Leakage in Regional Climate Policy?

Implications of Market Design from the Western Energy Imbalance Market

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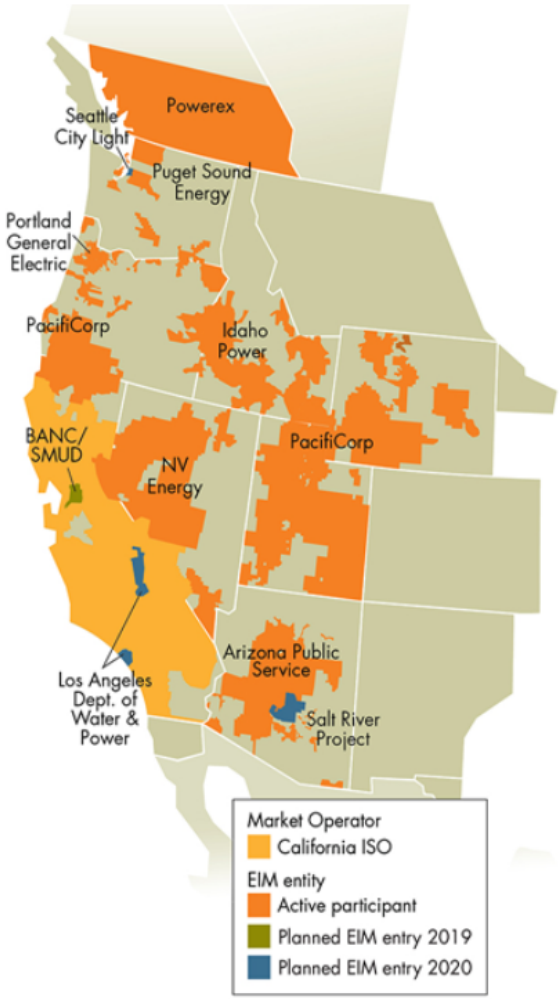
Motivation



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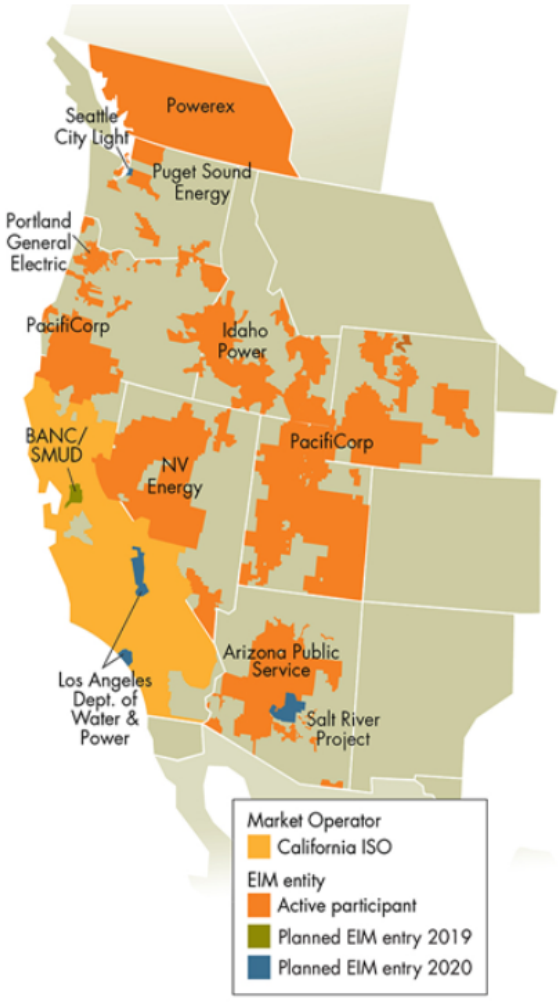

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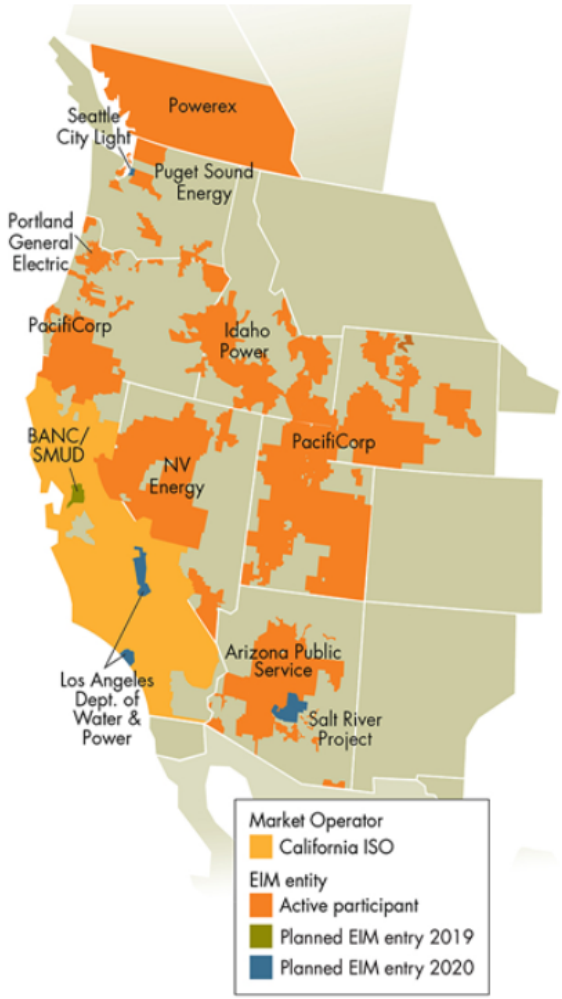

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- California Independent System Operator's (CAISO's) Western Energy Imbalance Market (EIM), and potential expansion to the Western electric region

Motivation

Goals of the EIM

- Centrally managed spot market over a rate-regulated region
- Support California's clean energy goals
- Enable access to a larger pool of renewable resources
- Displace higher emitting sources of generation when fulfilling demand

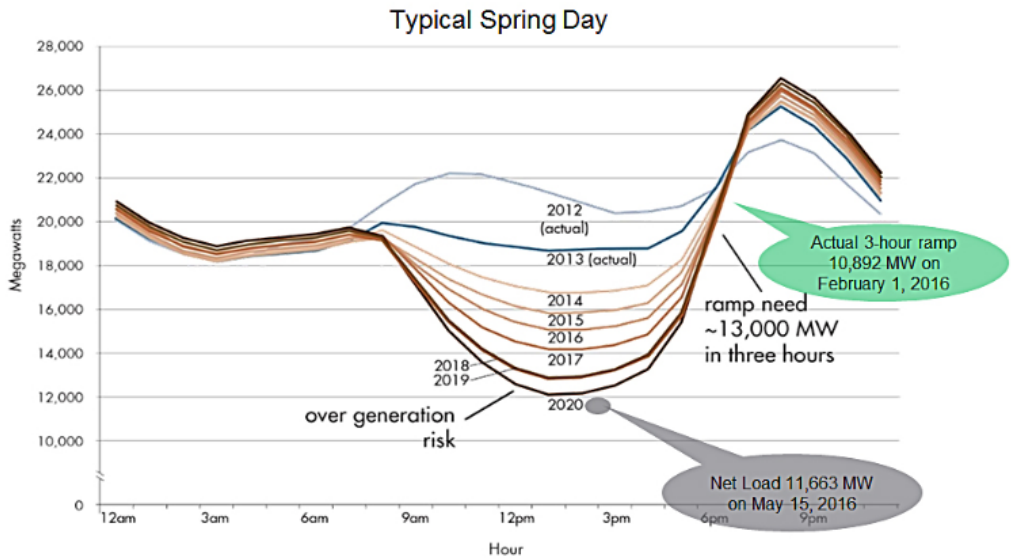

Figure: California Net Load: Actual and Forecasted as of 2016 - CAISO

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- There are concerns of resource shuffling / emissions leakage
- The actual atmospheric effect of the EIM remains a concern for regulators

Motivation

- Most research on emissions leakage and reshuffling from regional climate regulation is primarily ex-ante analysis using simulations to quantify leakage and reshuffling
  - Fowlie (2009); Bushnell and Mansur (2011); Bushnell and Chen (2012); Bushnell et al. (2014)
- There is some empirical analysis of emissions leakage from regional climate regulation
  - Fell and Maniloff (2015)
- Limited empirical analysis of energy imbalance market design on market outcomes, including emissions leakage and reshuffling

Research Question

- The goal of this research is to determine how the EIM actually impacted generator output and resulting emissions:
  - Does the EIM exacerbate or ameliorate leakage?
  - Does the EIM facilitate integration of renewables?

Findings

- Increased total emissions leakage to the EIM region outside of California
  - Primarily natural gas generators
- However, marginal EIM generators ramp down on average in response to CA load increases
  - Produce more in line with the duck curve
  - Ramp down on the margin during daylight hours, which we attribute to overgeneration
- Significant heterogeneity - strategies differ by BA

Identification Strategy

- We leverage variation in EIM participation across time and space in a diff-in-diff framework to estimate average effects, and use a triple-diff to estimate marginal ramping responses
- To deal with endogenous EIM participation, we pre-process the data by matching BAs based on characteristics known to influence participation
    - Robust to various matching methods (propensity score with calipers and trimming, nearest neighbors by Mahalanobis distance)

Identification Strategy

$$Y_{ijt} = \alpha + \beta Post_t + \delta EverEIM_i * Post_t + X_{jt}\gamma + \phi_i + \epsilon_{ijt} \quad (1)$$

$$\begin{aligned} Y_{ijt} = \alpha &+ \beta_1 Post_t + \delta_1 EverEIM_i * Post_t \\ &+ \beta_2 CALoad_t + \beta_3 CALoad_t * EverEIM_i + \beta_4 CALoad_t * Post_t \\ &+ \delta_2 CALoad_t * EverEIM_i * Post_t + X_{jt}\gamma + \phi_i + \epsilon_{ijt} \end{aligned} \quad (2)$$

- Total conventional generation or emissions (Y_{ijt}) of jth generator in BA i at hour t
- Hourly California ISO load ($CAload_t$)
- Treatment indicator equal to one if the BA is ever an EIM member in the post EIM period
- Vector of controls, $\mathbf{X}_{jt}$, including Hour FE, Day of Week FE, Month X Year FE, generator efficiency and generator age; and ϕ_i, BAA FE

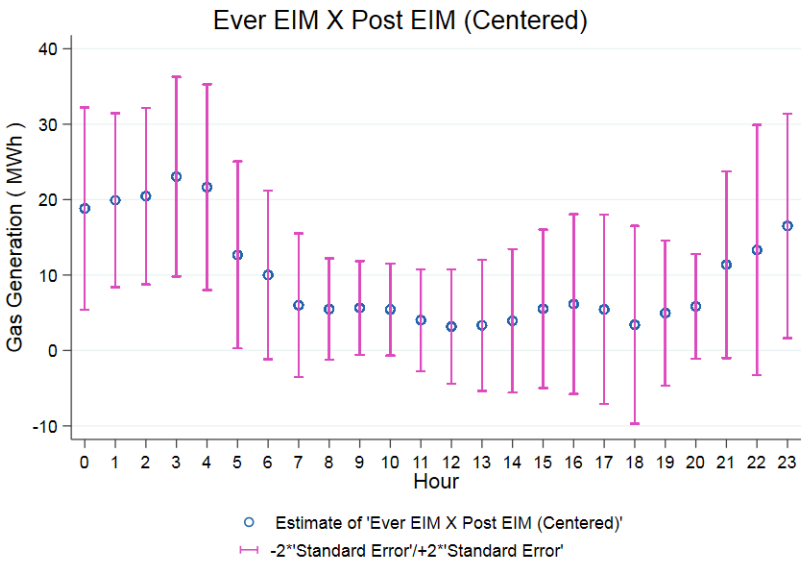
Natural Gas Generation and CA Load

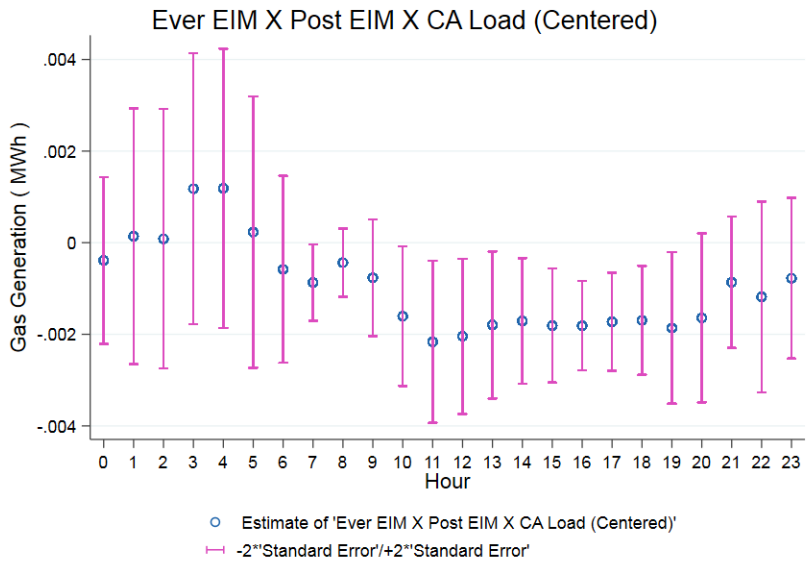
Dep. Var: Gross Generation (MWh)	Raw	Raw	PS Matched	PS Matched
Ever EIM X Post EIM (Centered)	13.74	13.18**	9.299***	9.389***
	(8.328)	(6.260)	(3.144)	(3.028)
Post EIM (Centered)	-2.831	-6.084	1.076	-0.703
	(7.779)	(7.275)	(6.413)	(5.926)
Ever EIM X CA Load (Centered)		-0.00146***		-0.00214***
		(0.000349)		(0.000607)
Ever EIM X Post				
X CA Load (Centered)		-0.00122		-0.00162*
		(0.000727)		(0.000816)
Post EIM X CA Load (Centered)		-0.000323		-0.000168
		(0.000284)		(0.000151)
CA Load (Centered)		-0.00180***		-0.000479**
		(0.000301)		(0.000198)
CA Solar PV (Centered)		-0.000777**		-0.00156**
		(0.000373)		(0.000702)
CA Wind (Centered)		-0.000215		-0.000943***
		(0.000185)		(0.000166)
Hourly FERC Load (Centered)	-0.00531	-0.000634	0.000561	0.00487
	(0.00340)	(0.00241)	(0.00378)	(0.00317)
Generator Efficiency (Centered)	179.8***	180.3***	203.7**	198.6**
	(22.79)	(22.97)	(88.02)	(87.72)
Generator Age (Centered)	-1.046***	-1.029***	-1.238**	-1.237**
	(0.311)	(0.307)	(0.529)	(0.531)
Constant	133.0***	120.2***	117.5***	112.0***
	(3.518)	(3.235)	(3.327)	(3.450)
Observations	5,682,165	5,666,886	3,809,660	3,799,100
R-squared	0.588	0.592	0.526	0.533
Hour FE	YES	YES	YES	YES
DOW FE	YES	YES	YES	YES
Month X Year FE	YES	YES	YES	YES

Natural Gas Generation and CA Forecast Load

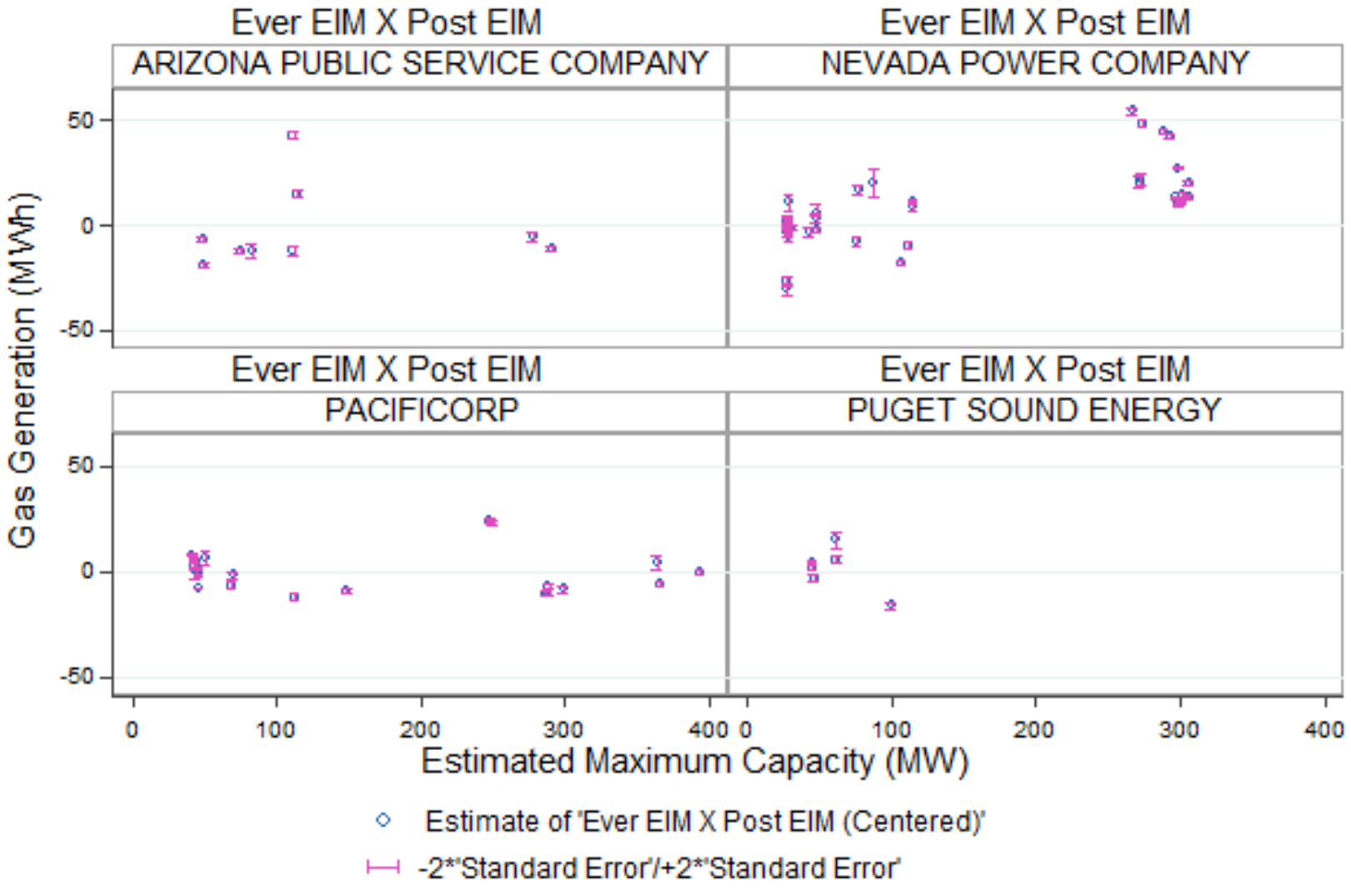
Dep. Var: Gross Generation (MWh)	Raw	PS Matched
Ever EIM X Post EIM (Centered)	13.69**	9.967***
	(6.079)	(3.103)
Post EIM (Centered)	-6.388	-1.227
	(7.258)	(5.769)
Ever EIM X CA Load Forecast (Centered)	-0.00148***	-0.00217***
	(0.000363)	(0.000616)
Ever EIM X Post		
X CA Load Forecast (Centered)	-0.00124	-0.00164*
	(0.000729)	(0.000828)
Post EIM X CA Load Forecast (Centered)	-0.000314	-0.000180
	(0.000286)	(0.000147)
Ever EIM X CA Load		
Actual - Forecast (Centered)	0.000356	-0.00171*
	(0.00105)	(0.000985)
Ever EIM X Post		
X CA Load Actual - Forecast (Centered)	-0.000919	0.000611
	(0.000715)	(0.00104)
Post EIM X CA Load		
Actual - Forecast (Centered)	7.68e-05	-0.000862
	(0.000533)	(0.000999)

Hour over Hour Natural Gas Generators' Response to California Load





Treatment Heterogeneity by BA and Capacity

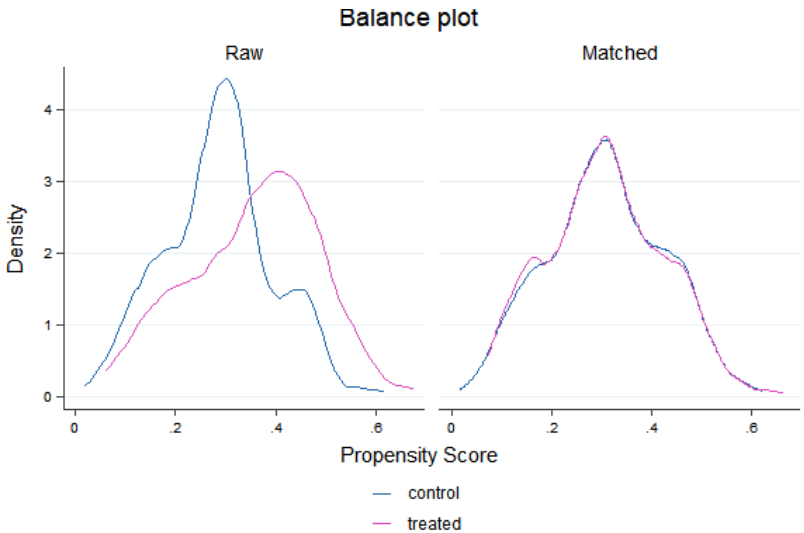


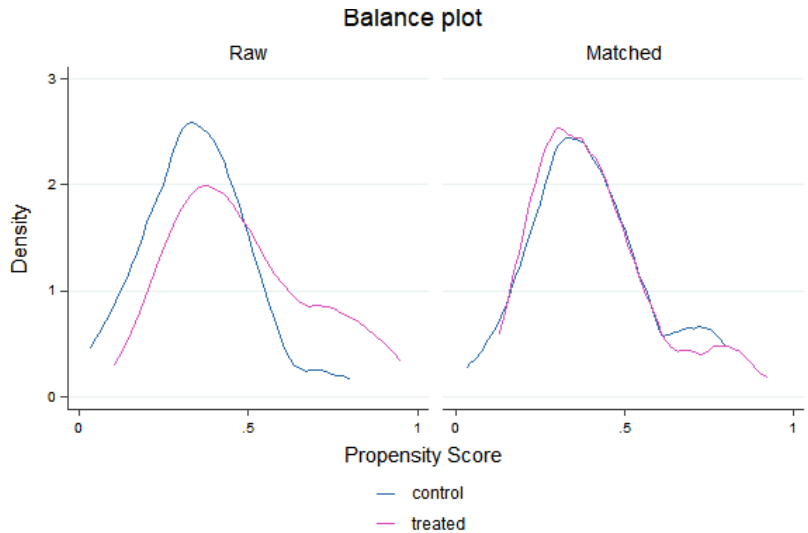
Summary

- The EIM is leading to increased emissions leakage in the EIM region outside of California
- EIM participant generators ramp down on the margin due to overgeneration, when California forecast exceeds its load
- Significant responses to California load follow the general shape of the duck curve
- There is significant heterogeneity in treatment effects in response to California load, strategies differ by BA
- Future research on reshuffling

Appendix: Assumptions for our Identification Strategy

- Unconfoundedness: Out-of-sample test in the pre-treatment period, we find no treatment effect
- Sufficient Overlap:





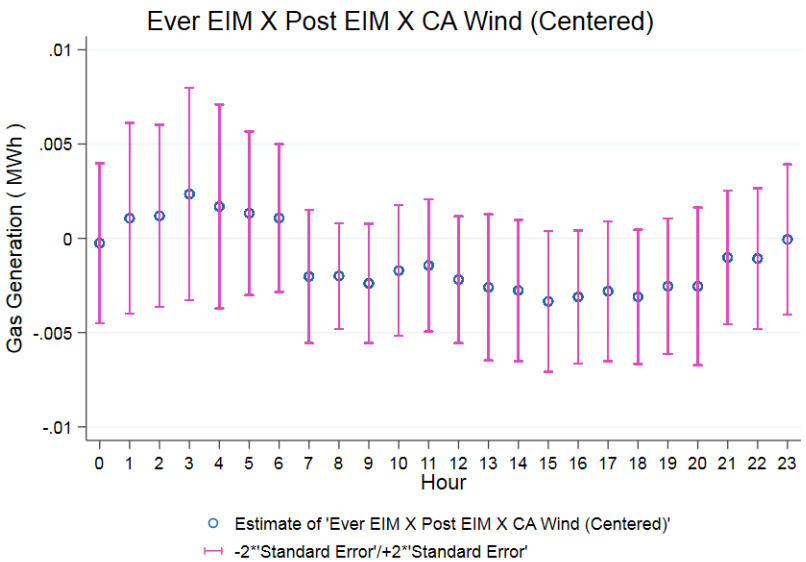
- Matching Variables are related to both the decision to participate in the EIM, and the potential change in generation or emissions outcomes from participating in the EIM. Estimated annual average capacity factor for the 2010-2012 period, a measure of grid voltage in 2012, a measure of generators propensity to respond to California load in 2011 and 2012, a measure of heat input, which affects emissions outcomes in 2012, and a measure of BA available capacity for 2012.

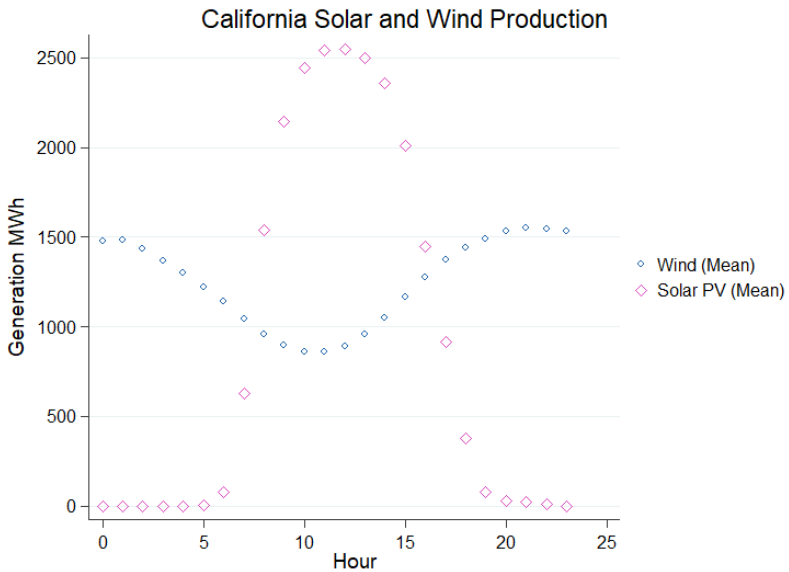
Natural Gas Generation and CA Renewables

Dep. Var: Gross Generation (MWh)	Raw	PS Matched
Ever EIM X Post EIM (Centered)	16.45**	14.90***
	(5.950)	(3.018)
Post EIM (Centered)	-4.540	-0.642
	(7.253)	(5.461)
Ever EIM X CA Solar (Centered)	0.000623	-0.00214**
	(0.00154)	(0.000900)
Ever EIM X Post		
X CA Solar (Centered)	-0.00353***	-0.00191
	(0.00117)	(0.00180)
Post EIM X CA Solar (Centered)	0.000931	-0.000391
	(0.000706)	(0.000528)

Dep. Var: Gross Generation (MWh)	Raw	PS Matched
Ever EIM X Post EIM (Centered)	13.80*	10.02***
	(7.796)	(3.306)
Post EIM (Centered)	-3.421	3.664
	(7.832)	(7.549)
Ever EIM X CA Wind (Centered)	0.000186	-0.00139
	(0.00168)	(0.00178)
Ever EIM X Post		
X CA Wind (Centered)	-0.00285**	-0.00117
	(0.00113)	(0.00167)
Post EIM X CA Wind (Centered)	0.000977	0.00115
	(0.000748)	(0.00101)

Hour over Hour Natural Gas Generators' Response to California Wind Production





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