine operating a dynamo and a suction-creating fan, the dynamo being suitably connected with a number of electrically-operated motors mounted upon a corresponding number of tubes, each tube being provided with a sliding cotton-picker head and each head carrying cotton-picking fingers periodically actuated by means carried by the sliding picker-heads, said means and the picker-heads being operated by the electric motor carried by the tube.

The machine also comprises a vacuum box or boxes in which a suction is created by the suction-fan and with which box or boxes the tubes of the cotton-picker heads communicate, so that as the pickers take the cotton from the bolls the cotton will be drawn through the tubes into the vacuum box or boxes and there deposited in suitable bags supported therein for the purpose, and from any one of which vacuum-boxes communication may be cut off between the same and the tubes, so as to permit the bag which receives the cotton to be removed from the box or boxes without interfering with the work of the other parts of the machine.

The invention has for its object to provide such a machine as that just described in general terms in which the several parts will coöperate, so that the cotton-picker heads will be automatically moved toward the cotton-bolls, so that the picker-fingers may grasp the cotton at the base of the boll and then be automatically retracted, so as to pull the cotton from the boll and then release their grip upon the cotton, so that the suction created by the suction-fan will draw the cotton through the tubes into the vacuum or suction box, whereby the cotton will be detached from the bolls without breaking the bolls or portions of the plant and without carrying any foreign matter with the cotton through the tubes and in which a greater quantity of cotton can be picked in less time and with the employment of less labor than heretofore.

To the accomplishment of the foregoing and such other objects as may hereinafter appear the invention consists in the features of construction and in the combination of parts hereinafter particularly described and then sought to be clearly defined by the claims, reference being had to the accompanying drawings, forming a part hereof, and in which—

Figure 1 is a plan view of a machine embodying my invention. Fig. 2 is a front elevation of the same. Fig. 3 is a side elevation of a portion of the machine. Fig. 4 is a side elevation of the vacuum-boxes and of the vacuum-trunk in communication with the same, one of the boxes being in vertical section, and a portion of the vacuum-trunk broken away. Fig. 5 is a side view of one of the tubes carrying its electric motor and provided with the sliding picker-head, the picker-fingers, and means for actuating the latter. Fig. 6 is a plan view of Fig. 5. Fig. 7 is an end view looking from the front of Fig. 6. Fig. 8 is a vertical section of the picker-head approaching the cotton-boll and with parts in position ready to open. Fig. 9 is a similar view showing the picker-head after it has reached the boll and with fingers open. Fig. 10 is a similar view showing position of the parts after the fingers have grasped the cotton. Fig. 11 is a similar view showing position of the parts after the fingers have grasped the cotton and the head pulled back, detaching the cotton from the boll. Fig. 12 is a similar view showing position of the parts after the head has been drawn back and the fingers opened to release the cotton, which is whipped back by suction through the tube. Fig. 13 is a front end view of the picker-head with a modified form of picker-finger, and Fig. 14 a vertical

(f) Text

Measuring Crop Energy Needs

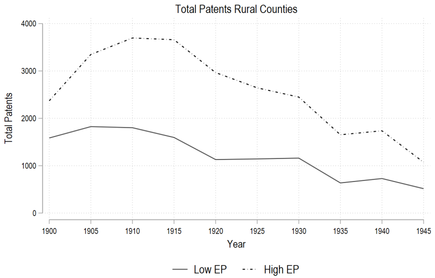
- To construct measures for crop-level energy-intensity ($\text{Energy Intensity}_{i,0}$), we use the same patents data
- We search for energy-related terms ("steam," "horsepower") before rural electrification (1850-1905)
- We calculate the fraction of patents associated to each each agricultural product that has energy-related terms

Measuring Crop Energy Needs

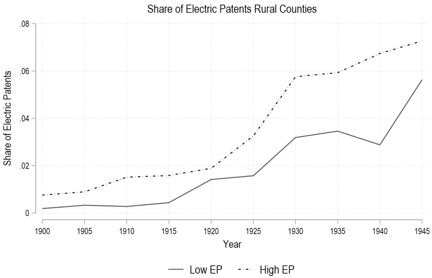
Crop	Main Energy Need Measure	Alternative Measures for Energy Needs			Proportion of Patents in 1910-1940
	Share Energy 2 1850-1905	*Share Energy 2 1850-1890*	*Share Energy 2 1850-1870*	*Share Energy 1850-1890*	
Milk	0.286	0.150	0.023	0.218	1.34%
Animal husbandry	0.074	0.047	0.006	0.113	16.06%
Nuts	0.059	0.059	0	0.294	0.20%
No-Crop	0.051	0.038	0.017	0.199	29.80%
Strawberry	0.047	0.028	0	0.066	0.40%
Wheat	0.030	0.030	0.010	0.120	0.50%
Tobacco	0.023	0.008	0	0.038	0.43%
Onion	0.022	0.022	0	0.043	0.56%
Rice	0.018	0.018	0.018	0.018	0.27%
Grass	0.017	0.010	0.004	0.101	7.92%
Grape	0.012	0.006	0	0.069	2.78%
Cotton	0.008	0.006	0.003	0.041	7.19%
Grain	0.007	0.005	0.002	0.107	9.37%
Potato	0.006	0.002	0.001	0.061	2.80%
Corn	0.004	0.003	0.001	0.059	11.51%
Hay	0.004	0.002	0.001	0.107	5.82%
Apple	0	0	0	0.045	0.37%
Asparagus	0	0	0	0	0.14%
Bean	0	0	0	0.083	1.28%
Celery	0	0	0	0	0.13%
Citrus	0	0	0	0	0.19%
Cucumber	0	0	0	0.200	0.03%
Lettuce	0	0	0	0	0.08%
Melon	0	0	0	0	0.05%
Oats	0	0	0	0.037	0.15%
Rye	0	0	0	0	0.04%
Sugarbeet	0	0	0	0	0.21%
Sugarcane	0	0	0	0.103	0.20%
Tomato	0	0	0	0	0.19%

Suggestive Time Pattern in Patents by Crop Group

Figure: Patents in Rural Counties by Initial Energy Intensity



(a) Total Patents



(b) Share Electric Patents

- High EP: main energy need measure above 0.025
- Low EP: main energy need measure below 0.025

Measuring Proximity to Electricity Sources

To proxy for access to electricy ($Prox_c$), we use various county-level measures of proximity to electric power sources

- distance to the nearest large hydroppower plant in 1912 (from Fiszbein, Lafortune, Lewis, and Tessada, 2020)
- distance to electric power grid in 1935 (from Fishback and Kitchens, 2015)
- in robustness checks, uses electricity capacity by county in 1911 and 1919 (from Vidart, 2024)

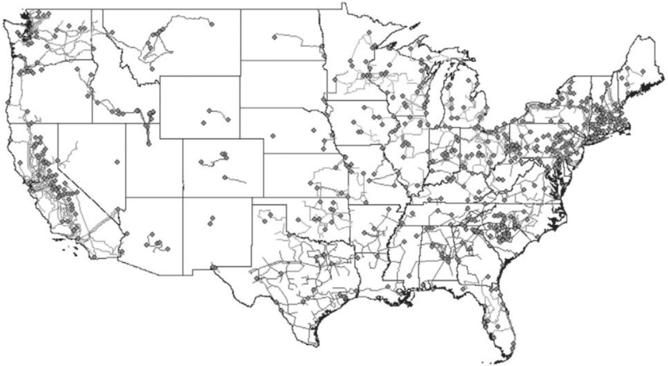
Proximity to Electricity (1912)

Figure: Location of Power Plants in 1912

Source: Census of Electrical Industries 1912, digitized by Fiszbein, Lafortune, Lewis and Tessada (2020)

Proximity to Electricity (1935)

Figure: Location of Electric Power Grid and Plants in 1935



Source: Kitchens and Fishback (2015), constructed with data from the Federal Power Commission

Suggestive Evidence of Correlation Between Drivers and Innovation

	% Electric Patents (1)	% Electric Patents (2)	% Electric Patents (3)
Crop Energy Intensity 1850-1905	0.965***		
	(0.094)		
County with close plant in 1912		0.016***	
		(0.005)	
County with close plant in 1935			0.016***
			(0.005)
N	8,883	8,883	8,883
Crop FE	✗	✓	✓
County FE	✓	✗	✗
Year FE	✓	✓	✓

Roadmap

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Cross-Section Results

Cross-Section Results

Pooled Regression

Table: Change in number of patents by 5-year periods relative to 1890-1895

	Electric (1)	Non-Electric (2)	Electric (3)	Non-Electric (4)
Within 70km of a plant*Energy intensity	0.199^{***}	0.219		
	(0.037)	(0.207)		
Log Inv. Dist. to nearest plant*Energy intensity			0.086^{***}	0.188^{*}
			(0.020)	(0.100)
Mean change for counties more than 70km away	0.006	-0.042	0.006	-0.042
Crop FE	✓	✓	✓	✓
County FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
N	64182	64182	64182	64182

Differential impact on electric patents

Table: Differential effect on electric patents

	$\Delta(Patents)$ (1)	$\Delta(Patents)$ (2)
Within 70km of power plant *Energy Intensity*Electric	0.402** (0.190)	
Log Inverse Distance to plant *Energy Intensity*Electric		0.085 (0.091)
N	128364	128364

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Use electricity

Farms reporting	(1) Electricity	(2) Electric motors	(3) Motor trucks	(4) Tractors
Within 70 km of power plant	189.256***	75.643***	131.407***	81.472***
	(18.106)	(8.932)	(14.729)	(16.499)

	(1) Electricity expenditure	(2) Machine expenditure	(3) N Motor trucks	(4) N electric motors
Within 70 km of power plant	14427.84***	11505.76	145.654***	114.275***
	(2914.771)	(13412.26)	(15.803)	(13.455)

Agriculture Output: Acreage - Pooled OLS

	(1)	(2)	(3)	(4)
	Δ output	Δ% output	Δ% output 2	Δ Ln(output)
Within 70km of power plant *Energy Intensity	6290.886***	175.704**	−185.672	0.469***
	(1772.124)	(77.255)	(189.797)	(0.091)
Crop FE	YES	YES	YES	YES
County FE	YES	YES	YES	YES
Year FE	YES	YES	YES	YES
N	148302	100245	148302	148302

Roadmap

- Background
- Empirical Strategy and Data
- Main Results
- Output Results
- **Further Analysis**

Further Analysis

- Types of activity
- Identity of Inventors
- Impactful Patents
- Human Capital

Electric Patents by Type of Activity

	(1) Pre-Harvest	(2) Post-Harvest	(3) In pictures	(4) Out of pictures
Within 70km of power plant *Energy Intensity	0.033**	0.130***	0.149***	0.047**
	(0.015)	(0.026)	(0.031)	(0.014)
Crop FE	✓	✓	✓	✓
County FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
N	64182	64182	64182	64182

- Terms indicating post-harvest activities: grind; harrow; harvest; mow; pack; pump.

Patenting by whom?

	(1) Old inventors	(2) New inventors	(3) Assigned	(4) Non-Assigned
Within 70km of power plant *Energy Intensity	0.039***	0.159***	0.069***	0.130***
	(0.013)	(0.034)	(0.021)	(0.030)
Crop FE	✓	✓	✓	✓
County FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
N	64182	64182	64182	64182

Irrelevant patenting?

	More than 10 cites		More than 5 cites	
	(1)	(2)	(3)	(4)
Within 70km of power plant *Energy Intensity	0.052***		0.109***	
	(0.014)		(0.023)	
Log Inverse Distance to plant*Energy Intensity		0.027***		0.056***
		(0.007)		(0.013)
Crop FE	✓	✓	✓	✓
County FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
N	64182	64182	64182	64182

Human Capital

	(1)	(2)	(3)
	Dependent Variable: Electrical Patents		
Variable capturing human capital:	Experimental Stations	Engineers	Rural Colleges
Within 70km of power plant × Energy Intensity	0.199***	0.175***	0.441**
	(0.037)	(0.045)	(0.144)
Energy Intensity × *Variable*	-0.042	0.000	0.107
	(0.386)	(0.001)	(0.071)
Within 70km of power plant × Energy Intensity × *Variable*	0.035	0.000	0.168*
	(0.473)	(0.001)	(0.089)
Crop FE	✓	✓	✓
County FE	✓	✓	✓
Year FE	✓	✓	✓
N	64,182	56,694	64,140

Concluding Remarks

- Provide an empirical test of the directed technological change where even local incentives appear to matter
- Local availability of cheaper electricity increases electric patenting, no significant effects for non-electric patents.
  - Mostly in post-harvest activities; tasks where electricity was anticipated to be useful
  - Mostly by new inventors and non-assigned
  - Visible even among highly-cited
- Heterogeneity exercises
  - Larger impacts in bigger markets and those with more labor shortages
  - No complementary role for education or state interventions
- One additional channel through which electrification can have affected local economic outcomes. May have impacted subsequently labor markets, still to explore.

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Suggestive Evidence Over Time

Period:	1910-1915	1915-1920	1920-1925	1925-1930	1930-1935	1935-1940	1940-1945	1945-1950
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: By energy intensity of crop								
Energy Intensity	0.327***	0.355***	0.548**	0.671***	0.984***	1.058***	2.169***	1.663***
	(0.102)	(0.112)	(0.245)	(0.198)	(0.277)	(0.401)	(0.486)	(0.502)
County and Year FE	✓	✓	✓	✓	✓	✓	✓	✓
Panel B: By whether the county had a power plant within 70km in 1912								
Plant within 70km in 1912	0.000	0.007	0.012	0.026**	0.025*	0.032*	-0.008	0.016
	(0.006)	(0.006)	(0.009)	(0.011)	(0.015)	(0.018)	(0.017)	(0.024)
Panel C: By whether the county had a power plant within 70km in 1935								
Plant within 70km in 1935	0.007	-0.008	0.015**	0.026***	0.033**	0.039**	0.037**	-0.012
	(0.005)	(0.007)	(0.007)	(0.010)	(0.014)	(0.016)	(0.016)	(0.025)
Crop and Year FE	✓	✓	✓	✓	✓	✓	✓	✓

Pooled Regression All patents

Table: Change in number of patents by 5-year periods relative to 1890-1895

	Electric (1)	Non-Electric (2)	Electric (3)	Non-Electric (4)
Within 70km of a plant*Energy intensity	0.122***	0.131		
	(0.023)	(0.171)		
Log Inv. Dist. to nearest plant*Energy intensity			0.058***	0.165*
			(0.020)	(0.100)
Mean change for counties more than 70km away	0.006	-0.042	0.006	-0.042
Crop FE	✓	✓	✓	✓
County FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
N	74244	74244	74244	74244

Robustness checks (I): alternative specifications

	Δ Electric Patents
Panel A: Base year as control	
Within 70km of power plant *Energy Intensity	0.205***
	(0.036)
N	64,182
Panel B: Change Base Period	
Within 70km of plant * Energy Intensity	0.200***
	(0.036)
N	64,182
Panel C: County-crop clusters	
Within 70km of plant * Energy Intensity	0.199***
	(0.036)
N	64,182

Robustness checks (II): geography

	Δ Electric Patents
Panel D: County Outliers	
Within 70km of plant * Energy Intensity	0.192***
	(0.037)
N	63,252
Panel E: Excluding extremely Close Counties	
Within 70km of plant * Energy Intensity	0.223***
	(0.047)
N	50,724
Panel F: Water Patents	
Within 70km of plant * Energy Intensity	0.090
	(0.073)
N	64,182

Robustness checks (III): outliers, alternative measures of intensity

	Δ Electric Patents
Panel G: Crop Outliers	
Within 70km of plant * Energy Intensity	0.197***
	(0.037)
N	62,371
Panel H: Share Energy 2 1850-1870	
Within 70km of plant * Energy Intensity	0.679***
	(0.195)
N	64,182
Panel I: Share Energy 1 1850-1890	
Within 70km of plant * Energy Intensity	0.072***
	(0.022)
N	64,182

Robustness checks (IV): excluding salient products

	Δ Electric Patents
Panel J: Without Animal Husbandry	
Within 70km of plant * Energy Intensity	0.151***
	(0.035)
N	56,460
Panel K: Without Milk	
Within 70km of plant * Energy Intensity	0.270***
	(0.074)
N	63,102
Panel L: Without No-Crop	
Within 70km of plant * Energy Intensity	0.205***
	(0.041)
N	53,316

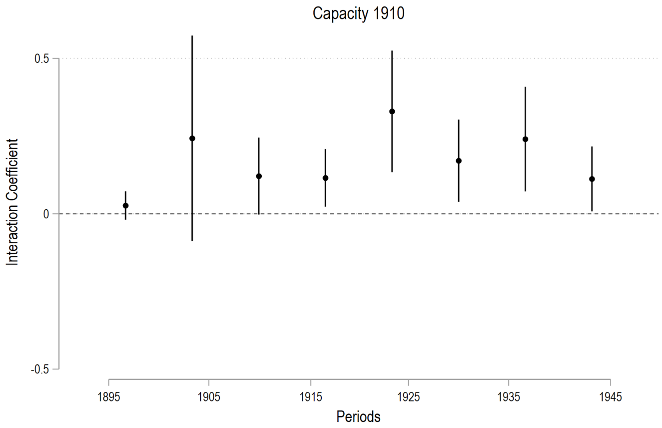
Robustness checks (V): alternative groupings

	Δ Electric Patents
Panel M: Only large groups 1850-1905	
Within 70km of plant * Energy Intensity	0.181***
	(0.037)
N	51,648
Panel N: Grouping marginal crops only 1850-1905	
Within 70km of plant * Energy Intensity	0.199***
	(0.037)
N	61,626
Panel O: Grouping by ICC	
Within 70km of plant * Energy Intensity	0.200***
	(0.037)
N	62,736

Robustness checks (VI):

Alternative measure of proximity in 1910 (from Vidart, 2024)

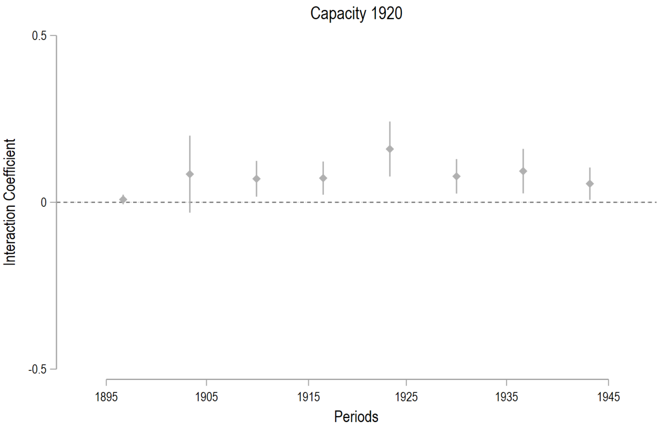
Figure: Effect of electricity on agricultural electric innovations in rural counties



Robustness checks (VII)

Alternative measure of proximity in 1920 (from Vidart, 2024)

Figure: Effect of electricity on agricultural electric innovations in rural counties



Robustness checks (VIII)

Alternative measure of proximity (from Vidart, 2024), pooling across periods

Table: Change in number of patents by 5-year periods relative to 1890-1895

	Electric (1)	Non-Electric (2)	Electric (3)	Non-Electric (4)
Capacity	0.088***	0.086		
*Energy intensity	(0.021)	(0.064)		
Change in			0.142***	0.128
capacity*Energy intensity			(0.031)	(0.097)
Crop FE	✓	✓	✓	✓
County FE	✓	✓	✓	✓
Year FE	✓	✓	✓	✓
N	64,182	64,182	64,182	64,182