Electrification, Agricultural Productivity and Deforestation in Brazil

Juliano Assunção
PUC-Rio and CPI

Molly Lipscomb
Univ. of Virginia

Dimitri Szerman
PUC-Rio and CPI

Ahmed Mushfiq Mobarak
Yale University

GGKP 2017

Washington DC

Electrification, Agricultural Productivity and Deforestation in Brazil

Juliano Assunção
PUC-Rio and
Climate Policy Initiative

Molly Lipscomb
Univ. of Virginia

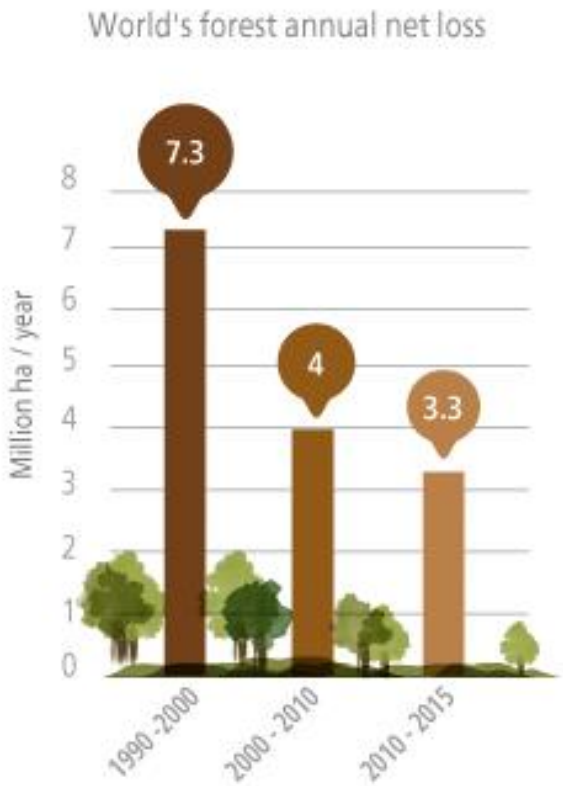
Dimitri Szerman
PUC-Rio and
Climate Policy Initiative

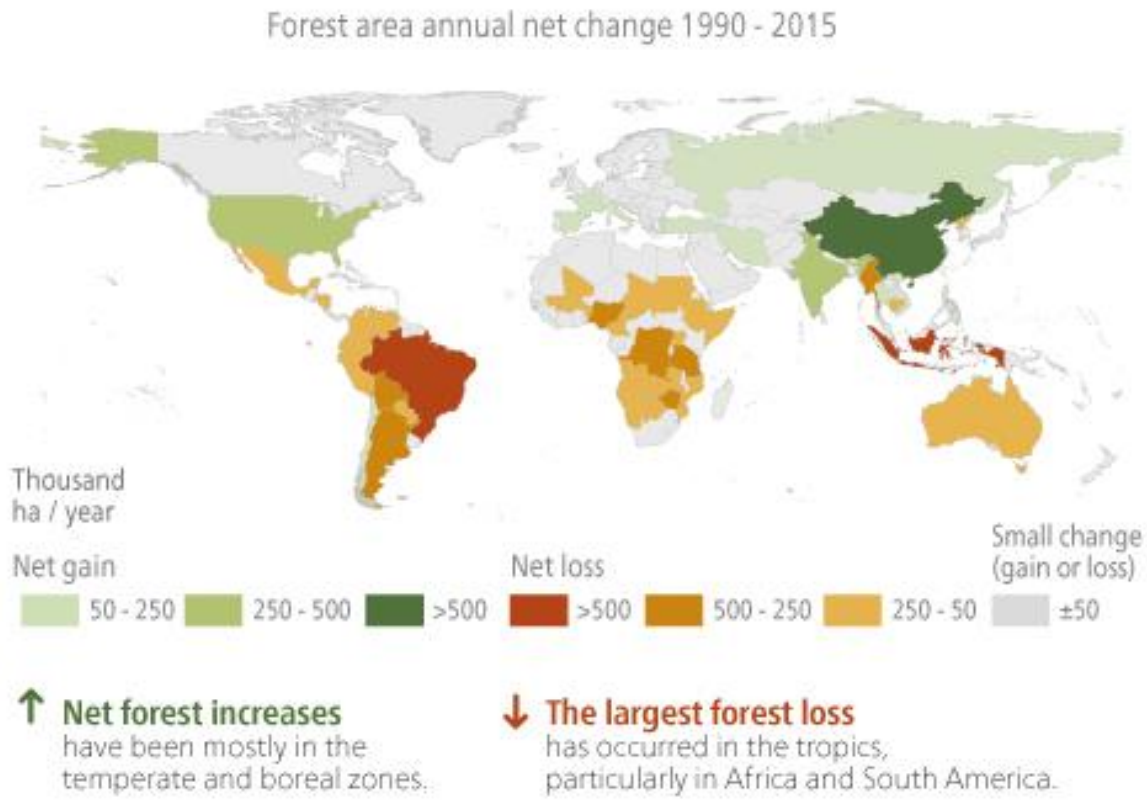
Ahmed Mushfiq Mobarak
Yale University

GGKP 2017

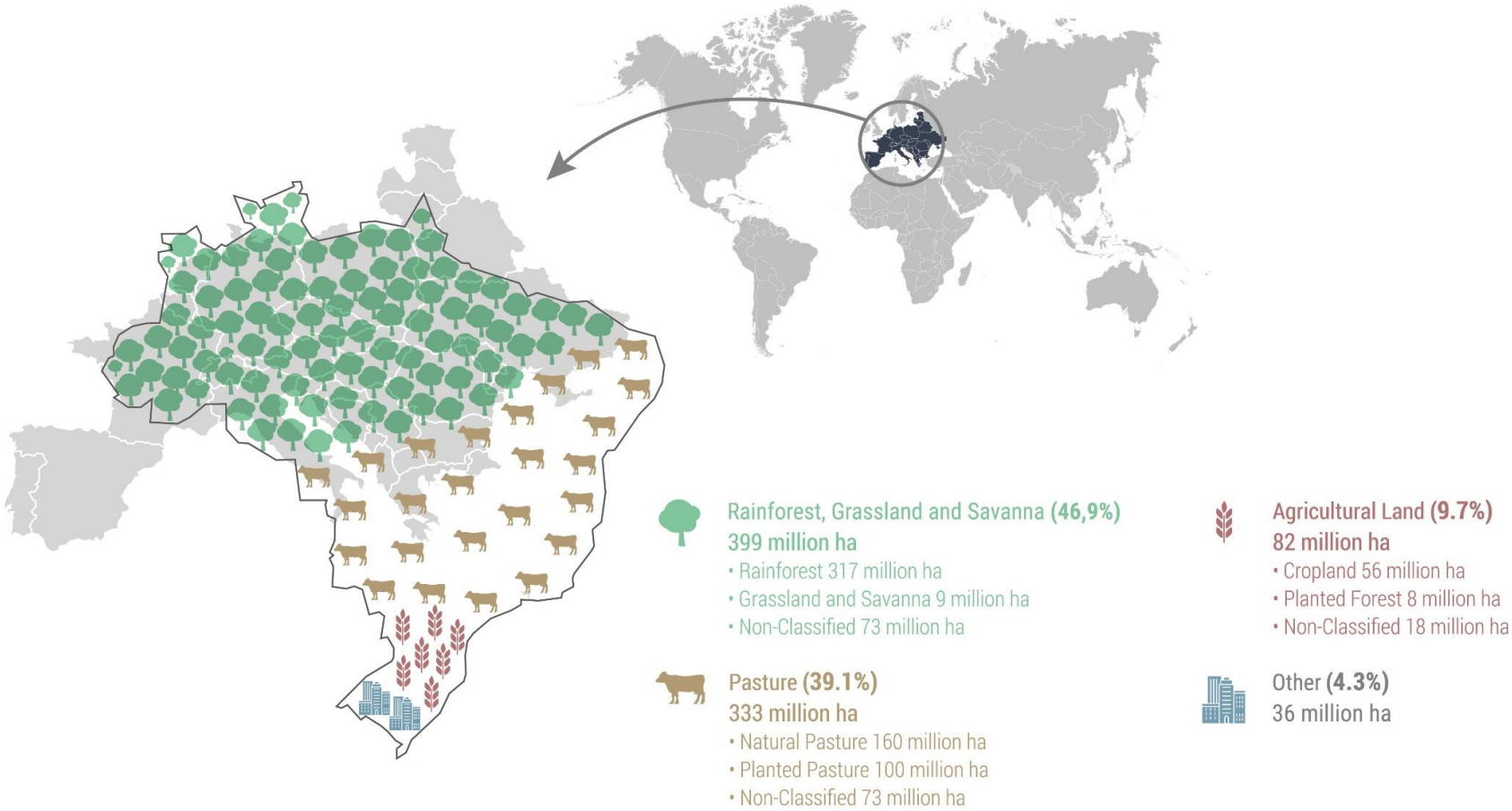
Washington DC

Motivation: Why deforestation in Brazil?





Motivation: Key facts to keep in mind



Motivation: Key facts to keep in mind

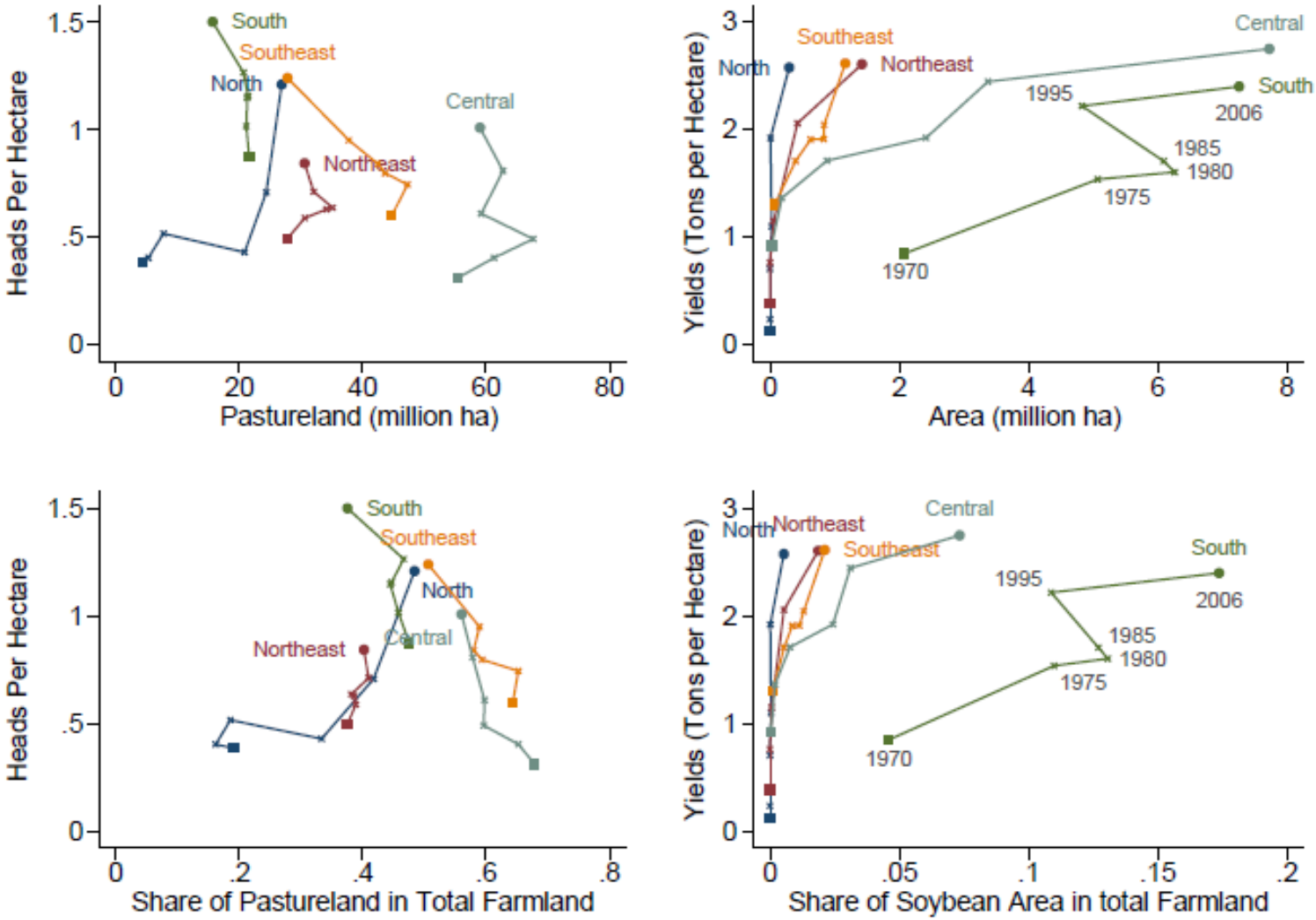


Figure 2: Evolution of Cattle Grazing and Soybean Cultuvation: Area and Productivity, Brazil 1960-2006

Motivation

- Opposing views on ag productivity and deforestation
- Borlaug hypothesis: "increasing the productivity of agriculture on the best farmland can help control deforestation by reducing the demand for new farmland."
- Simple economic theory: ↑ productivity, ↑ land demand

This paper

- Can productivity shocks in agriculture benefit the environment by changing private land use decisions?

- How?
  - *If* farmers face factor market constraints, then a productivity shock (in crops) will induce farmers to do more cropping
  - If crops are less land-intensive than cattle grazing → good for forests
  - But more people may switch into farming. Net effect is ambiguous

- Massive expansion of electricity infrastructure in Brazil 1960-2000 was a productivity shock to crop cultivation.
  - Overcome endogeneity problem of grid placement, building on the empirical strategy of Lipscomb et al. (2013).

Preview of findings

- Electrification increased productivity in cropping more than in cattle grazing

- Induced farmers to intensify production
  - Shift away from land-intensive cattle grazing
  - Investments in capital, away from land

- The net effect on forests is positive
  - Effect lasts for 20 years

Roadmap

- Analytical framework
- Background: Agriculture and Electrification in Brazil
- Empirical strategy
- Data
- Results

Analytical Framework – Farmer's problem

- Price of land is p, price of K is r. Prices of *C* and *G* normalized to 1.

- Farmer's problem:

$$\max_{\{K,\, H_c,\, H_g\}} \Omega K F(H_c) + F(H_g) - rK - p(H_c + H_g)$$

- Subject to
  - Land constraint: $H_c + H_g \leq H$: typically not binding.
  - Credit constraint: $rK + p\left(H_c + H_g\right) \leq M$: typically binding

Testable predictions associated with electrification

A shift in Ω leads to

- Investments in capital (for crop cultivation)
- Switch into crop cultivation
- Reduction of land demand for agriculture in the intensive margin

- Ambiguous effects in land demand for agriculture in the extensive margin
  - Net effect of electricity on demand for agricultural land (hence, native vegetation): ambiguous.

Roadmap

- Analytical framework
- Background: Agriculture and Electrification in Brazil
- Empirical strategy
- Data
- Results

Background - Electrification in Brazil

- Massive expansion of electricity into rural Brazil during 2nd half of 20th century
  - In 1960, 3.4% of farms utilized electricity vs 68% in 2006
  - 2,400km of transmission lines in 1950 vs 167,000+km in 2000.

- Most of this expansion supported by hydropower, which requires intercepting volume of water at high velocity

Roadmap

- Analytical framework
- Background: Agriculture and Electrification in Brazil
- Empirical strategy
- Data
- Results

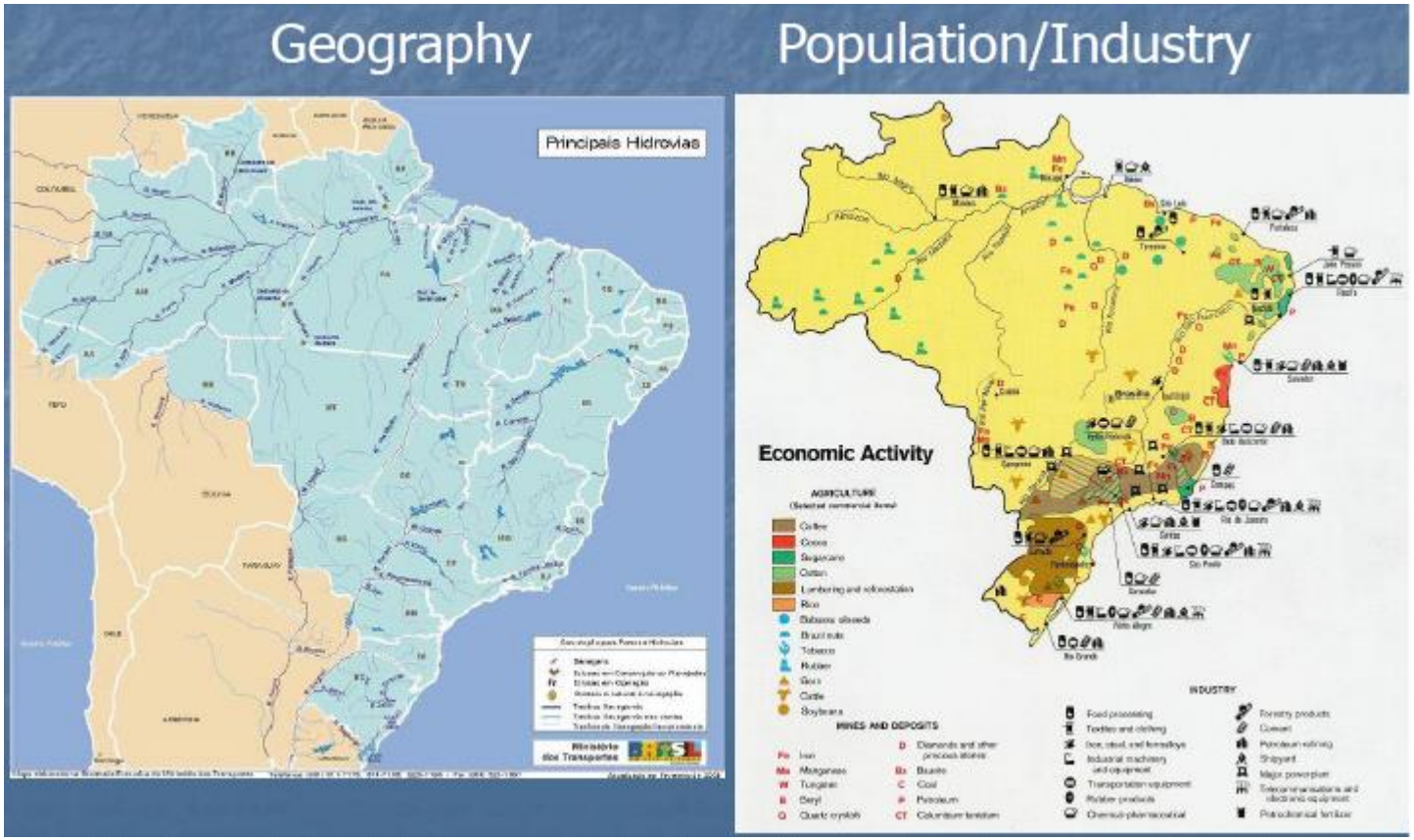
Main specification

$$y_{it} = \beta \widehat{E_{it}} + \alpha_i^1 + \delta_t^1 + \epsilon_{it}$$

$$E_{it} = \theta Z_{it} + \alpha_i^2 + \delta_t^2 + v_{it}$$

- E_{it}: proportion of grid points in county *i* that are electrified in period *t*
- Use an IV strategy that isolates cost-considerations only (Lipscomb, Mobarak, Barham, *AEJ-Applied* 2013)
- Z_{it}: proportion of grid points in county *i* predicted to be electrified in period *t* by the forecasting model

Thought Experiment



Pretend we don't know the information on the right

Roadmap

- Analytical framework
- Background: Agriculture and Electrification in Brazil
- Empirical strategy
- Data
- Results

Data

Create a panel of county (*municipio*)-decades, with

- Electricity infrastructure
  - Geo-code historical paper maps of generation plants and transmission lines. Inventory tables from electricity companies.
- 5 waves of Census of Agriculture (1970, 1975, 1980, 1996, 2006)
  - County-level aggregations of census microdata, with lots of info on rural establishments
- Gridded temperature and rainfall data
  - Monthly gridded data used to calculate rainfall volatility, drought indexes, etc

Roadmap

- Analytical framework
- Background: Electrification and Irrigation in Brazil
- Empirical strategy
- Data
- Results

First-stage results

First-Stage Results

Dependent Variable	Electricity Infrastructure			Fractions of Farms with Electricity	
	(1)	(2)	(3)	(4)	(5)
Modeled electricity availability	0.289***	0.282***	0.217***	0.100**	
	[0.0432]	[0.0426]	[0.0466]	[0.0416]	
Electricity Infrastructure					0.130***
					[0.0212]
Year dummies	Yes	Yes	Yes	Yes	Yes
Water flow × year dummies	No	Yes	No	No	No
River gradient × year dummies	No	Yes	No	No	No
Quartic suitability rank × year dummies	No	No	Yes	Yes	Yes
Observations	15,460	15,460	15,460	15,460	15,460
Mean dep. var.	0.740	0.740	0.740	0.338	0.338
F-stat	44.8	43.8	21.7		
p-value	0.000	0.000	0.000		

Notes: In columns 1–3 the dependent variable is prevalence of electricity infrastructure in the county, measured from infrastructur inventories. Each colum adds controls that soak up variation from our instrument. Adding water flow and river gradient interacted with year dummies (column 3) does not change the point estimate substatially. We therefore keep the specification in column 2 as our preferred specification througout the paper. In columns 4 amd 5, the dependent variable is the fraction of farms with electricity in the county, measured from the Censuses of Agriculture. Standard errors clustered at county level in brackets. All specifications include county fixed effects and use county area weights.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Electricity increases crop productivity but not cattle grazing productivity

The Effects of Electricity on Agricultural Productivity

	log Production Per Hectare of Farmland ($)			log Crop Production Per Hectare of Cropland ($)			log Cattle Production Per Hectare of Pastureland ($)		
	(1) OLS	(2) Reduced Form	(3) IV	(4) OLS	(5) Reduced Form	(6) IV	(7) OLS	(8) Reduced Form	(9) IV
Electricity Infrastructure	0.094		0.592	0.424***		2.182***	0.003		0.023
	[0.114]		[0.621]	[0.101]		[0.580]	[0.151]		[0.707]
Instrument		0.128			0.473***			0.005	
		[0.145]			[0.112]			[0.170]	
Observations	15,458	15,458	15,458	15,437	15,437	15,437	15,411	15,411	15,409
Mean dep. var.	12.48	12.48	12.48	6.67	6.67	6.67	4.86	4.86	4.86

Notes: The table shows that electricity infrastructure is a positive productivity schock to agriculture, and that it benefits crop cultivation more than cattle grazing. The dependent variable in columns 1–3 is the log of total farm production value divided by total farmland. The dependent variable in columns 4–6 is the log of total crop production value divided by total cropland. The dependent variable in columns 7–9 is the total production value of cattle per hectare of pastureland. Standard errors clustered at county level in brackets. All specifications include county fixed effects and use county area weights.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Lack of electricity causes farmland to expand; pastureland to increase; and native vegetation (within farmland) to decrease

The Effects of Electricity on the Allocation of Land

	Farmland / County Area		Pastures / Farmland		Cropland / Farmland		Native Vegetation / Farmland	
	(1) OLS	(2) IV	(3) OLS	(4) IV	(5) OLS	(6) IV	(7) OLS	(8) IV
Electricity Infrastructure	−0.044**	−0.328**	0.021	−0.517***	−0.031*	−0.050	0.039	0.556***
	[0.021]	[0.138]	[0.020]	[0.145]	[0.016]	[0.081]	[0.028]	[0.150]
Observations	15,460	15,460	15,460	15,460	15,460	15,460	15,460	15,460
Mean dep. var.	0.709	0.709	0.470	0.470	0.224	0.224	0.156	0.156
Mean dep. var. (weighted)	0.386	0.386	0.363	0.363	0.122	0.122	0.372	0.372

Notes: The table shows how, following a productivity schock, land use changes in the extensive and intensive margins. The extensive margin is analyzed in columns 1 and 2, where the dependent variable is the county's farm area divided by the county's total area. Land use in the intensive margin (within farms) is analyzed in the remaining columns. The dependent variable in columns 3 and 4 is the farm area in pastures divided by total farm area. The dependent variable in columns 5 and 6 is farm area in crops divided by the total farm area. The dependent variable in columns 7 and 8 is farm area in native negetation divided by the total farm area. Standard errors clustered at county level in brackets. All specifications include county fixed effects.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Lack of electricity causes farmland to expand; pastureland to increase; and native vegetation (within farmland) to decrease

The Effects of Electricity on the Allocation of Land

	Farmland / County Area		Pastures / Farmland		Cropland / Farmland		Native Vegetation / Farmland	
	(1) OLS	(2) IV	(3) OLS	(4) IV	(5) OLS	(6) IV	(7) OLS	(8) IV
Electricity Infrastructure	−0.044**	−0.328**	0.021	−0.517***	−0.031*	−0.050	0.039	0.556***
	[0.021]	[0.138]	[0.020]	[0.145]	[0.016]	[0.081]	[0.028]	[0.150]
Observations	15,460	15,460	15,460	15,460	15,460	15,460	15,460	15,460
Mean dep. var.	0.709	0.709	0.470	0.470	0.224	0.224	0.156	0.156
Mean dep. var. (weighted)	0.386	0.386	0.363	0.363	0.122	0.122	0.372	0.372

Notes: The table shows how, following a productivity schock, land use changes in the extensive and intensive margins. The extensive margin is analyzed in columns 1 and 2, where the dependent variable is the county's farm area divided by the county's total area. Land use in the intensive margin (within farms) is analyzed in the remaining columns. The dependent variable in columns 3 and 4 is the farm area in pastures divided by total farm area. The dependent variable in columns 5 and 6 is farm area in crops divided by the total farm area. The dependent variable in columns 7 and 8 is farm area in native negetation divided by the total farm area. Standard errors clustered at county level in brackets. All specifications include county fixed effects.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

$$\frac{\partial}{\partial e}\frac{V(e)}{T} = \frac{\partial}{\partial e}\frac{V_I(e)}{F(e)} \cdot \frac{F(e)}{T} + \left(\frac{V_I(e)}{F(e)} - \mathrm{k}\right) \cdot \frac{\partial}{\partial e}\frac{F(e)}{T}$$

$$= 0.56 \cdot 0.39 - (0.37 - \mathrm{k}) \cdot 0.33, \qquad k \in [0, 1]$$

overall impact on native vegetation: 9 – 40pp

These effects persist one decade later (dependent variables forward-lagged one period)

The Effects of Electricity on the Allocation of Land: Long Run

	Farmland / County Area		Pastures / Farmland		Cropland / Farmland		Native Vegetation / Farmland	
	(1) OLS	(2) IV	(3) OLS	(4) IV	(5) OLS	(6) IV	(7) OLS	(8) IV
Electricity Infrastructure	-0.071^{***}	-0.360^{**}	-0.023	-0.563^{***}	-0.013	0.050	0.069^{**}	0.654^{***}
	[0.021]	[0.142]	[0.023]	[0.143]	[0.017]	[0.068]	[0.028]	[0.177]
Observations	12,368	12,368	12,368	12,368	12,368	12,368	12,368	12,368
Mean dep. var.	0.706	0.706	0.471	0.471	0.172	0.172	0.157	0.157

Notes: This table is similar to table 3, except that the dependent variables are forward-lagged by one decade. The goal is to show that the increase in native vegetation within farms does not occur just a short-run. The number of observations drop because we loose one period of our panel of counties. The dependent variable in columns 1 and 2 is the county's farm area divided by the county's total area. The dependent variable in columns 3 and 4 is the farm area in pastures divided by total farm area. The dependent variable in columns 5 and 6 is farm area in crops divided by the total farm area. The dependent variable in columns 7 and 8 is farm area in native negetation divided by the total farm area. Standard errors clustered at county level in brackets. All specifications include county fixed effects.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

… the impact persists

Crop Choice – farmers allocate more land to soybeans, maize and other grains (cash crops), but to subsistence crops such as cassava

The Effects of Electricity on Crop Choices

	IHS Production (tons)		IHS Area (ha)		Area/Farmland	
	(1) OLS	(2) IV	(3) OLS	(4) IV	(5) OLS	(6) IV
			Panel A: Grains			
Electricity Infrastructure	−0.367	2.950**	−0.470**	1.749	0.001	0.232***
	[0.246]	[1.505]	[0.226]	[1.290]	[0.006]	[0.065]
Observations	15,423	15,423	15,423	15,423	15,423	15,423
Mean dep. var.	8.38	8.38	8.36	8.36	0.13	0.13
			Panel B: Cassava			
Electricity Infrastructure	−0.080	0.049	−0.245**	−0.873	−0.009*	−0.023
	[0.120]	[0.826]	[0.110]	[0.648]	[0.005]	[0.017]
Observations	15,423	15,423	15,423	15,423	15,423	15,423
Mean dep. var.	6.13	6.13	4.53	4.53	0.01	0.01

Notes: IHS stands for inverse hyperbolic sine. The table shows that the shift from land-intensive towards capital-intensive activities happens also between crops, and not only between cattle grazing and crops. To shows this, panel A shows the effects of electricity infrastructure on the production and harvested area (both in absolute terms and relative to overall farmland) of grains (cotton, maize, soybeans, rice, beans, and wheat), which benefit from electrification through irrigation, handling and storage, and mecanization in general. Panel B shows resutls for cassava, which benefits less than grains from electrification. The table shows that an increase in electricity infrastructure has an effect on the crop mix, leading to a shit into grains and out of cassava – production and area increase (respectively, decrease) for grains (respectively, cassava). This fact also helps explaining why we see little effect of electricity on the share of farmland allocated to crops in Table 3: the results suggest that farmers switch crops, keeping overall cropland as a fraction of farmland roughly constant. Standard errors clustered at county level in brackets. All specifications include county fixed effects.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

… farmers adjust their crop toward grains

Capital for crops: irrigation

The Effects of Electricity on Inputs and Capital for Crop Cultivation

	(1) Fraction of Farms with Irrigation	(2) Fraction of Farms ≥ 1 ha with Irrigation	(3) Fraction of Farms $\geq$ 10 ha with Irrigation	(4) Fraction of Farms $\geq$ 20 ha with Irrigation	(5) Irrigated Area (IHS of ha)
IV	0.055**	0.068***	0.240***	0.382***	0.523
	[0.024]	[0.025]	[0.063]	[0.104]	[1.787]
OLS	0.024***	0.027***	0.073***	0.118***	−0.082
	[0.004]	[0.005]	[0.011]	[0.018]	[0.389]
Observations	15,460	15,460	15,459	15,456	15,460
Mean dep. var.	0.058	0.064	0.132	0.212	4.097

... irrigation increases

Capital for crops: grain storage, tractors, inputs

The Effects of Electricity on Inputs and Capital for Crop Cultivation

	(1) Capacity of Grain Storage Per Hectare of Cropland (IHS tons per ha)	(2) Number of tractors per 10,000 Hectares (IHS)	(3) Fertilizer Per Hectare (IHS of $)	(4) Pesticides Per Hectare (IHS of $)
IV	1.114**	0.846	0.022	0.008
	[0.506]	[0.588]	[0.027]	[0.017]
OLS	0.230**	0.449***	0.004	−0.001
	[0.090]	[0.102]	[0.003]	[0.002]
Observations	15,450	15,460	15,460	15,460
Mean dep. var.	0.562	2.850	0.032	0.015

… more investment in grain storage

Conclusions

We show that electrification led to:

- A positive productivity shock in crop cultivation
- Intensification of agriculture, shift away from cattle grazing;
  - Investments in grain storage capacity (dry heat, humidity control), and irrigation are potential mechanisms
- Helped to protect the forest