The Shifting Finance of Electricity Generation

Stockholm Harnessing Finance for Climate Conference

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Competition and Financing the Adoption of Innovation

The relation between competition and financing the adoption of innovation:

- In perfect competition, firms have weaker incentives and capacity to innovate (Schumpeter, 1942).
- Market power stifles innovation, as firms protect their rents and avoid cannibalization (Arrow, 1962).
- Who provides capital for innovation?
- Dominant incumbent or smaller new entrants?

Our setting is the energy sector – Creation and destruction in electricity generating assets:

- Basic infrastructure that can stimulate long-term economic growth (Glaeser and Poterba, 2020).
  - Concerns about blackouts and pricing volatility.
  - Concerns about security and energy independence.
- Capital-intensive sector with substantial innovation (e.g., Gilje, Loutskina, and Strahan, 2016).
  - Adopting new renewable solar and wind technologies as well as the shale gas boom.
  - Owning and operating legacy assets using fossil fuels during the transition.
- Variation in demand, market regulation and policy incentives (e.g., Cicala, 2022).
  - Electricity generation is still a large source of emissions and pollution.
  - Which economic policies can stimulate the transition? (e.g., Hong, Karolyi, and Sheinkman, 2020; Giglio, Kelly, and Stroebel, 2021).

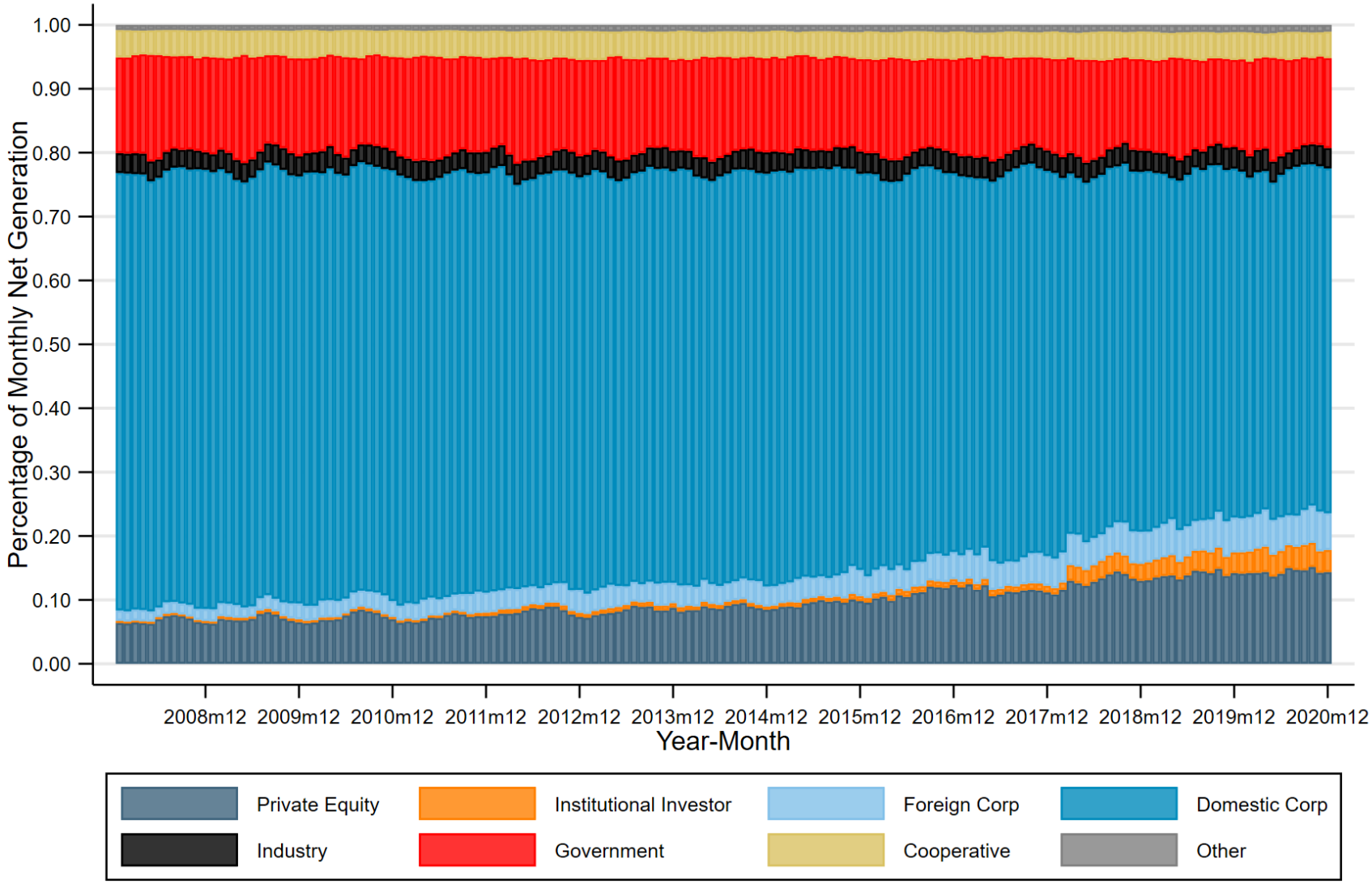
The Shifting Finance of Electricity Generation

Incumbent domestic listed corporations:

- Their share of electricity generation declines from 69% in 2008 to 54% in 2020.

New entrants – private equity, institutional investors, and foreign corporations:

- Their joint share increases from 8% to 24%.
- Jointly own 54% of wind, 44% of solar, and 28% of natural gas installed nameplate capacity.



This Research

1. **Which mechanisms drive these ownership changes? Creating, selling, or decommissioning?**
   - Incumbent domestic publicly listed corporations are less likely to create new power plants.
   - Private equity and foreign corporations are more likely to finance and adopt innovative generation.
   - Limited evidence of leakage of older fossil fuel plants from domestic listed corporations.

2. **Which economic conditions facilitate the ownership changes?**
   - Restructured competitive markets with an ISO balancing authority (and retail choice) attract new capital and facilitate the adoption of innovation and destruction.
   - The role of market competition in explaining variation is robust to controls for climate concerns and energy policy measures.

3. **What are the implications for electricity markets?**
   - Limited differences in operating intensity, but new owners operate power plants more efficiently.
   - Private equity establishes contracts with short duration, short increments, and peak period sales.
   - Institutional investors go for the opposite contracts; evidence of misalignment of objectives.
   - Private equity sells electricity for $1.97 higher average price per MWh.

Contribution

Financing the adoption of innovation and climate finance:

- Market regulation (e.g., Shapiro, 2012; Aghion, Bergeaud, and Van Reenen, 2021).
- Implications for climate finance (Hong, Karolyi and Sheinkman 2020; Giglio, Kelly and Stroebel 2021).

Energy economics:

- The impact of deregulation of electricity markets on market concentration, costs, and consumer markets (e.g., Borenstein, Bushnell, and Wolak, 2002; Borenstein, 2002; Fabrizio, Rose, and Wolfram, 2007; Borenstein and Bushnell, 2015; Cicala, 2015; Cicala 2022).
- Ownership structure also changes, and new participants potentially drive the improvements.

The impact of private equity ownership:

- Operational performance, productivity, and employment (e.g., Davis et al., 2014; Bernstein and Sheen, 2016; Antoni, Maug and Obernberger, 2019; Davis et al., 2021); environment and pollution (Shive and Forster, 2020; Bellon, 2022); customers in regulated industries (e.g., Eaton, Howell and Yannelis, 2020).
- Creation and destruction of assets, rather than ownership changes only through acquisitions.
- Private equity high powered incentives or incumbent vs. new entrant status.

Outline

- **Institutional Setting: Power Plants and Electricity Markets.**
- The Determinants of Ownership Changes.
- Implications of the Ownership Changes.

U.S. Power Plants

All U.S. power plants reporting to the Energy Information Administration over 2008-2020 time period:

- EIA Form 860 and Form 923 data on plant characteristics and net generation.
- Observations on a power-plant-prime-mover level and always weighted by nameplate capacity.

Ownership data:

- Regulatory announcements, Preqin, S&P Global, and newswire articles.
- If a plant has multiple owners, we divide the percentage ownership equally across the ownership types.

	All	NatGas	Coal	Nuclear	Hydro	Wind	Solar
Panel A: Power Plant Characteristics							
# Unique Plants	11,421	2,916	737	66	1,481	1,289	3,940
# Unique Plants-Prime-Mover	13,035	3,997	845	66	1,481	1,289	3,940
Observations	1,288,171	472,593	92,281	9,839	220,419	126,822	187,873
Capacity (GWh)	0.973	0.706	1.441	2.042	1.094	0.177	0.100
Capacity Factor	0.398	0.312	0.504	0.856	0.401	0.329	0.241
Heat Rate		11.659	10.754	10.463			
Age (Years)	31.307	26.471	42.752	34.549	60.373	6.154	2.910
# Unique Greenfield	5,871	633	36	0	51	980	3,633
Greenfield 12m	0.018	0.015	0.003	0.000	0.001	0.114	0.244
# Unique Decommissioned	1,748	834	297	10	83	87	43
Decommissioned 12m	0.012	0.011	0.020	0.006	0.000	0.002	0.001

Incumbent and New Ownership Categories

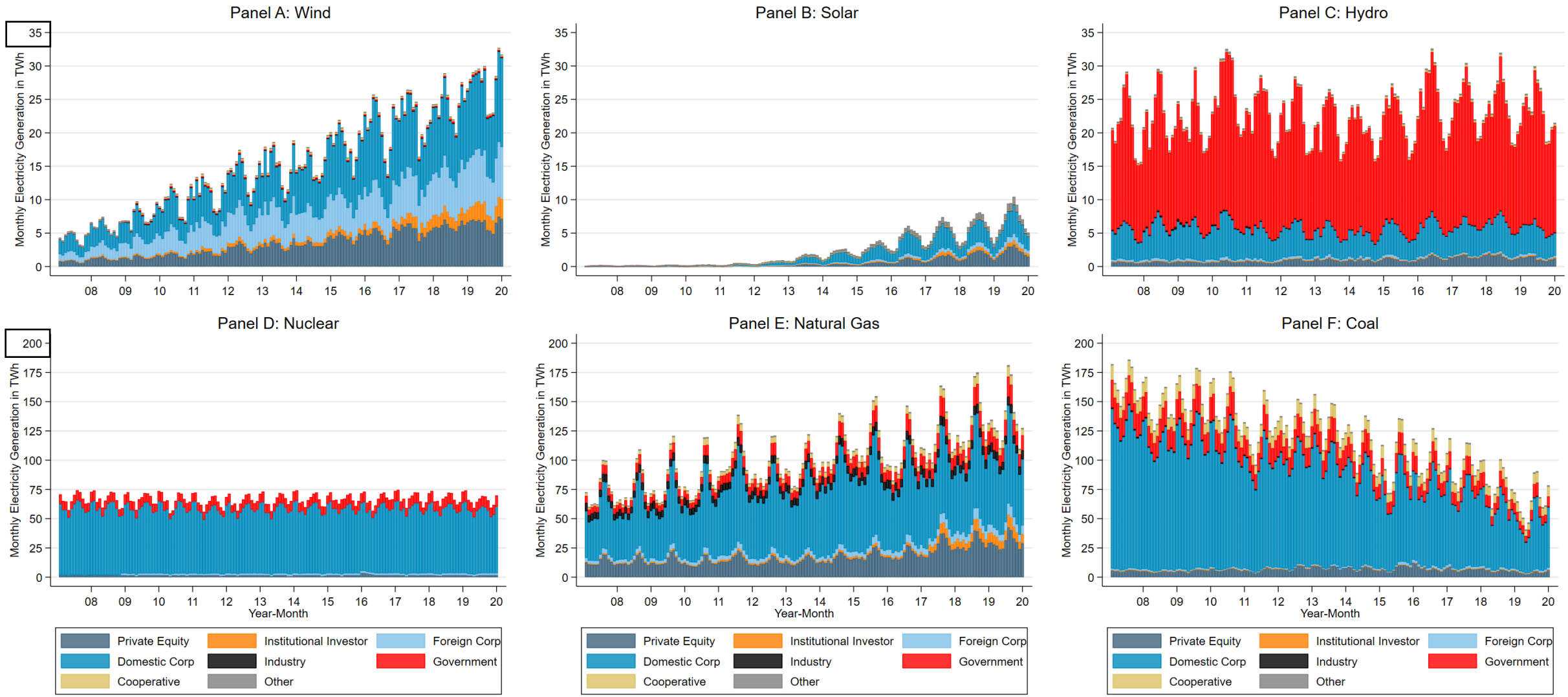
1. **Domestic Publicly Listed Corporations:** includes traditional utilities and listed independent power producers (e.g., Duke Energy, Exelon Corporation, PG&E Corporation, Southern Company).

2. **Private Equity:** buyout funds, infrastructure funds, other investment vehicles (e.g., ArcLight, KKR, LS Power, Macquarie), and small number of private companies (e.g, Koch Industries, Tenaska).
3. **Institutional Investors:** mostly foreign institutional investors, such as Canadian and Dutch pension funds (e.g., CPPIB, OMERS, Ontario Teachers, APG); co-invest (share ownership) in 93% of their observations.
4. **Foreign Publicly Listed Corporations:** power plants owned by European, Canadian, and Asian energy companies (e.g., EDP Group, Engie, Iberdrola, Itochu Corporation, Kansai Electric Power Co., Osaka Gas).

5. **Government:** power plants owned by federal, state, and local governmental entities (e.g., Tennessee Valley Authority, U.S. Bureau of Reclamation, Los Angeles Department of Water and Power).
6. **Cooperatives:** power plants built and owned by the communities they serve (e.g., Basin Electric Power Coop, Associated Electric Coop, East Kentucky Power Coop).
7. **Industry Firms:** large companies engaged in energy-intensive manufacturing, such as production of paper, steel, aluminum, and chemicals (e.g., International Paper Co, Dow Chemical Co, Alcoa Corp).

8. **Other:** small power plants (<1% of generation) not classified yet in one of the other categories.

Ownership and Electricity Generation by Fuel Type



Electricity Markets

Wholesale electricity markets:

- Traditional electricity markets with vertically integrated utilities:
  - Could exclude independent producers by denying grid access (Borenstein and Bushnell, 2015).
- Restructured markets with an Independent System Operator (ISO) as a balancing authority:
  - Market dispatch mechanism and non-discriminatory grid access: Control of the transmission system moves from the local utility to the ISO balancing authority, which conducts auctions (Cicala, 2022).

Retail electricity markets:

- Residential or business customers have full or limited choice of who provides their electricity.
- Serves like a triple interaction term: almost all areas with retail choice have also a restructured wholesale market (but not the other way around).

Market regulation stays stable during our sample period:

- ISO operated wholesale markets were established around 2000, no changes since 2008.
- Also no changes in retail market choice since 2007.
- Before wind and solar technologies became competitive as well as before the shale gas revolution.

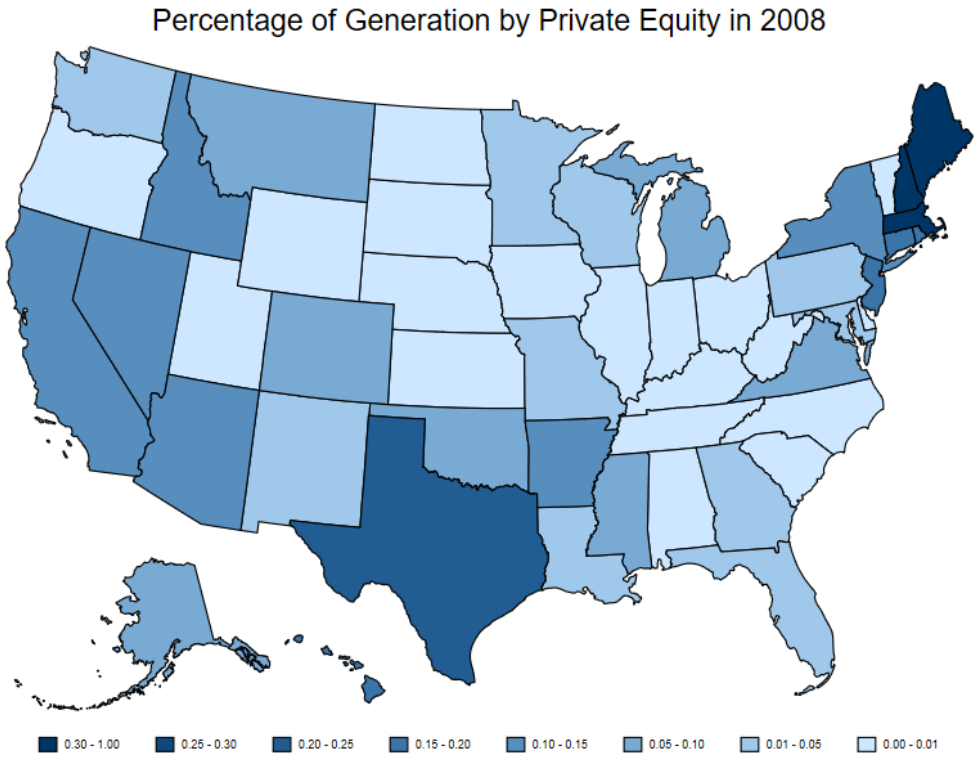
Electricity Markets and Ownership Changes

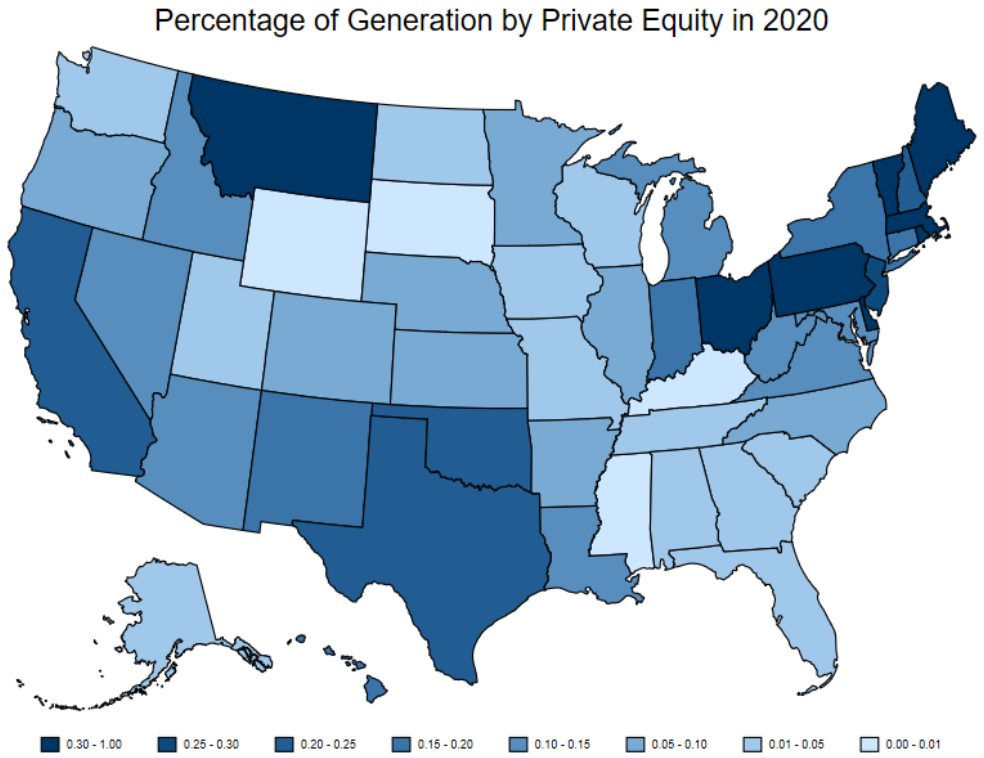
Traditional electricity markets with vertically integrated utilities:

- Domestic publicly listed corp. from 62% to 61% in Alabama, from 53% to 55% in Colorado.

Restructured markets with an independent (ISO) balancing authority:

- California: Domestic corp. from 56% to 38%; PE 13% to 22%; II 0% to 9%; Foreign corp. 2% to 4%.
- Ohio: Domestic corp. from 94% to 55%; PE 0% to 32%; II 0% to 4%; Foreign corp. 0% to 4%.





Outline

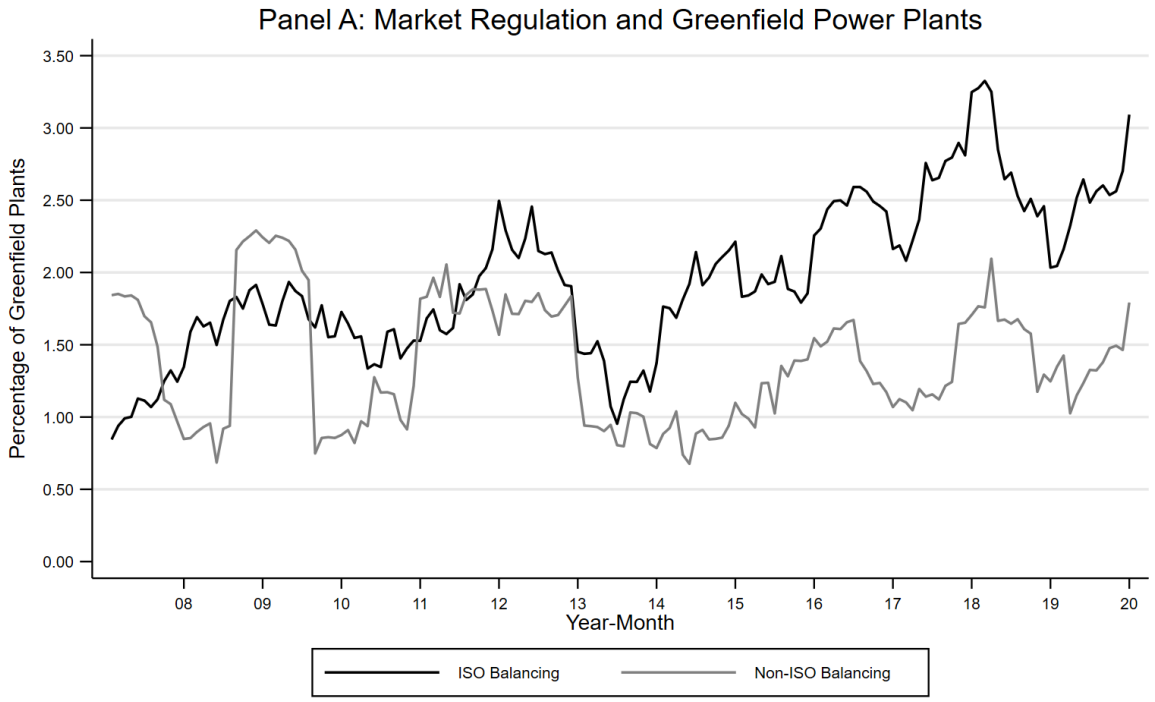
- Institutional Setting: Power Plants and Electricity Markets.
- **The Determinants of Ownership Changes.**
  - **Creating New Greenfield Power Plants.**
  - **Selling Existing Power Plants.**
  - **Decommissioning Power Plants.**
- Implications of the Ownership Changes.

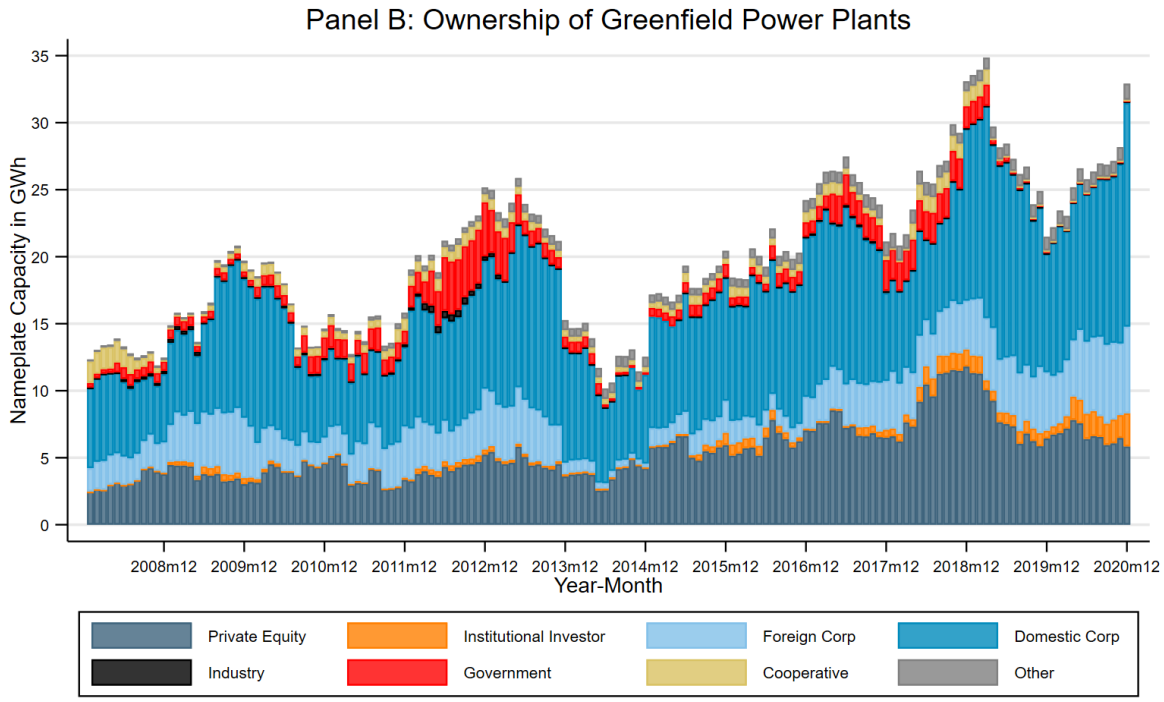
First Mechanism: Creating New Greenfield Power Plants

Greenfield variable: Indicator equal to one for the first 12 months of plant operation.

Who creates new power plants? Incumbent domestic listed corporations vs new entrants?

- Advantages of incumbents: size, access to transmission, synergies, government relations.
- But also incentives to delay implementation of new technology, especially under the protection of market power (Arrow, 1962; Bertrand and Mullainathan, 2003; Cunningham, Ederer, and Ma, 2021).





First Mechanism: Creating New Greenfield Power Plants

Probability of owning new plants within the same fuel type, state, and time.

- Observations weighted by capacity.
- Robustness with logit models and without weighting.

Domestic corporations are 1.18pp less likely to own new plants, especially in deregulated markets:

- **Decompose 1.18pp:** 0.66pp due to solar and wind farms; 0.43pp due to natural gas power plants.

All Greenfield Power Plants (Unconditional Prob. = 1.75%)

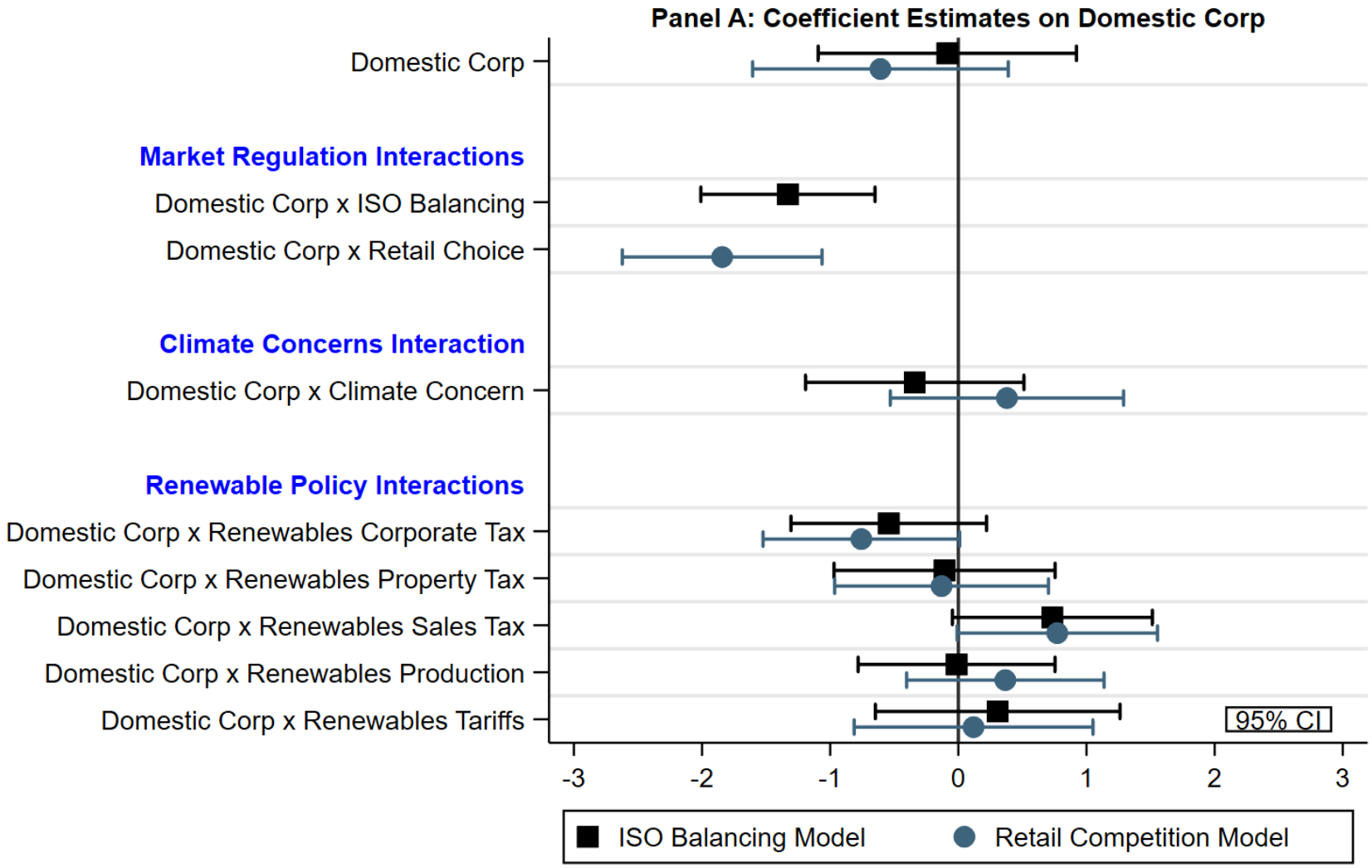
	(1)	(2)	(3)	(4)
Domestic Corp	-1.178***		-0.161	-0.301
	[0.290]		[0.340]	[0.325]
Domestic Corp × ISO Balancing			-1.402***	
			[0.324]	
Domestic Corp × Retail Choice				-1.591***
				[0.349]
Private Equity		1.506***		
		[0.335]		
Institutional Investor		-1.774**		
		[0.892]		
Foreign Corp		1.122**		
		[0.567]		
ln Plant Capacity	0.132*	0.137*	0.155**	0.142**
	[0.071]	[0.071]	[0.071]	[0.070]
Other Owners	Yes	Yes	Yes	Yes
Fuel-State-Year-Month FE	Yes	Yes	Yes	Yes
Observations	1,288,206	1,288,206	1,288,206	1,288,206
Adjusted R-squared	0.178	0.178	0.178	0.178

Market Regulation and Domestic Listed Corporations

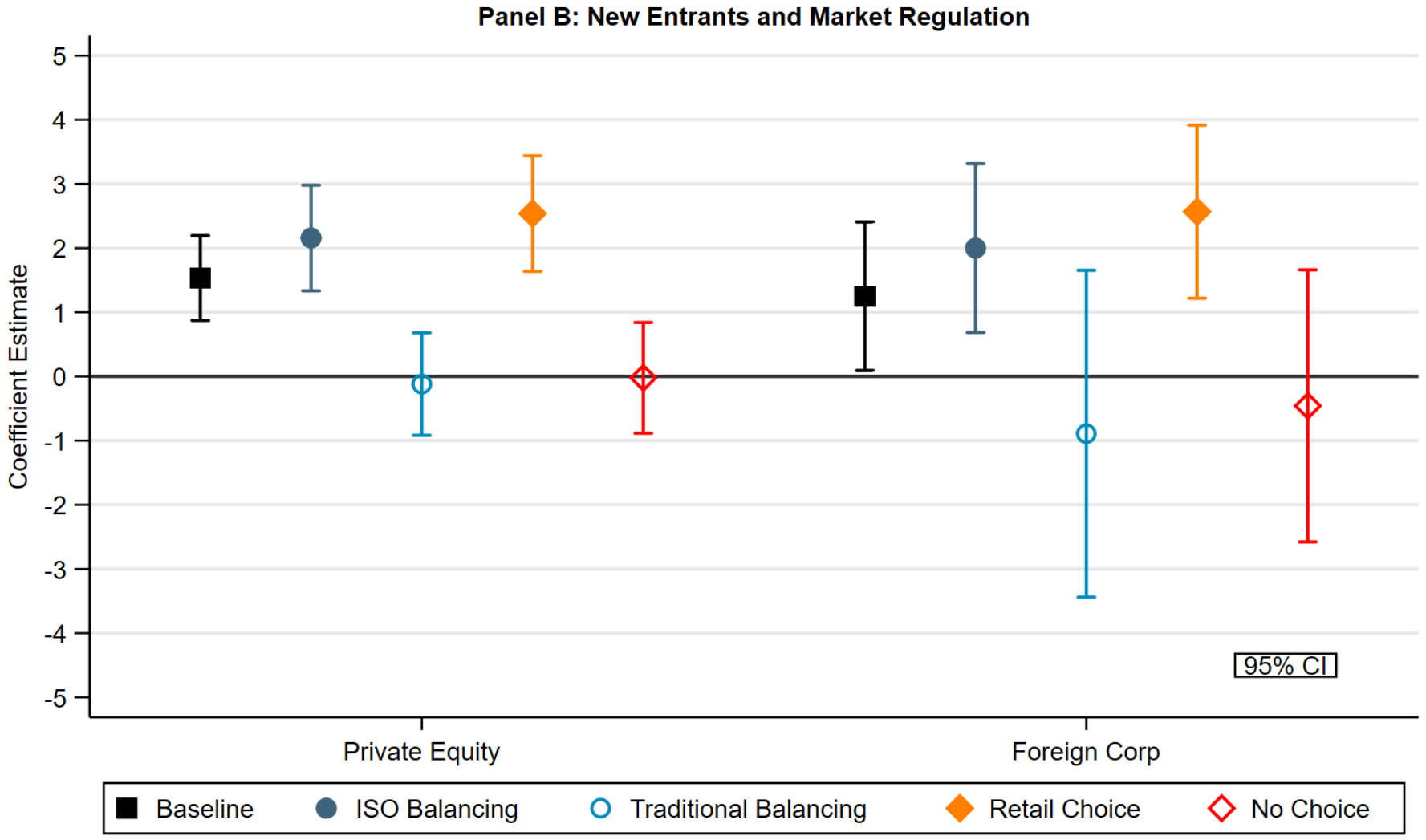
Wholesale and retail market deregulation explains variation in ownership of greenfield plants.

Demand and preferences: climate concerns among local population (Yale Climate Opinion Maps).

Renewables policy: tax incentives and production-based incentives (DSIRE data).



Sample Splits: Market Regulation and New Entrants



Second Mechanism: Selling Existing Power Plants

Leakage hypothesis: Domestic listed corp. sell older fossil fuel power plants.

- Subject to more disclosure, regulation, and public scrutiny (Benthem et al, 2022; Bolton and Kacperczyk, 2022).
- Private equity and foreign corp. may acquire older fossil fuel plants (Shive and Forster, 2020; Bernstein, 2022).

Multinomial logit analysis: All plants owned by domestic corp. in Jan 2008; study the outcome based on the last observation.

No evidence of leakage:

- Domestic corporations shut down older fossil fuel power plants.
- They are not selling plants where population has high climate concerns.

	Still Own & Operating	Owned & Retired	Sold & Operating	Sold & Retired
# Unique Plants	1,276	444	484	63
Unconditional Prob.	0.685	0.153	0.153	0.009
ISO Balancing	-0.116***	0.048**	0.068**	0.001
	[0.035]	[0.024]	[0.028]	[0.004]
Climate Concern	-0.050	0.044*	-0.001	0.008*
	[0.037]	[0.026]	[0.028]	[0.004]
Renewables Incentives	-0.040**	0.005	0.031**	0.005
	[0.018]	[0.013]	[0.014]	[0.003]
ln Plant Capacity	0.103***	-0.073***	-0.022*	-0.008***
	[0.015]	[0.010]	[0.011]	[0.001]
ln Plant Age	-0.089***	0.181***	-0.088***	-0.005*
	[0.026]	[0.024]	[0.014]	[0.003]
Coal & Petroleum	-0.317***	0.313***	-0.041	0.046**
	[0.050]	[0.040]	[0.041]	[0.018]
Natural Gas	-0.334***	0.334***	-0.005	0.006
	[0.058]	[0.052]	[0.035]	[0.007]
Fuel FE	Yes	Yes	Yes	Yes
Observations	2,267	2,267	2,267	2,267

Third Mechanism: Decommissioning Power Plants

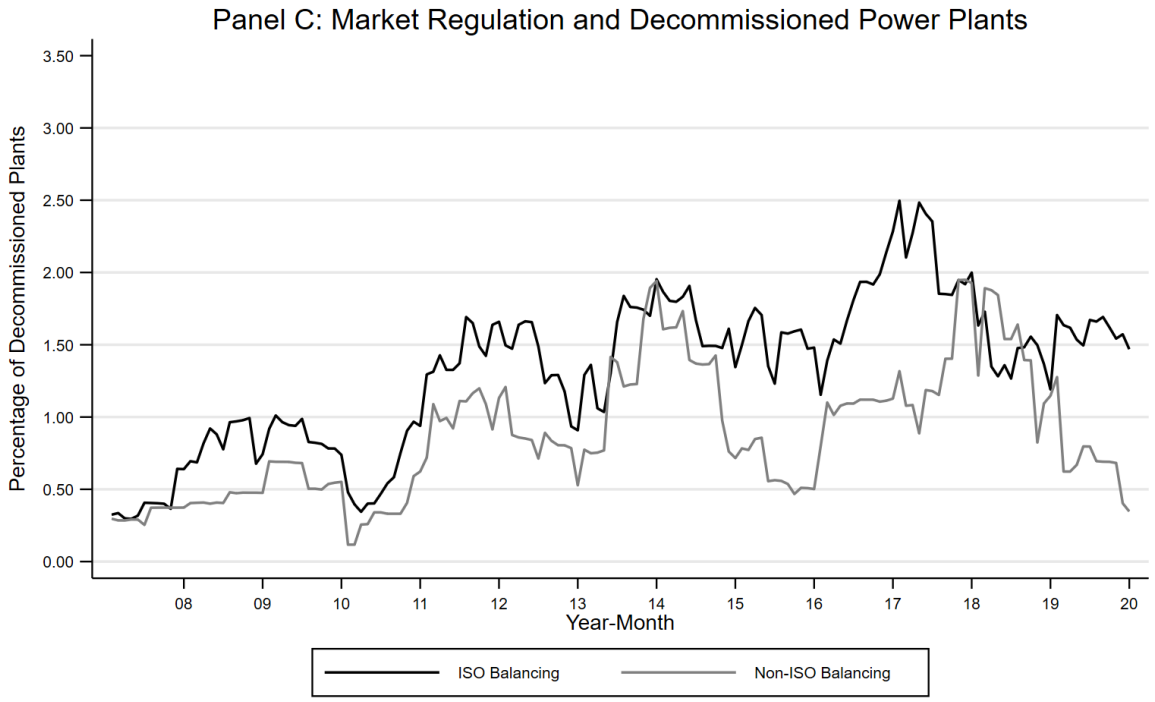
Decommissioned variable: Indicator equal to one for the last 12 months of plant operation.

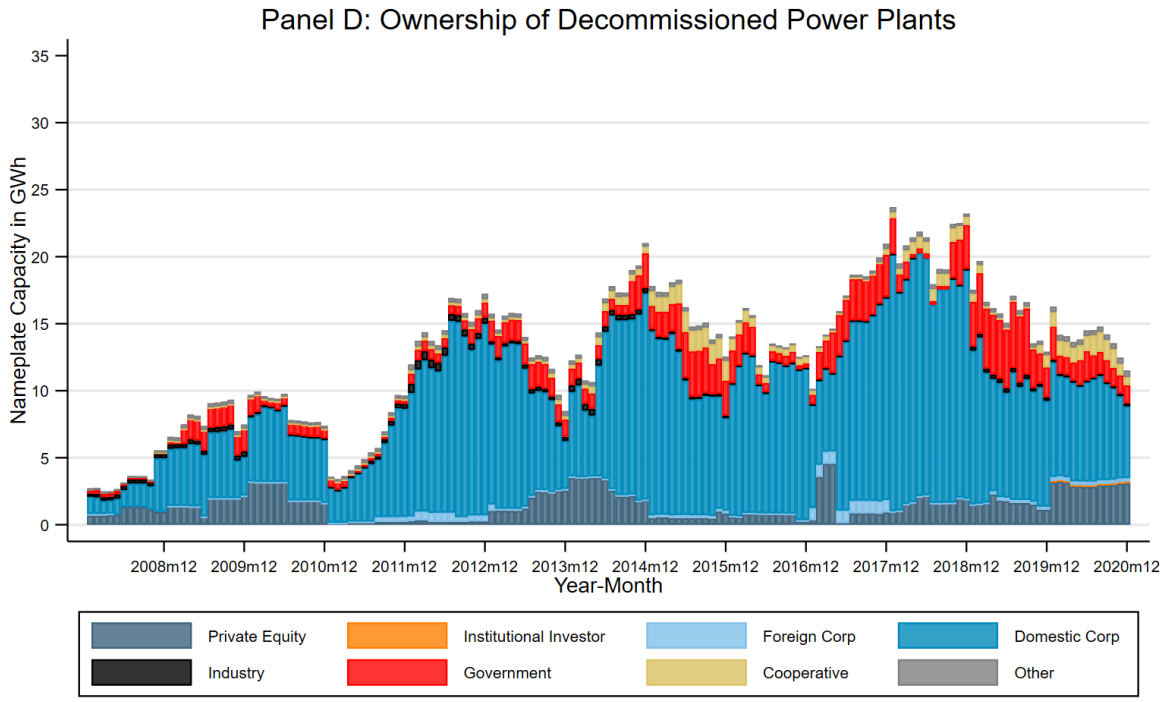
Deregulated energy markets experience more destruction of old plants:

- 1.32% retired assets in liberalized markets vs 0.86% in traditional markets (obs. weighted by capacity).

Domestic corporations are more likely to own power plants in decommission stage:

- Private equity firms own 10.7% of the retired plants vs. 11.8% of all plants. Evidence of leakage?





Third Mechanism: Decommissioning Power Plants

Probability of owning retired plants within the same fuel type, state, and time.

- Robustness with Cox hazard survival model and without weighting.

Domestic corp. are not more likely to decommission power plants (0.19pp insignificant):

- Baseline in traditional markets: 0.53pp lower probability to retire a power plant.
- Interaction term with ISO Balancing: domestic corporations are 1.00pp more likely to retire a plant.

All Decommissioned Power Plants (Unconditional Prob. = 1.17%)				
	(1)	(2)	(3)	(4)
Domestic Corp	0.192		-0.530*	-0.149
	[0.229]		[0.291]	[0.316]
Domestic Corp × ISO Balancing			1.002***	
			[0.322]	
Domestic Corp × Retail Choice				0.622
				[0.443]
Private Equity		0.070		
		[0.287]		
Institutional Investor		-1.106***		
		[0.268]		
Foreign Corp		-0.714***		
		[0.271]		
ln Plant Capacity	-0.747***	-0.746***	-0.764***	-0.751***
	[0.093]	[0.093]	[0.093]	[0.093]
ln Plant Age	1.184***	1.195***	1.162***	1.175***
	[0.146]	[0.147]	[0.146]	[0.147]
Other Owners	Yes	Yes	Yes	Yes
Fuel-State-Year-Month FE	Yes	Yes	Yes	Yes
Observations	1,288,206	1,288,206	1,288,206	1,288,206
Adjusted R-squared	0.253	0.253	0.253	0.253

Outline

- Institutional Setting: Power Plants and Electricity Markets.
- The Determinants of Ownership Changes.
- **Implications of the Ownership Changes:**
  - **Operating Performance.**
  - **Contractual Terms.**
  - **Electricity Pricing.**

Operating Performance: Capacity Factor and Heat Rate

Capacity factor: ratio of monthly net generation to nameplate capacity.

- Measures operating **intensity**.

Heat rate: ratio of fuel consumption in millions Btu to net generation.

- Measures operating **efficiency**.

Creating new plants and retiring old plants is costly.

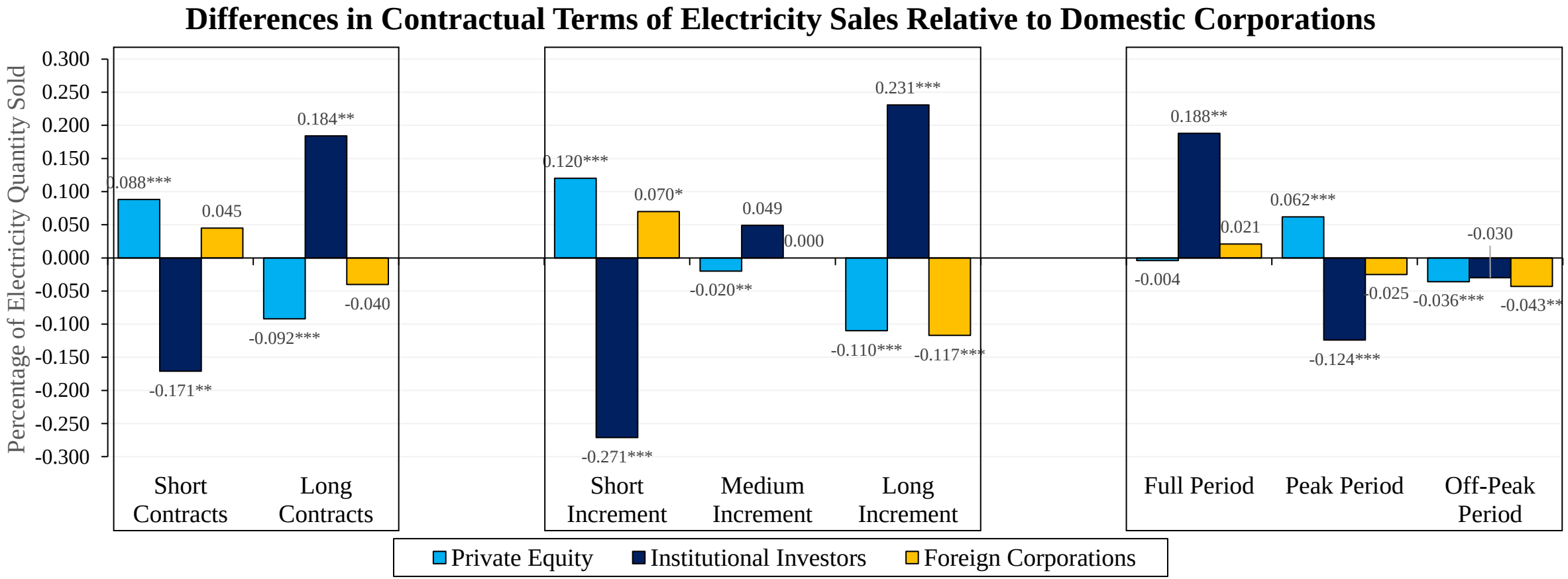
Domestic corporations have a lower operating efficiency:

- But operate plants more intensely in traditional markets.

	Capacity Factor All Plants Mean Dep. Variable = 0.396			Heat Rate Fossil Fuel Plants Mean Dep. Variable = 11.265		
	(1)	(2)	(3)	(4)	(5)	(6)
Domestic Corp	0.018*		0.047**	0.565***		0.886***
	[0.011]		[0.024]	[0.165]		[0.294]
Domestic Corp × ISO Balancing			-0.053***			0.292
			[0.016]			[0.215]
Domestic Corp × Climate Concern			0.020			-0.626**
			[0.019]			[0.253]
Domestic Corp x Renewables Incentives			-0.002			-0.047
			[0.007]			[0.102]
Private Equity		-0.031**			-0.429**	
		[0.012]			[0.186]	
Institutional Investor		0.097***			-1.679***	
		[0.034]			[0.511]	
Foreign Corp		-0.018			-0.686**	
		[0.015]			[0.312]	
ln Plant Capacity	0.020***	0.020***	0.021***	-0.459***	-0.459***	-0.448***
	[0.004]	[0.004]	[0.004]	[0.076]	[0.076]	[0.076]
ln Plant Age	-0.117***	-0.118***	-0.116***	1.320***	1.328***	1.328***
	[0.007]	[0.007]	[0.007]	[0.123]	[0.122]	[0.123]
Greenfield 12m	-0.159***	-0.159***	-0.160***	1.915***	1.920***	1.947***
	[0.012]	[0.012]	[0.012]	[0.257]	[0.256]	[0.256]
Decommissioned 12m	-0.121***	-0.120***	-0.119***	0.482***	0.476***	0.478***
	[0.012]	[0.012]	[0.012]	[0.176]	[0.176]	[0.177]
Other Owners	Yes	Yes	Yes	Yes	Yes	Yes
Fuel-State-Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,288,206	1,288,206	1,288,206	397,220	397,220	397,220
Adjusted R-squared	0.650	0.651	0.651	0.295	0.296	0.296

Contractual Terms of Electricity Sales and Capacity Sales

Private equity: Short duration, short increments, and peak period sales.
Institutional investors: Long duration, long increments, and full period sales; stable cash flows.
Capacity sales: 76% of the contract are long-term, but private equity use 9pp more short contracts.



Pricing of Electricity Sales

Pricing of Electricity Sales:

- Private equity sells electricity for $1.97 higher average price per MWh.
- Observations weighted by quantity sold.
- Part of the higher prices driven by more flexible choices which power plants to operate in a given state-month situation.

Adopting innovation is challenging:

- Greenfield plants have a 0.159 lower capacity factor (out of average 0.398) and sell electricity for $5 lower price per MWh.
- New owners need time to gain market share and establish contracts as well as to gain experience how to operate the power plant efficiently.

	Mean Price		Median Price	
	(1)	(2)	(3)	(4)
Private Equity	4.543***	1.972*	4.513***	2.101**
	[0.972]	[1.087]	[0.944]	[1.054]
Institutional Investor	0.793	1.639	-0.739	-0.206
	[3.162]	[2.831]	[2.663]	[2.422]
Foreign Corp	1.041	-1.570	1.081	-1.166
	[1.544]	[1.634]	[1.441]	[1.674]
ln Plant Capacity	-0.506	-0.225	-0.421	0.001
	[0.489]	[0.571]	[0.467]	[0.574]
ln Plant Age	1.232**	1.034*	1.183**	0.858
	[0.482]	[0.568]	[0.480]	[0.561]
Greenfield 12m	-5.115***	-5.496***	-5.014***	-5.620***
	[1.137]	[1.215]	[1.085]	[1.152]
Decommissioned 12m	-1.406	-1.451	-2.122	-2.798
	[1.409]	[1.674]	[1.801]	[2.385]
State-Year-Month FE	Yes	No	Yes	No
Fuel FE	Yes	No	Yes	No
Fuel-State-Year-Month FE	No	Yes	No	Yes
Observations	236,035	236,035	236,035	236,035
Adjusted R-squared	0.591	0.721	0.521	0.678

Implications and Discussion

1. **Creation of new plants and retirement of old fossil fuel plants drive the ownership changes, while acquisitions of existing assets account for less than 1/3 of the changes.**
   - Limited evidence of leakage of old fossil fuel power plants (Shive and Forster, 2020).
   - Implications for climate finance (Hong, Karolyi and Sheinkman 2020; Giglio, Kelly and Stroebel 2021).
   - New entrants improve the operating efficiency of fossil fuel power plants.

2. **Competitive markets attract new capital and facilitate adoption of innovation and destruction.**
   - Market deregulation dominates climate concerns and renewable policy incentives.

3. **Incumbent owners of (stranded) assets vs. new entrants seems more important than the private equity business model to stimulate changes.**
   - Incumbents do not finance the energy transition (Aghion, Bergeaud, and Van Reenen, 2021).
   - Fits into the broader trend of declining number of U.S. listed companies (Doidge, Karolyi, and Stulz, 2017; Ewens and Farre-Mensa, 2020).

4. **Private equity establishes short contracts with more volatility and higher prices:**
   - Institutional investors go for the opposite contracts; Evidence of misalignment of objectives.
   - Easier for power plant owners to pass the volatility in resources to the final consumers.