Gone With the Wind: Consumer Surplus from Renewable Generation

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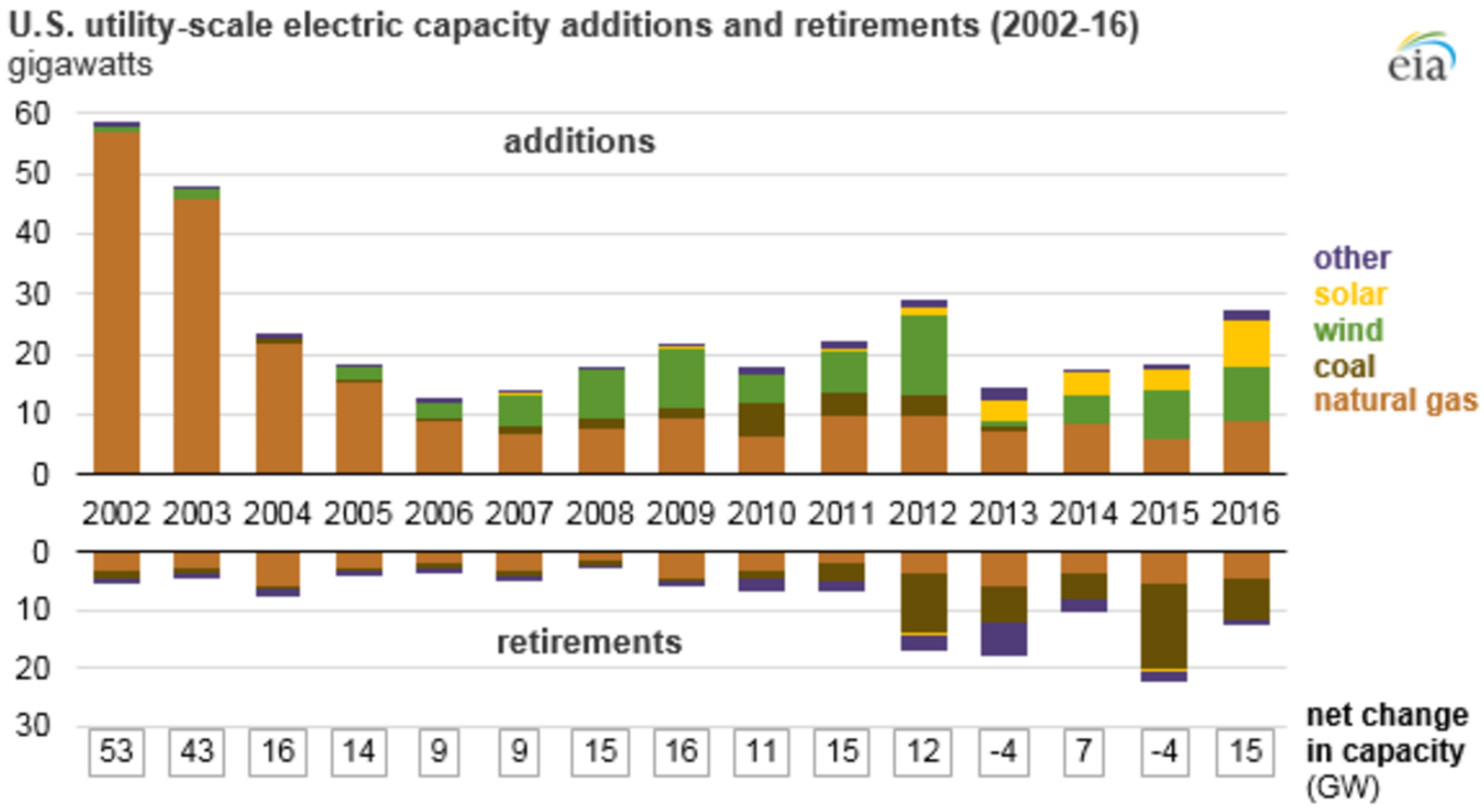
Increase in Renewable Electricity Generation Capacity



Source: U.S. Energy Information Administration, *Electric Power Annual* and *Preliminary Monthly Electric Generator Inventory*

Implications:

- Decreased pollution
- Increased intermittent electricity generation
- **Increased low marginal cost generation**

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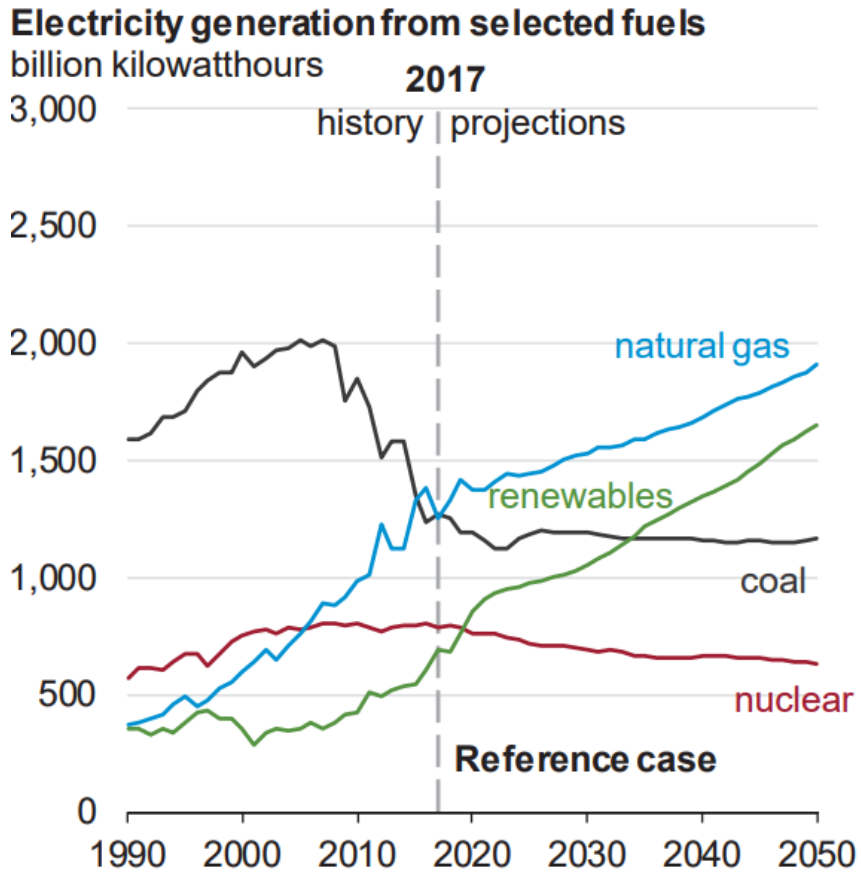

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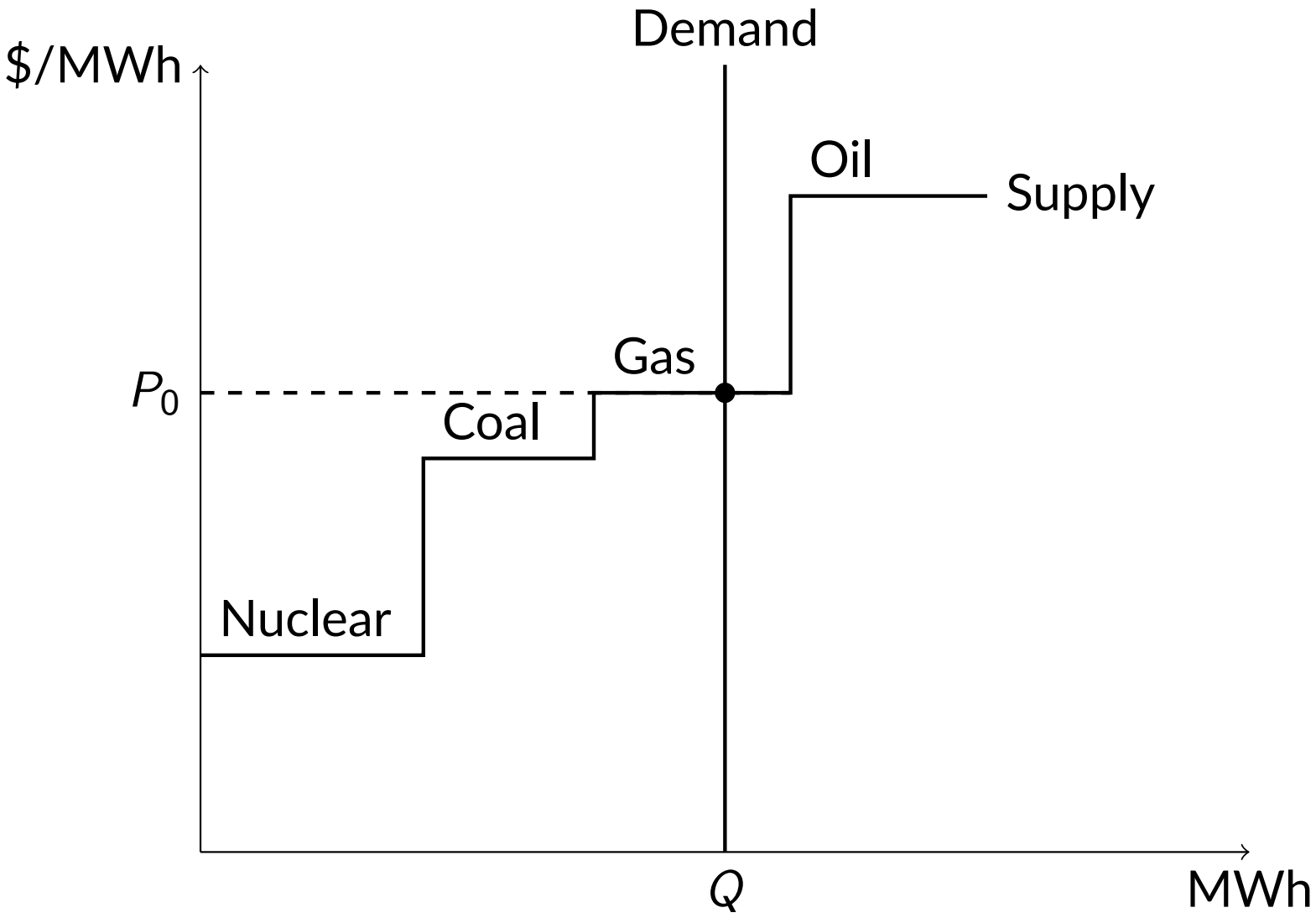
Wind generation impact on the Merit Order

Merit Order Effect of Renewable Generation



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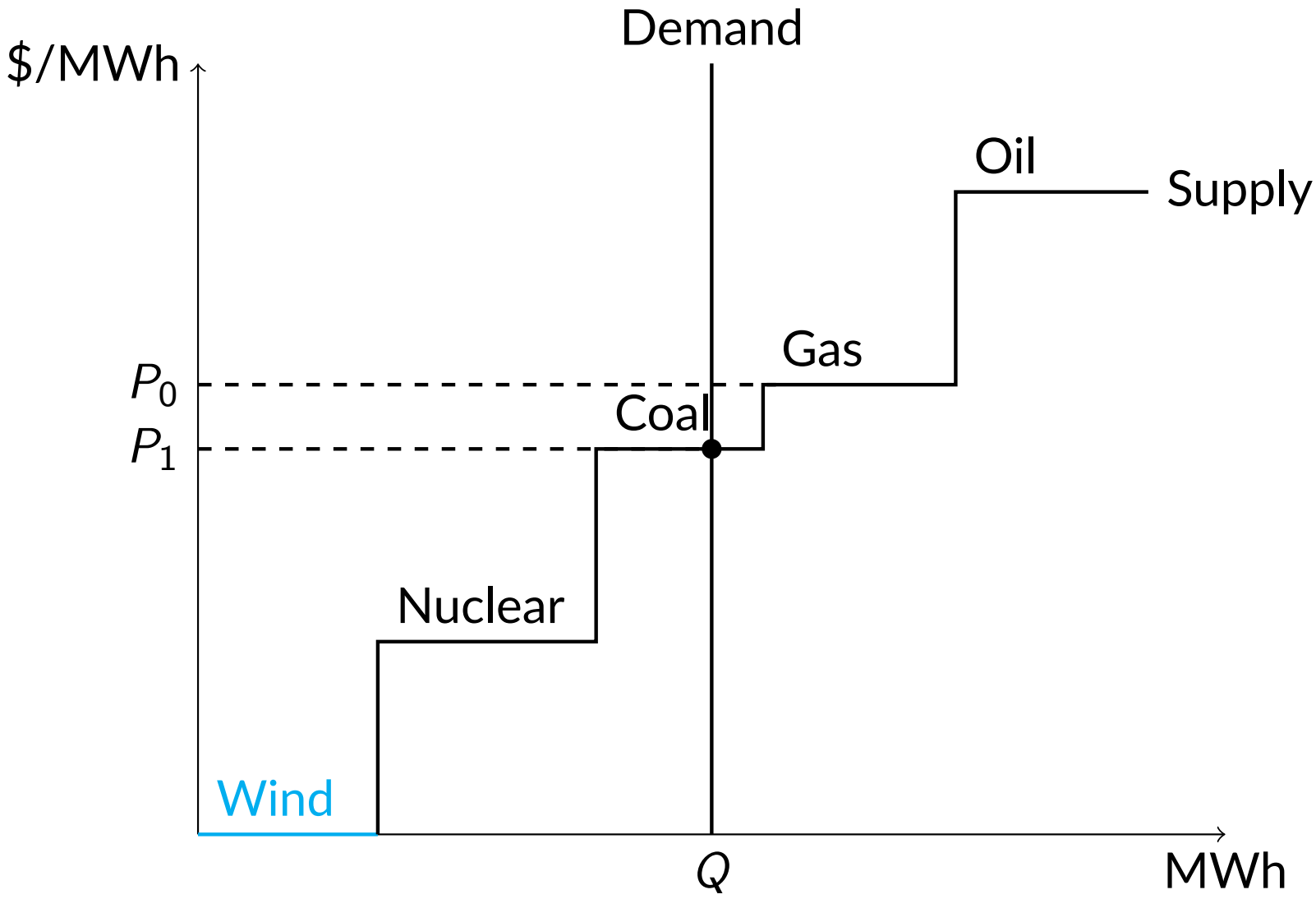

This Decrease in Price is Good for Consumers

Midwest:
Wind energy reduces electricity prices to consumers

"According to a May 2012, MISO-Commissioned study by Synapse Energy Economics, Inc., in addition to the benefits to local economics, **wind has show to reduce overall energy costs for consumers saving ratepayers $63 to $147 per year** (assuming a 20 GW scenario in 2020) …"

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- However, this assumes perfectly competitive markets.

Research Questions

1. **How much do consumers benefit from reduced operating cost associated with increased renewable generation?**

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2. **How do firm's change their strategy** in response to increased renewable generation?
    - There is an incentive for firms to **withhold their output** when their wind turbines are generating electricity.

Results:

1. Consumer benefit can be up to 68 USD per person per year
2. Observed withholding reduces consumer surplus by $> 30\%$.

Theory: How Wind Generation Impacts the Price

Market equilibrium:

$$\underbrace{d(p)}_{\text{Demand}} = \underbrace{\sum_{o} S_o(p)}_{\text{Conventional Supply}} + \underbrace{W}_{Wind}$$

Differentiating the market equilibrium with respect to wind generation provides:

$$\frac{dp}{dW} = -\frac{1 + \sum_o \frac{\partial S_o(p)}{\partial W}}{\sum S_o'(p) - d'(p)}$$

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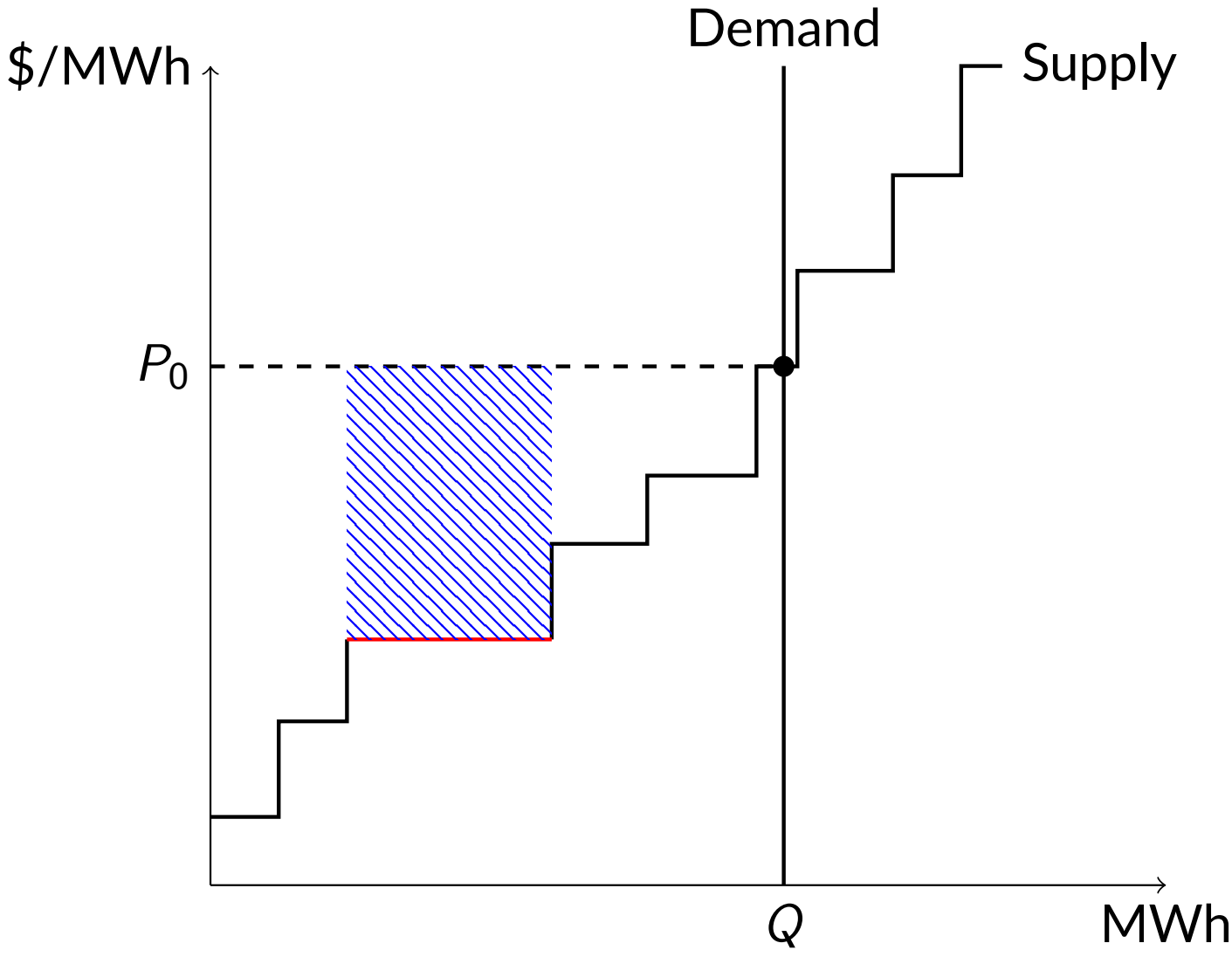
- I observe $\sum S_o'(p)$ and $d'(p)$
- I need firm theory to find $\frac{\partial S_o(p)}{\partial W}$

Firm's incentives to withhold output



Trade off between $\downarrow P$ and $\uparrow S_o(p)$ or $\uparrow P$ and $\downarrow S_o(p)$

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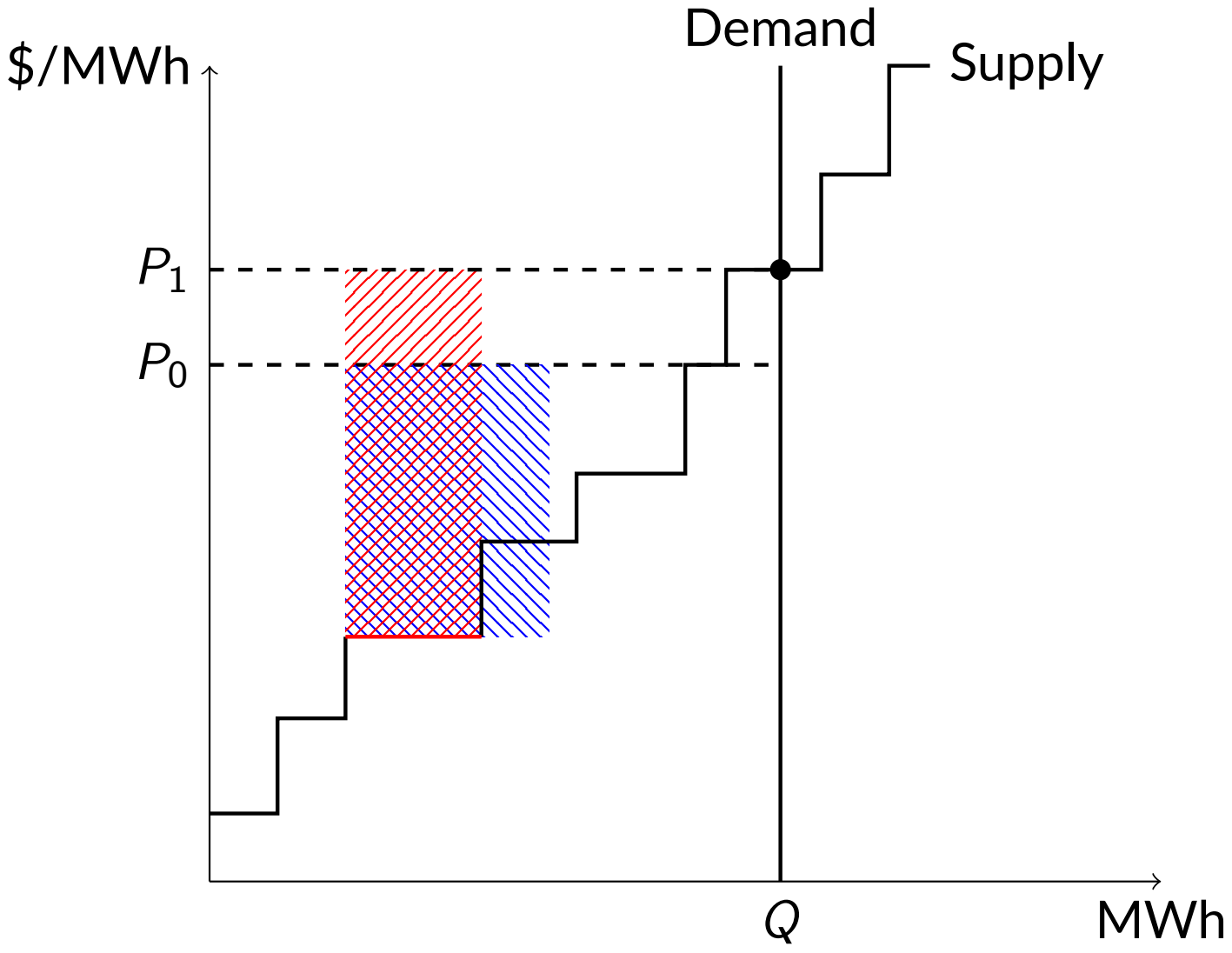

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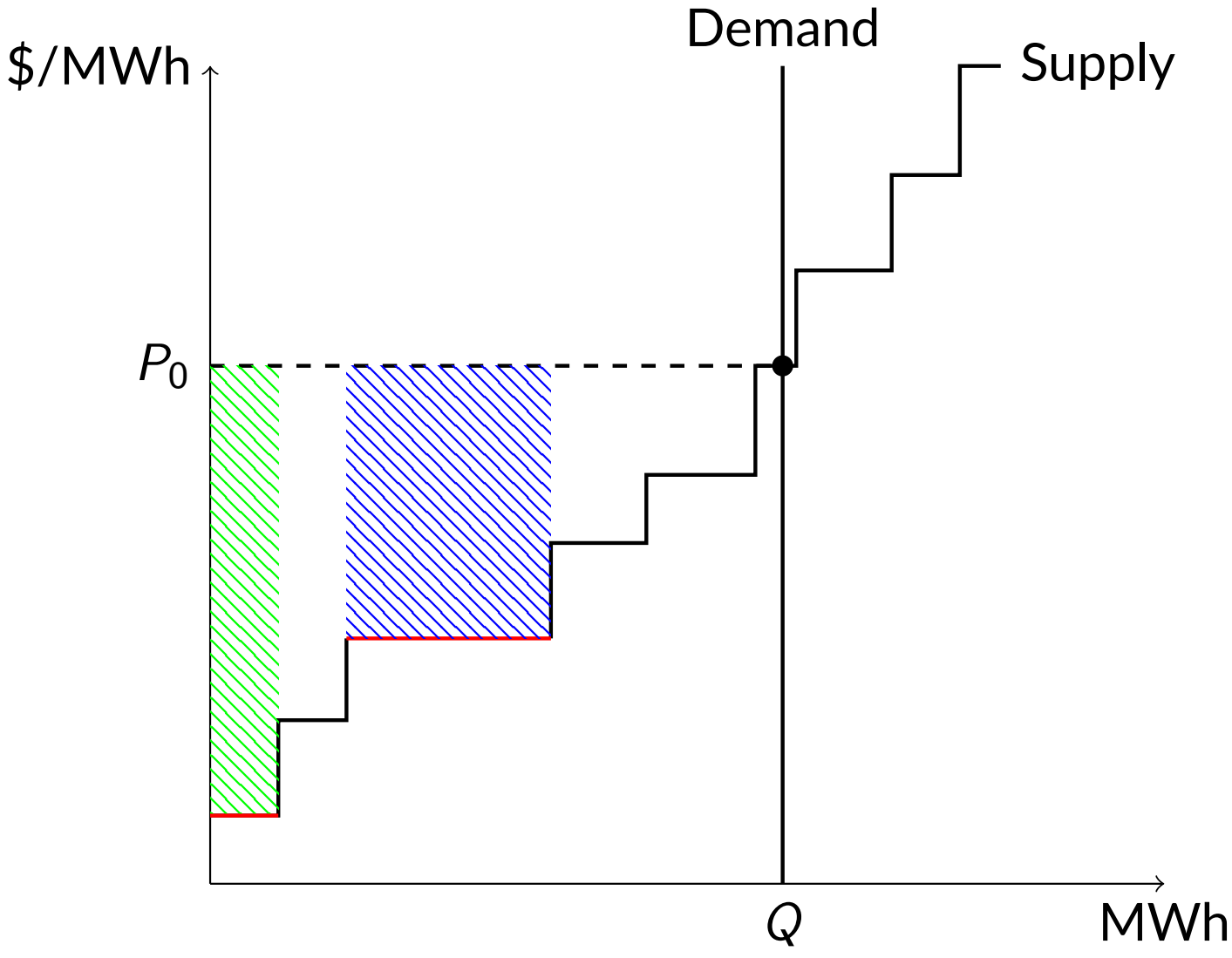
Diverse firm's incentives to withhold output



Benefits increase when you own wind generation, math proof

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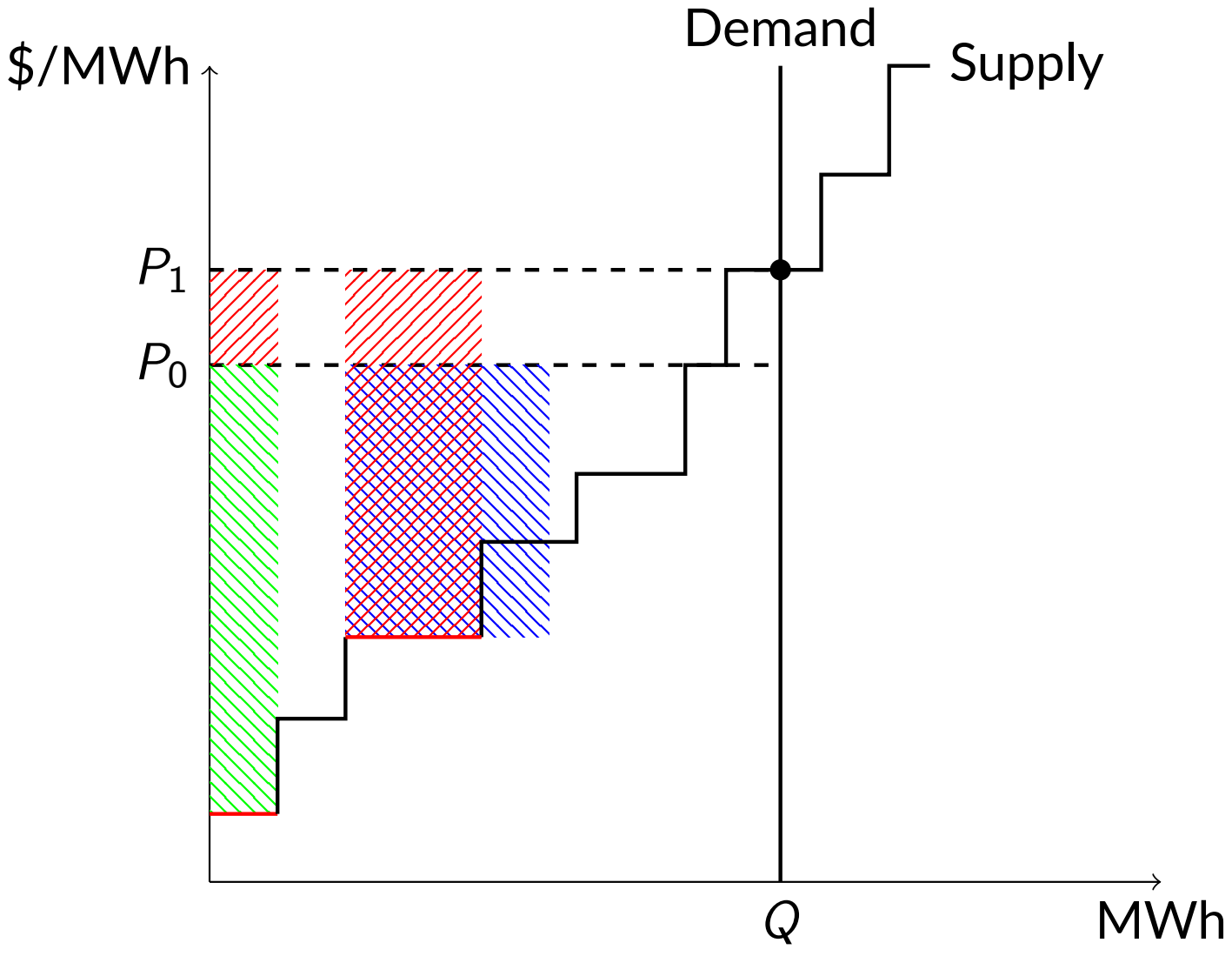


Benefits increase when you own wind generation, math proof

Theoretical predictions

We expect

1. **Only diverse market participants**, owning wind turbines and other assets, **will withhold their generation offer** from their traditional units in response to wind generation.

2. Market participants that **own more wind generation capacity** will **withhold their traditional units more.**

3. Market participants will **withhold more in response to wind generation from their own wind turbines**.

MISO Wholesale Electricity Market, 2014-2016

- Multi-unit uniform price auction
- 70 GWh on average
- 1/2 coal, 1/4 gas
- 5 to 15 GWh of wind
- Average 27 $/MWh
- Locational Marginal Price
  - Energy
  - Losses
  - Congestion

Supplemental information:

Owner Portfolios Wind PPAs Vertical Arrangements

Testing for Physical Withholding, Estimating $\frac{\partial S_o(p)}{\partial W}$

Use hourly ex-ante supply curves of all market participants

- Aggregate supply curves at the owner level
- Exclude bids from wind turbines
- Interpolate / Extrapolate supply curve on a common domain
  - Data are q_{otb}, p_b

Estimate δ in the following equation

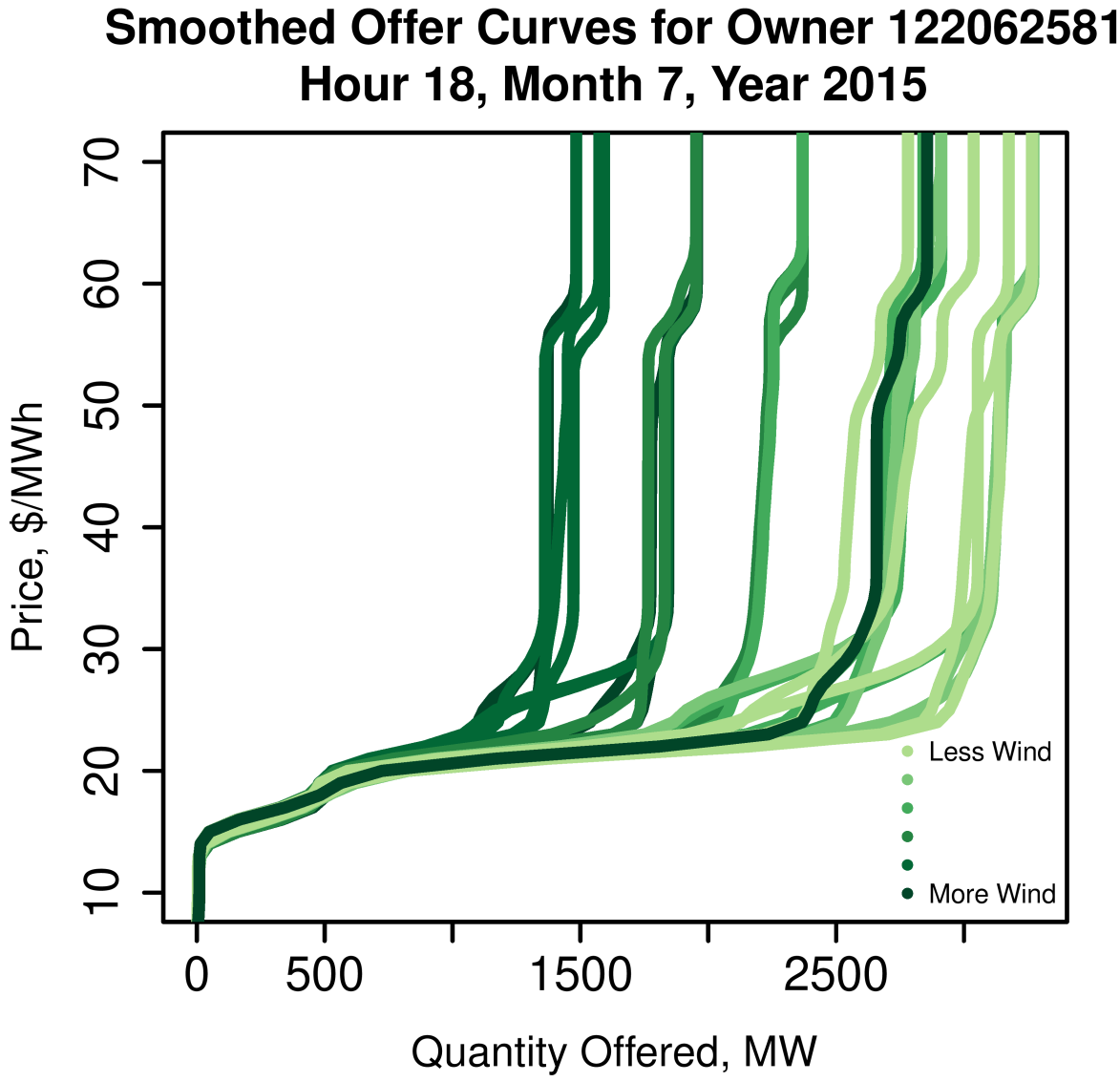
$$q_{otb} = \delta WindGWh_t + X\beta + \eta_{op_bymh} + \varepsilon_{otb}$$

- X includes load, net exports, congestion, wind forecast error, natural gas prices, temperature. sources.
- η_{op_bymh} is owner, year-month-hour, average supply curve

If $\delta < 0$ then the conventional assets are being withheld.

Variation in Supply Offer Curves

All supply curves, by owner *o*, hour *h*, month *m*, year *y*.



Result 1 - Withholding Full Sample

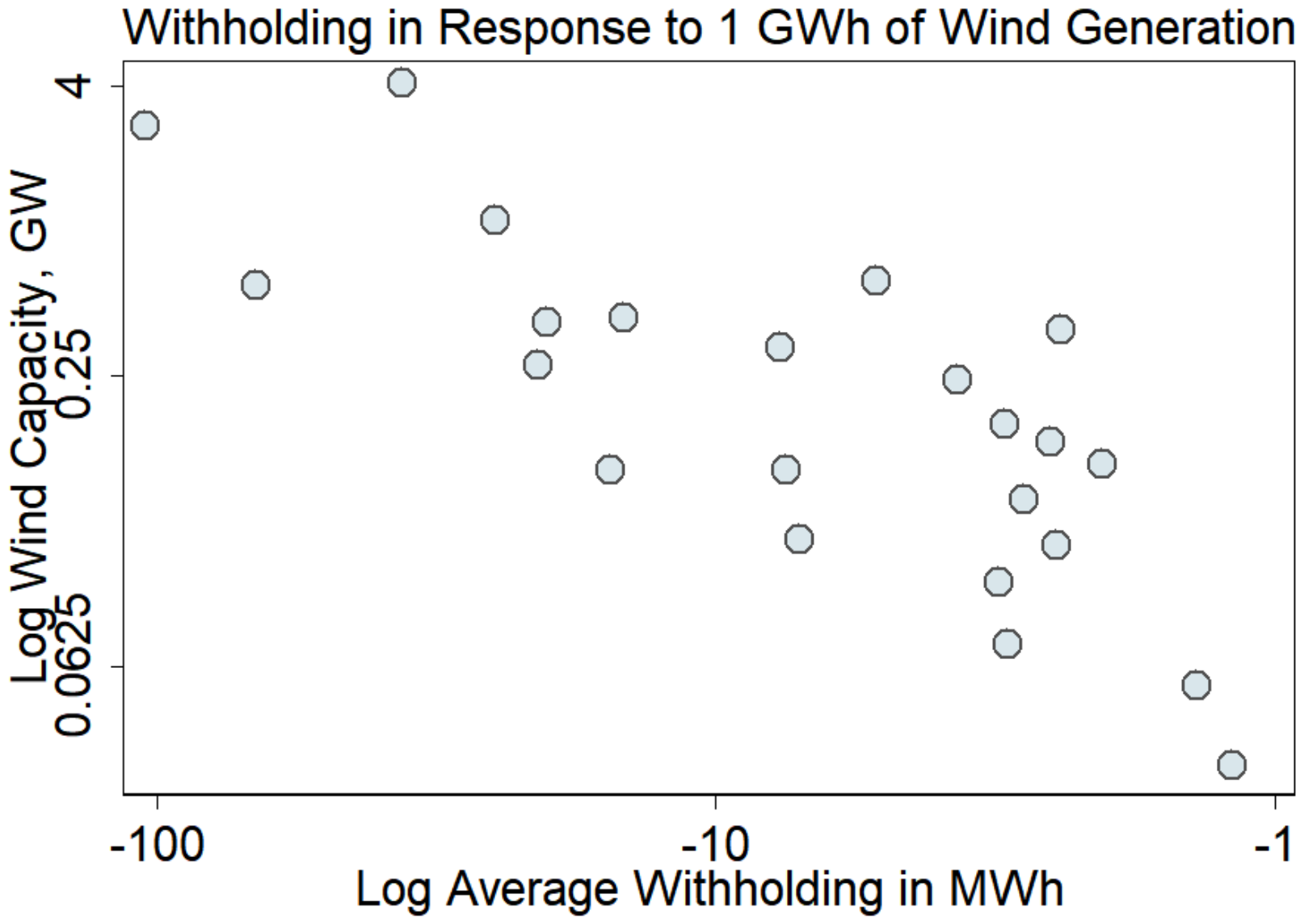
Firm's that own wind turbines withhold in response to more W.

	Quantity Offered, MWh	
Wind GWh, δ	-2.042***	
	(0.558)	
Doesn't Own Wind $\times$ Wind GWh		-0.805***
		(0.163)
Owns Wind $\times$ Wind GWh		-10.48**
		(3.728)
Owner-Price-Year-Month-Hour Fixed Effects	Yes	Yes
Observations	28,811,160	28,811,160
R-squared	0.97	0.97

Source: MISO Real Time Offer Market Reports January 1, 2014 to December 24, 2016. Peak hours, defined as 3pm to 8pm inclusive. Offer curves are interpolated and defined at $3 intervals between 0 and 60 USD. Standard errors, in parenthesis, are clustered by month of sample and owner. *, **, *** denote p-value less than 0.1, 0.05, and 0.01 respectively.

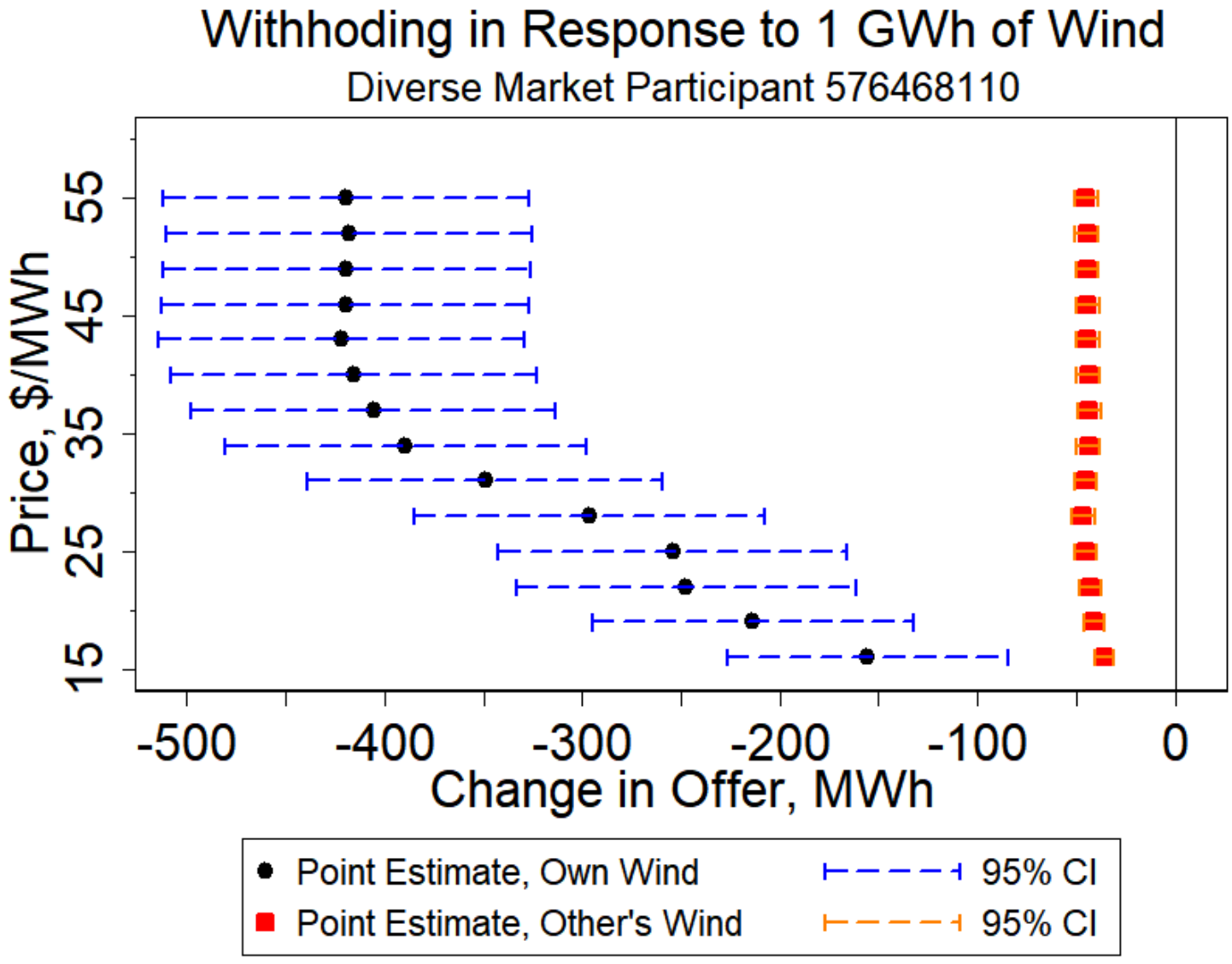
Result 2 - Market Participant Specific $\hat{\delta}$

Firm's that own more wind generation, withhold more.



Result 3

Firm's that own wind withhold more in response to their own wind



Implications for Consumer Surplus

Consumer surplus from electricity, hour t at market price p

$$CS_t(p) = \int_p^{\infty} D_t(x)dx$$

implies the total change in consumer surplus is

$$\Delta CS = -\sum_t D_t(p)\frac{dp}{dW}_t dW_t. \quad (1)$$

I directly calculate two versions of $\frac{dp}{dW}_t$

- No withholding, perfect competition
- Observed withholding, using estimates $\hat{\delta}_o$

Details on $\frac{dp}{dw}$ Statistics of $\frac{dp}{dw}$ Reconstructing Equilibrium

Consumer Surplus Calculation, MISO, 2014-2016

	Consumer Surplus	
	Total, Billion $	Annual $/person
Expenditure	55.3	371.3
ΔCS_{comp}, no withhold	10.1	67.8
ΔCS_{obs}, obs. withhold	6.9	46.0
$\Delta CS_{comp} - \Delta CS_{obs}$	3.3	21.8

Notes: Time period of interest is from January 1st, 2014 to December 24th, 2016. Revenue is the sum of Market MEC and market generation quantity in MWh for all hours. The equilibrium is where supply net of wind equals total demand within MISO. Annual per person calculations divides the total quantity by 2.98 years and 50 million people. All numbers are in nominal US dollars.

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Policy Implications

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I find a *potential* consumer benefit of $68 per year, with 17 GW of capacity.

However, $22 per person per year is lost to uncompetitive behavior by electricity generators.

Discussion

- It's important to have competitive markets
  - That's the goal of the Federal Energy Regulatory Commission and Independent System Operators
- This is due to how markets are structured
  - Alternative pricing agreements will reduce the incentive to withhold.
- However, should all of the benefit go to consumers?
  - Capturing benefit could incentivize investment
  - Electricity generation in competitive markets has a fixed cost recovery problem

Thank you!

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Proof of firm's incentives

Profit Function

$$\Pi_o(S_o(p)) = p[S_o(p) + \theta_o W] - C_o(S_o(p)) \tag{2}$$

First Order Conditions Provide

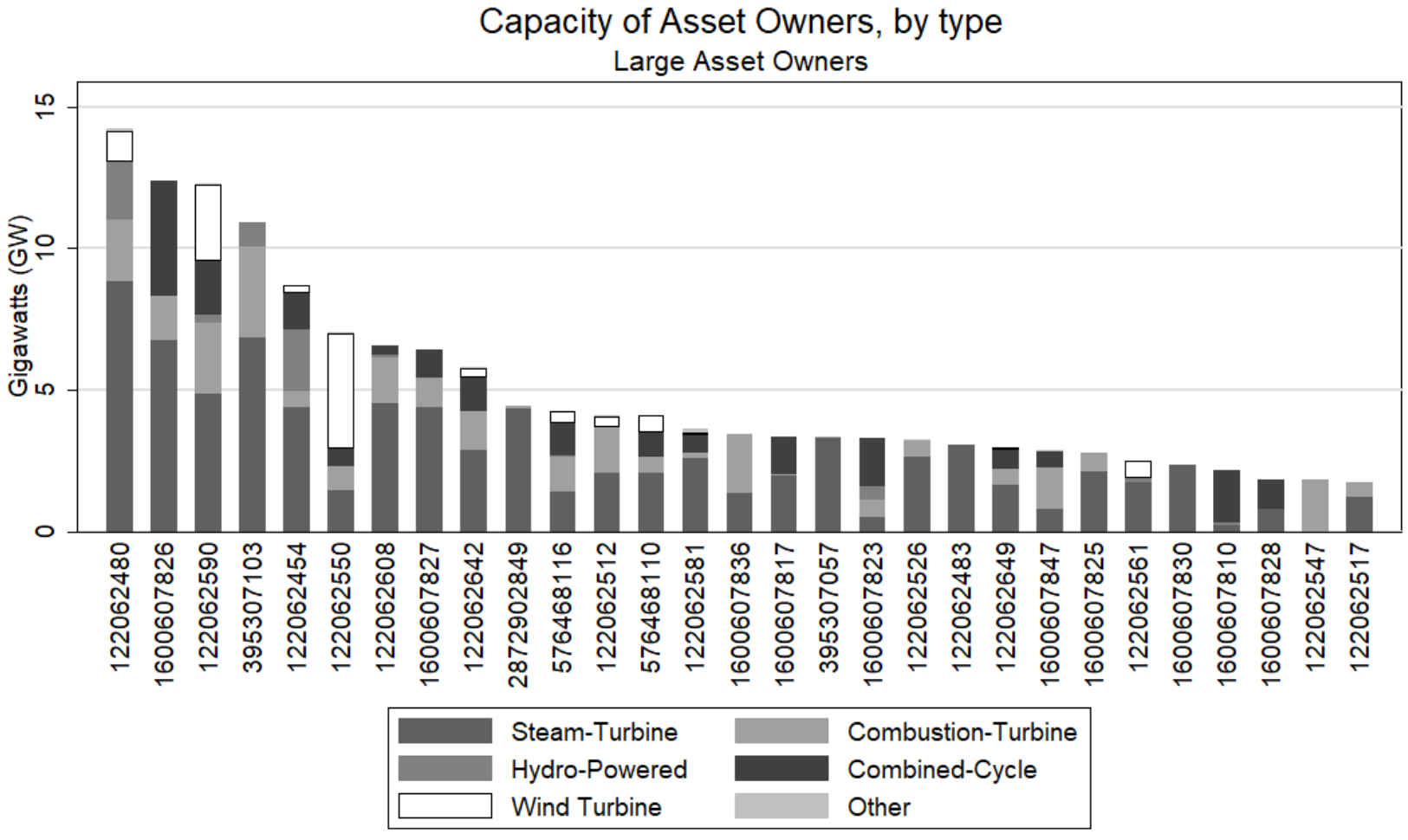
$$p - C'(S_o(p)) = -\frac{S_o(p) + \theta_o W}{d'(p) - \sum_{j \neq o} S'_j(p)}$$

Comparative Static

$$\frac{\partial S_o(p)}{\partial W} = -\theta_o$$

Back to picture proof

Market Concentration and Diversity



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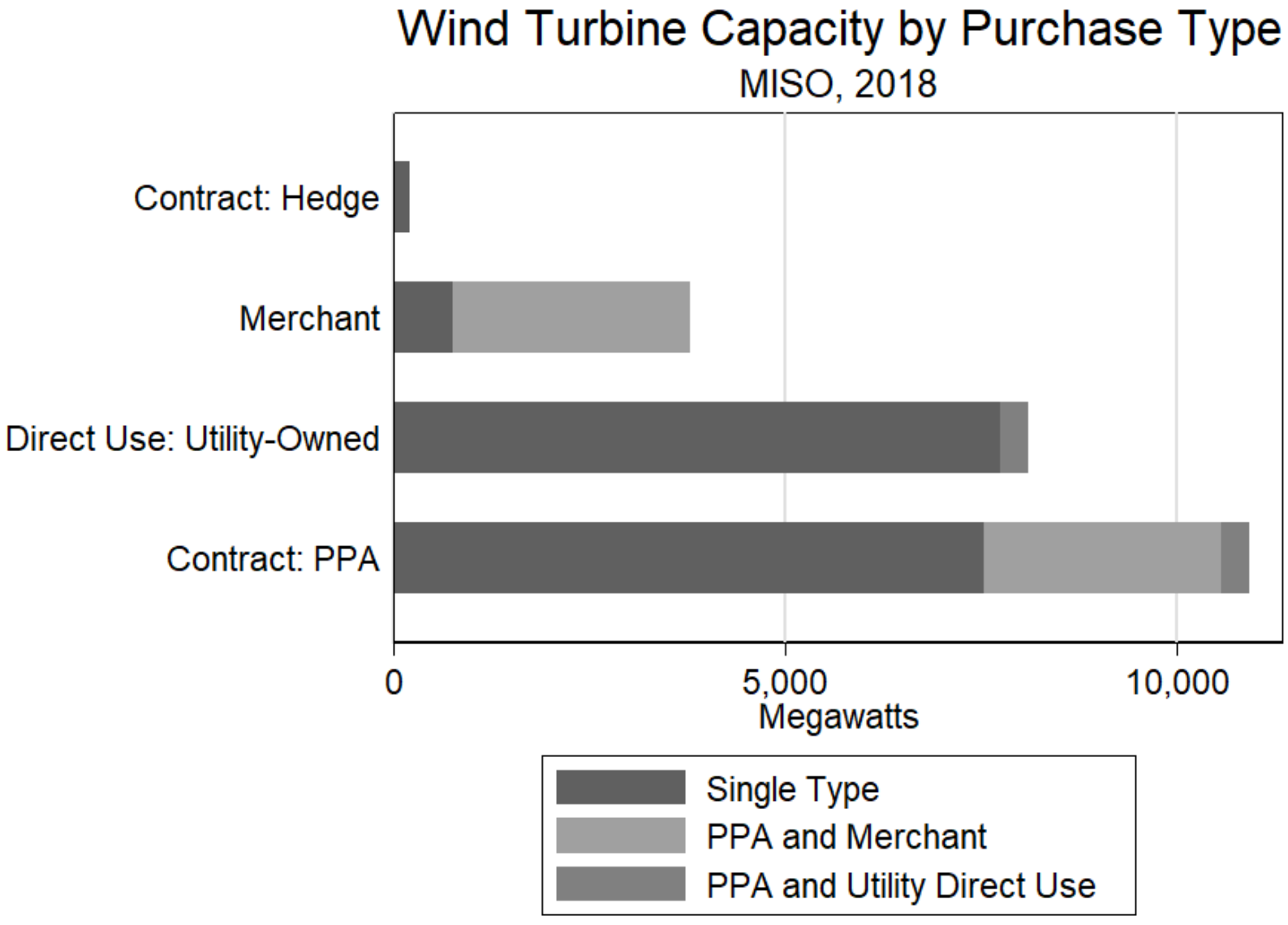
Purchasing Power Agreements



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Vertical Arrangements

Table: Operations of Utilities with Large Wind Capacity in MISO, 2016

Utility	TWh	% Wholesale Purchase	% Sale for Resale
MidAmerican Energy	33.2	0.12	0.26
Northern States Power	48.6	0.27	0.26
ALLETE, Inc.	14.7	0.33	0.41
DTE Electric Company	47.3	0.21	0.05
Wisconsin Electric Power	36.8	0.29	0.26
Basin Electric Power	29.6	0.37	0.94
Wisconsin Power & Light	14.8	0.39	0.24
Consumers Energy	38.6	0.58	0.08
Interstate Power and Light	17.1	0.53	0.12
Montana-Dakota Utilities	3.5	0.25	0.01

Notes: Capacity is total installed, operating, capacity in megawatts. Wind capacity is the capacity of all wind turbines. All data comes from EIA-860 and EIA-861 for the year 2016. TWh stands for terawatt-hour, and represents the thousand of gigawatt-hours sourced and dispositioned that year. Of the total amount sources, the % Wholesale Purchase represents the amount of electricity they purchased from the wholesale market, the remaining percent (from 100) is the share they generated. The % Sale for Resale is the percentage of total disposition that was sold to a third party (e.g. the wholesale market) the remaining share was sold to retail customers.

Back to MISO details

Addition control variables

- Load
  - MISO
- Net Exports
  - MISO
- Daily maximum temperature
  - NOAA
- Hourly number of binding constraints
  - MISO
- Hourly shadow price of congestion
  - MISO
- Daily Henry Hub natural gas price
  - YES Energy
- Wind forecast error
  - Yes Energy

Back to Specification

Three calculations of consumer surplus

1. Perfect Competition, no withholding

$$\Delta CS_{comp} = \sum_t D_t(p) \frac{1}{\sum_o S'_{ot}(p) - d'_t(p)} dW_t$$

2. Supply Function Equilibrium, perfect withholding

$$\Delta CS_{SFE} = \sum_t D_t(p) \frac{1 - \left(\sum_{o \in V} \theta_o\right)_t}{\sum_o S'_{ot}(p) - d'_t(p)} dW_t$$

3. Observed Withholding Estimates

$$\Delta CS_{obs} = \sum_t D_t(p) \frac{1 - \sum_{o \in V} \hat{\delta}_o}{\sum_o S'_{ot}(p) - d'_t(p)} dW_t$$

where $\hat{\delta}_o$ is an estimate of $\frac{\partial S_o(p)}{\partial W}$.

Back to Consumer Surplus

Summary Statistics of Expected Price Change

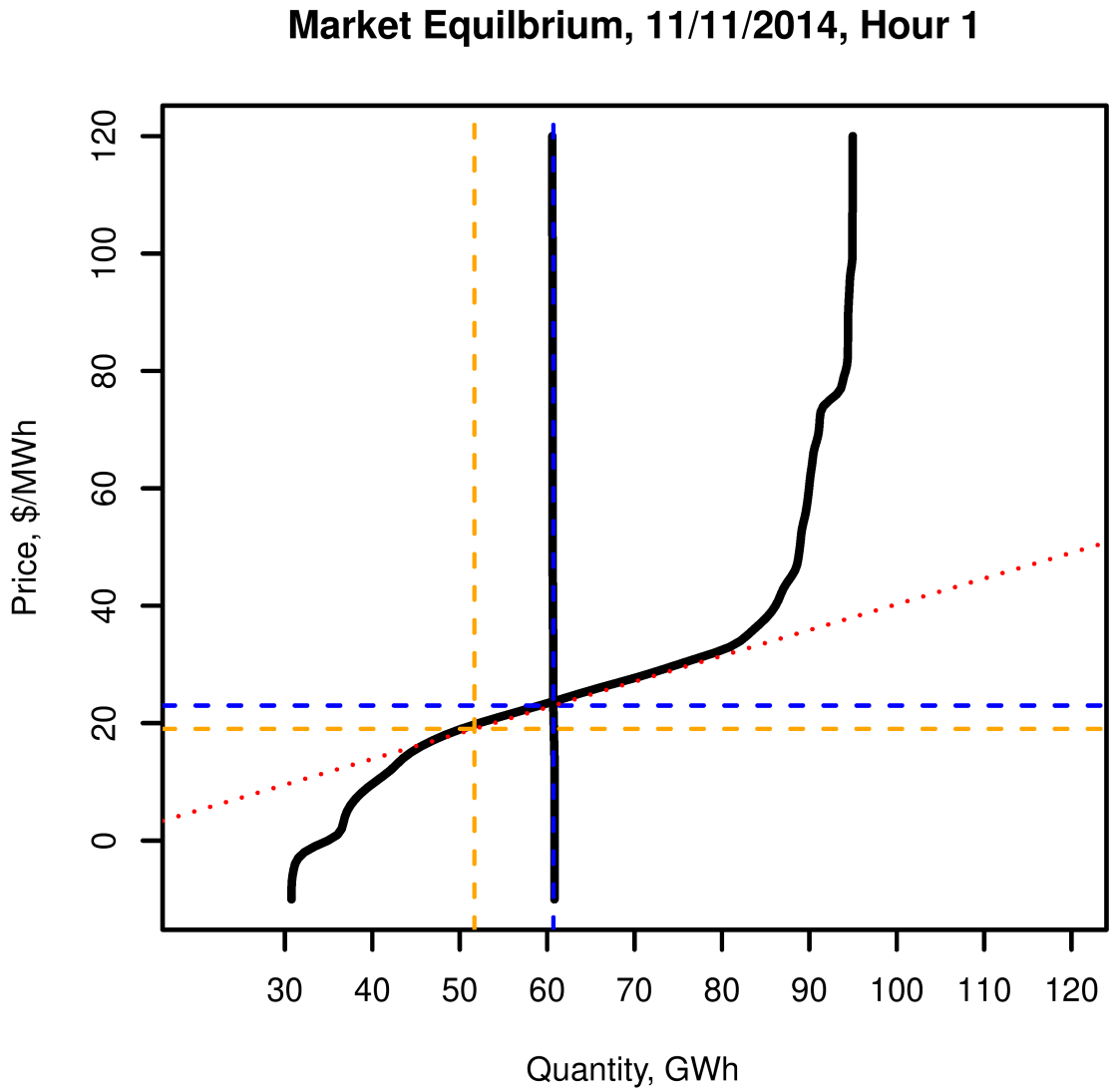
Table: Analytical Merit Order Effect

	Mean	Std. Dev.	Minimum	Maximum	Observations
$\frac{dp}{dW}_{comp}$, USD/GWh	-0.63	0.86	-30.73	-0.16	26,117
$\frac{dp}{dW}_{sfe}$, USD/GWh	-0.18	0.24	-8.97	-0.03	26,117
dp_{comp}, *USD*	-3.54	7.84	-360.81	-0.04	26,117
dp_{sfe}, *USD*	-0.97	2.10	-92.99	-0.02	26,117

Notes: $\frac{dp}{dW}$ come from the theoretical prediction of the impact of 1 GWh of wind on the price of electricity with the corresponding assumptions on the price of electricity. *comp* corresponds to competitive conduct and *sfe* corresponds to the supply function equilibrium model. The values of $dp_{comp,sfe}$ come from multiplying $\frac{dp}{dW}$ by the GWh of wind based electricity. The slopes of supply and demand come from the equilibrium without wind bids and demand less of net exports. The value of $\sum_{o \in V} \theta_o$ is set equal to the proportion of wind that is generated by diverse market participants in a hour.

Back to Consumer Surplus

Reconstructing the Equilibrium



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