COLORADO SCHOOL OF MINES

A ONE-TWO PUNCH: JOINT EFFECTS OF NATURAL GAS ABUNDANCE & RENEWABLES ON COAL-FIRED POWER PLANTS

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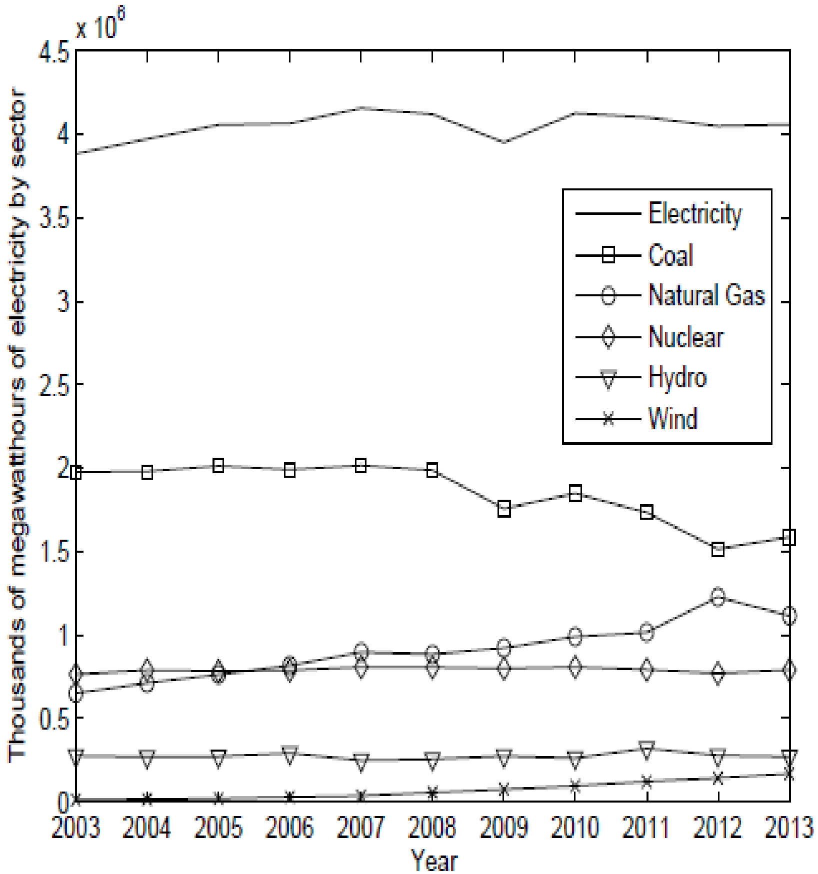
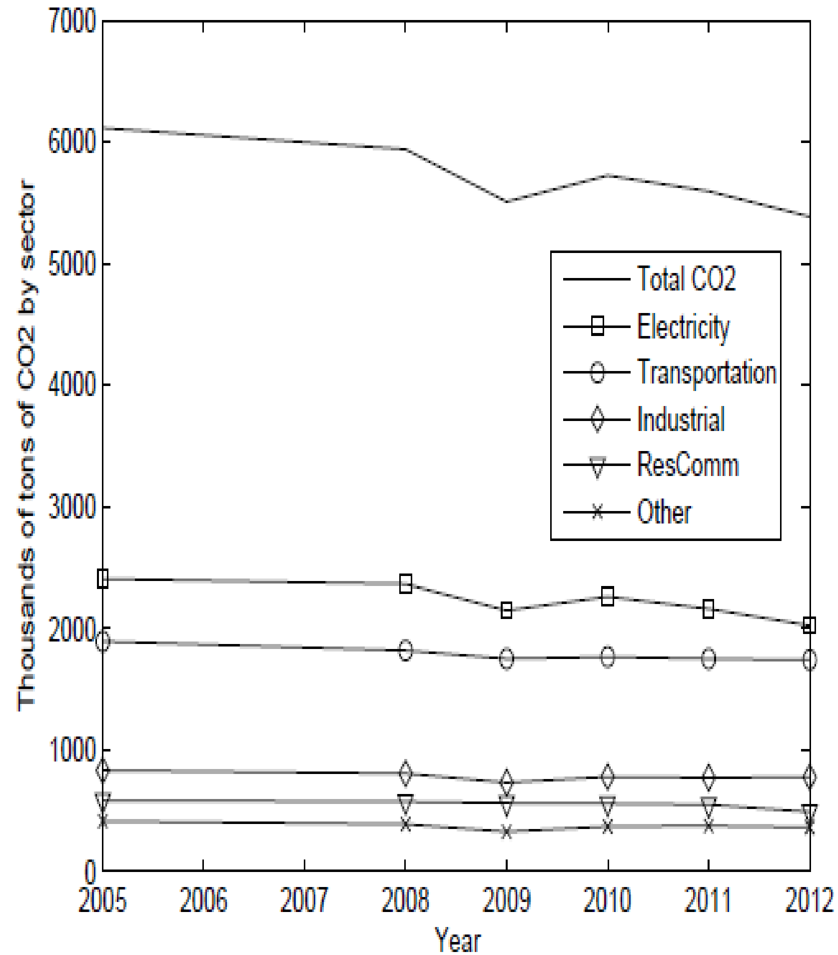
Generation and Emissions





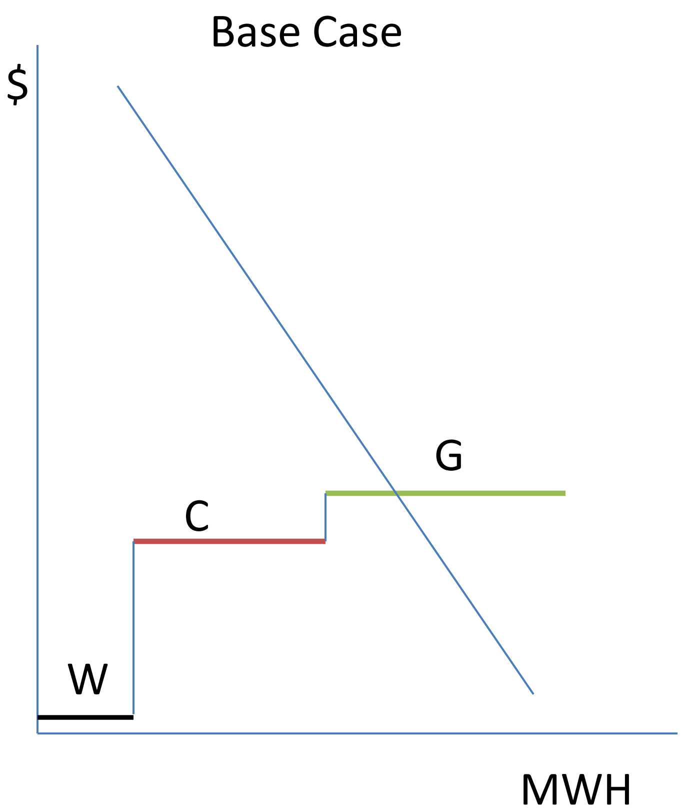
Research Questions

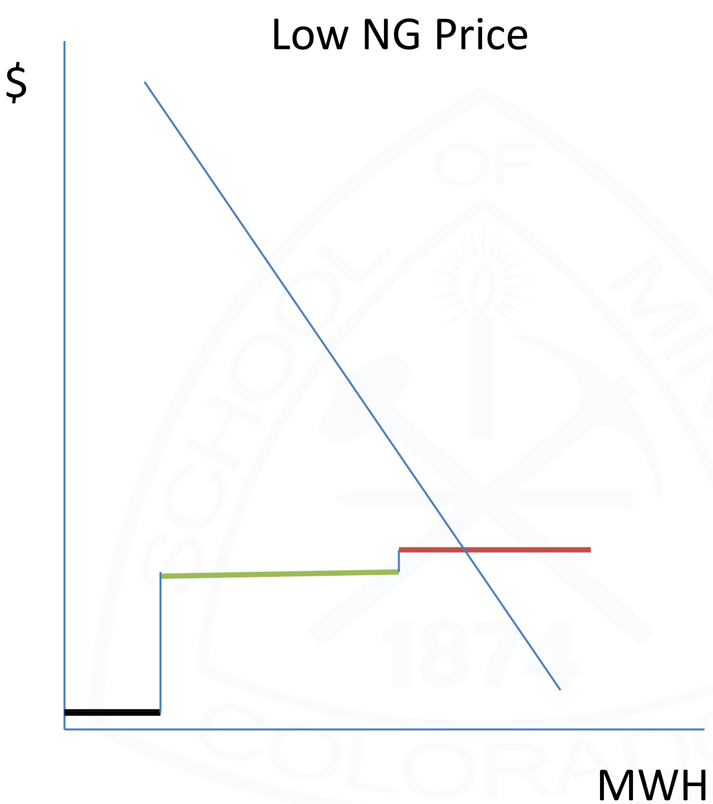
- How sensitive is coal-fired generation to natural gas prices and wind-generation?
- Are wind and gas compliments or substitutes for coal displacement?
  - Complementarity possible for several reasons
- Are there important energy policy interactions to consider?
  - For example, would increased wind generation exacerbate or relegate the impact of carbon pricing on coal generation?

Related Literature

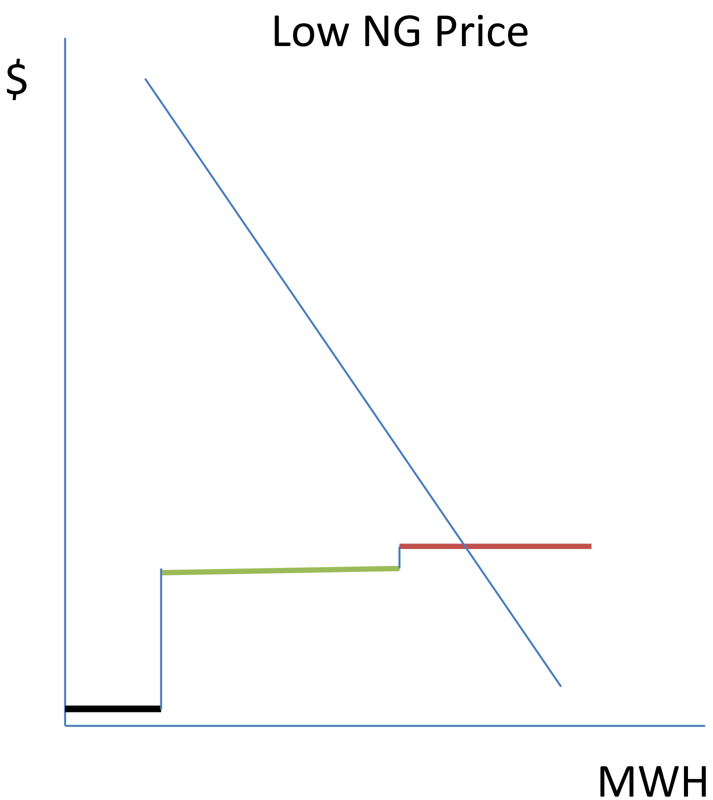
- Generation and emissions response to prices
  - Holland and Mansur (2008), Lu et al. (2012), Cullen and Mansur (2013), Holladay and LaRiverie (2014), Holladay and Soloway (2014), Linn et al. (2014), Knittel et al. (2014)
- Generation and emissions response to wind
  - Calloway and Fowlie (2009), Novan (2015), Cullen (2013), Kaffine et al. (2013), Amor et al. (2014), Dorsey-Palmateer (2014)
- To our knowledge, nothing in the literature has looked at both gas and wind on coal
  - Crucial to understand how the 2 interact – many ongoing and proposed policies are likely to affect both gas and wind

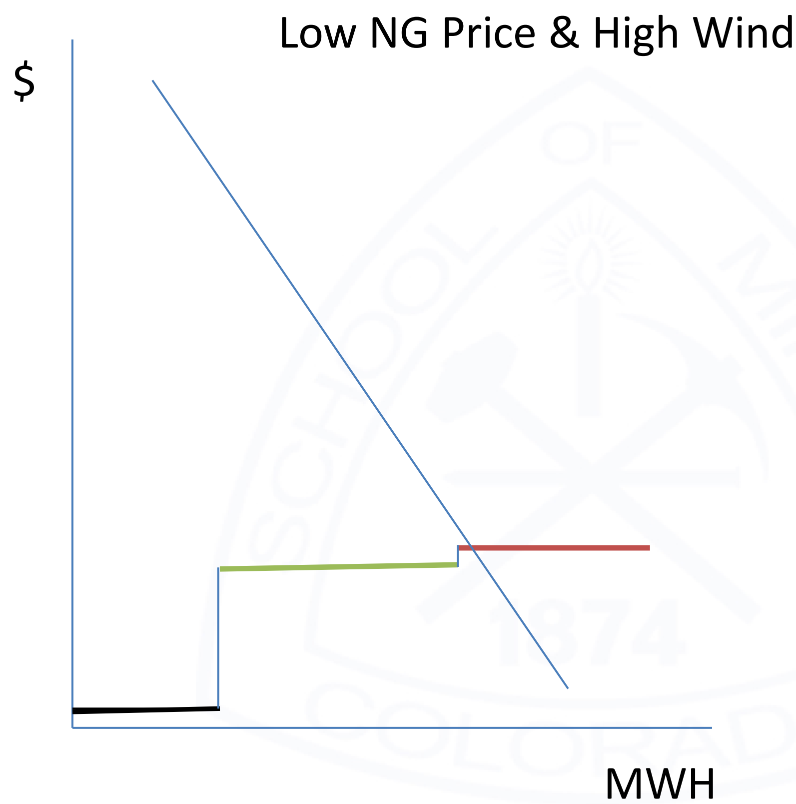
Basic Dispatch Model





Basic Dispatch Model





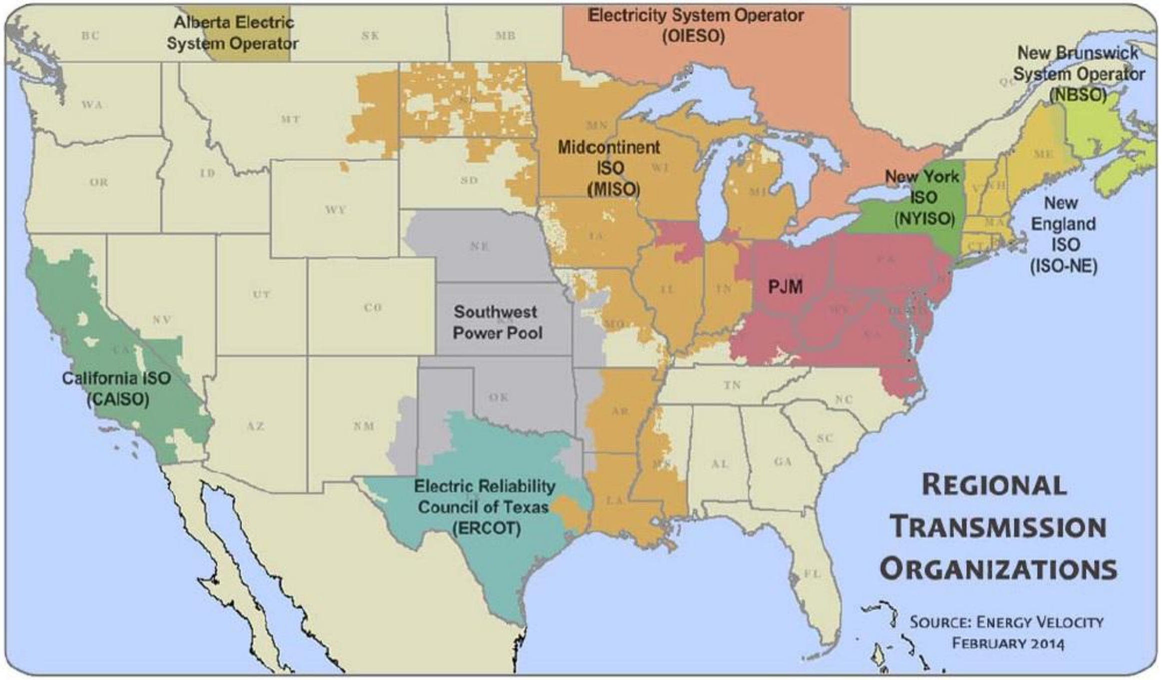
Data

- Look at changes in unit-level daily capacity factor and emissions due to changes in natural gas prices and wind generation at the ISO scale
  - Primary constraint is availability of ISO wind generation – has become available for different ISOs in different years after 2007
- Daily data from 2008 – 2013
- Merger of a substantial number of datasets
  - Hourly generation and emissions, aggregated to daily – unit level
  - Daily gas prices, monthly coal prices – plant level
  - Daily electricity prices and load – Transmission-zone level
  - Daily wind generation – ISO level
  - Capacity, regulatory status, control tech, age – unit level

Data – ISO

- Who's in (>60% of wind)
  - ERCOT (Texas)
  - MISO (Upper Midwest)
  - PJM (Midatlantic+)
  - SPP
- Also did
  - NYISO (New York)
  - ISONE (New England)
- Who's out
  - CAISO (California), BPA (PacNW)

    Rest of WECC, Southeast



Summary Statistics

	ERCOT				MISO		
	Mean	Mean-2008	Mean-2013		Mean	Mean-2008	Mean-2013
CF	0.73	0.788	0.706		0.542	0.62	0.495
E	0.818	0.902	0.791		0.655	0.762	0.587
P^R	0.496	0.222	0.553		0.519	0.306	0.579
W	0.694	0.416	0.896		0.625	0.232	0.969
Load	278198	268226	286543		84123	84944	85614

	PJM				SPP		
	Mean	Mean-2008	Mean-2013		Mean	Mean-2008	Mean-2013
CF	0.486	0.597	0.435		0.643	0.707	0.614
E	0.512	0.618	0.466		0.737	0.826	0.698
P^R	0.662	0.381	0.716		0.429	0.287	0.465
W	0.261	0.094	0.403		0.374	0.162	0.697
Load	216029	247614	215562		54246	53026	56441

Estimation Strategy

- Basic estimating equation:

$$y_{it} = \beta_1 P_{it}^R + \beta_2 \left(P_{it}^R\right)^2 + \beta_3 \left(P_{it}^R\right)^3 + \beta_4 W_t + \beta_5 W_t^2 + \beta_6 W_t^3 + \beta_7 W_t P_{it}^R + \boldsymbol{x}'_{it}\boldsymbol{\gamma} + d_{sy} + \alpha_i + \epsilon_{it}$$

y_{it}: Capacity Factor (CF) or $\frac{CO_2}{Capacity}$

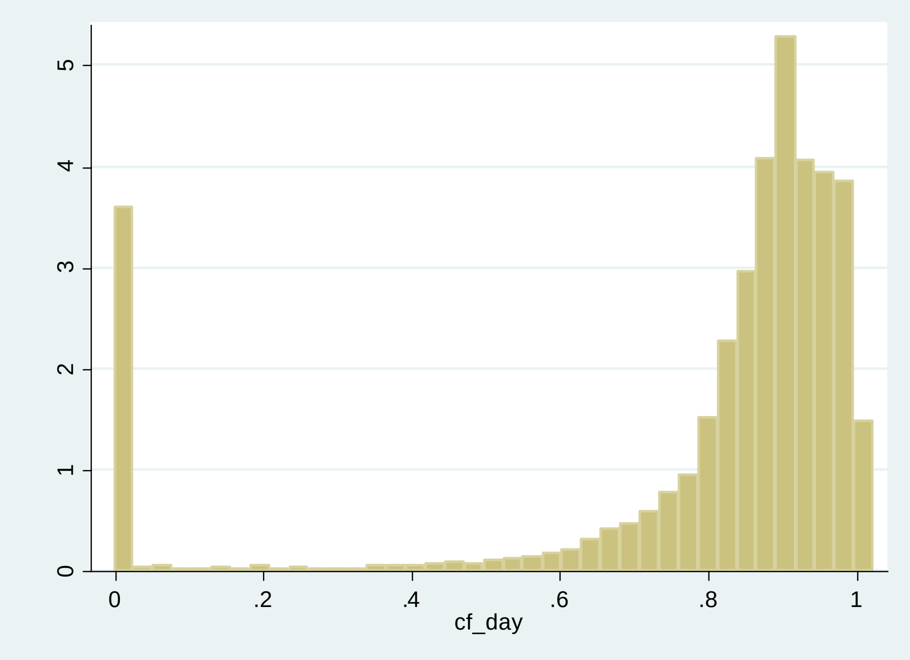
$P_{it}^R = \left(\frac{P_{it}^C}{P_{it}^{NG}}\right)$, W_t - daily ISO wind generation (100's of GW)

$\boldsymbol{x}'_{it}$: Load, Load^2, age, RGGI; d_{st}: season–by–year FE

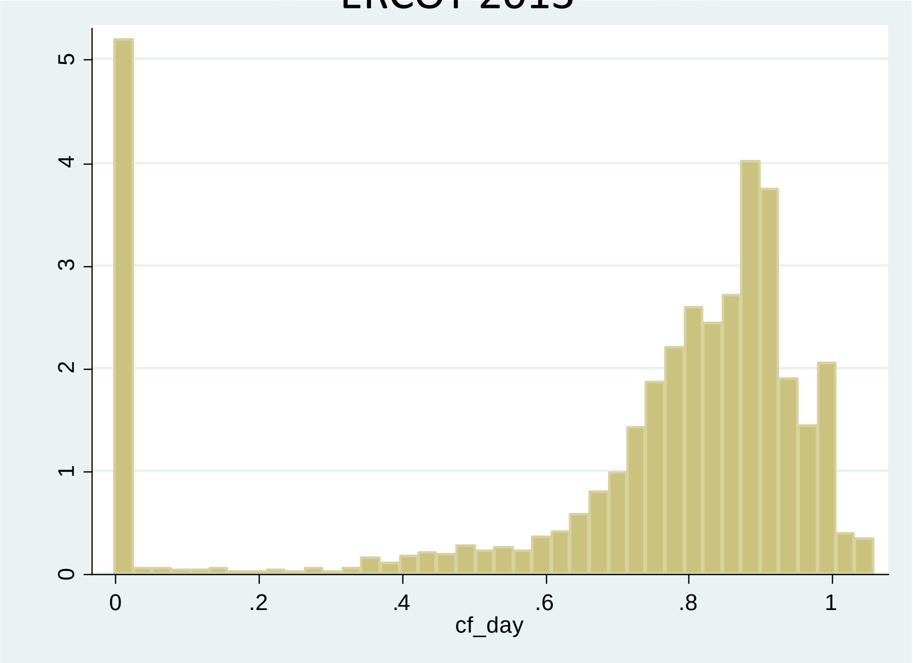
Estimation Challenges

- Using daily data, so many "0" observations
  - Standard OLS will be biased

ERCOT 2008



ERCOT 2013



Estimation Strategy

- Censored-quantile regression approach
  - Adaptation for panel data with FE's recently developed in Galvao, Lamarche, Lima (JASA, 2013)
  - Marginal effects relatively easy to interpret and easy to counterfactuals
  - Added benefit of allowing different responses by different quantiles
- Selection model using a Heckman 2-step approach
  - Method exists to adapt this to panel data with FE (Fernandez-Val and Villa (2011))
  - Difficulty in interpreting the marginal effects and doing counterfactuals → IMR is complex non-linear function of variables

Capacity Factors Results (q = 0.50)

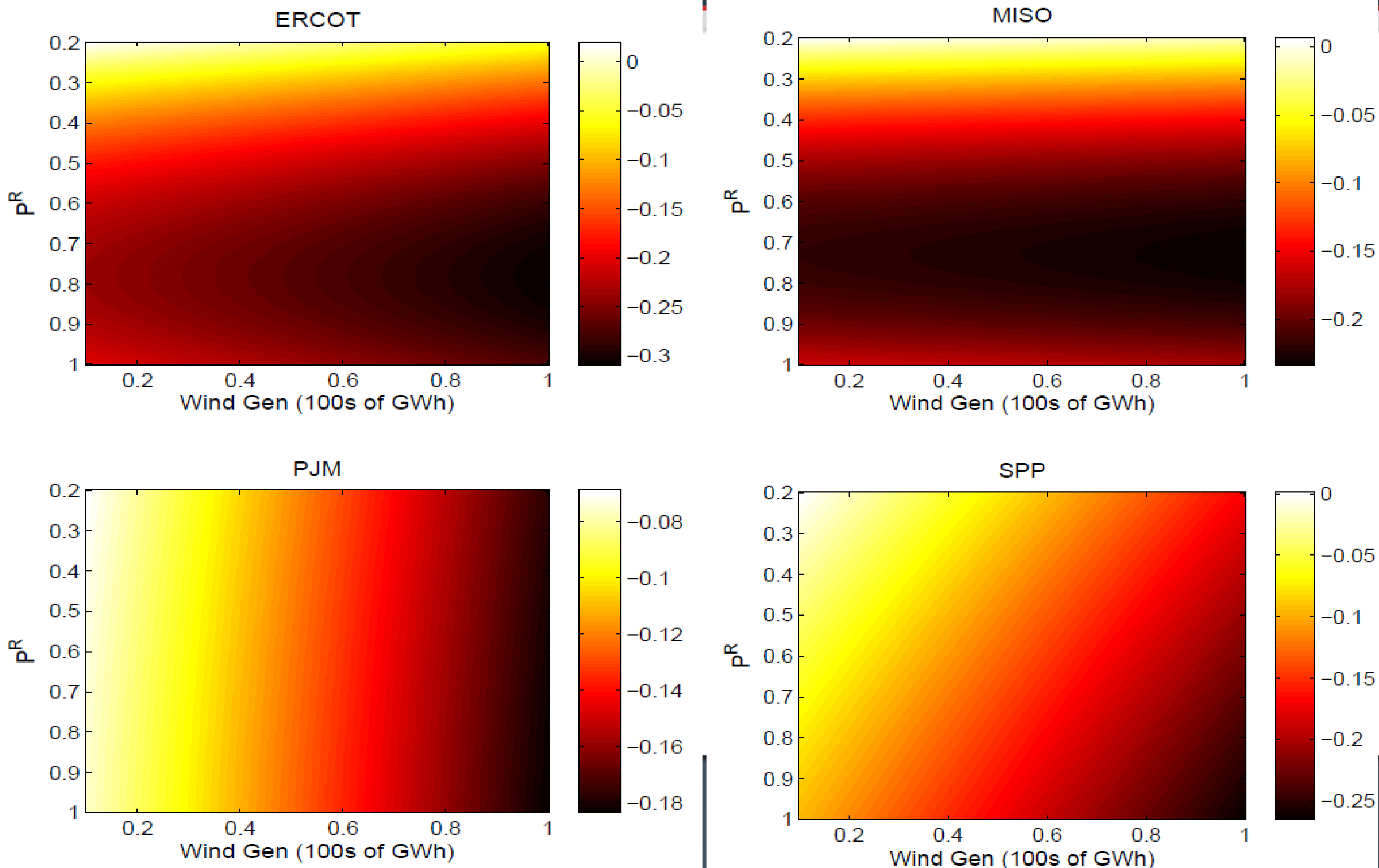
	ERCOT	MISO	PJM	SPP
P^R	0.235	0.209**	-0.0543**	0.049
$(P^R)^2$	-0.594*	-0.581***	-0.007	-0.0751
$(P^R)^3$	0.253**	0.264***	0.001	0.00832
W	0.007	-0.028***	0.070***	0.034*
W^2	-0.023	0.008	-0.0001	-0.034
W^3	0.011**	-0.005**	-0.021	0.014
$P^R * W$	-0.080**	-0.017	-0.120***	-0.189***
Obs.	55,014	349,316	254,332	125,430
Units	30	204	162	68

Marginal Effects

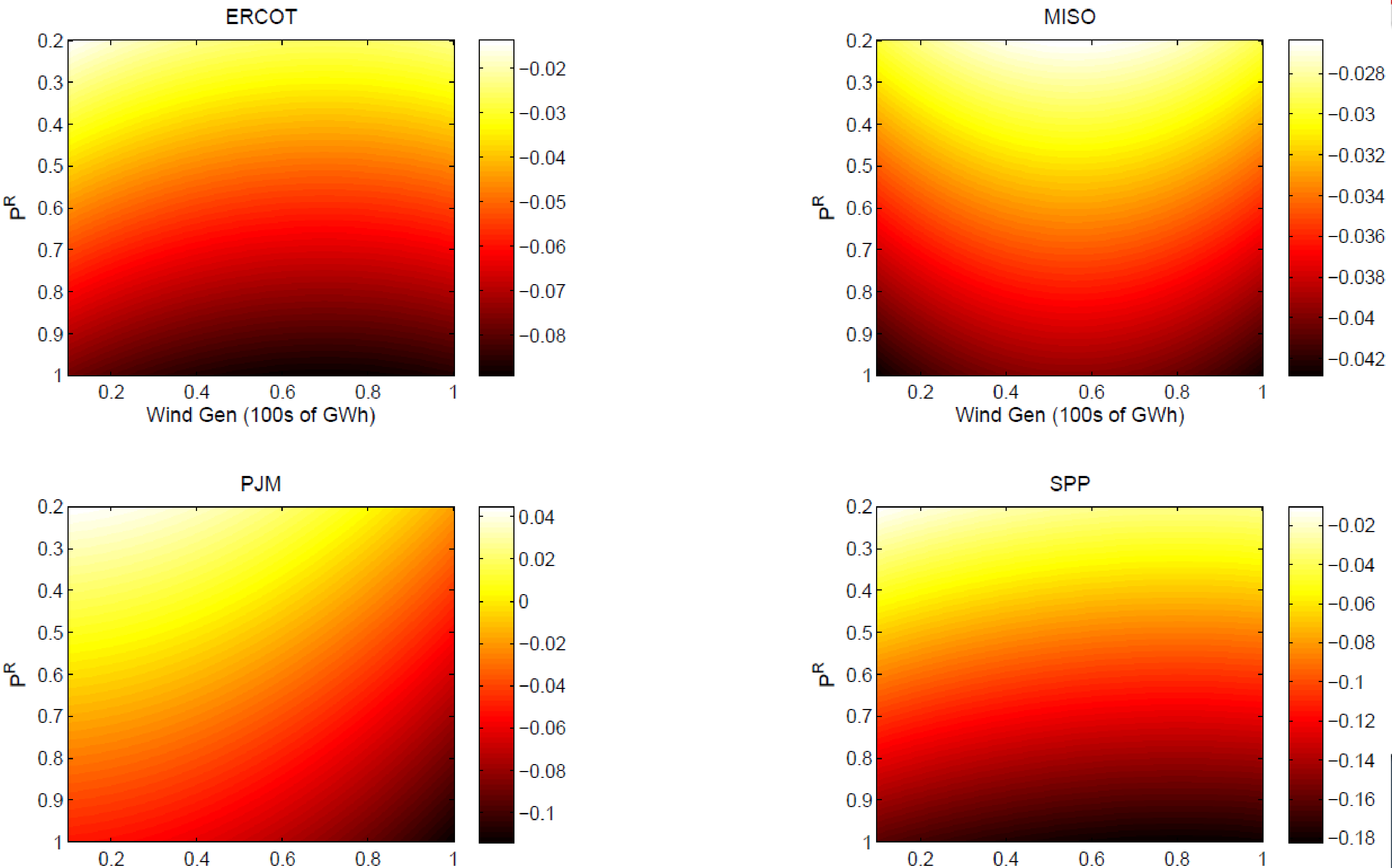
$\partial CF / \partial P^R$	ERCOT		MISO		PJM		SPP	
	Actual	W2008	Actual	W2008	Actual	W2008	Actual	W2008
2008	-0.018	-0.018	-0.064**	-0.064**	-0.07**	-0.07**	-0.022	-0.022
	(0.11)	(0.11)	(0.03)	(0.03)	(0.02)	(0.02)	(0.04)	(0.04)
2013	-0.254***	-0.216***	-0.201***	-0.189***	-0.11***	-0.073***	-0.147**	-0.046**
	(0.07)	(0.06)	(0.02)	(0.02)	(0.02)	(0.02)	(0.05)	(0.02)

$\partial CF / \partial W$	ERCOT		MISO		PJM		SPP	
	Actual	P2008	Actual	P2008	Actual	P2008	Actual	W2008
2008	-0.023**	-0.023**	-0.03***	-0.03***	0.023*	0.023*	-0.03**	-0.03**
	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)
2013	-0.045***	-0.019**	-0.039***	-0.034***	-0.027**	0.014	-0.077***	-0.043***
	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)

Marginal Effects – $\frac{\partial CF}{\partial P^R}$



Marginal Effects – $\partial CF / \partial W$



Quantile differences: $\partial CF / \partial P^R$

	ERCOT	MISO	PJM	SPP
Q = 0.25	-0.388 (0.072)	-0.204 (0.023)	-0.113 (0.017)	-0.107 (0.056)
Q = 0.5	-0.254 (0.065)	-0.201 (0.019)	-0.110 (0.016)	-0.147 (0.016)
Q = 0.75	-0.161 (0.070)	-0.174 (0.019)	-0.098 (0.013)	-0.125 (0.046)

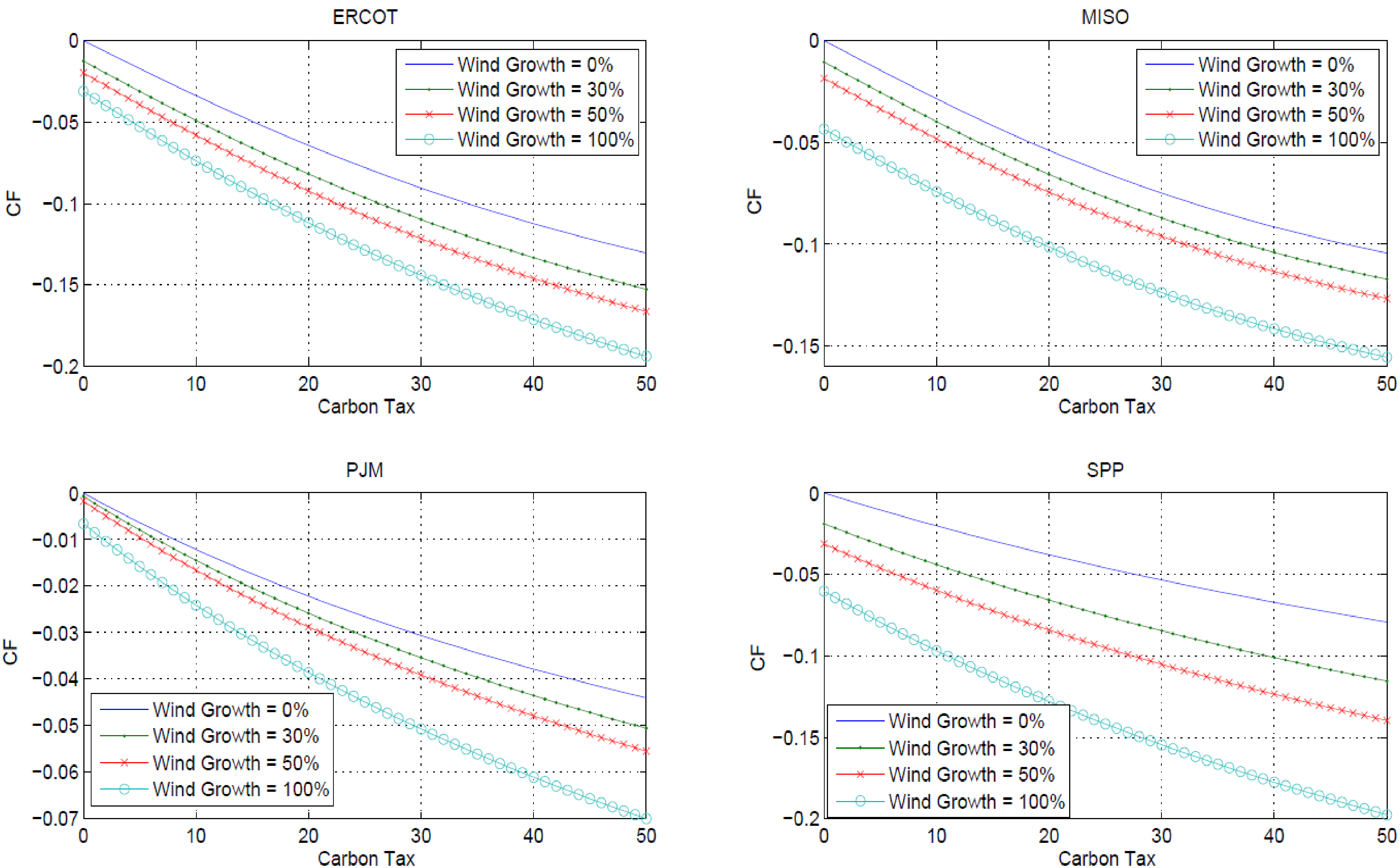
Additional Specifications

- Also considered specifications with:
  - Higher and lower order polynomials of W and P^R
  - Load from surrounding regions outside of ISO
  - Replacing daily wind generation with avg. hourly (wind/load)
- Results from these alternative specifications generally follow those shown here

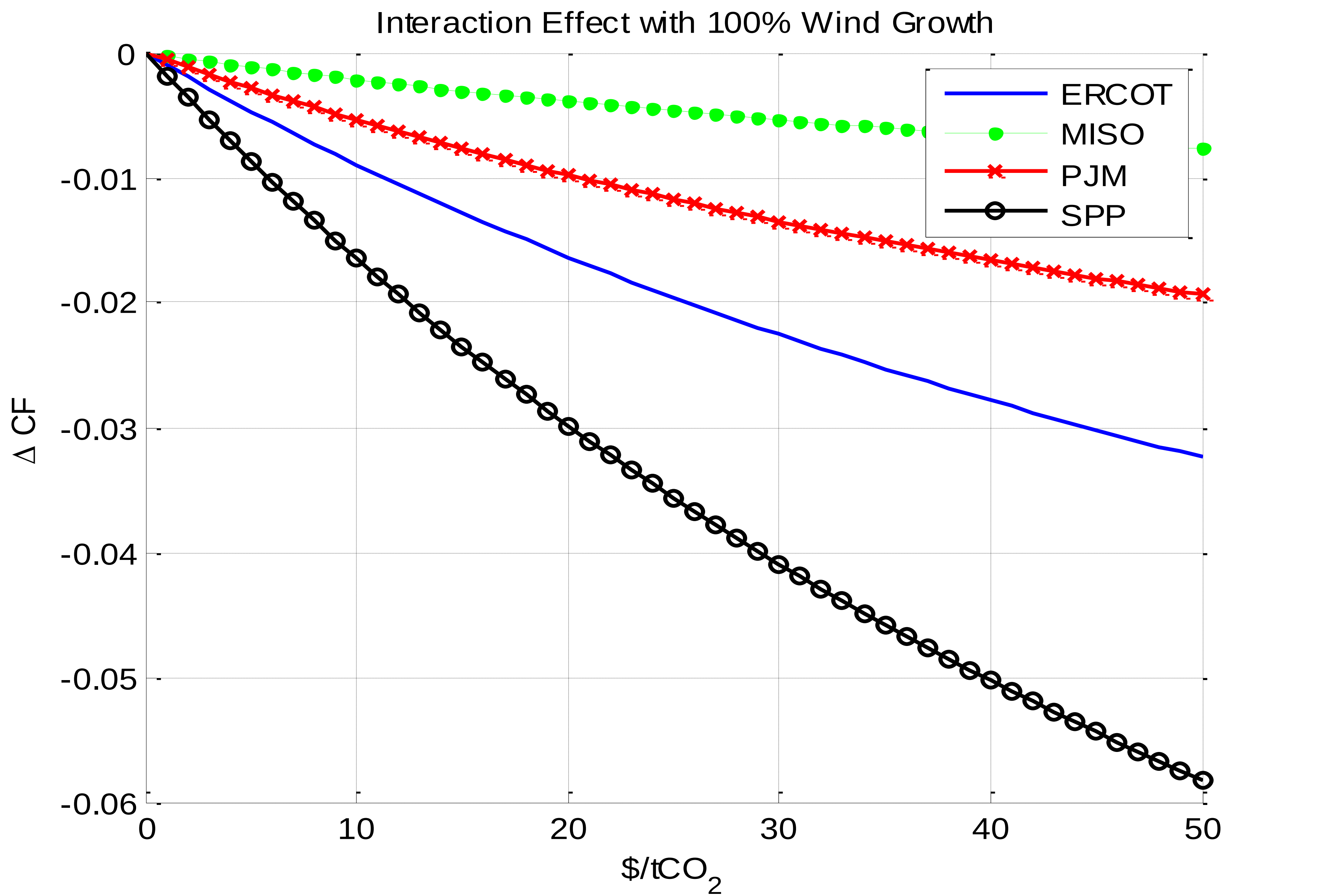
Back of the Envelope Policy Analysis

- How much different would 2020 capacity factors/emissions for coal be under various carbon pricing and wind growth scenarios?
- Plot the difference between 2020 projected CF with no wind growth and no carbon price and projected CF's under carbon price and wind growth
- Based on based on 2020 projections from AEO 2014
  - Base case used here is $P^R = 0.51$, wind at 2013 levels, no carbon price

Policy Analysis



Policy Analysis – Interaction Effect Impact



Summary

- Increasing wind *and* falling NG prices both negatively impact generation from coal
- Importantly – most regions show a significant interaction effect
- Marginal effect of Price Ratio and Wind on CF is negative and significant in most regions
  - Marginal effects generally grow over time
  - Marginal effect are now larger than they would have been if price ratio or wind generation were at 2008 levels in several regions
- CO_2 results generally follow that of CF
- Significant additional emission reductions from carbon price if wind generation continues to grow

Policy Analysis