When Cryptomining Comes to Town: High Electricity-use Spillovers to the Local Economy

Matteo Benetton[1], Giovanni Compiani[2], Adair Morse[1]

[1]University of California, Berkeley
[2]University of Chicago

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Cryptomining: The Physical Footprint of Digital Currencies

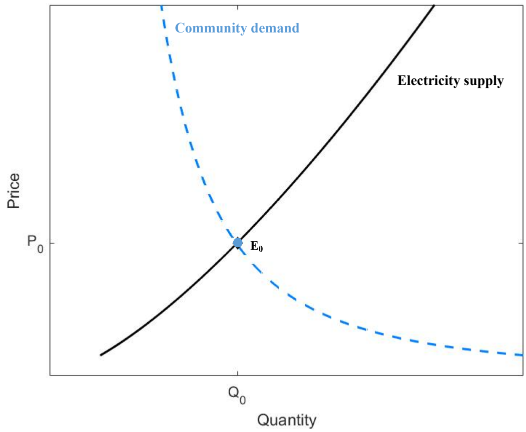
- Technology processing (AI, large language models, ...) consumes large quantities of electricity: 1% of world energy in 2010 and is on trajectory to increase to 6%by 2030 (Masanet et al., 2020)
- Our focus: cryptocurrency mining ("cryptomining")
  - Proof-of-work cryptos require solving increasingly complex computational puzzles
  - An arms race in processing $\rightarrow$ massive buildup and use of cryptomining processing
  - No central agent, rather, free entry into cryptomining
- Bitcoin network now consumes more electricity than the Netherlands

Paper Contribution: Community Spillovers

- This paper: Externalities on local community through electricity markets
  - Other papers: Global negative externalities of cryptomining in the form of carbon emissions [De Vries (2018), Bandin et al. (2020), Goodkind et al. (2020)]
- Our story: entrance of cryptoming into a community causes
  - Small businesses and households
    - ↑ prices for other community members ... OR
    - ↓ availability of electricity for constrained grids (grid and congestion)
  - Electricity producers
    - ↑ revenues (market expansion, higher prices)
  - Governments
    - ↑ tax revenues (more locally profitable than other sources of electricity)
- Partial welfare punchline... other factors: pollution, innovation, etc)

Framework

Electricity Market: Flexible Prices

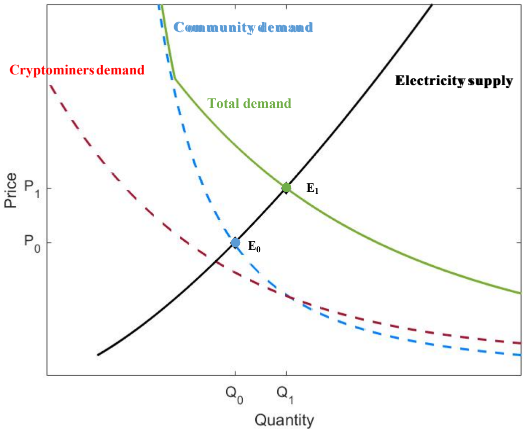


Local energy costs for community

Provider profits

Added tax revenues (not shown)

Electricity Market: Flexible Prices + Cryptomining



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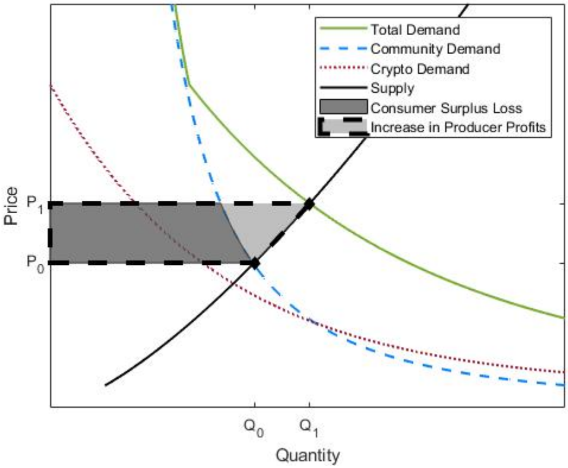

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Setting and Data

The Electricity Market of Upstate NY

- NYstate emits 1 out of every 200 tons of energy-related carbon dioxide in the world
- Cold temperatures, hydro & coal power plants, cheap industrial electricity
  $\Rightarrow$ A number of highly publicized cryptomining facilities
- Location-Based Marginal Pricing (LBMP)
  - Electricity generators input supply schedules (prices and quantities)
  - Grid system dynamically decides what generator is at the margin for each demand by a local provider at each hour
  - LBMP = reference price + adjustments for transmission distance and congestion
    $\Rightarrow$ electricity supply charge shows up on residential and small business electricity bills
    $\Rightarrow$ A demand shock transmits throughout the system

Data

- Electricity consumption data at the town-month level from New York State Energy Research and Development Authority (NYSERDA), and high-frequency data on electricity prices from New York Independent System Operator (NYISO).
  - Electricity consumption by month, provider, town and user type (residential, business)
    Prices at the month and generator level
- Government data at the town-year level from the Office of State Comptroller
  - Local tax revenues and expenditures per capita
- Hand-collected data on cryptomining locations
  - Keywords search in Google for local news about crytomining for each town in energy dataset
  - 13 out of 62 counties with at least one cryptomining facility

Households and small businesses

#1) Spillovers to Electricity Consumers: Identification Strategy

- Electricity consumption q by user type u (household or small business) in community c from provider p in month t.

$$OLS: \quad \log q^u_{pct} = \beta^u \log p_{ct} + \gamma^u X_{ct} + \mu^u_p + \mu^u_c + \epsilon^u_{pct}$$

- Classic endogeneity problem: supply+demand

- Approach:
  - $\uparrow$ BTC price $\Rightarrow \uparrow$ electricity demand by cryptominers $\Rightarrow$ exogenous effect on portion of supply curve faced by local community (residual supply)
  - Bitcoin price as instrument for LBMP NY Prices

$$FS: \quad \log p_{ct} = \alpha^u \log p^{BTC}_t + \gamma^u X_{ct} + \mu^u_p + \mu^u_c + \varepsilon^u_{pct}$$

$$IV: \quad \log q^u_{pct} = \beta^u \widehat{\log p_{ct}} + \gamma^u X_{pct} + \mu^u_p + \mu^u_c + \epsilon^u_{pct}$$

#1) Spillovers to Electricity Consumers: Results

	Small Businesses			Residential		
	FS	OLS	IV	FS	OLS	IV
BTC price (log)	0.139***			0.145***		
	(0.005)			(0.006)		
Price (log)		0.056***	-0.179***		0.155***	-0.074**
		(0.021)	(0.057)		(0.015)	(0.031)
Temperature (log)	-0.195***	-0.088***	-0.133***	-0.233***	-0.093***	-0.145***
	(0.020)	(0.024)	(0.031)	(0.020)	(0.020)	(0.024)
Community Fixed Effects	Y	Y	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y	Y	Y
Provider Fixed Effects	Y	Y	Y	Y	Y	Y
Mean Y	3.23	5.70	5.70	3.23	7.56	7.56
SD Y	0.35	2.00	2.00	0.36	1.34	1.34
F stat	713.88			656.89		
Obs.	2977	2977	2977	3251	3251	3251
R2adj	0.37	0.98	0.98	0.39	0.98	0.97

- FS: expected sign, High F-stat
- OLS: upward sloping demand
- IV: residential elasticity = 0.07 cf. 0.071-0.088, Ito (2014)
- Robust to different controls for seasonality (winter-summer, orthogonalized demand)

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Local Consumer Surplus: Steps

1. Use First Stage to predict price of electricity with (2018) and w/o (2016) cryptomining:

$$\log p_{ct,nocrypto} = \alpha^u \log p_{2016}^{BTC} + \gamma^u X_{pct} + \mu_p^u + \mu_c^u$$

$$\log p_{ct,crypto} = \alpha^u \log p_{2018}^{BTC} + \gamma^u X_{pct} + \mu_p^u + \mu_c^u$$

2. Use predicted prices and IV estimates to construct consumer loss

$$\Delta\text{Consumer Surplus} = -\int_{p_{ct,nocrypto}}^{p_{ct,crypto}} D_{community}(p)dp = -\frac{\exp(\alpha + \gamma X)}{1-\beta} \quad p_{ct,crypto}^{1-\beta} - p_{ct,nocrypto}^{1-\beta}$$

3. Scale up estimates by number of exposed households, small businesses, communities

Back

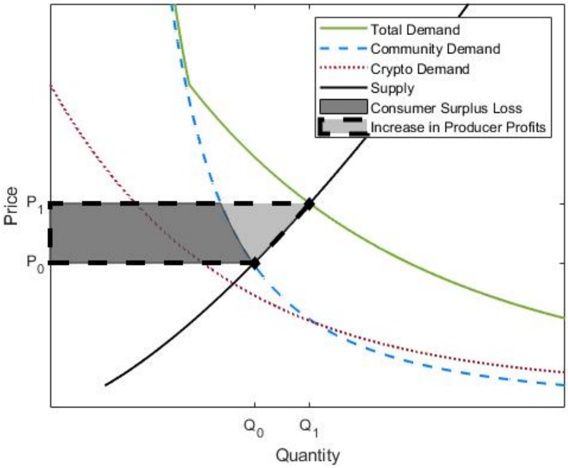
Local Consumer Loss: Results

Use first stage to obtain predicted electricity prices pre- and post-entry of cryptominers

	(1) Monthly Δ Consumer Surplus (\$)	(2) Annual Δ Consumer Surplus (\$)	(3) Count of Exposed (,000)	(4) Total Δ Consumer Surplus (\$M)
Households	-7.3	-88	2,321	-204
Small businesses	-14.0	-168	550	-92
				-296

Calculation

Electricity Market: Flexible Prices + Cryptomining



: Local energy costs for community

: Provider profits

: Tax revenues (not shown)

Government Revenues

#2) Government Revenues: Identification Strategy

- Effect of cryptomining on local tax revenues in community c when price of Bitcoin is high:

$$Y_{ct} = \alpha \times cryptomining_c \times \log p_t^{BTC} + \mu_c + \mu_t + \epsilon_{ct}$$

  - $cryptomining_c$: dummy for hosting cryptomining operations in the county
  - μ_c, μ_t: community and time fixed effects

- Concern: Non-parallel trends due to selection of locations

- Approach:
  - Logit model for mining location:

$$cryptomining_c = f(\textit{average temperature}, \textit{Distance to closest power stations}) + \xi_c$$

  - DinD with Inverse probability weighting (IPW)

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#2) Government Revenues: Results

	Location	Taxes		Robustness		
	(1)	(2)	(3)	(4)	(5)	(6)
		OLS	IPW	2016	2017	2018
Capacity mw (log)	0.302***					
	(0.051)					
Temperature	-0.406***					
	(0.059)					
BTC price (log) X Cryptomining		4.110***	6.087***			
		(0.983)	(1.155)			
Post X Cryptomining				33.982***	29.461***	27.074**
				(7.639)	(8.894)	(12.501)
Community Fixed Effects		Yes	Yes	Yes	Yes	Yes
Year Fixed Effects		Yes	Yes	Yes	Yes	Yes
Mean Y		524.37	498.60	498.60	498.60	498.60
SD Y		505.92	426.95	426.95	426.95	426.95
Observations	719	6851	6135	6135	6135	6135
Adjusted R-squared		0.97	0.96	0.96	0.96	0.96
Pseudo R-squared	0.10					
Area under ROC Curve	.71					

Social Local Welfare: Updated Results

	(1) Monthly Δ Consumer Surplus (\$)	(2) Annual Δ Consumer Surplus (\$)	(3) Count of Exposed (,000)	(4) Total Δ Consumer Surplus (\$M)
Households	-7.3	-88	2,321	-204
Small businesses	-14.0	-168	550	-92
				-296
Taxes		29	1,340	39
				-257

Calculation

Provider Profits

#3) Electricity Provider Revenues: Results

	Industrial		Residential + Small business	
	(1) Sales (log(MWh))	(2) Revenues (log($.000))	(3) Sales (log(MWh))	(4) Revenues (log($.000))
Cryptomining	-2.161	-1.826	2.894***	5.570***
	(6.560)	(5.162)	(0.767)	(1.519)
Cryptomining × Post	0.121*	0.136**	-0.008	0.053**
	(0.067)	(0.056)	(0.013)	(0.022)
Temperature controls	Y	Y	Y	Y
Provider Fixed Effects	Y	Y	Y	Y
Year Fixed Effects	Y	Y	Y	Y
Mean Y	11.62	8.68	12.13	9.54
SD Y	2.32	2.12	1.96	2.23
Obs.	50	50	116	116
Adjusted R-squared	0.907	0.921	0.999	0.999

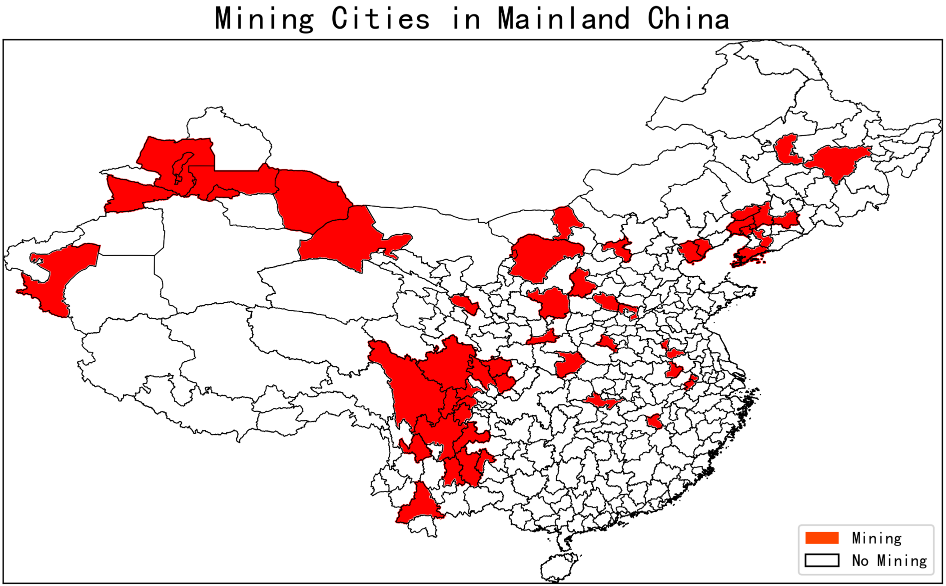
- Hosting cryptomining ⇒ 3.6% higher revenues for treated electricity providers for industrial users (also increase in sales volume).
- Sales unchanged and revenues go up for residential and small business users

Local Community Surplus

- Economic magnitude of provider results
  - Assuming a profit margin of 15% for electric utilities (Froelich and McLagan II,2008), the increase in revenues leads to a $62 million increase in profits
    - Presumably a lower bound, since average profit margin < at the margin
    - To offset the net $257 million in community losses, profit margin would have to be >58% (very unlikely)

China Analysis, summary

Cryptomining in China



China Analysis

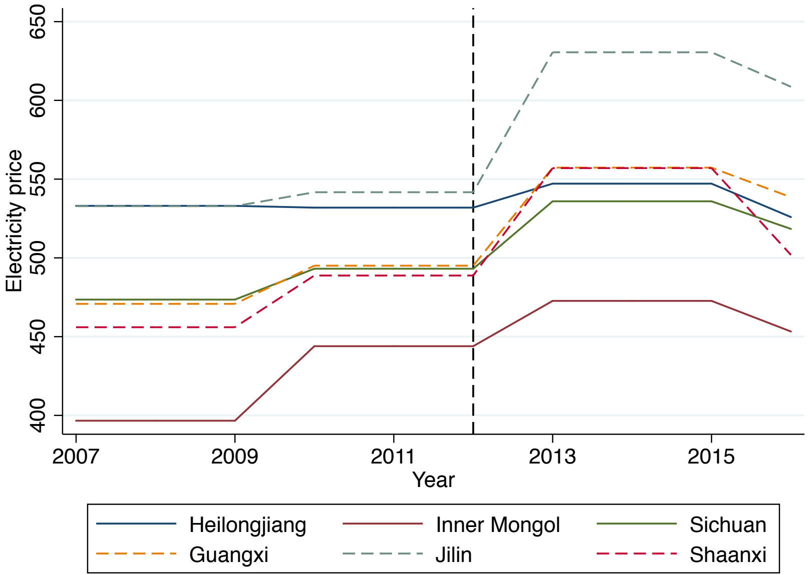
- China
  - Prices are fixed within provinces $\Rightarrow$ Capacity constraints more likely to bite
  - We find evidence of crowding out of local "next best" use of electricity
    - Fixed asset investment, GDP and wage rates tend to decrease as a result of cryptomining locating, within a location selection model

Conclusion

Conclusions

- We provide new local-level evidence that cryptomining:
  - increases local consumption of energy $\Rightarrow$ higher prices for small businesses and households (indirectly "paying for" cryptomining)
  - increases tax revenues $\Rightarrow$ incentive for local governments to attract cryptominers
  - Causes consumer surplus loss of $\approx$ \$260 million per year in Upstate NY
- Measurement and policy implications:
  - Local spillovers effects need to enter full "welfare" analysis of cryptocurrencies (together with pollution costs, transaction benefits - outside the scope of this paper)
  - Consider less energy-intensive non-PoW protocols? Taxes? Some communities considering surcharge for high-usage customers (e.g., cryptominers)
- Local energy supply effects may be important for technology processing beyond cryptocurrencies (e.g., data centers)

Limited Variation over Time in Electricity Prices



Appendix

#3) Electricity Provider Revenues: Identification Strategy

- Effect of cryptomining on electricity provider p's revenues after 2016 for user type u:

$$Y^u_{pt} = \alpha \times cryptomining_p \times Post_t + X_{pt} + \mu^u_p + \mu^u_t + \epsilon^u_{pt}$$

  - $cryptomining_p$: fraction of communities hosting cryptomining
  - $Post_t$: after 2016 dummy
  - X_{pt}: high and low temperature
  - μ^u_p, μ^u_t: provider and time fixed effects

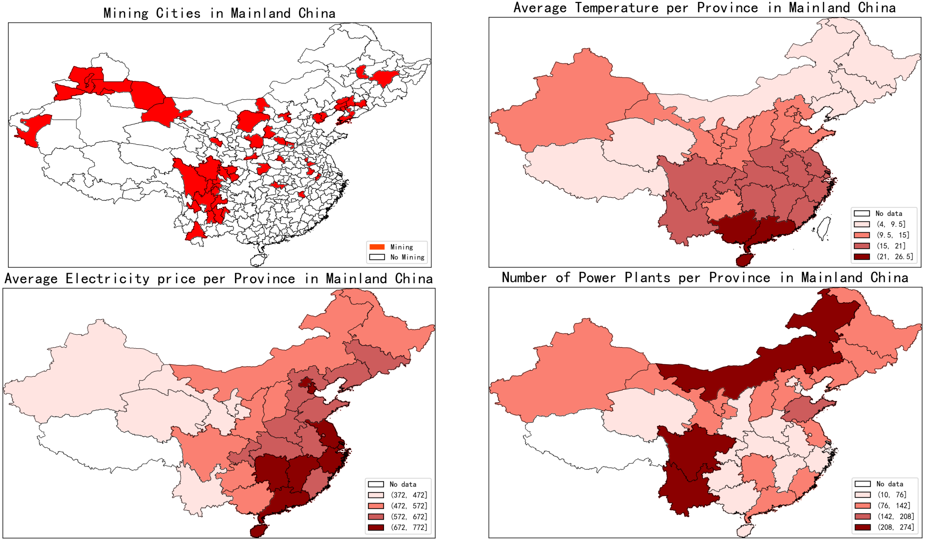
- Theory predicts:
  - $\uparrow$ sales and revenues for industrial users
  - $\downarrow$ sales and $\uparrow$ revenue for residential and small business users (inelastic demand)

Back

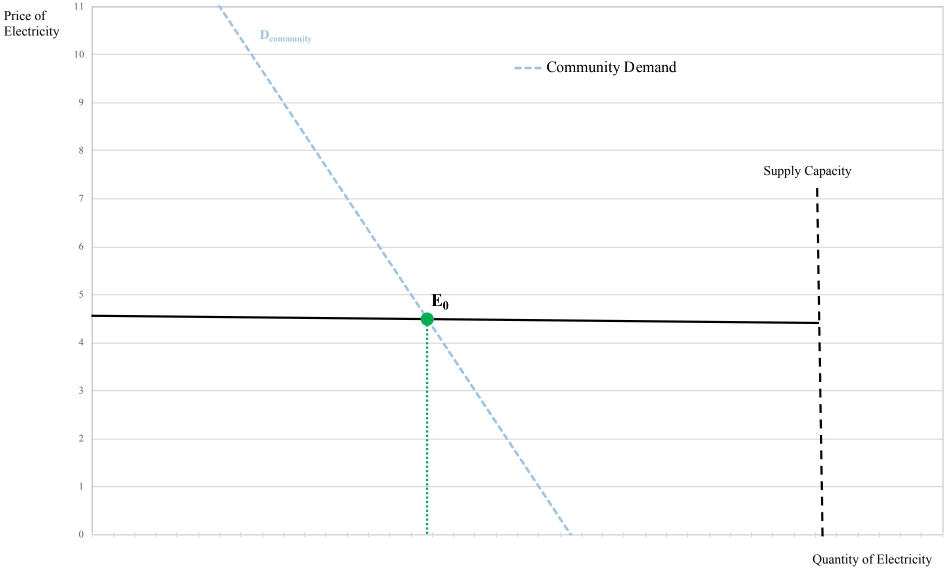
Drivers of Location Choice

	Dummy = 1 if mining evidence in county			
	(1)	(2)	(3)	(4)
High power plant	1.833**			2.046*
	(0.868)			(1.103)
High temperature		-1.511*		-3.098*
		(0.864)		(1.782)
High electricity price			-2.028*	-0.846
			(1.108)	(1.355)
Macro controls	No	No	No	Yes
Mean Y	0.19	0.19	0.19	0.19
SD Y	0.39	0.39	0.39	0.39
Obs.	48	48	48	48
Pseudo R2	0.12	0.08	0.11	0.30

Graphical "First Stage": China



Framework: Electricity Market with Fixed Prices



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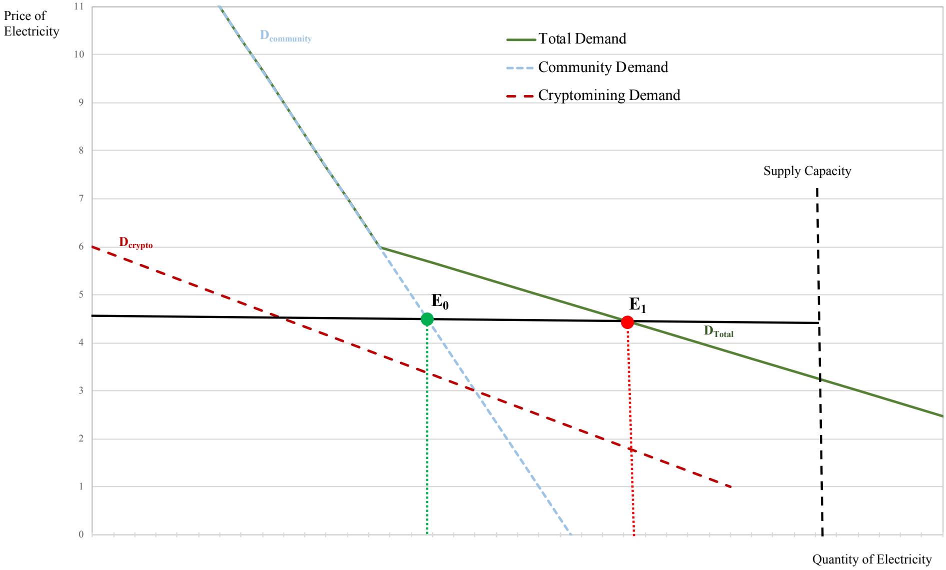

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