The Dynamic Efficiency of Policy Uncertainty: Evidence from the Wind Industry

Luming Chen

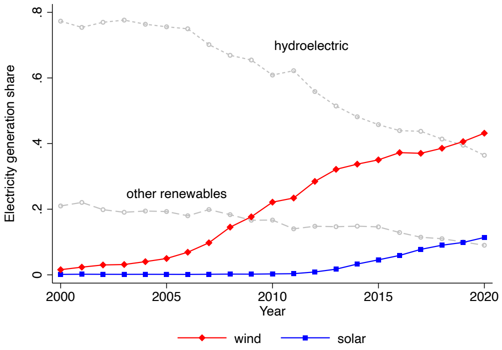
DSE Conference

August $7^{\text{th}}, 2024$

Booming Wind Energy

- Wind power is America's #1 renewable energy source.
- 8.3% of electricity; 42% of new power plant installations in 2020.

Figure: Share of Electricity Generation by Renewable Sources



Massive Subsidies

The New York Times

Clean Energy Projects Surge After Climate Bill Passage

Forbes

FORBES › BUSINESS › ENERGY

Inflation Reduction Act Benefits: Clean Energy Tax Credits Could Double Deployment

THE WALL STREET JOURNAL.

BUSINESS

Biden's Big Infrastructure Plan Would Further Boost Renewable Energy

The president's proposal to address climate change would extend wind and solar tax credits another decade, and create new incentives for transmission lines

Introduction

- Government subsidies play a crucial role in boosting renewable energy development.
- Policy expiration and uncertainty.
  - enactment – expiration date – **renew/pause** – expiration date – $\cdots$ – termination.
- Research question: How does policy uncertainty affect the dynamic market efficiency?
  - empirical setting: US wind industry + Production Tax Credit (lapsed in 2012)
  - **policy uncertainty**: whether the policy would be renewed beyond the expiration date.

What This Paper Does

- Compile a comprehensive data set of the US wind energy market (2003-2018).
  - investment, production, and long-term contracts between utilities and wind farms.
- Document three key stylized facts.
  1. the time to start operation was bunched around subsidy expiration dates.

     → expedited entry and environmental benefits (+).
  2. the upstream turbine technology is continuously and quickly improving.

     → timing misalignment between technology and investment (-).
  3. the unfulfilled demand from the utility sector is decreasing.

     → early entrants using less productive turbines matched with utilities of larger demand (-).

Fact 1 Fact 2 Fact 3

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  - dynamic entry of wind farms with time-varying policy beliefs.
  - stage game of bilateral bargaining of long-term contracts between wind farms and utilities.
  - key identification of beliefs: temporal variation in the policy implementation.
- Implement counterfactual exercises.
  1. no policy uncertainty (set the perceived likelihood of policy renewal $= 1$).
     - ⋆ Inflation Reduction Act 2022-2032.
  2. policy uncertainty under different subsidy levels.

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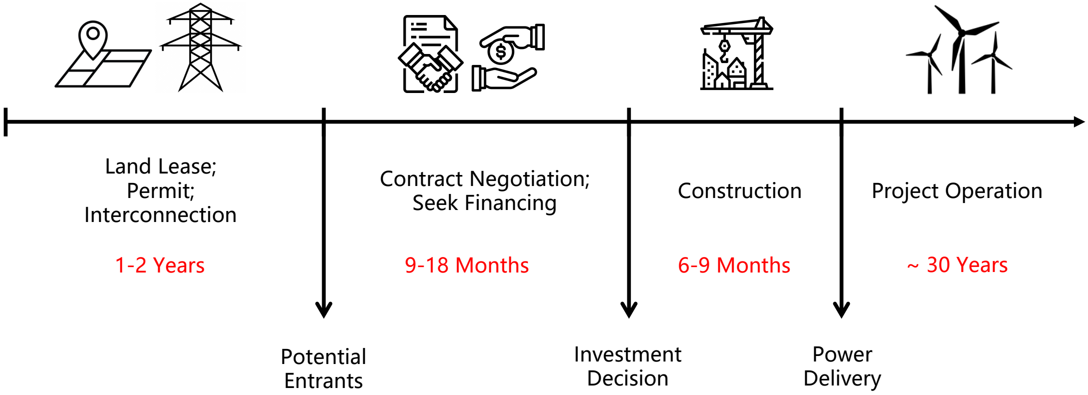
Preview of Findings

- Policy lapse reduced the perceived likelihood of renewal to 30% for the 2011 cohort.
- Without policy uncertainty,
  1. # of new wind farms in 2011 was reduced by 53%.
  2. these wind farms postpone their entry by 3.5 years.
  3. the net social surplus of wind energy increases by 5.9 billion dollars.
  4. the subsidy level could be lowered by 10% without sacrificing social welfare.

Institutional Background

Background: Build a Wind Farm



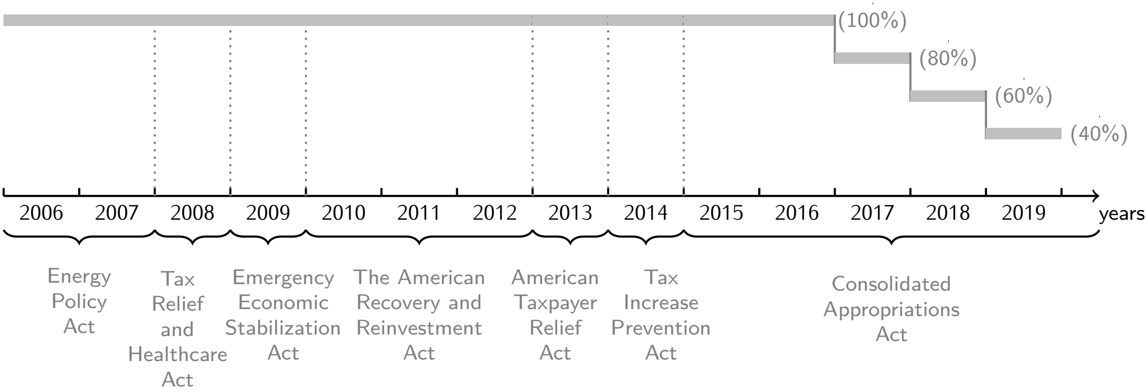
▸ Full Timeline ▸ Queue ▸ Construction Time

Background: Government Subsidies

- The Production Tax Credit (PTC) since 1992.
  - 10-year inflation-adjusted tax credit for wind power generation.
  - Stood at \$24/MWh in 2018 $\sim$ 50% of the wind procurement price.
- Conditions to qualify for the PTC
  - starts the project operation before the expiration (before 2012).
  - starts the project construction before the expiration + safe harbor period (after 2013).

▸ Section 1603 Grants ▸ State Subsidies

Background: Policy Implementation



Source: 2018 Wind Technologies Market Report, Department of Energy

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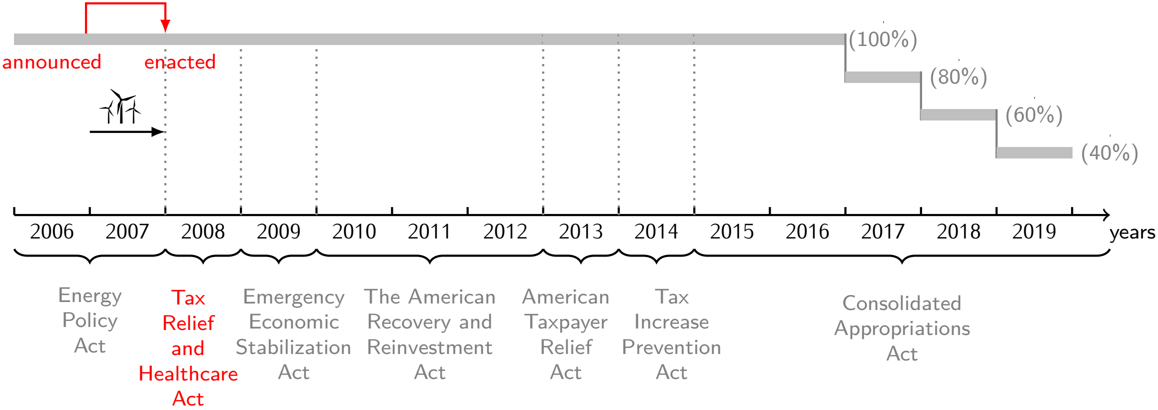

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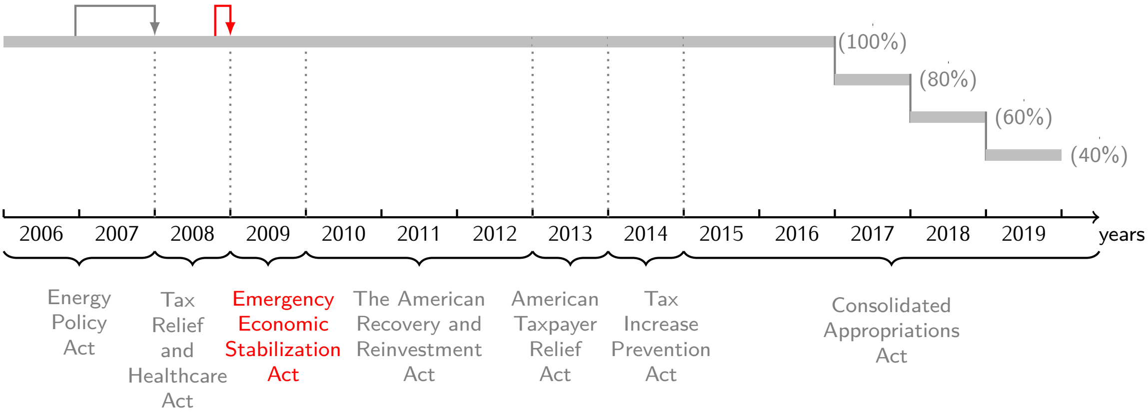

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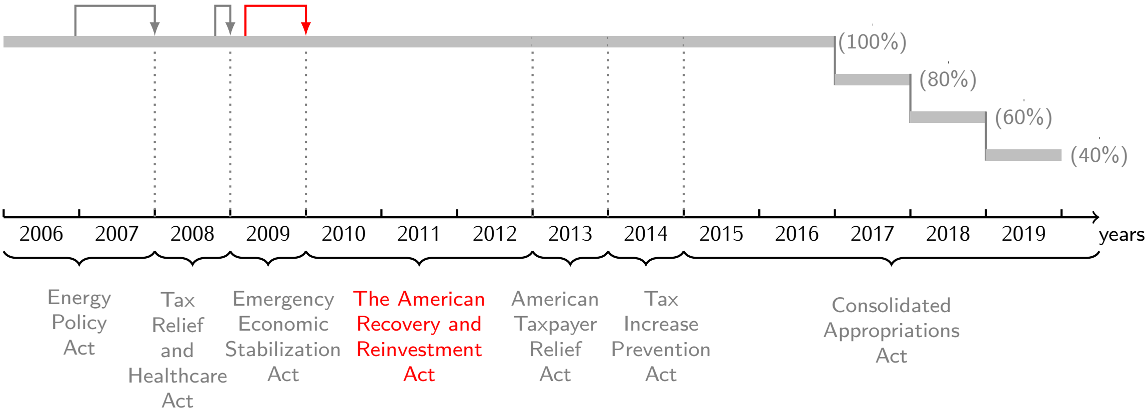

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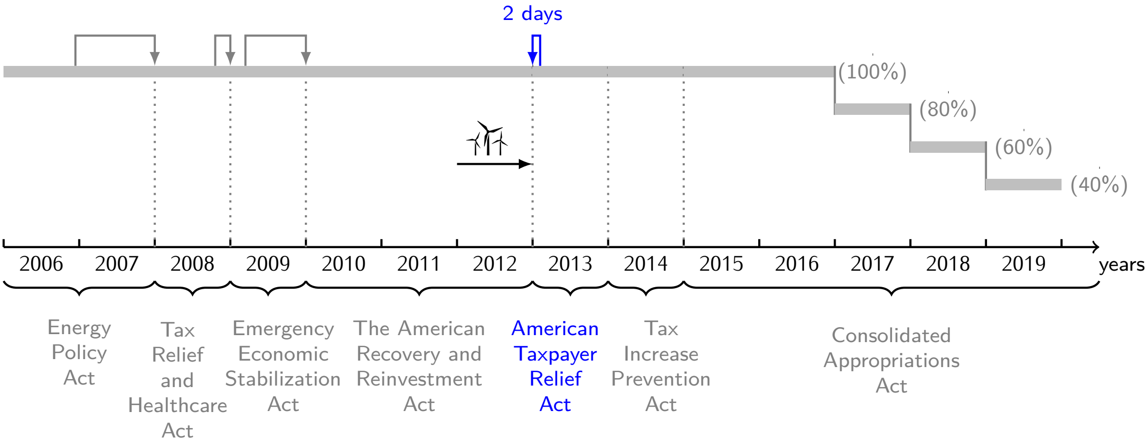

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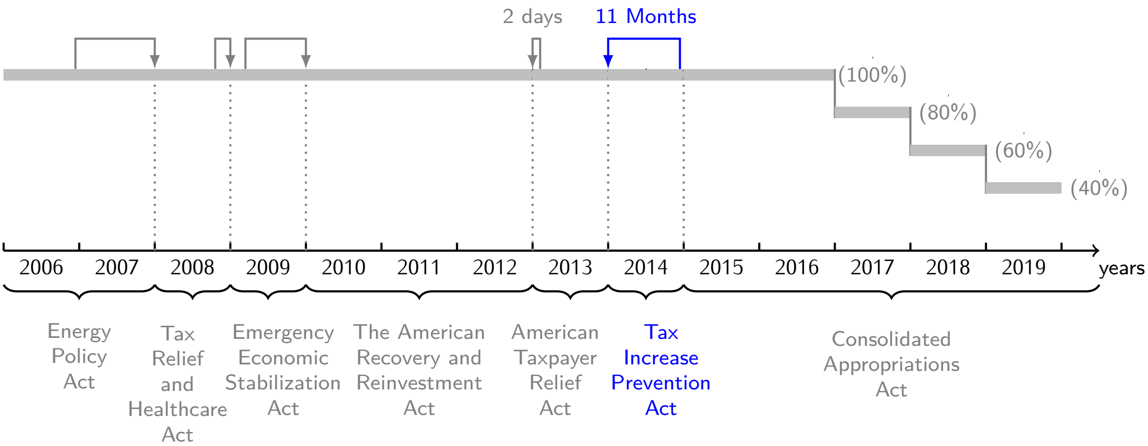

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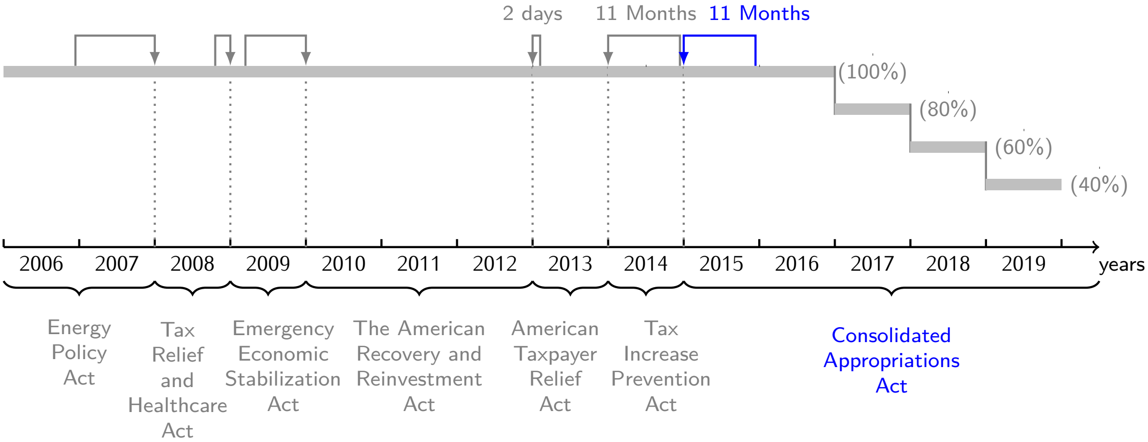

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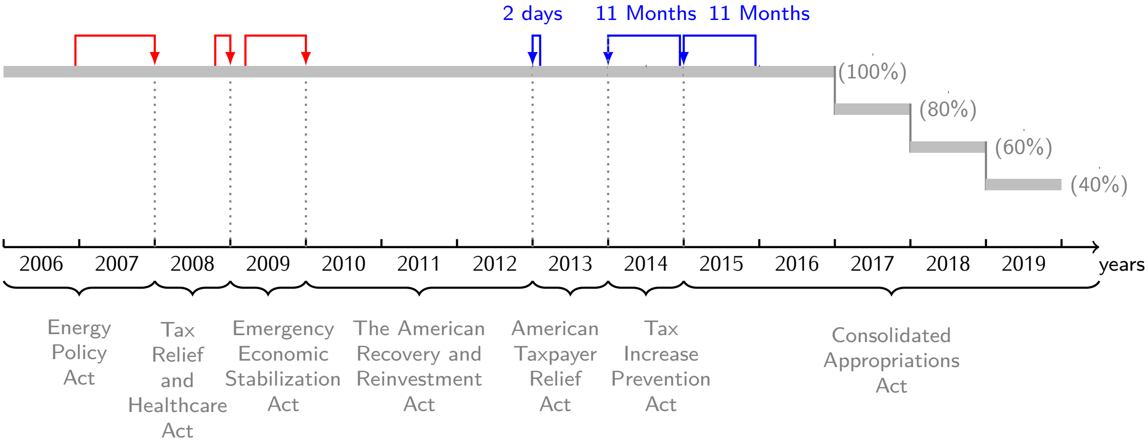


Source: 2018 Wind Technologies Market Report, Department of Energy

Background: Policy Uncertainty

> With federal tax incentives for wind energy currently slated to expire at the end of 2012, new capacity additions in 2012 are anticipated to exceed 2011 levels and perhaps even the highs in 2009 as developers rush to commission projects.
>
> — Department of Energy

> Our financial expectations do not include any additional U.S. wind build beyond 2012 due to the uncertainty surrounding the extension of PTC after the end of this year.
>
> — NextEra Energy

> Vestas is preparing for a significant slowdown in the US market in case the PTC scheme is not extended beyond 2012. If the PTC is not extended, this could result in the lay-off of approx 1,600 employees at the US factories.
>
> — Vestas

Motivating Facts

Fact 1: Bunching in the Operation Starting Time

Figure: Annual Pattern

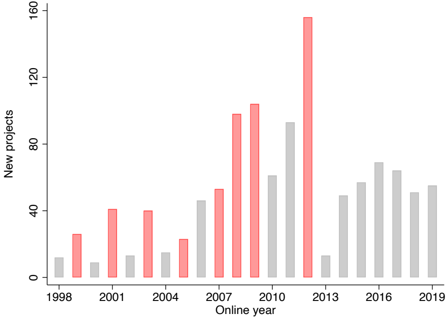
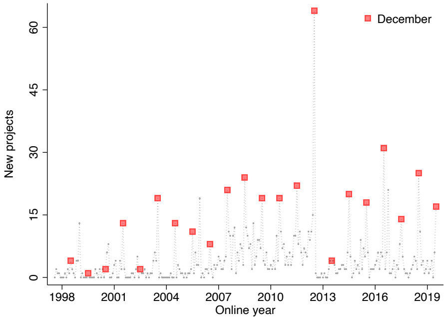


Figure: Monthly Pattern



- The online time of new wind farms bunched in the month of expiration of Production Tax Credit.

Fact 2: Investment and Technological Improvement

Figure: Capacity Factor $\sim Y/K$

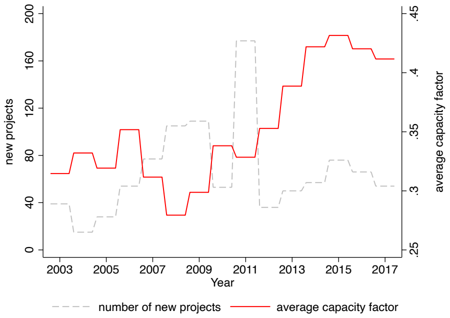
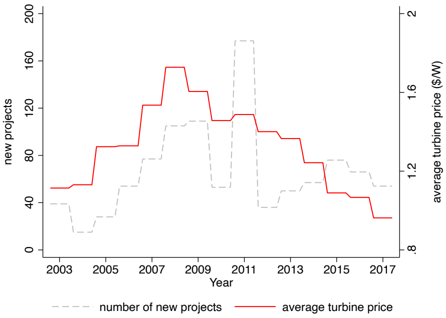


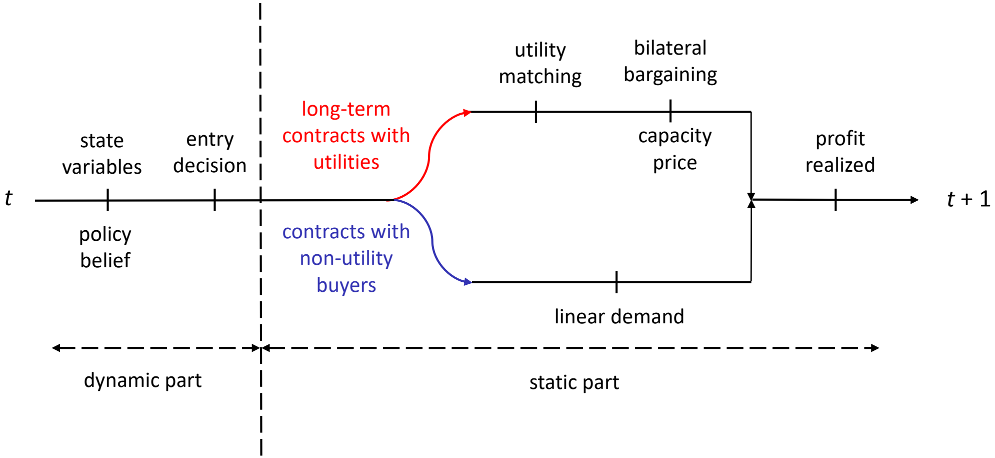
Figure: Turbine Price



- Mismatch between the timings of investment and turbine technological advancement.

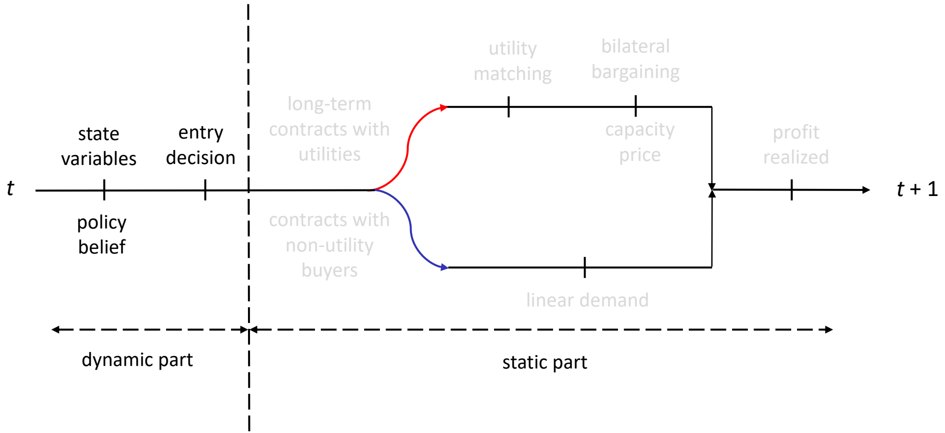
Structural Model

Model Overview



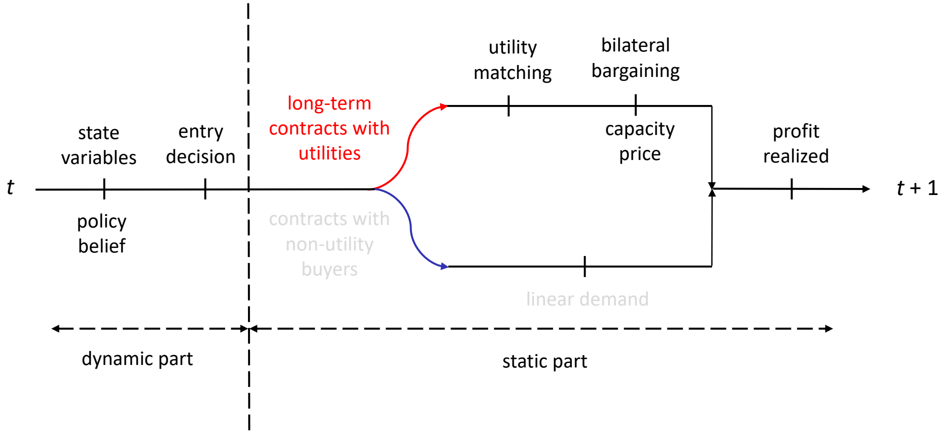
- Dynamic part + static part.

Model Overview (Cont'd)



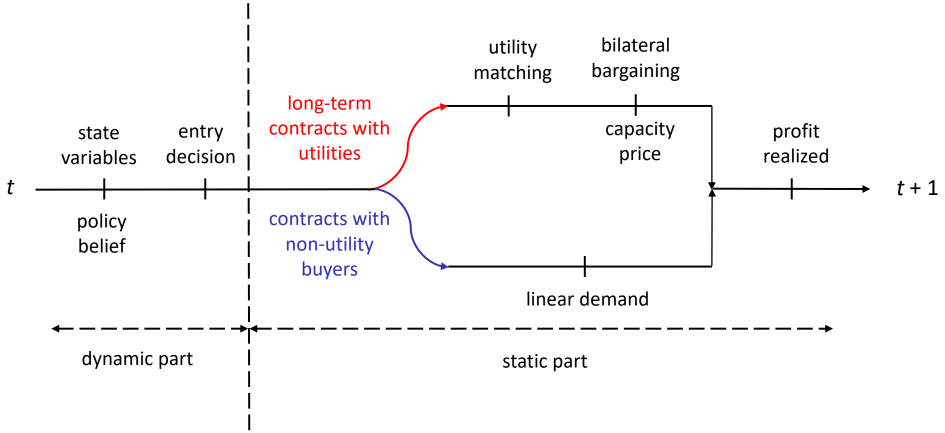
- At the beginning of the year t, wind farm i decides whether to enter this period under policy uncertainty. (Dynamic Part)

Model Overview (Cont'd)



- Choose a utility and negotiate about the power purchase agreement (PPA). (Channel I)

Model Overview (Cont'd)



- Alternatively, sell capacity to corporations or the financial market. (Channel II)

Static: Long-term Contracts with Utilities

Bilateral Bargaining

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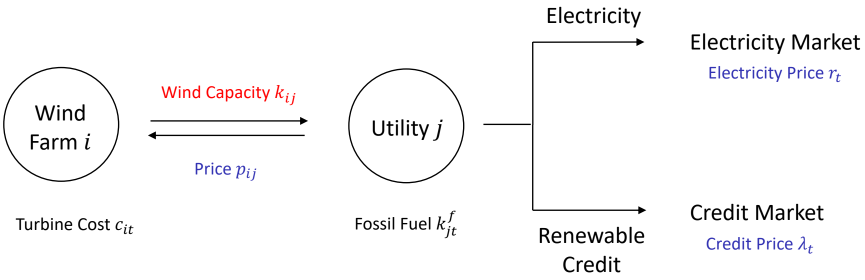
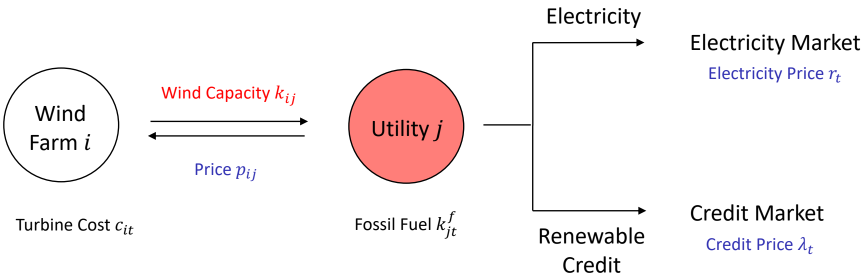


- Utilities procure capacity from wind farms through power purchase agreements (PPA).

Static: Bilateral Bargaining



- Utilities procure capacity from wind farms through power purchase agreements (PPA).
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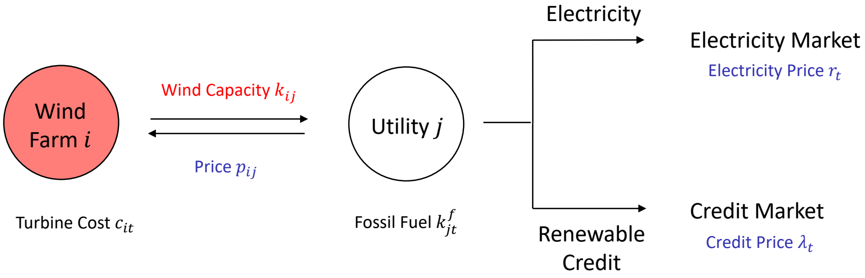

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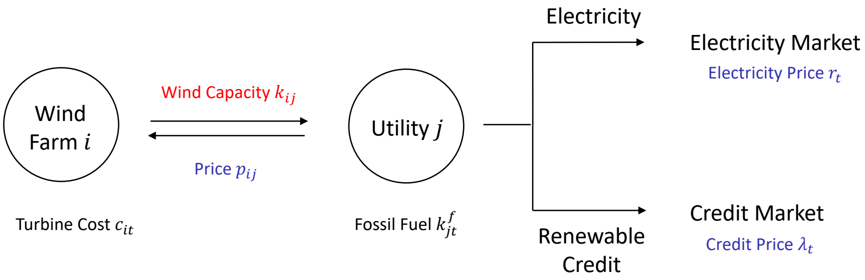

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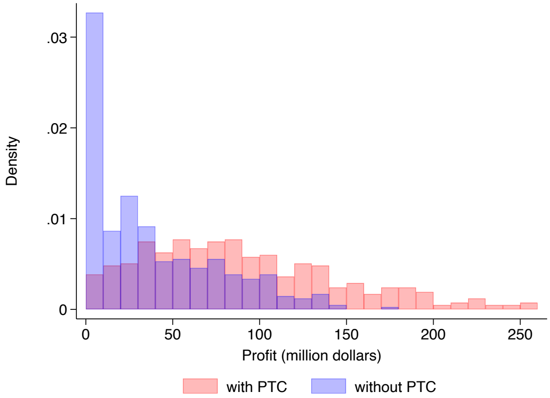
- They negotiate over wind farm capacity and PPA price at the same time.

Results: Profits w/o PTC



- 22.4% wind farms unprofitable without PTC. Average profit decreases by 47.0%.

Dynamic: When to Enter

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- At the beginning of year t, wind farm i draws a random entry cost v_{it}.
- The optimization problem

$$V_t(s_{it}, \omega_t, v_{it}) = \max\{\pi(s_{it}, \omega_t) - v_{it}, \beta E_t[V_{t+1}(s_{it+1}, \omega_{t+1}, v_{it+1}) | s_{it}, \omega_t]\}$$

  - s_{it} includes the electricity and renewable credit prices, buyers' renewable portfolio gaps, turbine productivity, turbine cost, the subsidy level, etc.
  - ω_t: the status of policy, 1 if extended.
- The definition of potential entrants
  - projects that have been in the interconnection queue for two or more years that haven't built a wind farm nor withdrawn from the queue.

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- $b_t(\omega_{t+1}|\omega_t)$: *ex-ante* belief for the policy evolution due to policy uncertainty

Assumption (Absorbing state)

$b(\omega_{t+1} = 0 \mid \omega_t = 0) = 1.$

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$$
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Identification of Belief Parameters

- Key identification challenge
  - separately identify policy beliefs b_t from cost primitives
- Years without policy uncertainty (2013-2018) $\Rightarrow$ identify entry cost distribution.
  - long policy window + safe harbor regulation + stable investment flow
  - the mean of entry cost distribution depends on time-varying land prices
- Years with policy uncertainty $\Rightarrow$ identify firm beliefs b_t.
  - larger investment bunching $\Leftrightarrow$ smaller b_t

▸ Policy

Dynamic Part: Results

Results: Dynamic Parameters

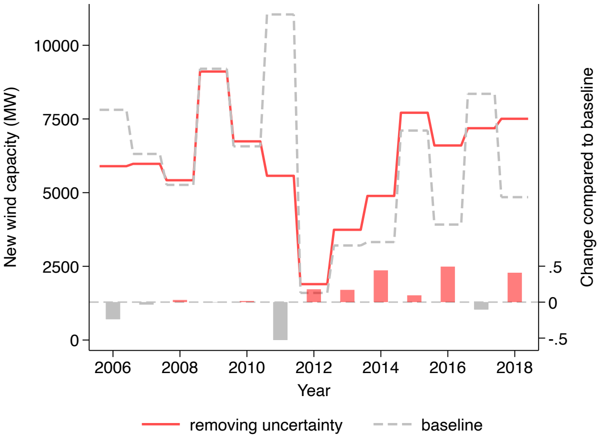
Parameter	Estimate	SE
ϕ (mean of entry cost dist.)	290.87	105.84
μ (coef. of land price)	67.42	34.71
b_{2006}	0.58	0.15
b_{2007}	0.76	0.22
b_{2008}	0.99	0.01
b_{2009}	0.93	0.21
b_{2010}	0.93	0.15
b_{2011}	0.32	0.11
b_{2012}	0.84	0.26

- A lapse in policy extension reduced the perceived likelihood of policy renewal to 30%.

Model Fit

Counterfactual Exercises

Counterfactual I: Removing Policy Uncertainty



- Removing policy uncertainty postpones the 53% of the 2011 cohort by 3.5 years.

Counterfactual I: Welfare Consequences (2008-2018)

	Baseline	No Uncertainty	Difference	Percentage
Number of Projects	464.1	468.8	4.7	1.0%
Total Output (10^6 MWh)	1598.5	1738.3	139.8	8.7%
Subsidy (Billion USD)	16.5	17.3	0.9	5.2%
Social Surplus (Billion USD)	37.0	43.8	6.8	18.4%
Net Social Surplus (Billion USD)	20.6	26.5	5.9	28.9%

- Social Surplus = Reduced Social Cost of Carbon + Saved Fossil Fuel Cost + Increased Capacity Value - Turbine Cost - Entry Cost
- Net Social Surplus = Social Surplus - Total Subsidy

Counterfactual II: Vary Subsidy Levels

Figure: Social Surplus

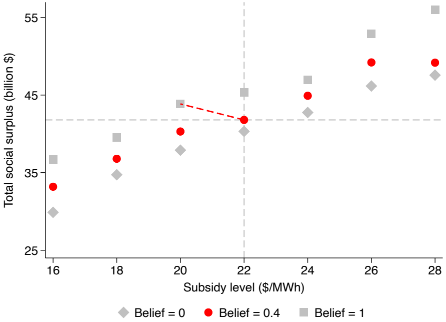
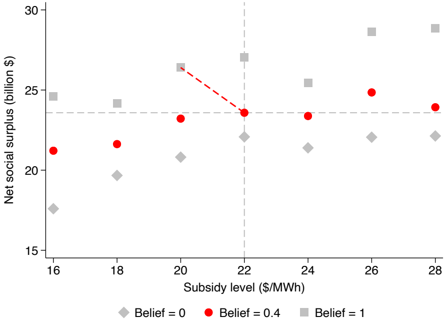


Figure: Net Social Surplus



- Current level of uncertainty + 22 $/MWh < no uncertainty + 20 $/MWh
- Save subsidies by containing uncertainty without hurting social surplus.

Conclusion

- A dynamic model of the US wind energy industry under policy uncertainty; recovers the policy beliefs of investors.
- Removing policy uncertainty aligns the timing of investment better with technology and demand. It improves the social benefits of wind capacity.
- Early resolution of the policy uncertainty also improves social welfare.
- This research highlights the importance of containing policy uncertainty in the dynamic industrial environment.

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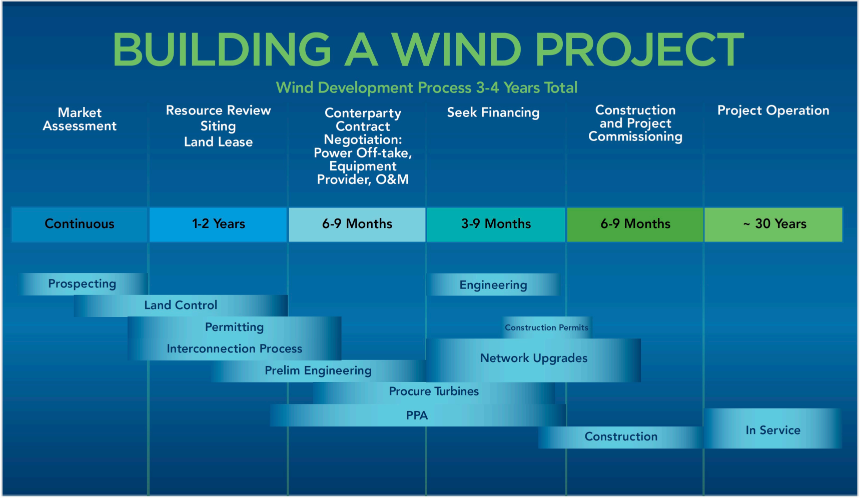
APPENDIX

Comparison with Gowrisankaran, Langer, and Zhang (2023)

- Welfare effects of policy uncertainty in the Air Toxics Standards in coal power industry.
- Three key differences:
    1. Different industry and policy.
    2. Different identification strategy for the belief parameters.
        - ★ GLZ (2023): geographical variation in the state regulation.
        - ★ Chen (2023): the temporal variation in the policy design.
    3. Different welfare tradeoffs.
        - ★ timing alignment between investment and technology.
        - ★ matching efficiency.

▸ Main Literature

Background: Timeline



Background: Interconnection Queues

Figure: Average Time

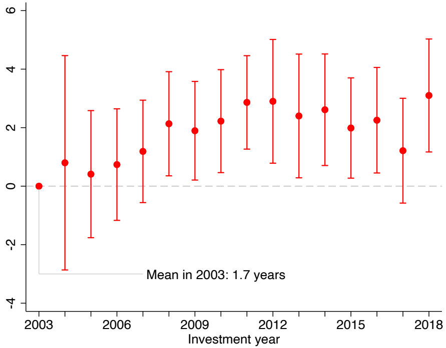
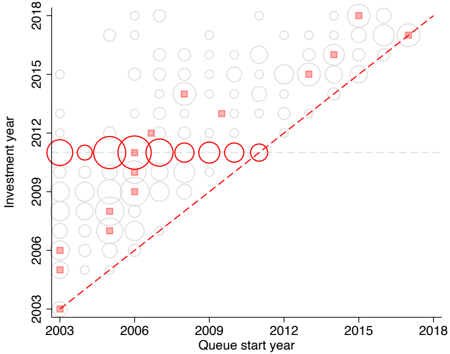


Figure: Distribution of Queue Start Years



Timeline

Background: Construction Time

Figure: by Online Years

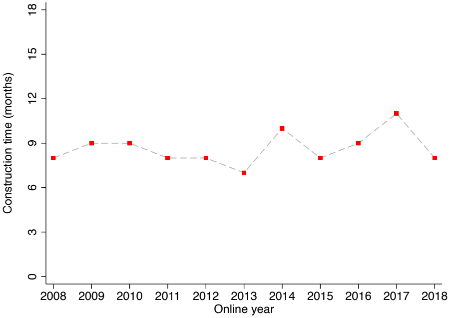
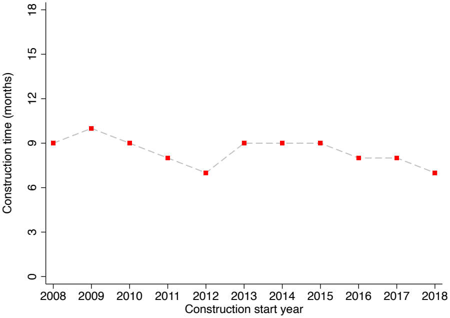


Figure: by Construction Start Years



Timeline

Section 1603 Grant

- Wind projects select either the Section 1603 Grant or the Production Tax Credit in 2009-2012.
- Upfront cash grant that was equal to 30% of total investment costs.
- This paper incorporates:
  - a static choice of the policy tool.
  - discount for tax credits relative to cash grants.
- This paper abstracts away:
  - policy uncertainty in Section 1603 Grant.

▸ Subsidy

State Policies

Figure: Tax Policies

Figure: Financing Policies

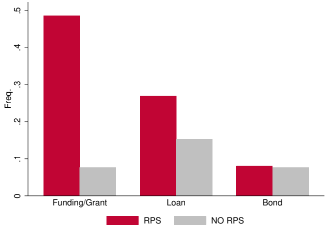
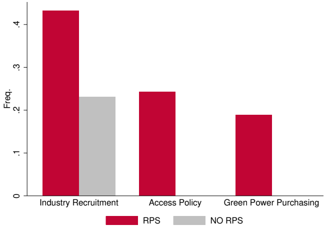


Figure: Other Policies



- States with Renewable Portfolio Standards are more likely to have different kinds of state incentives for wind energy.

Subsidy

Background: Policy Implementation

PTC	Enacted	Start	End	Window (Month)	Others
Energy Policy Act	8/8/2005	1/1/2006	12/31/2007	29	
Tax Relief and Healthcare Act	12/20/2006	1/1/2008	12/31/2008	24	
Emergency Economic Stabilization Act	10/3/2008	1/1/2009	12/31/2009	15	Section 1603 grant
The American Recovery and Reinvestment Act	2/17/2009	1/1/2010	12/31/2012	46	Section 1603 grant
2-day lapse before expired PTC was extended					
American Taxpayer Relief Act	1/2/2013	1/1/2013	12/31/2013	12	
>11-month lapse before expired PTC was extended					
Tax Increase Prevention Act	12/19/2014	1/1/2014	12/31/2014	2 weeks	
>11-month lapse before expired PTC was extended					
Consolidated Appropriations Act	12/18/2015	1/1/2015	12/31/2016 12/31/2017 12/31/2018 12/31/2019	12 (100%) 24 (80%) 36 (60%) 48 (40%)	

Source: 2018 Wind Technologies Market Report, Department of Energy

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Policy Lapse

- The United States fiscal cliff
  - the combined effect of several previously-enacted laws (January 2013)
  - to increase taxes and decrease spending
- American Taxpayer Relief Act of 2012
  - permanence to the lower rate of much of the Bush tax cuts (Republican).
  - retaining the higher tax rate at upper income levels (Democratic).
  - introduced on July 24, 2012.
  - House agreed to Senate amendment on January 1, 2013; signed into law on January 2, 2013.

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Fact 1: Capacity over Time

Figure: Total Capacity

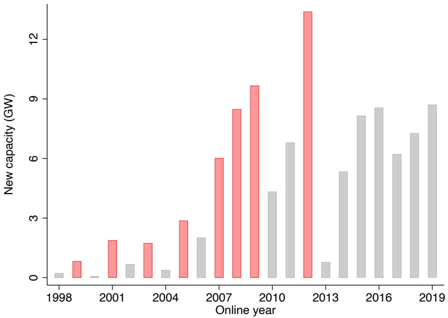
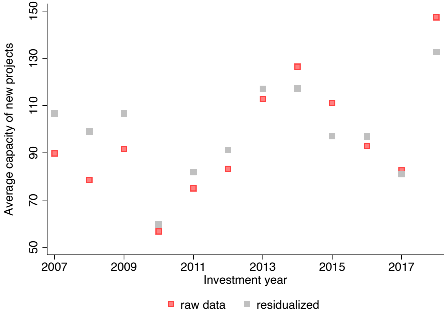


Figure: Average Capacity



- The online time of new wind farms bunched in the month of expiration of PTC.

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Fact 2: Technological Improvement

Figure: Hub Heights

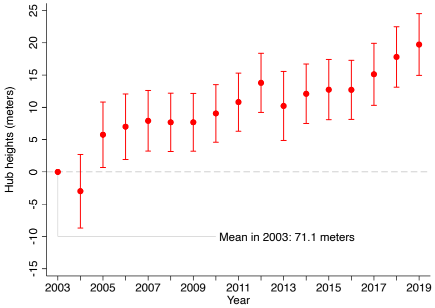
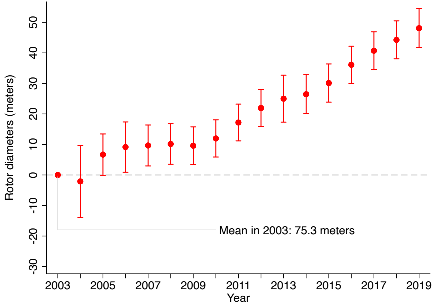


Figure: Rotor Diameters



- The average hub heights and rotor diameters in 2014-2019 are 6.5% and 24.6% larger than that in 2008-2013.

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Fact 2: Technological Improvement

- "Betz" law $\quad Q = C_p \times \frac{1}{2}\pi r^2 \times dv^3$
  - C_p: the ratio of the power flowing through the device that is captured.
  - d: the density of the air the turbine is exposed to.
- Galileo's "square-cube" law
  - Materials necessary to produce a rotor of radius r^2 should be proportional to r^3.
  - While large turbines produce more power than smaller turbines do, the costs of manufacturing are more than proportionately larger (for the same material and design) (Covert and Sweeney, 2022).

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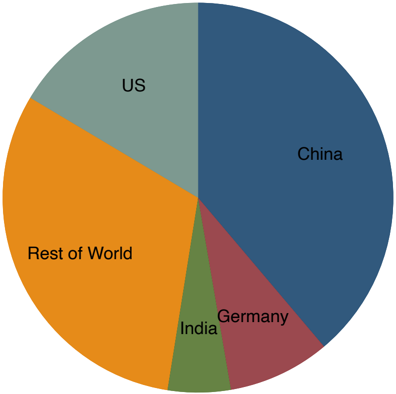
Global Wind Capacity Share

Figure: Capacity Share



Static: Wind Farm's Profit Function

- The profit of wind farm i

$$\pi^W(p_{ij}, k_{ij}^w, \mathcal{D}_{ij}) = \underbrace{\sum_{s=t+1}^{t+T} E_t\beta^{s-t} p_{ij}\alpha_{is}k_{ij}^w}_{\text{revenues from contracts}} + \underbrace{TS(k_{ij}^w, \mathcal{D}_{ij})}_{\text{total subsidy}} - c_{it}k_{ij}^w$$

$$TS(k_{ij}^w, \mathcal{D}_{ij}) = \mathcal{D}_{ij} \times \underbrace{\tau \times d_t \times (\sum_{s=t+1}^{t+10} E_t\beta^{s-t}\alpha_{is}k_{ij}^w)}_{\text{subsidy under Production Tax Credit}} + (1 - \mathcal{D}_{ij}) \times \underbrace{(30\% - \tau C_1) \times \eta k_{ij}^w}_{\text{subsidy under Section 1603 Grant}}$$

  - $\mathcal{D}_{ij}$: policy tool choice, 1 if PTC.
  - d_t: unit PTC amount; η: unit investment cost; C_1: corporate tax deduction.
  - τ: how much 1$ tax credit is valued compared to 1$ grant. (Johnston, 2019)

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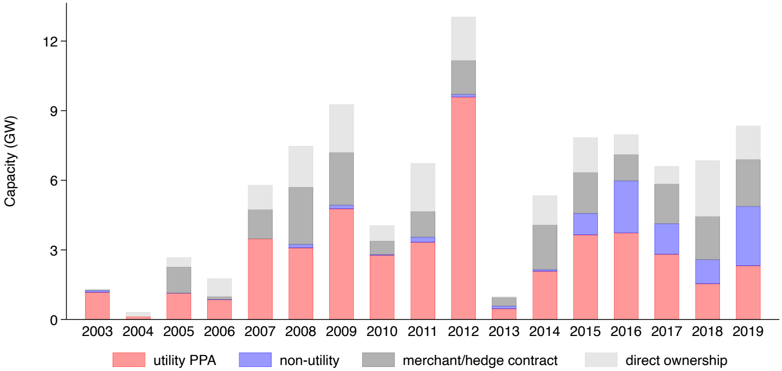
Offtake Types

Figure: Capacity by Offtake Types



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Summary of Results

- Utilities value wind energy more if they are further away from the state-level goal.
- Wind farms have a convex cost function w.r.t. the total capacity.
- Utilities have two-thirds of the bargaining weight.
- The estimated average demand elasticity for non-utility buyers is around -1.6.

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Results: Bilateral Bargaining

	(1)	(2)	(3)
Panel A: Utility Willingness to Pay			
Hassle Cost, δ	4.686	6.164	5.920
	(2.678)	(2.673)	(4.033)
Willingness to Pay, β_1	0.100	0.102	0.105
	(0.023)	(0.007)	(0.022)
Interaction: WTP and Capacity Factor, β_2	-0.005	-0.004	-0.004
	(0.002)	(0.002)	(0.003)
Panel B: Wind Farm Cost, Subsidy, and Bargaining			
Unit Capacity Cost Convexity, γ_2	0.117	0.109	0.117
	(0.013)	(0.011)	(0.015)
Turbine Price, β_3	-0.067	-0.068	-0.068
	(0.008)	(0.008)	(0.018)
Bargaining Weight, ρ_1	0.615	0.674	0.682
	(0.025)	(0.023)	(0.042)
Control for $\pi^W(p_{ij} = \infty)$		✓	✓
Utility-State, Term-Length, and Utility-Type FE	✓	✓	✓

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renewable portfolio gap $\uparrow \rightarrow$ capacity $\uparrow$

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Utility-State, Term-Length, and Utility-Type FE	✓	✓	✓

total turbine cost is convex

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Utility-State, Term-Length, and Utility-Type FE	✓	✓	✓

utilities have two-thirds of the bargaining power

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Results: Demand for Non-Utility Buyers

	Capacity		log(Capacity)	
	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)
Price	-0.491***	-0.517***		
	(0.084)	(0.120)		
log(Price)			-1.022***	-1.391***
			(0.143)	(0.248)
Productivity (Ω_{it})	-0.997*	-1.017*	-0.012	-0.016
	(0.562)	(0.571)	(0.013)	(0.013)
Turbine Price	-1.181	-1.148	-0.035	-0.025
	(1.962)	(1.958)	(0.039)	(0.041)
Observations	330	330	330	330
R^2	0.376	0.101	0.559	0.227
Turbine Brand, BA, Offtake-Type Dummies		✓	✓	✓

- Instruments: land prices, state subsidies, renewable credit prices

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Results: Choice of Power Offtaker

Coefficients	Parameters	Estimates
Matching Cost, Different States	μ_1	0.124
		(0.018)
Matching Cost, Distance	μ_2	0.262
		(0.052)
Scale of ϵ_{ijt}	σ_2	0.061
		(0.008)
Non-utility Probability	ζ_3	0.242
		(0.019)
Non-utility Probability, Texas	$\zeta_{3,TX}$	0.795
		(0.033)
Non-utility Probability, Illinois	$\zeta_{3,IL}$	0.541
		(0.082)
Non-utility Probability, New York	$\zeta_{3,NY}$	0.950
		(0.049)

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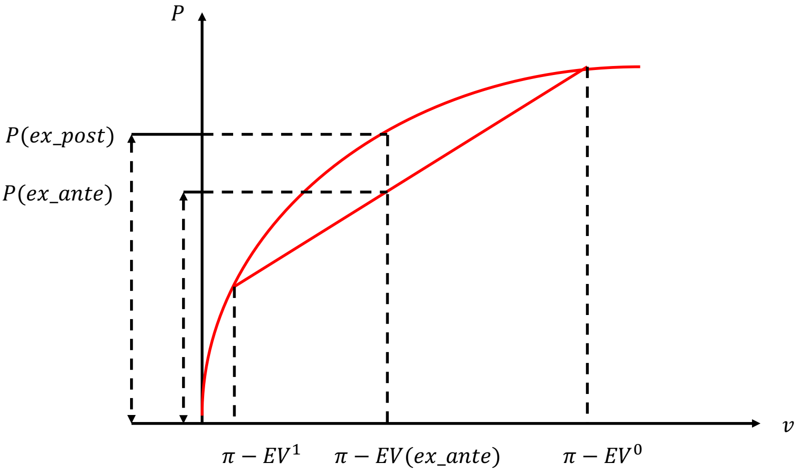
Model Fit

Number of new wind farms
150
120
90
60
30
0
2006
2008
2010
2012
2014
2016
2018
Year
model fit
data

Counterfactual III: *Ex-ante* versus *Ex-post* Policy Uncertainty



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