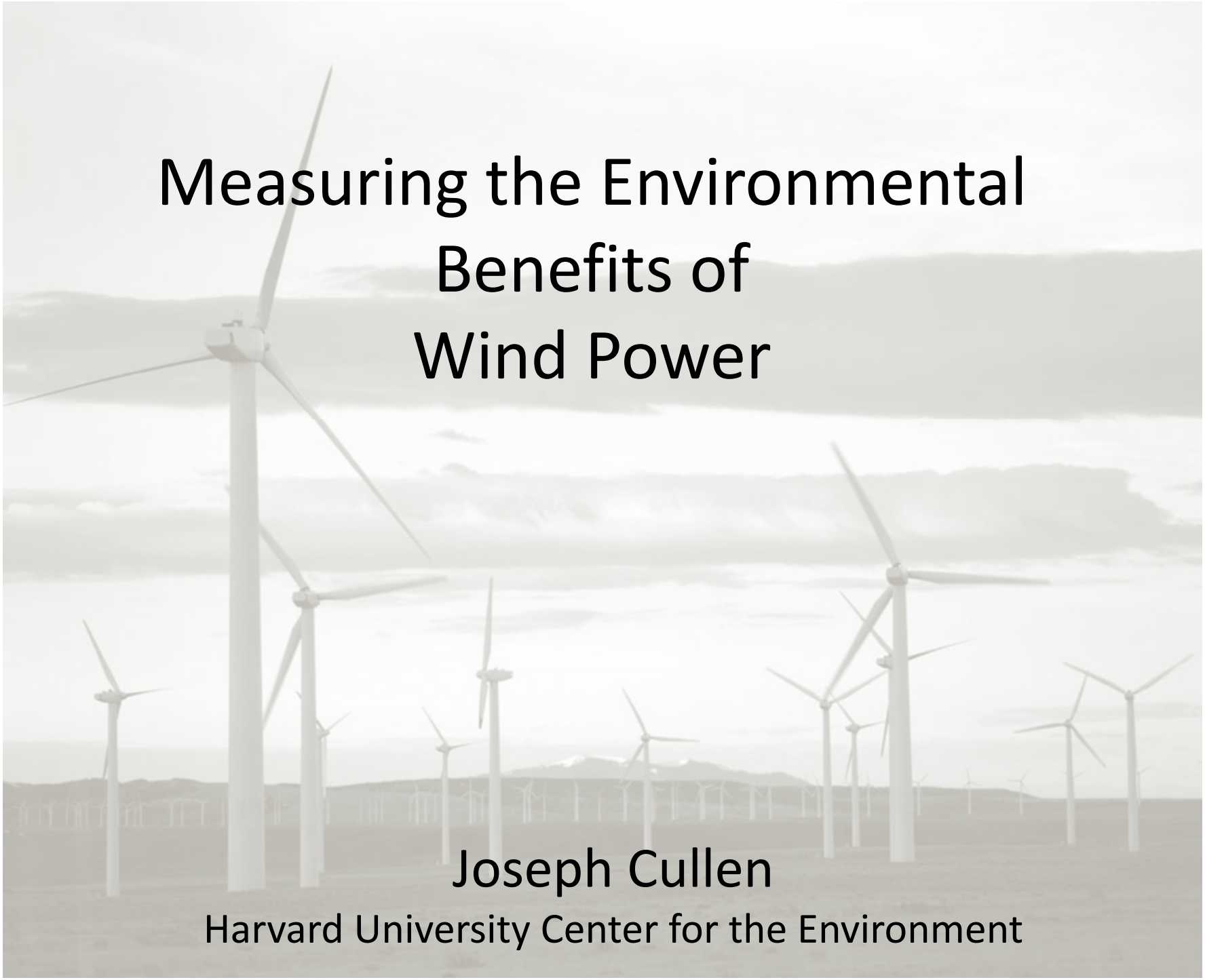

Measuring the Environmental Benefits of Wind Power

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Motivation

- Environmental policies to reduce emissions
- Energy Policy
- Subsidies
  - "Green" energy production
  - Wind power
  - Conventional generators emissions offset
- Important question:
  - What is the quantity (value) of emissions offset due to wind subsidies?

Research Question

- Two parts
  1. **How much investment do subsidies induce?**
     - Evidence indicates that investment is highly dependent on subsidies
     - Assume wind farms would not have been installed without subsidy
  2. **What is the quantity and value of offset emissions?**
     - Depend on generating unit specific substitution patterns
       - Substitute for “dirty” generators (coal)
       - Substitute for cleaner more efficient generators

Contribution

- Little empirical research on quantifying offsets
  - Engineering simulations of wind entry on grid
- This paper
  - Measures actual offset emissions
  - On a grid with operating wind farms
  - Observed behavior for conventional generators

Overview

- Fine scale data electricity data
- Quasi-experimental variation in wind
- Generator specific substitution patterns
- Emissions profiles → total offset emissions
- Emissions value compared to subsidies

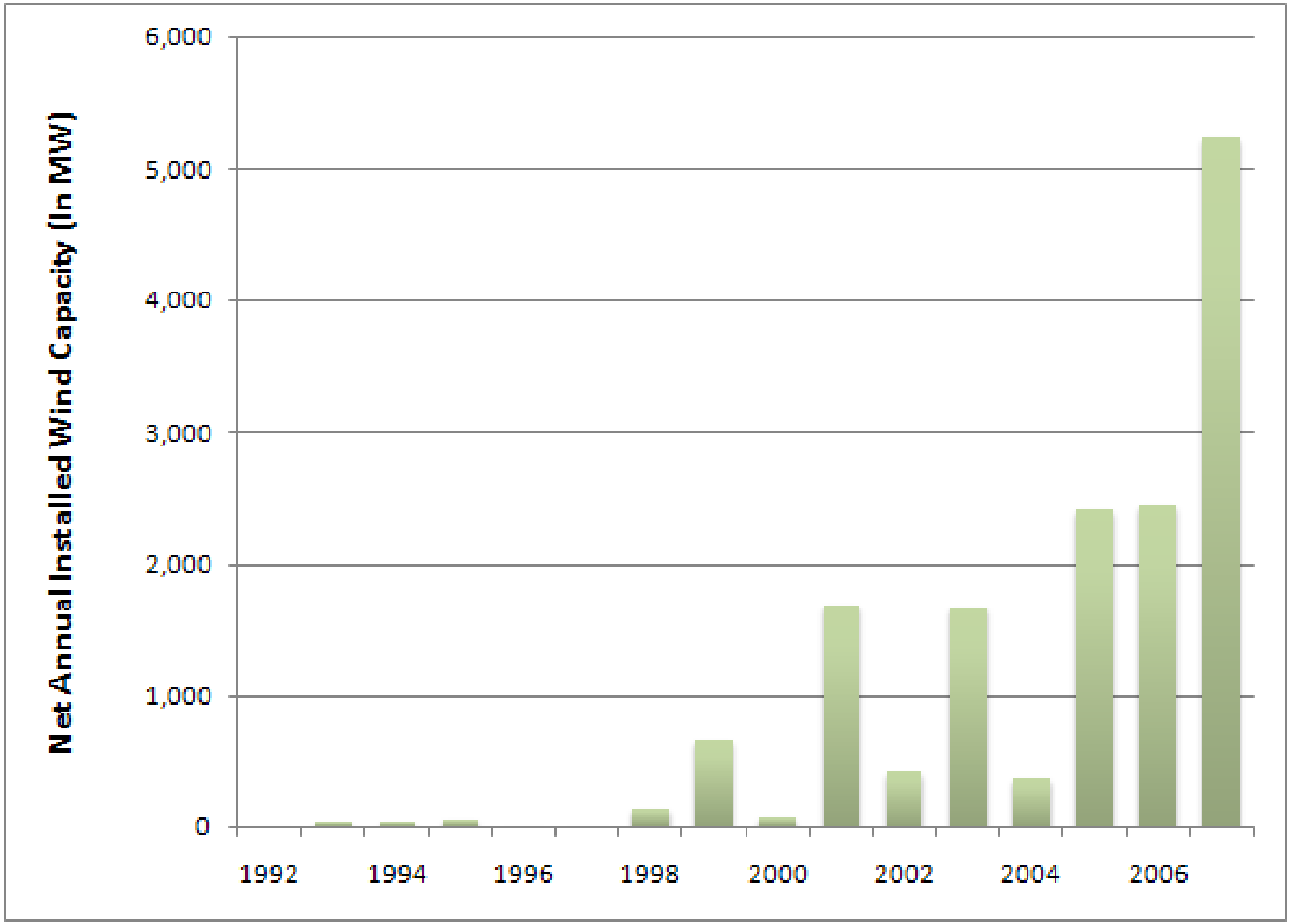
Results

- On aggregate 78% gas, 21% coal
- Per MWH Wind:
  - 1 lb NOx
  - 2 lbs SO_2
  - ¾ ton CO_2
- Value of emissions depends on CO_2
- At more than \$25/ton CO_2, the subsidy/MWH > value of offset emissions/MWH

Wind Subsidies

- Needs subsidies to operate competitively
- Output based subsidies
  1. Federal Production Tax Credit (PTC)
     - $20 MWH tax credit for first 10 years
     - Federal subsidies have expired 3 times since 2000
  2. State Renewable Portfolio Standards
     - $5 - $15 MWH subsidy
- Wholesale power
  - $30-$50MWH

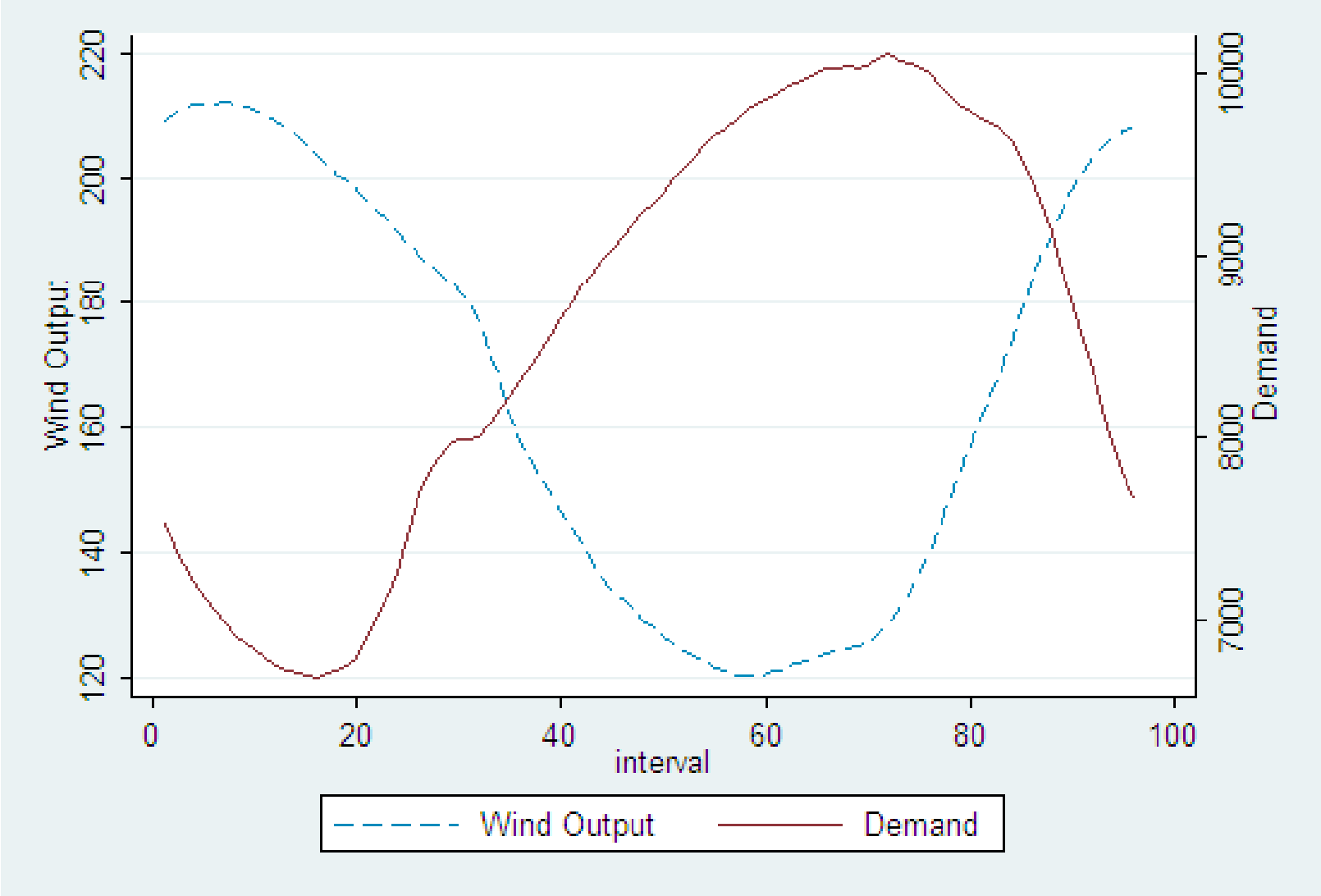
Wind Capacity Expansion



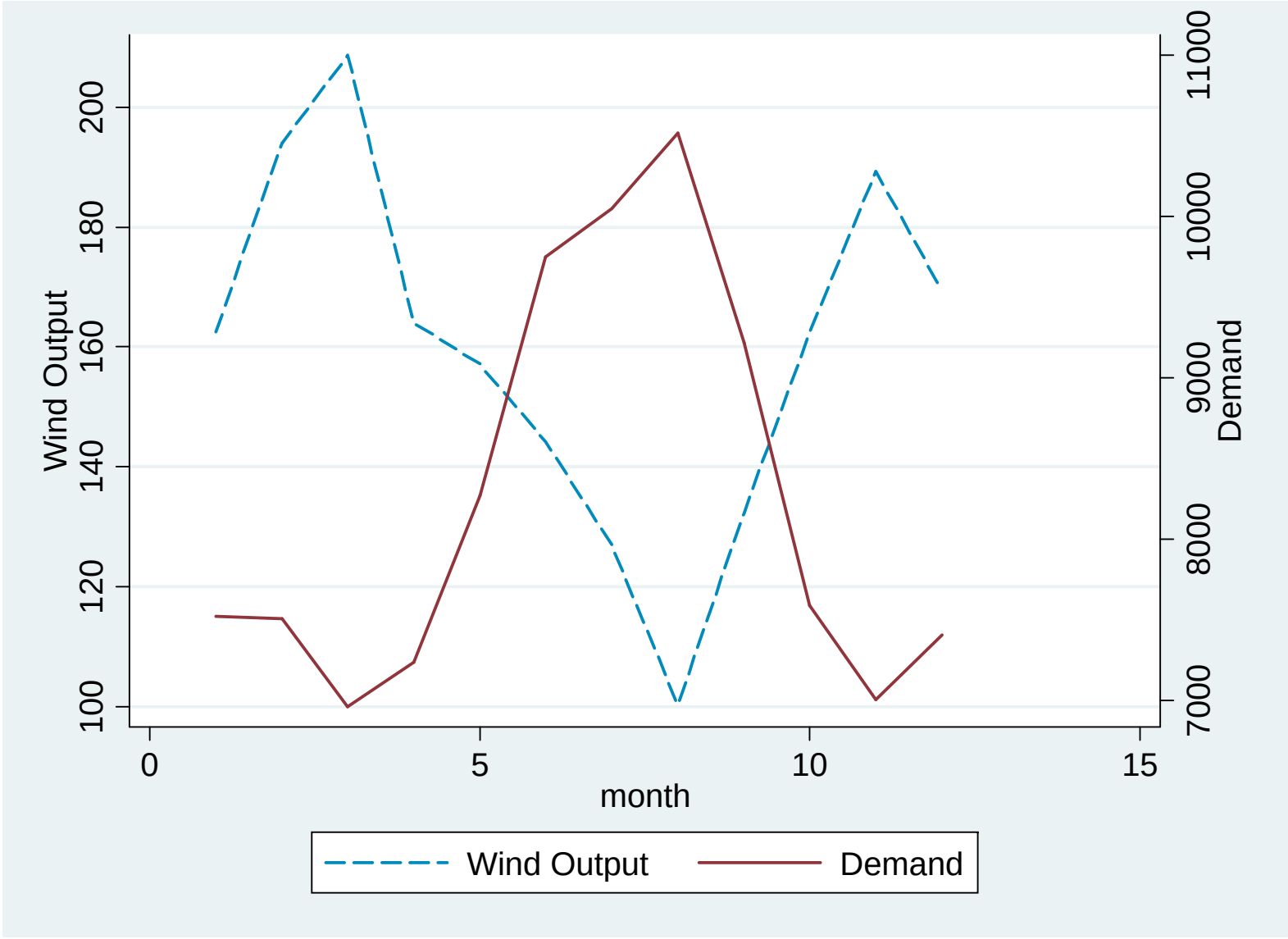
Market

- Electricity Markets
  - Demand
    - Inelastic
    - Highly variable
  - Supply
    - Conventional Generation
      - Baseload: coal, nuclear
      - Peak: CC gas, gas turbine, gas steam
    - Wind power
      - Low marginal cost
      - Not dispatchable
      - Daily /seasonal variation
  - Electricity is not storable
    - Supply=Demand each second

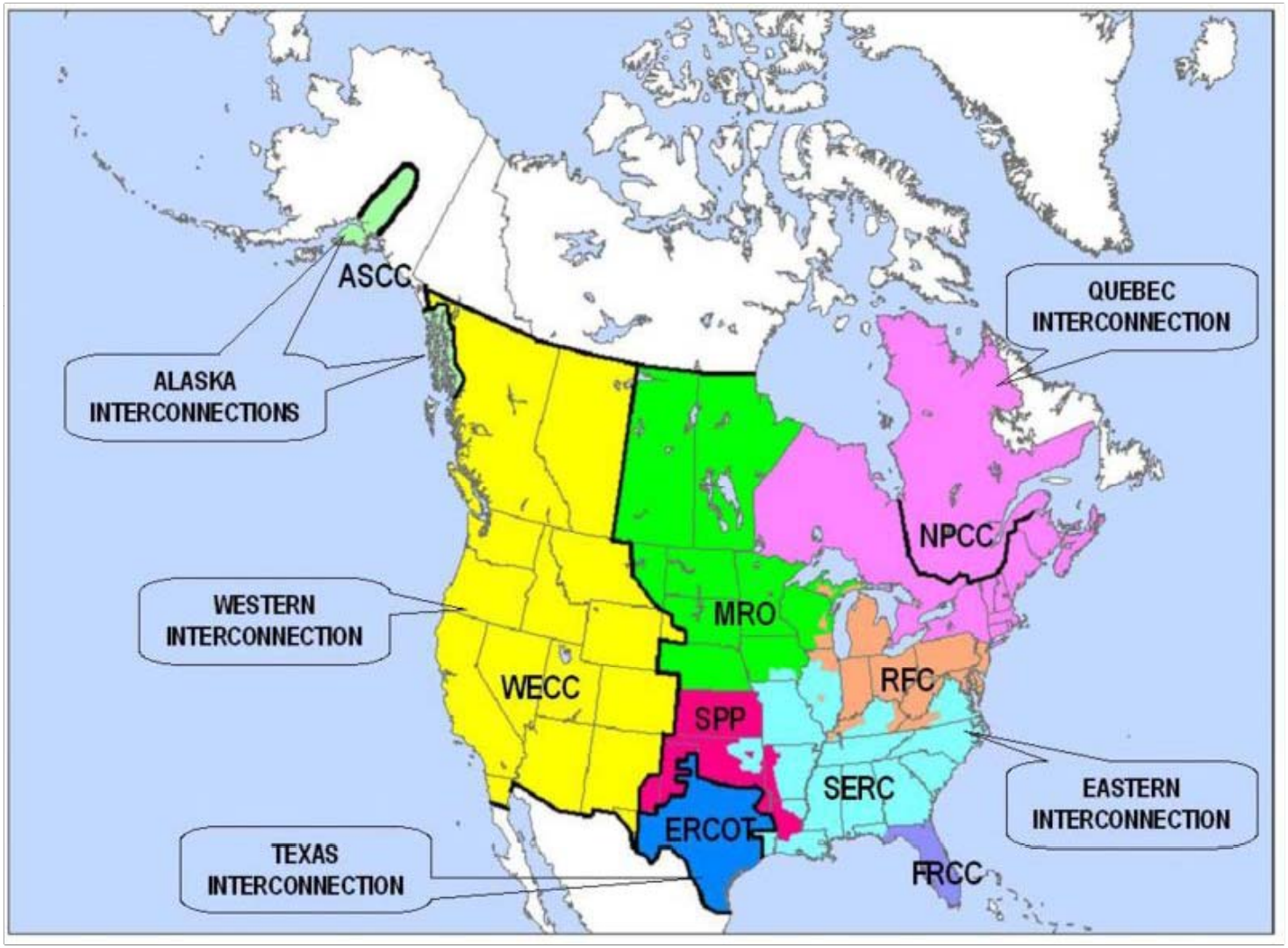
Daily Variation



Seasonality



ERCOT GRID


ASCC
ALASKA
INTERCONNECTIONS
QUEBEC
INTERCONNECTION
NPCC
WESTERN
INTERCONNECTION
MRO
WECC
RFC
SPP
SERC
EASTERN
INTERCONNECTION
ERCOT
TEXAS
INTERCONNECTION
FRCC

Data

- Plant output every 15 min
  - 180 plants + windfarms
  - 2005-2007
- Characteristics of each plant
- Temperature data (hourly)
- Plant level emissions data
  - SO_2, NO_x, CO_2
  - MWH ⟶ lbs Pollution

Model

- Wind affects output through price only.
  - Changes the residual demand curve
- Reduced form model
  - model the effect of wind on output directly.
- Identification
  - Exploit the exogeneity of wind power
  - Wind farms do not have control over output
  - Wind is low cost producer
  - Cannot store fuel nor output

Model

- Wind output is exogenous, but not random.
- Diurnal and seasonal variations
  - Peak and seasonal demand
- Trends
  - Capacity changes
  - Input price tends
- Control for seasonality and trends in a reduced form model
- Random variation in wind output

Estimation

- Controls in the model
  - Local and system hourly weather
  - Date dummies
    - Day specific effects
    - Fuel, wind capacity, demand growth, etc.
  - Interval dummies
    - Diurnal variation in demand and wind
- Separate regression for each plant on the grid
- Plant specific substitution coefficient

$$Y_{ijd} = \beta_{i0} + \beta_{i1} Wind + Z\alpha_i + D_{id} + I_{ij} + \varepsilon_{ijd}$$

Offset Emissions

- $\hat{\beta}_{i1} \Longrightarrow$ Plant output reduction
- EPA plant emissions characteristics $\Longrightarrow$ offset emissions
- Summing over all units gives the total emissions offset

Results

EPA Plant ID	Substitution Coefficient	SE	Fuel	Zone	Emissions Rate lb/MWH SO2	NOx	CO2	Avoided Emissions lb/MWH Wind SO2	NOx	CO2
6179	-5.63E-02	1.88E-03	Coal	4	5.236	1.945	2126	-0.29	-0.11	-119.71
55132	-4.80E-02	1.91E-03	Gas	2	0.004	0.195	799	0	-0.01	-38.34
3497	-4.39E-02	1.46E-03	Coal	2	19.760	1.617	2405	-0.87	-0.07	-105.56
3470	-4.31E-02	2.39E-03	Coal	1	5.781	0.447	2150	-0.25	-0.02	-92.61
55501	-4.03E-02	2.54E-03	Gas	2	0.005	0.270	917	0	-0.01	-36.9
3494	-3.80E-02	1.39E-03	Gas	5	0.502	1.975	1327	-0.02	-0.07	-50.37
6147	-3.62E-02	1.47E-03	Coal	2	10.770	1.829	2361	-0.39	-0.07	-85.38
55226	-3.52E-02	2.08E-03	Gas	2	0.005	0.216	933	0	-0.01	-32.84
55480	-2.85E-02	3.30E-03	Gas	2	0.004	0.280	874	0	-0.01	-24.91
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Total	-0.983	0.010						-2.00	-0.99	-1484

Annual offsets:

6,540 tons of SO_2

3,237 tons of NO_x

4,852,000 tons of CO_2.

Valuing Emissions Results

- Cap and Trade Regulated Emissions (NO_x, SO_2)
  - Aggregate emissions level does not change
    - No social benefit
  - Firms reduce costly abatement
  - Permit prices = abatement costs
    - Constant over some range
- Unregulated emissions (CO_2)
  - Real reductions in emissions of CO_2
  - Estimates of marginal damage costs (Tol, 2005)

Value of Offset Emissions

	Prices or Costs/ton			Values/MWH			Offset
	SO_2	NO_x	CO_2	SO_2	NO_x	CO_2	Value
Low	\$200	\$2,000	\$5	\$0.20	\$0.99	\$3.71	\$4.90
Middle	\$433	\$5,000	\$20	\$0.43	\$2.48	\$14.85	\$17.76
High	\$700	\$10,000	\$50	\$0.70	\$4.95	\$37.15	\$42.80

Prices for pollution are in \$/ton

- Driven mostly by CO2 emissions
- Subsidies
  - $30 MWH over 10 years
  - $20 MWH over 20 years

Conclusion

- Identified substitutes for wind power
  - Included both coal and natural gas plants
- Calculated and valued offset emissions
- Justification for subsidies driven by estimated CO_2 benefits
  - marginal damage costs of CO_2 > $25/ton
  - Least cost policy to achieve outcome??