The Dynamic Efficiency of Policy Uncertainty: Evidence from Wind Industry

Luming Chen

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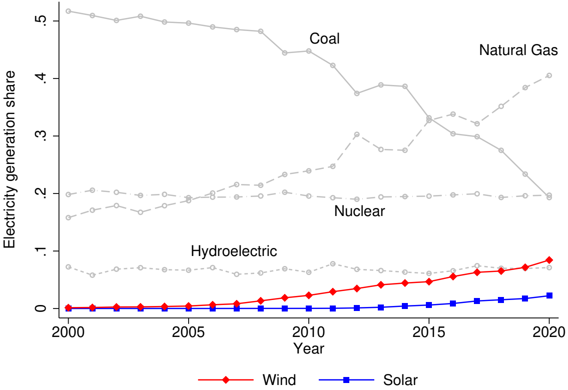
Booming Wind Energy

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

Figure: Share of Electricity Generation by 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 deadlines and uncertainty.
  - enactment – deadlines – extend/pause – deadlines – .. – termination.
- Empirical setting: the US wind energy industry.
  - requiring heavy investment ($100 M in 2019)
  - reliant on the federal subsidies (Production Tax Credit, PTC)

Introduction

- Research question: How does policy uncertainty affect the dynamic market efficiency?
  - Channels and Consequences
- What the data suggests:
  - bunching of the time to start operation for wind farms around subsidy deadlines

    $\Rightarrow$ investment timing distorted by the policy deadlines.
  - the upstream turbine technology is continuously and quickly improving.

    $\Rightarrow$ mismatch between timing of the technological improvement and the investment.

Introduction

- Policy deadlines leads to earlier investment $\Rightarrow$ opposing effects on social welfare:
  - expedited environmental benefits $(+)$
  - investment timing distortion (-)
- Structural model of the US wind industry
  - static profit under bilateral bargaining of long-term contracts
  - dynamic entry decision of wind farms under policy uncertainty
- Counterfactual exercises
  - Removing policy uncertainty delays entry but increases the net value of wind capacity by 20%.

Literature

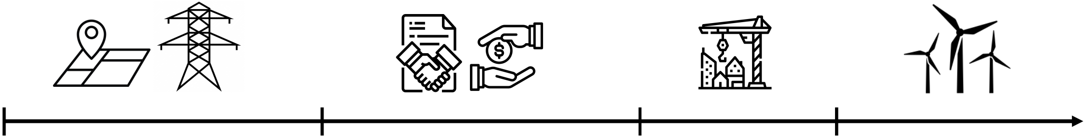
- Industrial policies in the energy sector
  - Langer and Lemoine (2018), Johnston (2019), Johnston and Yang (2020), Aldy et al. (2022)
  - This paper: policy uncertainty; dynamic efficiency of investment timing.
- Renewable energy market
  - Cullen (2013), Novan (2015), Gowrisankaran et al. (2016), Butters et al. (2021)
  - This paper: an empirical structural model for the wind energy market in the US.
- Dynamic model and firm beliefs
  - Doraszelski et al. (2018), Jeon (2018), Gowrisankaran et al. (2022)
  - This paper: to identify the investors' belief in the industrial dynamic model.

Roadmap

- Wind Industry and Government Policies in the US
- Data and Descriptive Evidence
- An Empirical Model of the Wind Market
- Identification and Estimation
- Empirical Results
- Counterfactual Analysis and Next Step

Institutional Background

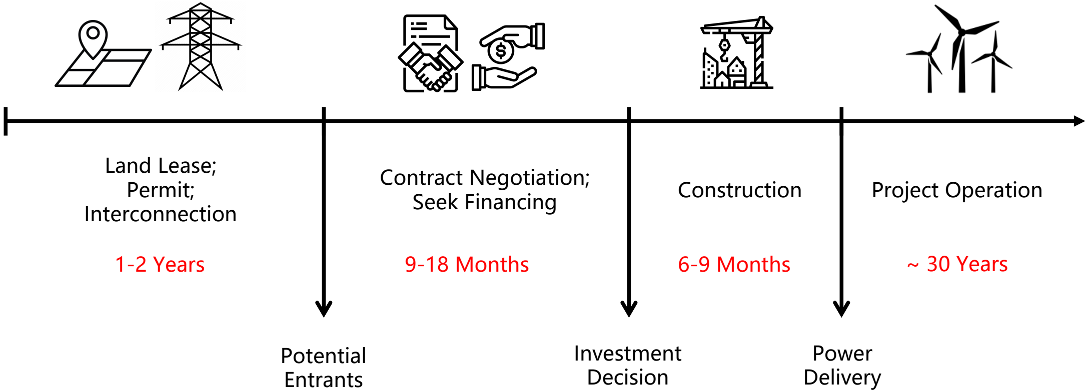
Background: Build a Wind Farm



Land Lease; Permit; Interconnection	Contract Negotiation; Seek Financing	Construction	Project Operation
1-2 Years	9-18 Months	6-9 Months	~ 30 Years

Source: Wind Powers America Annual Report 2019 AWEA

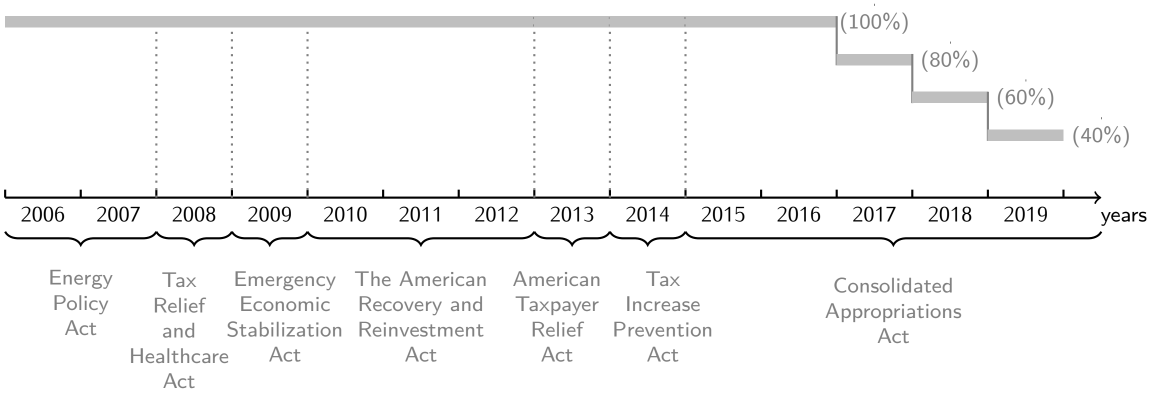
Background: Build a Wind Farm



Background: Government Subsidies

- Federal tax credit + numerous state-level policies.
- 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 the PTC
  - start the project operation before the deadline (prior to 2012)
  - start the project construction before the deadline (after 2013)

Background: Policy Implementation



Source: 2018 Wind Technologies Market Report, Department of Energy

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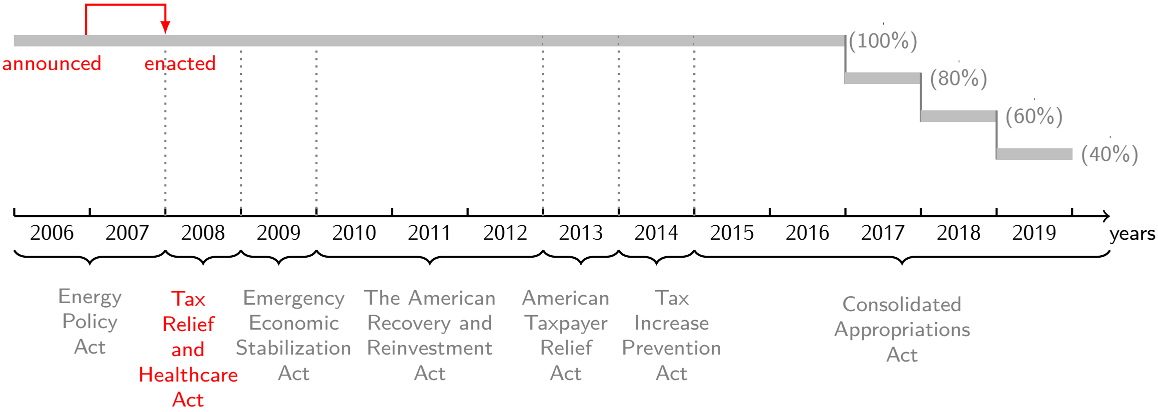

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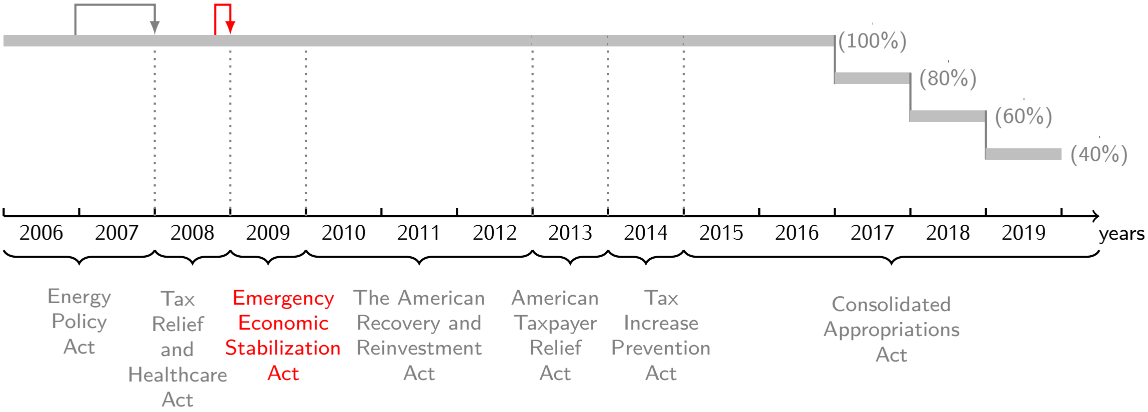

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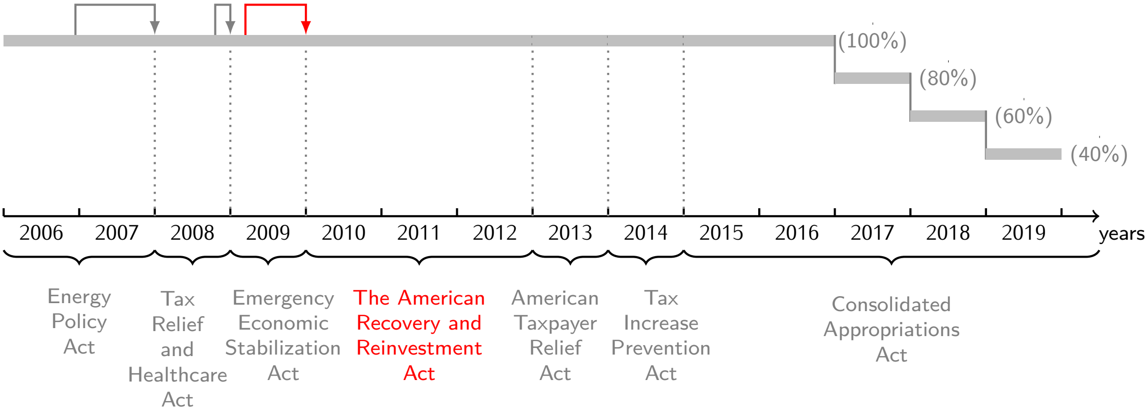

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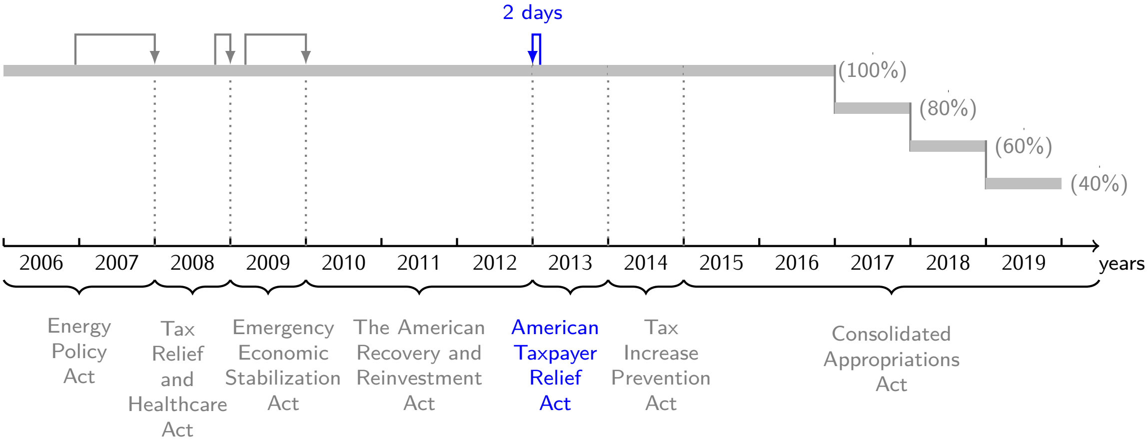

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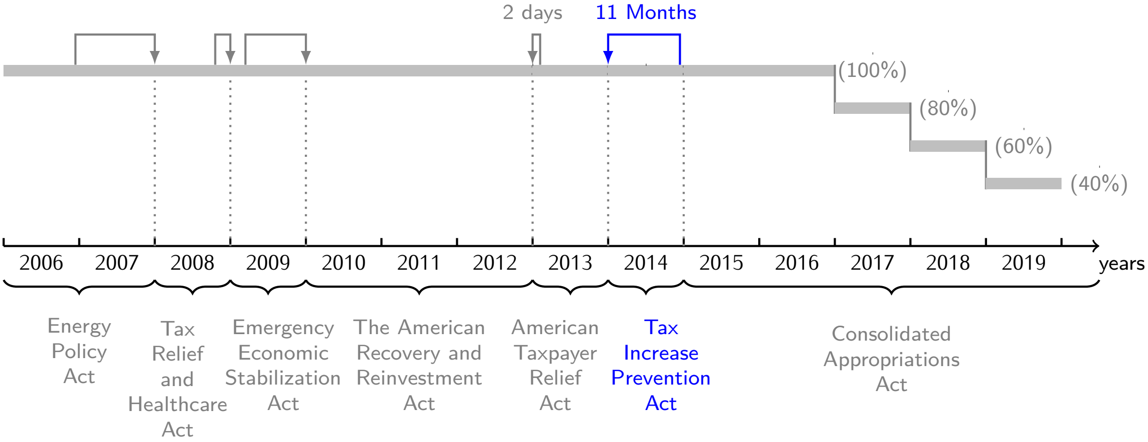

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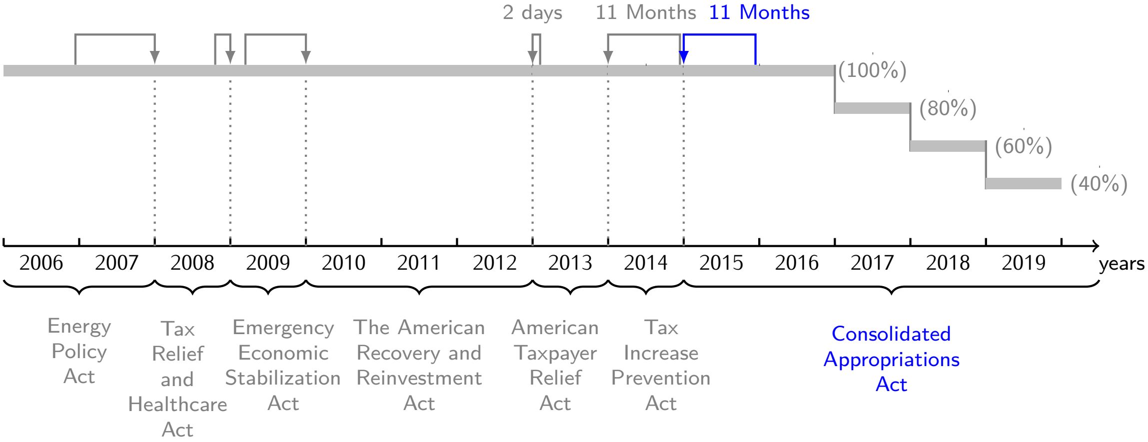

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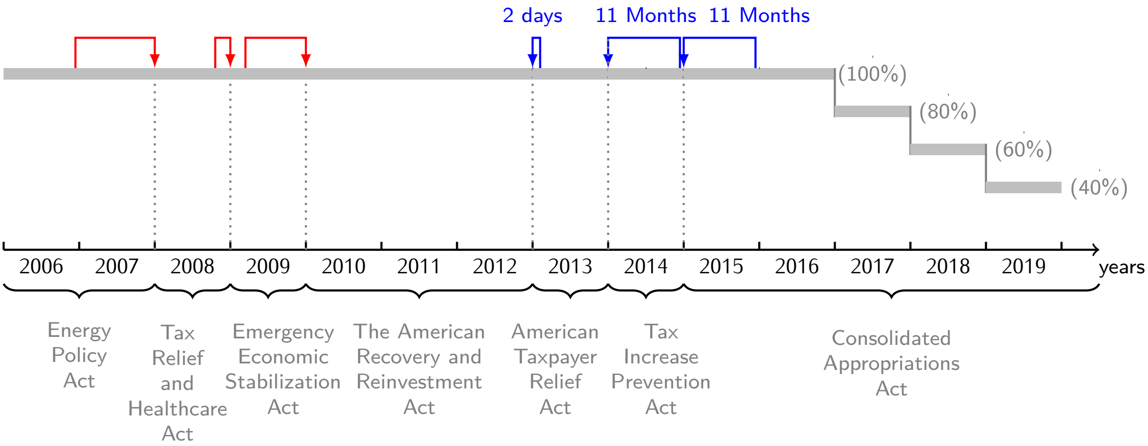


Source: 2018 Wind Technologies Market Report, Department of Energy

▸ Full Table ▸ Identification

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 in 2009 as developers rush to commission projects.
>
> — Vestas

Data and Descriptive Evidence

Data

- Wind Farms
  - **USGS Wind Turbine Database and EIA-860**: operation time, turbine models, location
  - **EIA-923**: monthly and annual output (electricity generation)
  - **FAA**: construction time
- Power Purchase Agreements
  - **AWEA Database**: contracted price, capacity, and length
- Utilities
  - **EIA-860/923**: location, energy composition
- Market Prices
  - **EIA-861**: electricity price
  - **Marex Spectron Market Data**: renewable energy credit price

Fact 1: Bunching in the Operation Starting Time

Figure: Annual Pattern

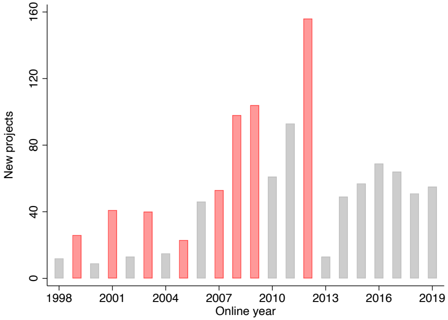
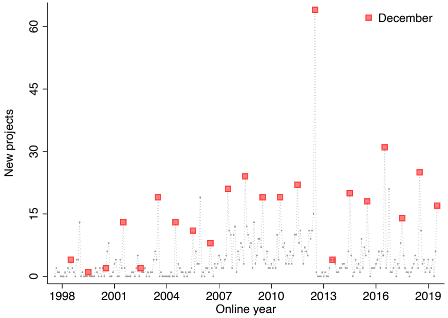


Figure: Monthly Pattern



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

▸ Measured by capacity

Fact 2: Investment and Technological Improvement

Figure: Capacity Factor $\sim Y/K$

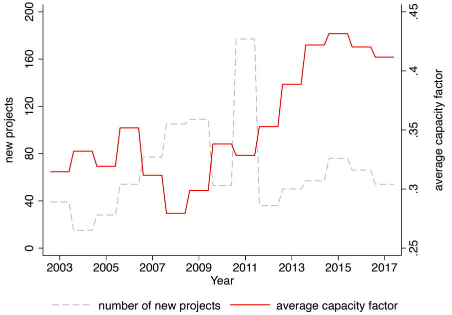
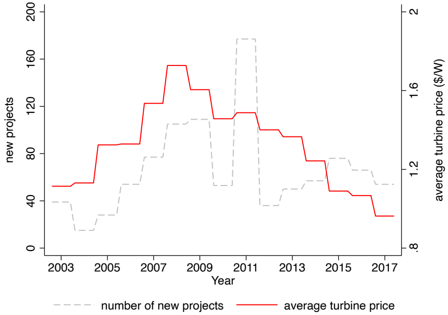


Figure: Turbine Price

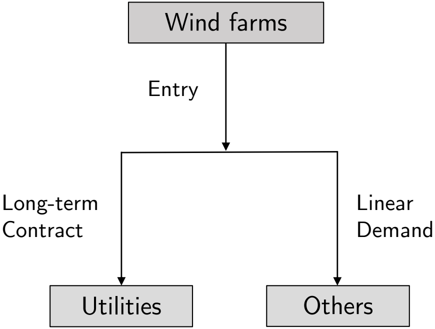


- Mismatch between the timings of investment and turbine technological advancement.
- Mismatch between the timings of investment and turbine cost change.

Hub heights and rotor diameters

Structural Model

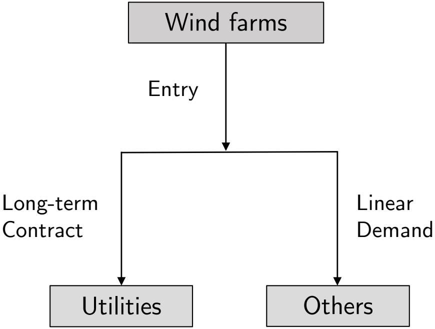
Model Overview



- At the beginning of the year t, wind farm i is faced with the random entry cost shock, and decides whether to enter in this period. (Dynamic)
  - policy uncertainty in deadline years

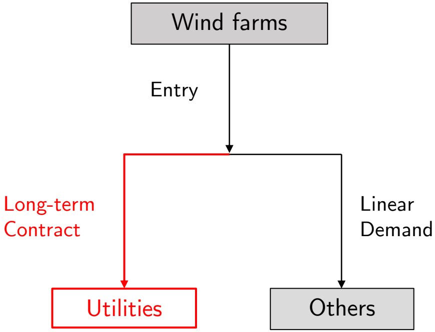
Offtake Types

Model Overview (Cont')



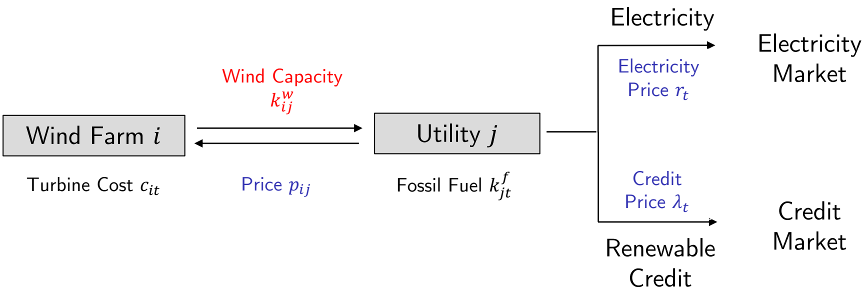
- If wind farm i decides to enter in t, there are two channels to sell capacity. (Static)
  - negotiate with a utility about the power purchase agreement (PPA) over prices and procured capacity
  - sell capacity to corporations or the financial market

Offtake Types



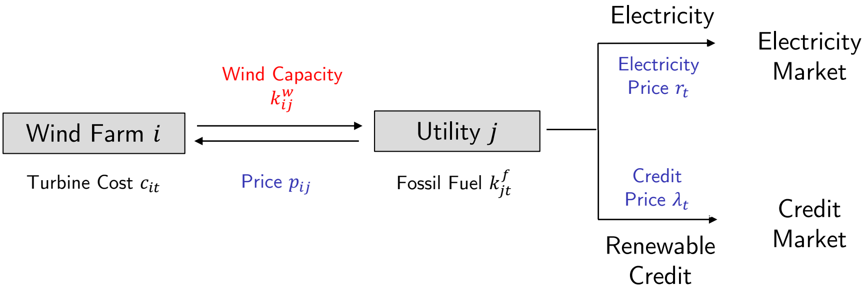
Static: Bilateral Bargaining

Static: Utility's Profit Function



- Utility j has generation capacity using different fuel sources
  - fossil fuels (exogenous) + procured wind $Q^w_{ijt} = k^w_{ij} \times \alpha_{it}$
- Utility j generates total electricity $Q_{jt} = Q^f_{jt} + Q^w_{jt}$ that sells at the electricity price r_t.

Static: Utility's Profit Function



- There are Renewable Portfolio Standards at the state level $Q^w_{jt}/Q_{jt} \geqslant z_t$.
- If the renewable share exceeds z_t, they could sell renewable credits on the credit market at the price λ_t. Otherwise, they could buy credits.

Static: Utility's Profit Function

- Suppose the contract terms are for T years. The profit function of utility j is

$$\pi^U(\boldsymbol{p_j}, \boldsymbol{k_j^w}) = \sum_{s=t}^{t+T} E_t \beta^{s-t} \{ \underbrace{r_s Q_{js} - \sum_{i \in \mathcal{I}_{jt}} p_{ij} \alpha_{is} k_{ij}^w - c(Q_{js}^f)}_{\text{profit from electricity generation}} + \underbrace{\lambda_s(\alpha_{is} k_{ij}^w - z_s Q_{js}) - h_{js}}_{\text{profit from renewable credit}} \}$$

  where

  - $Q_{ijs}^w = \alpha_{is} \times k_{ij}^w$, α_{is} is the turbine productivity
  - $c(\cdot)$ is the total cost for fossil fuels
  - $\mathcal{I}_{jt}$ is the set of independent power producers utility j signed contracts with

- The hassle cost on the renewable credit market depends on utility's energy composition

$$h_{js} = \kappa(Q_{js}^w - z_s Q_{js})^2.$$

Static: Wind Farm's Profit Function

- The profit of wind farm i

$$\pi^W(p_{ij}, k_{ij}^w) = \sum_{s=t}^{t+T} E_t \beta^{s-t}(p_{ij} + d_s)\alpha_{is}k_{ij}^w - c_{it}k_{ij}^w$$

$$c_{it} = \mu X_{it} + \frac{k_{ij}^w}{2\gamma} + \xi_{it}$$

  - p_{ij}: negotiated power purchase agreement price
  - d_s: production tax credit
  - c_{it}: turbine cost per capacity
  - X_{it}: turbine cost shifters

Static: Bilateral Bargaining

- Wind farms and utilities negotiate the capacity and price at the same time.
  - The procured capacity k_{ij}^w maximizes the joint surplus.

$$k_{ij}^w = \text{argmax } \pi^U(k_{ij}^w, p_{ij}) + \pi^W(k_{ij}^w, p_{ij})$$

  - The price p_{ij} splits the total surplus between utilities and wind farms.

$$p_{ij} = \text{argmax}[\pi^U(k_{ij}^w, p_{ij}) - \pi^U(p_{ij} = \infty)]^\rho \times [\pi_{ij}^W(k_{ij}^w, p_{ij}) - \pi^W(p_{ij} = \infty)]^{1-\rho}$$

    - ★ $\pi^U(p_{ij} = \infty)$: expected payoff from not procuring any wind capacity.
    - ★ $\pi^W(p_{ij} = \infty)$: expected payoff from selling capacities to other nearby utilities.

Static: Bilateral Bargaining

- The optimal capacity function is

$$k_{ijt}^{w} = \gamma(d_t \times \Omega_{it}) + \beta_1 \underbrace{(\Theta_{jt} + \kappa\Phi_{jt})}_{\text{willingness-to-pay}} + \beta_2 X_{it} + \beta_3 Z_{jt} + \epsilon_{ijt}$$

  - $\Omega_{it} = \sum_{s=t}^{t+T} \beta^s E_t(\alpha_{is}|\alpha_{it})$; wind farm productivity
  - $\Theta_{jt} = \sum_{s=t}^{t+T} \beta^s E_t(r_s + \lambda_s \times (1 - z_s)|r_t, \lambda_t, z_t)$; effective market price
  - $\Phi_{jt} \approx \sum_{s=t}^{t+T} \beta^s E_t(z_s \times Q_{js}|z_t, Q_{jt})$; utility energy composition
  - X_{it}: turbine cost shifters; Z_{jt}: demand-side controls.
- The transition dynamics of r_s, λ_s, and Q_{jt}^F are estimated with AR(1) models.
- The unit turbine cost is $c_{it} = -\frac{\beta_2 X_{it}}{\gamma} + \frac{k_{ijt}^{w}}{2\gamma}$

Static: Bilateral Bargaining

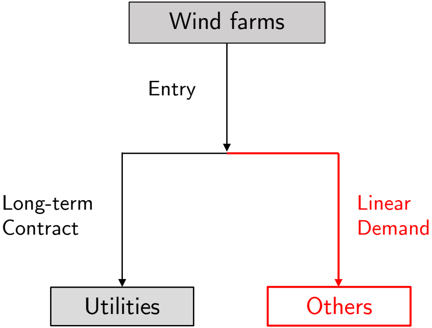
$$p_{ij} = (1-\rho)(\underbrace{\Theta_{jt} + \kappa\Phi_{jt}}_{\text{willingness to pay}}) + \rho(\underbrace{\frac{c_{it}}{\Omega_{it}}}_{\text{turbine cost}} - d_t + \underbrace{\frac{\pi^W(\mu_{ij}=\infty)}{\Omega_{it}k^w_{ijt}}}_{\text{bargaining leverage}})$$

- control flexibly some important shifters of $\pi^W(\mu_{ij}=\infty)$.

$$p_{ij} = (1-\rho)(\Theta_{jt} + \kappa\Phi_{jt}) + \rho(\frac{\eta_{it}}{\Omega_{it}} - cD_t) + g(\bar{\Theta}_{-jt}, \bar{\Phi}_{-jt})$$

where $\bar{\Theta}_{-jt}$ and $\bar{\Phi}_{-jt}$ denote willingness-to-pay for alternative nearby utilities.

Shifters



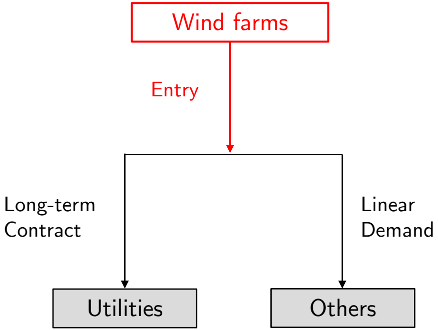
Static: Linear Demand

Static II: Demand from Non-Utility Buyers

- The demand curve from non-utility buyers faced by each wind farm.

$$k_i^w = -\zeta_1 p_i + \zeta_3 \Omega_i + \boldsymbol{\zeta_2 X_i} + \boldsymbol{\zeta_4 Z_i} + \upsilon_i.$$

  - k_i^w and p_i represent the capacity demanded and wind energy price for wind farm i.
  - Ω_i is the productivity of wind farms.
  - X_i includes average turbine prices as well as turbine brand dummies.
  - Z_i includes a set of demand shifters: balanced authority dummies and buyers type dummies.
  - υ_i represents other unobserved demand shifters.



Dynamic: Entry under Policy Uncertainty

Dynamic: When to Enter

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

$$V_t(\boldsymbol{s}_{it}, D_t, \nu_{it}) = \max\{\pi^W(\boldsymbol{s}_{it}) - \psi_{it}, \beta E_t[V_{t+1}(\boldsymbol{s}_{it+1}, D_{t+1}, \nu_{it+1})|\boldsymbol{s}_{it}, D_t]\}.$$

$$\begin{aligned} E_t[V_{t+1}(\boldsymbol{s}_{it+1}, D_{t+1}, \nu_{it+1})|D_t] = & \ U^1(\boldsymbol{s}_{it+1}, \nu_{it+1}) \times \mathcal{P}_t^*(D_{t+1} = 1|D_t) \\ & + U^0(\boldsymbol{s}_{it+1}, \nu_{it+1}) \times \mathcal{P}_t^*(D_{t+1} = 0|D_t). \end{aligned}$$

  - $\boldsymbol{s}_{it}$: state variables
  - D_t: whether the PTC is in place
  - $\mathcal{P}_t^*(D_{t+1} = 1|D_t)$ and $\mathcal{P}_t^*(D_{t+1} = 0|D_t)$: policy belief

Static Part

Identification, Estimation, and Results

Identification of Static Part

- The optimal capacity function identifies the unit capacity cost.
  - a rich set of controls for the utilities' willingness to pay and demand shifters.
- The pass-through ratio of WTP and cost on the price identifies the bargaining weight.
  - a flexible control of shifters for bargaining leverages.
- Supply-side cost shifters and state-level policies as instruments identify the price coefficient for non-utility buyers.

Results: Bilateral Bargaining

	(1)	(2)
Willingness to Pay, β_1	0.186	0.161
	(0.003)	(0.003)
Hassle Cost, κ	3.323	4.165
	(0.652)	(0.845)
Unit Capacity Cost Convexity, γ	0.098	0.098
	(0.008)	(0.008)
Bargaining Weight, ρ	0.639	0.639
	(0.015)	(0.016)
Interaction: Market Price and Capacity Factor		-0.008
		(0.003)
Interaction: Energy Mix and Capacity Factor		-0.129
		(0.194)
Observations	503	503
Control for $\pi^I(\mu_{ij} = \infty)$	✓	✓
State, Term-Length, Utility-Type FE	✓	✓

Results: Bilateral Bargaining (Cont')

	(1)	(2)
Turbine Price, $\beta_{2,\text{Turbine Price}}$	-0.048	-0.046
	(0.005)	(0.005)
GE, $\beta_{2,\text{GE}}$	-0.171	-0.467
	(6.265)	(6.273)
Siemens, $\beta_{2,\text{Siemens}}$	-5.580	-6.583
	(8.822)	(8.865)
Other Brands, $\beta_{2,\text{Other Bands}}$	-19.183	-20.394
	(6.099)	(6.161)
Observations	503	503
Control for $\pi^{I}(\mu_{ij} = \infty)$	✓	✓
State, Term-Length, Utility-Type FE	✓	✓

Results: Profits w/o PTC

Figure: Negotiated Price

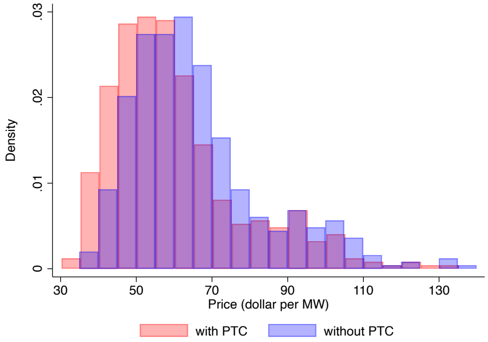
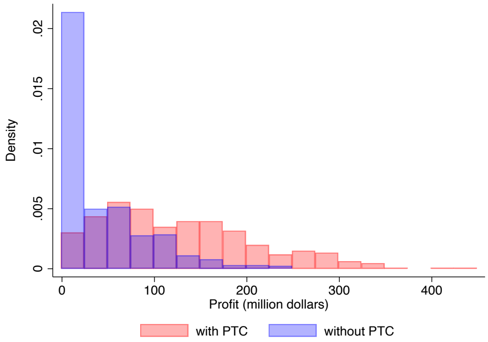


Figure: Profit



- 31% wind farms unprofitable without PTC. Average profit decreases by 54%.

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, Balance-Authority, Offtake-Type Dummies		✓	✓	✓

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

Dynamic Part

Identification, Estimation, and Results

Identification of the Belief $\mathcal{P}^*(D_{t+1} = 1|D_t)$

- The optimization problem

$$V_t(\boldsymbol{s}_{it}, D_t, v_{it}) = \max\{\pi^W(\boldsymbol{s}_{it}) - \psi_{it}, \beta E_t[V_{t+1}(\boldsymbol{s}_{it+1}, D_{t+1}, v_{it+1})|\boldsymbol{s}_{it}, D_t]\}.$$

$$\begin{aligned} E_t[V_{t+1}(\boldsymbol{s}_{it+1}, D_{t+1}, v_{it+1})|D_t] = {} & U^1(\boldsymbol{s}_{it+1}, v_{it+1}) \times \mathcal{P}_t^*(D_{t+1} = 1|D_t) \\ & + U^0(\boldsymbol{s}_{it+1}, v_{it+1}) \times \mathcal{P}_t^*(D_{t+1} = 0|D_t). \end{aligned}$$

- $\psi_{it} = \mu W_{it} + v_{it}, v_{it} \sim F(v) = 1 - e^{-\frac{v_{it}}{\phi}}$. W_{it}: entry cost shifters.
- Years without policy uncertainty $\Rightarrow$ identify ζ and ϕ.
- Years with policy uncertainty $\Rightarrow$ identify $\mathcal{P}_t^*(D_{t+1} = 1|D_t)$.

▸ Policy

Estimation: Step 1

- Focusing on the policy windows (2016-2018) when there is no uncertainty $\mathcal{P}_t^*(D_{t+1} = 1|D_t) = 1$.
- Terminal decision and finite dependence. Following De Groot and Verboven (2019) to apply discrete Euler methods,

$$\log(1 - P^E(\boldsymbol{s}_{it})) + \beta E[P^E(\boldsymbol{s}_{it+1})|\boldsymbol{s}_{it}] = -\frac{\pi(\boldsymbol{s}_{it}) - \beta E[\pi(\boldsymbol{s}_{it+1})|\boldsymbol{s}_{it}]}{\phi} + \frac{\mu[W_{it} - \beta E(W_{it+1}|W_{it})]}{\phi} \tag{1}$$

  - $P^E(s_{it})$: entry probability.
- Estimate the $P^E(s_{it})$ using function approximation and transition dynamics of s_{it} with AR(1).

Estimation: Step 2

- With the estimated cost parameters μ and ϕ, simulate stationary value functions $U^1(\boldsymbol{s}_{it}, v_{it})$ and $U^0(\boldsymbol{s}_{it}, v_{it})$.

$$U^1(\boldsymbol{s}_{it}, v_{it}) = \max\{\pi(\boldsymbol{s}_{it}) - v_{it}, \beta E[U^1(\boldsymbol{s}_{it+1}, v_{it+1})|\boldsymbol{s}_{it}, v_{it}]\}.$$

$$U^0(\boldsymbol{s}_{it}, v_{it}) = \max\{\pi^0(\boldsymbol{s}_{it}) - v_{it}, \beta E[U^0(\boldsymbol{s}_{it+1}, v_{it+1})|\boldsymbol{s}_{it}, v_{it}]\}.$$

- Concerns of non-stationarity: full solution approach.
- Solve the value function via backward induction for 2007-2015.

Estimation: Step 2 (Cont')

- Focus on the policy windows when there is a deadline.

$$G_t(\boldsymbol{s}_{it}, D_t) = \pi(\boldsymbol{s}_{it}) - \oint_{\boldsymbol{s}_{it+1}} [U^1(\boldsymbol{s}_{it+1}) \times \mathcal{P}_t^*(D_{t+1} = 1|D_t) +$$
$$U^0(\boldsymbol{s}_{it+1}) \times \mathcal{P}_t^*(D_{t+1} = 0|D_t)] dG(\boldsymbol{s}_{it+1}|\boldsymbol{s}_{it})$$

$$L_t = \sum_{it} \{1 - exp[-\frac{G(\boldsymbol{s}_{it}, D_t)}{\phi}] - \hat{P}_t(E_{it})\}^2 \tag{2}$$

- Match the model predicted entry rate with data to estimate $\mathcal{P}_t^*(D_{t+1} = 1|D_t)$.

Results: Dynamic Parameters

Parameter	Estimate	SE
ϕ (mean of entry cost dist.)	88.06	2.64
μ (coef. of land price)	0.02	0.01
$\mathcal{P}^*_{2006}(D_{2007} = 1)$	0.87	0.03
$\mathcal{P}^*_{2007}(D_{2008} = 1)$	0.56	0.10
$\mathcal{P}^*_{2008}(D_{2009} = 1)$	0.48	0.09
$\mathcal{P}^*_{2009}(D_{2012} = 1)$	0.99	0.02
$\mathcal{P}^*_{2010}(D_{2012} = 1)$	0.86	0.03
$\mathcal{P}^*_{2011}(D_{2012} = 1)$	0.42	0.10
$\mathcal{P}^*_{2012}(D_{2013} = 1)$	0.88	0.10
$\mathcal{P}^*_{2013}(D_{2014} = 1)$	0.94	0.04
$\mathcal{P}^*_{2014}(D_{2015} = 1)$	0.91	0.11

Results: Model Fit

Figure: Utility Buyers

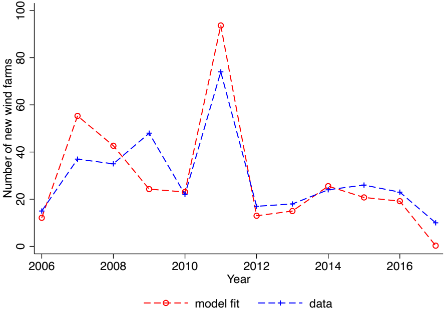
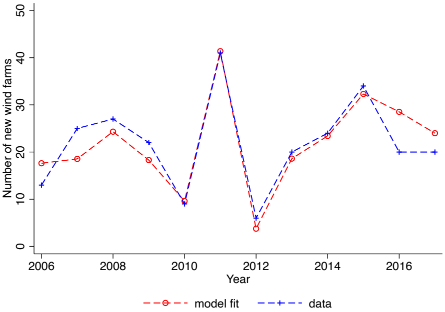
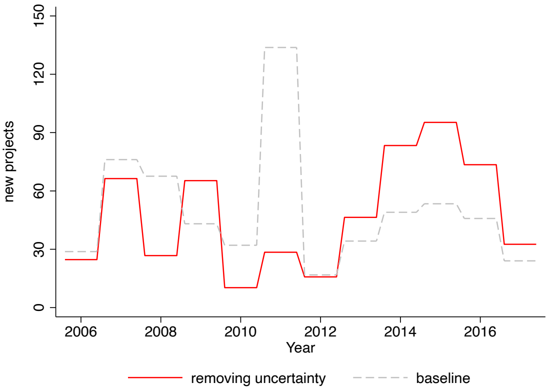


Figure: Non-Utility Buyers



Counterfactuals: Removing Policy Uncertainty



- # of new wind farms ↓ from 277 to 131 in 2008-2011
- # of new wind farms ↑ from 223 to 347 in 2012-2017.

Counterfactuals: Removing Policy Uncertainty

	Baseline	Removing Uncertainty	Difference	Percentage
Number of Projects	447.7	427.6	-20.1	-4.5%
Total Capacity (MW)	30383.7	31257.3	873.6	2.9%
Total Output (10^6 MWh)	1226.7	1332.2	105.5	8.6%
Total Benefits (Billion $)	51.8	54.3	2.5	4.8%
Turbine Costs (Billion $)	32.6	31.0	-1.6	-5.0%
Net Benefit (Billion $)	19.3	23.4	4.1	21.2%

- Total number of wind farms ↓
- Total capacity and output ↑
- Better match with technology dominates delayed entry in environmental benefits
- Total turbine cost saved due to cheaper technology
- Net benefit of wind energy ↑ by 21.2%.

Conclusion

- I develop a dynamic model in the US wind energy industry and recover the policy beliefs of investors.
- Removing policy uncertainty aligns the timing of investment better with technology and improves the value of wind capacity.
- This research highlights the importance of containing policy uncertainty in the dynamic industrial environment.

THANKS!

Luming Chen

lchen598@wisc.edu

APPENDIX

Background: Timeline

Background: Interconnection Queues

Figure: Average Time

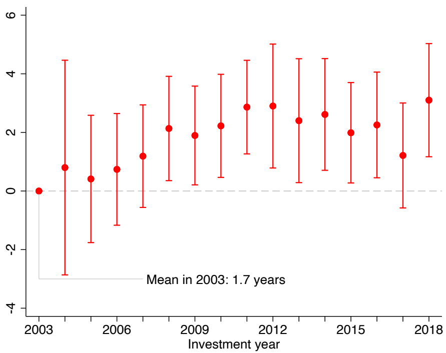
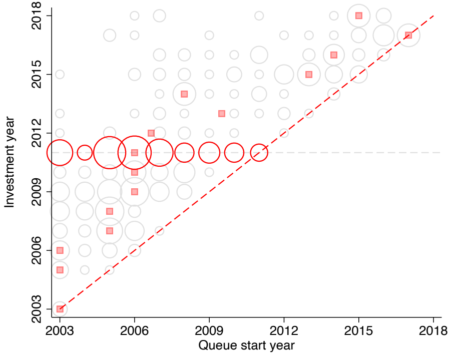


Figure: Distribution of Queue Start Years



Background: Construction Time

Figure: by Online Years

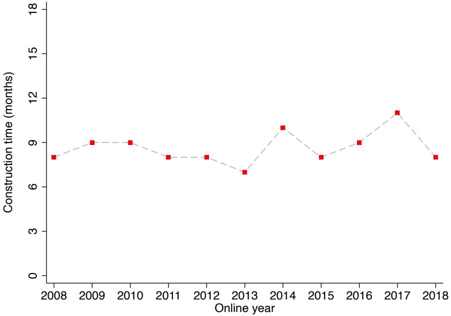
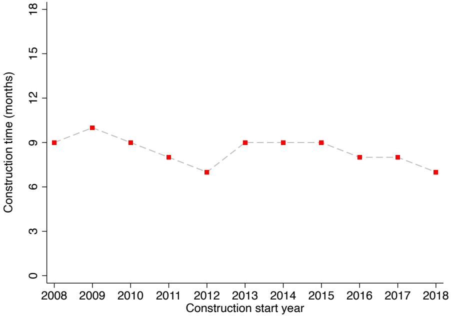


Figure: by Construction Start Years



Timeline

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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Fact 1: Capacity over Time

Figure: Total Capacity

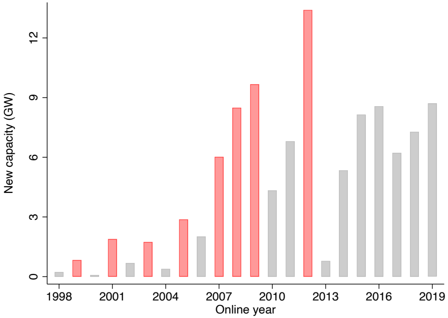
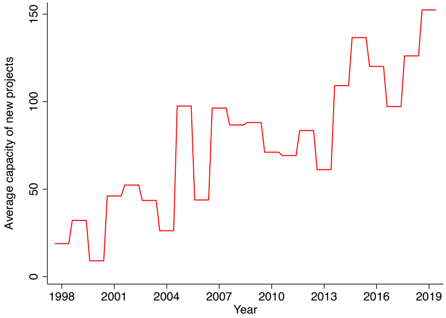


Figure: Average Capacity



- 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

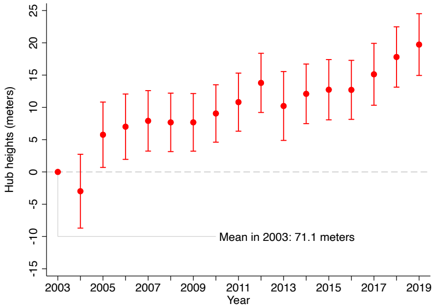
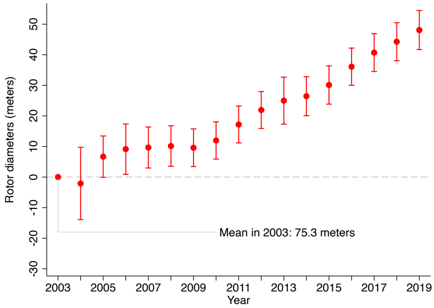


Figure: Rotor Diameters



- Both hub heights and rotor diameters are increasing over time.
- 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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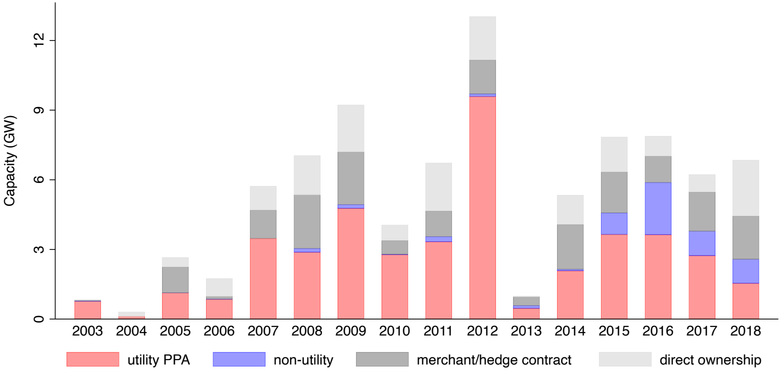
Offtake Types

Figure: Capacity by Offtake Types



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