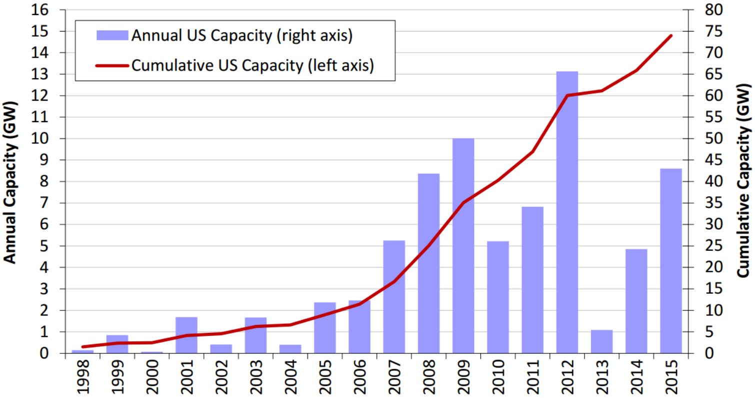
Economics of Wind Power

ECON3391.01, Boston College

Intro

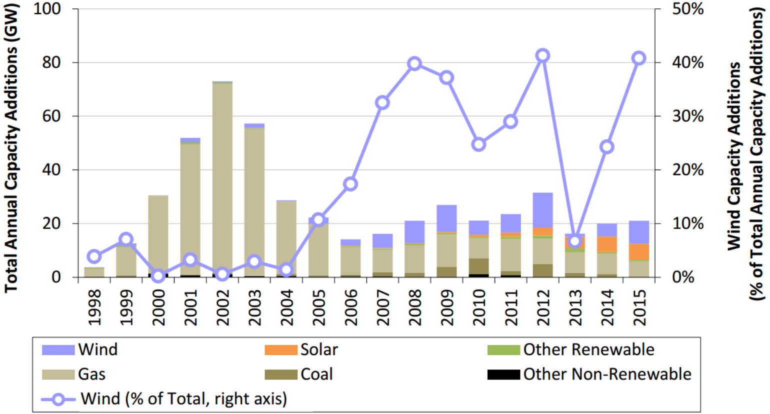
- Overview
- PTC
- Capital vs output subsidies

Wind has expanded rapidly over past decade

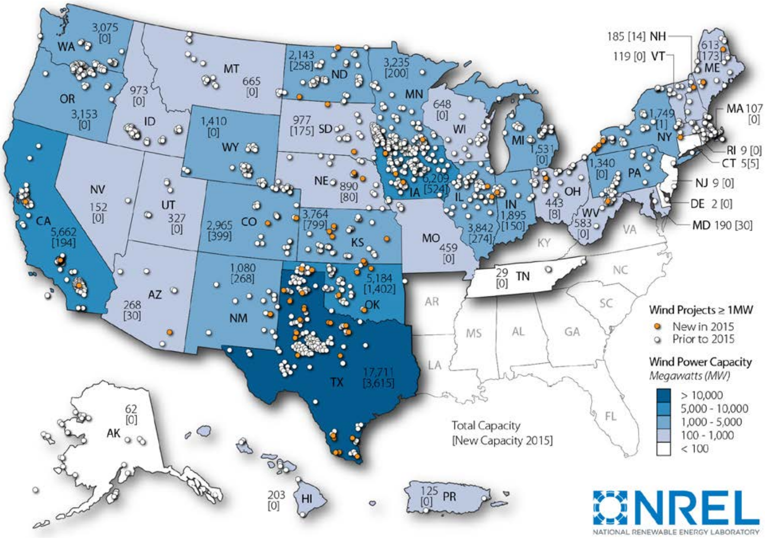


Source: AWEA project database

True both in relative and absolute terms



Source: ABB, AWEA, GTM Research, Berkeley Lab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CA 5,662 [194]
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UT 327 [0]
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CO 2,965 [399]
NM 1,080 [268]
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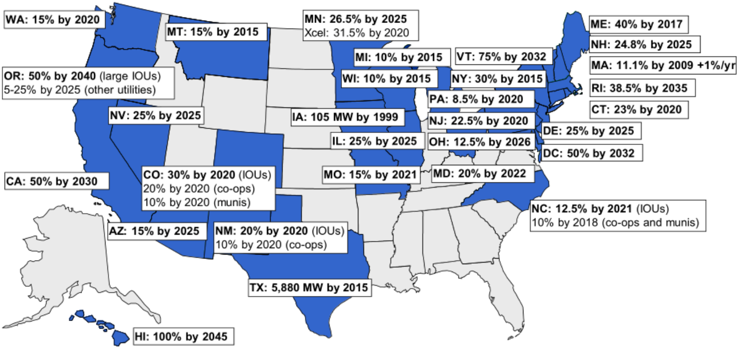
NY 1,749 [1]
TN 29 [0]
ME 613 [173]
185 [14] NH
119 [0] VT
MA 107 [0]
RI 9 [0]
CT 5[5]
NJ 9 [0]
DE 2 [0]
MD 190 [30]
AK 62 [0]
HI 203 [0]
PR 125 [0]
KY
VA
NC
SC
GA
AL
MS
AR
LA
FL
Total Capacity
[New Capacity 2015]
Wind Projects ≥ 1MW
New in 2015
Prior to 2015
Wind Power Capacity
Megawatts (MW)
> 10,000
5,000 - 10,000
1,000 - 5,000
100 - 1,000
< 100
NREL
NATIONAL RENEWABLE ENERGY LABORATORY



Notes: The figure does not include mandatory RPS policies established in U.S. territories or non-binding renewable energy goals adopted in U.S. states and territories. Note also that many states have multiple “tiers” within their RPS policies, though those details are not summarized in the figure.

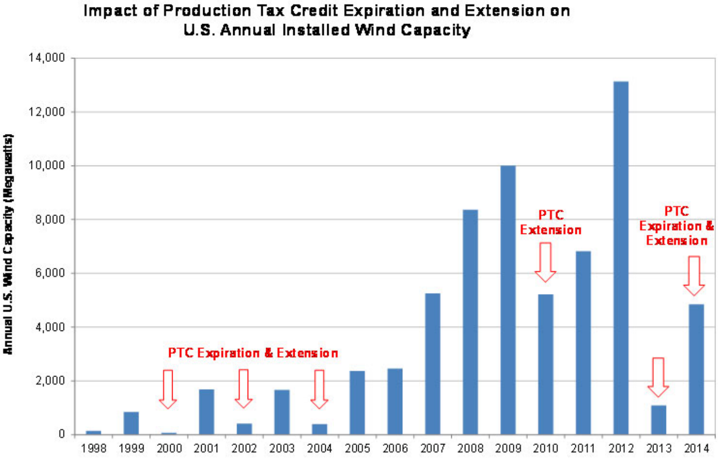
Source: Berkeley Lab

Figure 51. State RPS policies as of July 2016

Production tax credits

- Originally enacted as part of the Energy Policy Act of 1992
- Provides wind operators a $23 tax credit for each MWh generated during first 10 years of operation
- How does a tax credit work?
- Why do we use tax credits instead of subsidies?
    - political?

Congress has allowed the PTC to lapse 6 times



How should we think about the impact of these lapses?
How much more wind would we have if the PTC had never lapsed?

Alternative to the PTC: Capital subsidies

- 2009 ARRA introduced a new subsidy type that targeted wind investment rather than electricity output
  - 1603 grant program
- Initially proposed in January 2009 during ARRA negotiations
  - Motivated by concern over limited tax equity
- Cash payment for 30% of capital costs
- Firms choose PTC or §1603 grant

- Is this shift from output subsidies to input subsidies good public policy?

Aldy, Gerarden and Sweeney (2018)

- We estimate the impact of this switch on the industry

Timeline:

- §1603 grant program signed into law in February 2009
- Eligibility: wind farms placed into service between January 1, 2009 and October 2012
- Long development timelines for wind farms (12 months minimum)
  - turbine orders backlogged over 2 years in 2008 (NREL)

Take advantage of the "natural experiment" created by ARRA

Are wind farms less productive if they receive a capital subsidy rather than an output subsidy?

Broader Motivation

- Government often has choice between subsidizing inputs or outputs
  - LIHTC vs. Section 8 housing vouchers
  - Subsidize fertilizer or farmland vs. crop prices
  - R&D grants/tax credits vs. innovation prizes
  - Renewable capacity vs. renewable generation
- Policy objective is typically related to output
- What happens when we use capital subsidies to encourage output?
  - Intensive margin: Less production?
  - Extensive margin: More investment?
- Empirically rarely observe competing subsidies in same setting
  - 1603 was novel in that there was a simultaneous choice

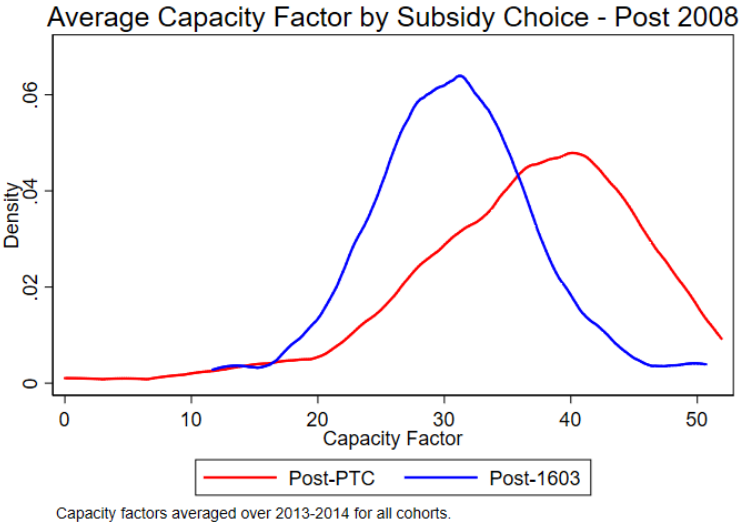
Economics of Wind Power

- Large initial capital investment
  - Siting, financing, procurement, etc.
  - Long lead times – average time in MISO queue > 3 years
- Once online, generation each period is a function of wind speeds
- ... and managerial / operational decisions
  - Is the wind turbine available?
    - downtime after failure
  - State of operational efficiency
    - maintenance frequency and quality
  - McKinsey (2008) - "improved O&M could account for a nearly 20% increase in the equity IRR"
- Marginal effort can increase performance

Data

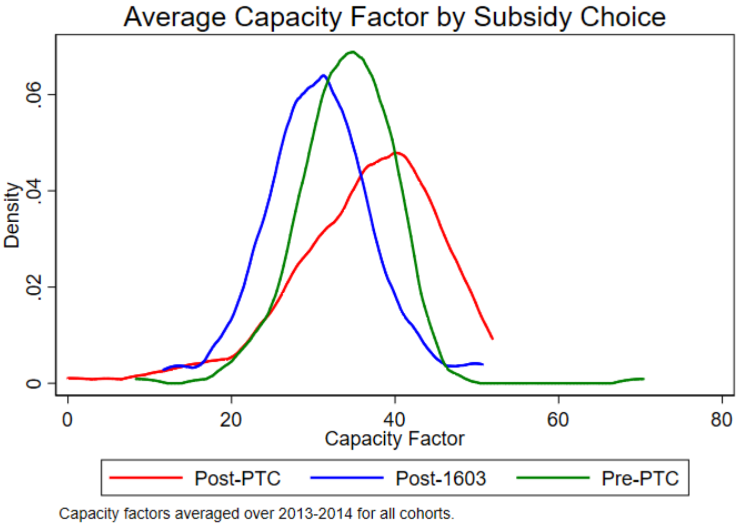
- **EIA Form 860:** plant characteristics
- **EIA Form 923:** monthly generation
- **Department of Treasury:** §1603 cash grant information
- **3TIER:** hourly windspeeds by location
- **American Wind Energy Association:** turbine info and offtake type

Producitivity by Subsidy Choice



Number of plants: 111 Post PTC, 205 Post 1603

Producitivity by Subsidy Choice



Number of plants: 258 Pre-PTC, 111 Post PTC, 205 Post 1603

Comparison of Projects by Subsidy Choice

Projects entering 2009-2012

	PTC	1603	Difference	p-value
Nameplate Capacity	98.72	88.77	9.95	0.31
Turbine Size (MW)	1.83	1.95	-0.12	0.06
Design Wind Speed (MPH)	17.83	17.25	0.57	0.17
Regulated	0.23	0.03	0.20	0.00
IPP	0.69	0.87	-0.17	0.00
PPA	0.68	0.84	-0.17	0.00
Potential Capacity Factor	39.21	33.98	5.23	0.00
Capacity Factor	36.46	30.78	5.67	0.00
New Wind Farms	111	205		

Empirical Model

$$q_{it} = \delta D_i + \beta X_{it} + \nu_t + \epsilon_{it}$$

- q is capacity factor = (generation / capacity) X 100
- D indicator for §1603 grant receipt
- δ captures effect of capital subsidy
- X vector of wind farm characteristics
    - wind speed (hourly), contract type, age, etc

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Empirical challenge: D_i was chosen with knowledge of ϵ_{it}

Research Design

- Ordinary Least Squares
  - Conflates selection and policy effects
- Fuzzy Regression Discontinuity Design (IV)
  - Focus on 2008-2009
  - Instrument for D with temporal discontinuity in §1603 grant eligibility
- Matching
  - Model selection on observables for post-ARRA entrants
    - Predict subsidy preference for pre-ARRA plants
    - Difference-in-differences on subsidy preference groups

Fuzzy Regression Discontinuity (IV) Overview

1. Restrict post-ARRA projects to those planned before the 1603 program was announced
   - Sample: all entrants 2008-2009
2. Instrument for 1603 selection with date placed in service
   - First stage:

$$D_i = \gamma \cdot 1\left\{\text{1603 eligible}\right\}_i + \xi X_i + \mu_i$$

   - Second stage:

$$q_{it} = \delta \hat{D}_i + \beta X_{it} + \nu_t + \epsilon_{it}$$

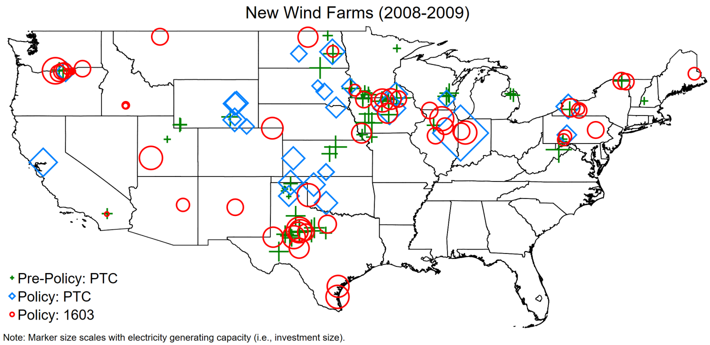
Exclusion restriction: instrument only acts through treatment

- no time trends

RD Sample Summary Statistics

	2008	2009	Difference	p-value
Nameplate Capacity	84.23	102.16	-17.93	0.15
Turbine Size (MW)	1.85	1.82	0.03	0.68
Design Wind Speed (MPH)	18.04	17.32	0.72	0.12
Regulated	0.14	0.11	0.03	0.53
IPP	0.58	0.74	-0.16	0.03
PPA	0.75	0.69	0.06	0.44
Potential Capacity Factor	37.03	35.84	1.19	0.38
Capacity Factor	34.35	31.75	2.60	0.01
New Wind Farms	71	84		
1603 Recipients	0	58		

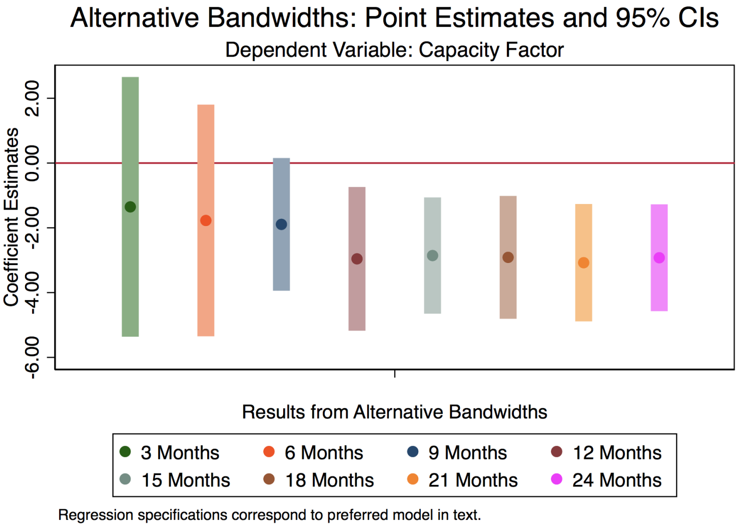
Wind Farm Locations



Fuzzy RD (IV) Results

	(1)	(2)	(3)	(4)
1603 Grant	-3.31***	-2.62***	-2.54**	-2.96***
	(0.87)	(0.80)	(1.16)	(1.13)
Regression Type	OLS	OLS	2SLS	2SLS
Controls	Y	Y	Y	Y
State FE	N	Y	N	Y
R-sq.	0.52	0.63	0.52	0.63
N	9292	9292	9292	9292
F-stat			199	119

Robustness: Alternative Bandwidths



We Also Look For Capital Bias

Altering relative prices should increase cost of production

- Averch and Johnson (1962), Goolsbee (1998, 2004)

$$y_i = \alpha + \beta\{1603\} + \gamma\{1603 \text{ \& Post } 2010\} + \eta_{year} + \epsilon_i$$

	Capacity (MW)	Turbine Size (MW)	Design Wind (MPH)
1603 Grant	-2.19	-0.057	-1.01
	(19.7)	(0.12)	(0.84)
1603 Grant - Post 2010	-9.05	0.29**	0.64
	(22.9)	(0.14)	(0.98)
Mean(Y)	85.41	1.79	17.76
R-sq.	-0.0044	0.044	-0.0074
N	316	316	316

Sample restricted to plants coming online during the 1603 grant eligibility period, 2009-2012. All models contain cohort dummies. Standard errors reported in parentheses.

What was the net impact of the 1603 Program?

- 1603 plants produced less ***conditional on operating***
- However, the program may have encouraged entry
- We check if 1603 plants appear profitable under PTC counterfactual

$$\pi^{1603} = \sum_t \left(\frac{1}{1+r}\right)^t (p_t - c_t) Q_t^{1603} - (0.7) * F$$

$$\pi^{PTC} = \sum_t \left(\frac{1}{1+r}\right)^t (p_t + PTC_t - c_t) Q_t^{PTC} - F$$

Steps for estimating profits under each subsidy

- Predict lifetime output (25 years) Details
- Counterfactual capacity factor 2.96% higher for first 10 years
- Resale Prices from EIA and AWEA PPA information
  - Monthly average REC prices from Marex Spectrom
  - Operating costs assumed 9$/MWh
- (real) Discount rate (5%)
  - PTC revenue deflated by assumed 8% tax equity yield
- Investment costs from 1603 grant awards

Policy evaluation

Table: Estimated Output and Subsidy by Group

Group	N	1603 Output (MMWh)	1603 Subsidy ($M)	1603 Subsidy ($/MWh)	PTC Output (MMWh)	PTC Subsidy ($M)	PTC Subsidy ($/MWh)
Always Profitable	151	697	7,807	11.20	732	7,593	10.38
Marginal	4	9	181	19.25	10	109	10.89
Never Profitable	44	188	2,423	12.90	198	2,103	10.60

Policy evaluation

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If "never profitable" plants were marginal:

- 1603 increased lifetime wind production by 162 MMWh
- Average public cost per wind MWh increased from $10.37 to $11.64

If "never profitable" plants would have entered anyway:

- 1603 *reduced* total wind output by over 36 MMWh
- At additional cost of $714 million

Discussion: Mechanism

- 1603 plants ~ 10-11% less productive than under PTC
- Consistent with a simple model of convex operating costs

Alternative mechanism: Negative prices

- Wholesale prices sometimes go below zero at periods of low demand
  - transmission constraints, costly storage, large startup costs
- PTC recipients willing to pay $23 to claim credit

How much of the estimated effect does this explain?

Negative Prices in Six ISO's (2011-2014)

	CAISO	ERCOT	ISONE	MISO	NYISO	PJM
All nodes						
Mean	3.87	1.19	0.09	2.88	0.56	0.54
Median	2.53	0.00	0.00	0.97	0.28	0.13
95th pctile	16.26	6.11	0.00	13.04	1.88	2.36
Summer(mean)	4.56	0.62	0.01	2.54	0.63	0.68
Post 2012 (mean)	2.25	0.51	0.16	2.65	0.59	0.39
Near wind						
Mean	3.94	4.21	0.09	5.44	1.05	1.21
Summer(mean)	2.26	0.26	0.01	3.18	0.77	1.01
Post 2012 (mean)	2.51	1.10	0.17	5.48	1.40	1.06

Frequencies (in percentage points) based on hourly nodal price data from the six listed ISOs, collapsed to the node-month level.

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Frequencies (in percentage points) based on hourly nodal price data from the six listed ISOs, collapsed to the node-month level.

Productivity estimates and negative electricity prices

Table: IV Results

	(1)	(2)	(3)	(4)	(5)	(6)
1603 Grant	-2.958***	-3.254***	-0.988	-1.727	-2.759**	0.183
	(1.132)	(1.228)	(1.402)	(1.122)	(1.143)	(1.671)
R-sq.	0.625	0.654	0.633	0.703	0.699	0.634
N	9292	8932	5876	4650	3720	5815

Table: Matching Results

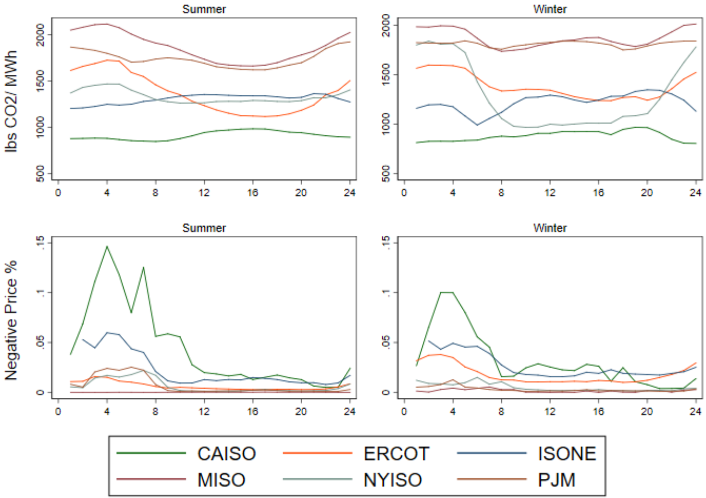
	(1)	(2)	(3)	(4)	(5)	(6)
1603 Grant	-3.488***	-3.480***	-3.213**	-4.416***	-2.902***	-2.724**
	(1.178)	(1.131)	(1.606)	(1.086)	(1.049)	(1.103)
R-sq.	0.746	0.654	0.636	0.676	0.650	0.630
N	10538	10111	7698	5298	4809	7171

(1) full sample; (2) excludes CAISO; (3) excludes MISO too; (4) all plants May - October; (5) all plants post 2012; (6) excludes plants near nodes above median,.

Do negative prices alter the policy implications?

- Negative prices probably explain some but not all of the estimated productivity effects
- But that does not necessarily undermine their importance
- Goal of policy is to displace emissions:
  - Price is not a sufficient statistic for welfare

Callaway et al (2017) calculate marginal emissions



Emissions *positively* correlated with negative prices in 4 ISOs (CAISO, ISO-NE negative)

Discussion

- Same point applies to main finding: to evaluate the true welfare impact, we would need to know the emissions displaced under both regimes.
- What we can say is introducing a capital subsidy reduced cost-effectiveness (govt spending per wind MWh) by ~ 18%
- Highlights the tradeoff between program efficiency and expansion

- Policy suggestion: when capital subsidies are used, try to replicate output subsidy (Schmalensee 1980)
- In this context, could tie grants to expected output, rather than a fixed proportion of investment costs

Announcements