California's cap-and-trade program and emission leakage: an empirical analysis

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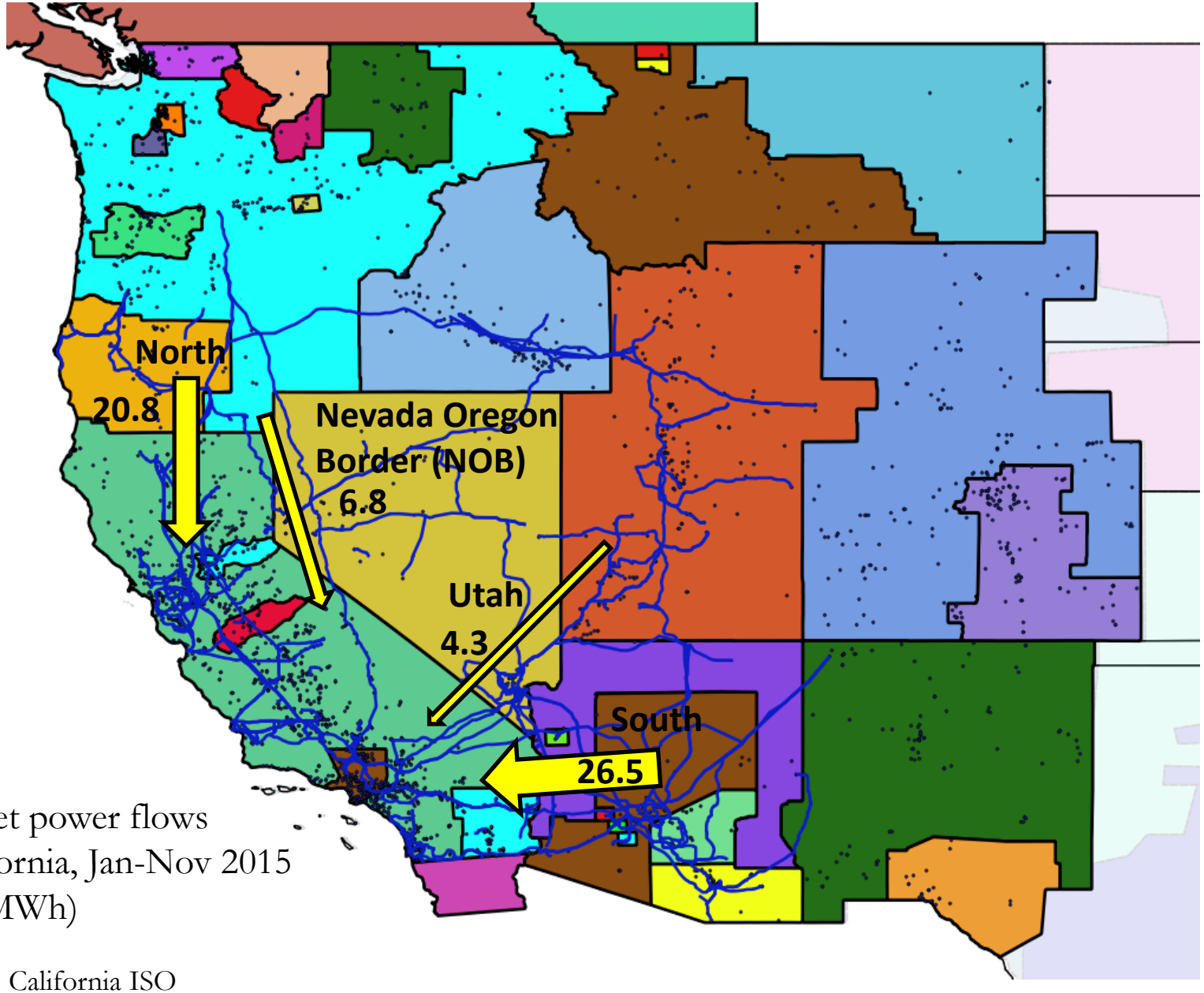
California's GHG emissions

Data source: California Air Resources Board

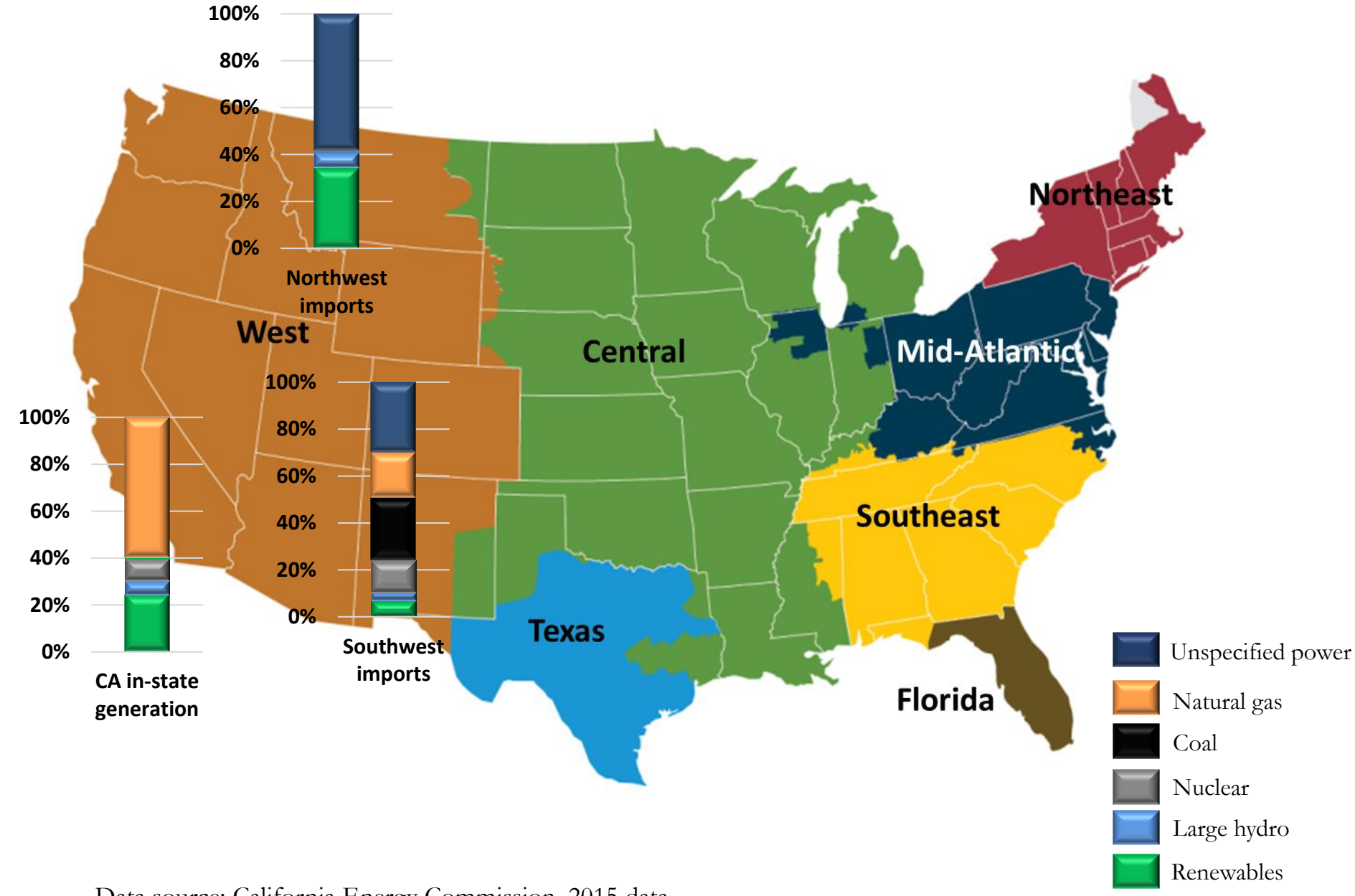
California's GHG cap-and-trade program

- California's emission trading scheme is the first multi-sector cap-and-trade program in North America
- It covers about 85% of the state's GHG emissions (as of 2015)
- **Status:** compliance obligations began in January 2013, sunset in 2020
- **Target:** approximately 17% below 2013 emissions by 2020
- **First deliverer approach:** in-state electricity generators and electricity importers are the point of regulation



Annual net power flows into California, Jan-Nov 2015 (Million MWh)

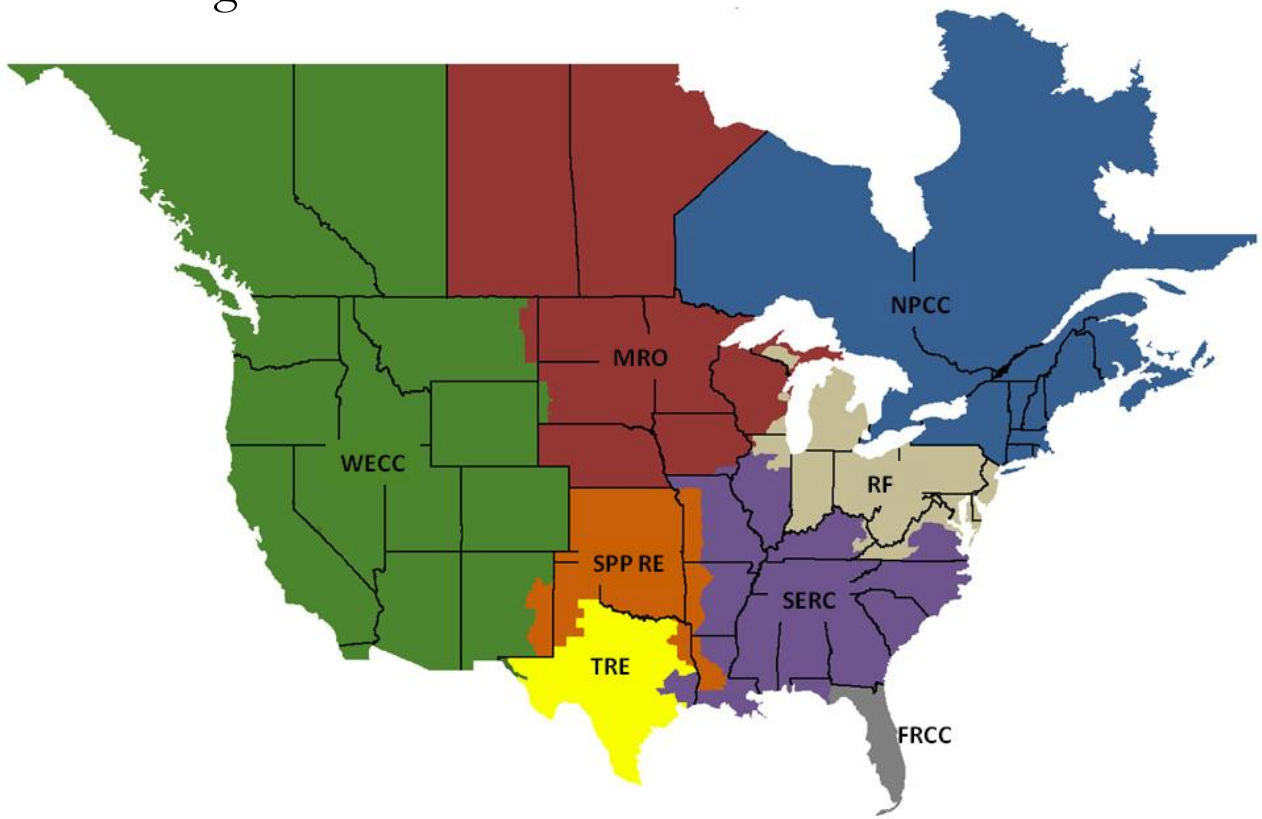
Data source: California ISO



Data source: California Energy Commission, 2015 data

«Repeal and replace» after 2020?

- The design of the existing cap-and-trade program has been the subject of much debate. Concern has been voiced about:
  - Emission leakage
  - Contract shuffling
  - Laundering



Incomplete environmental regulation and emission leakage

- Incomplete environmental regulation is likely to lead to emission leakage (Bushnell et al., 2008; Fowlie, 2009; Goulder and Stavins, 2011; Goulder et al., 2012)

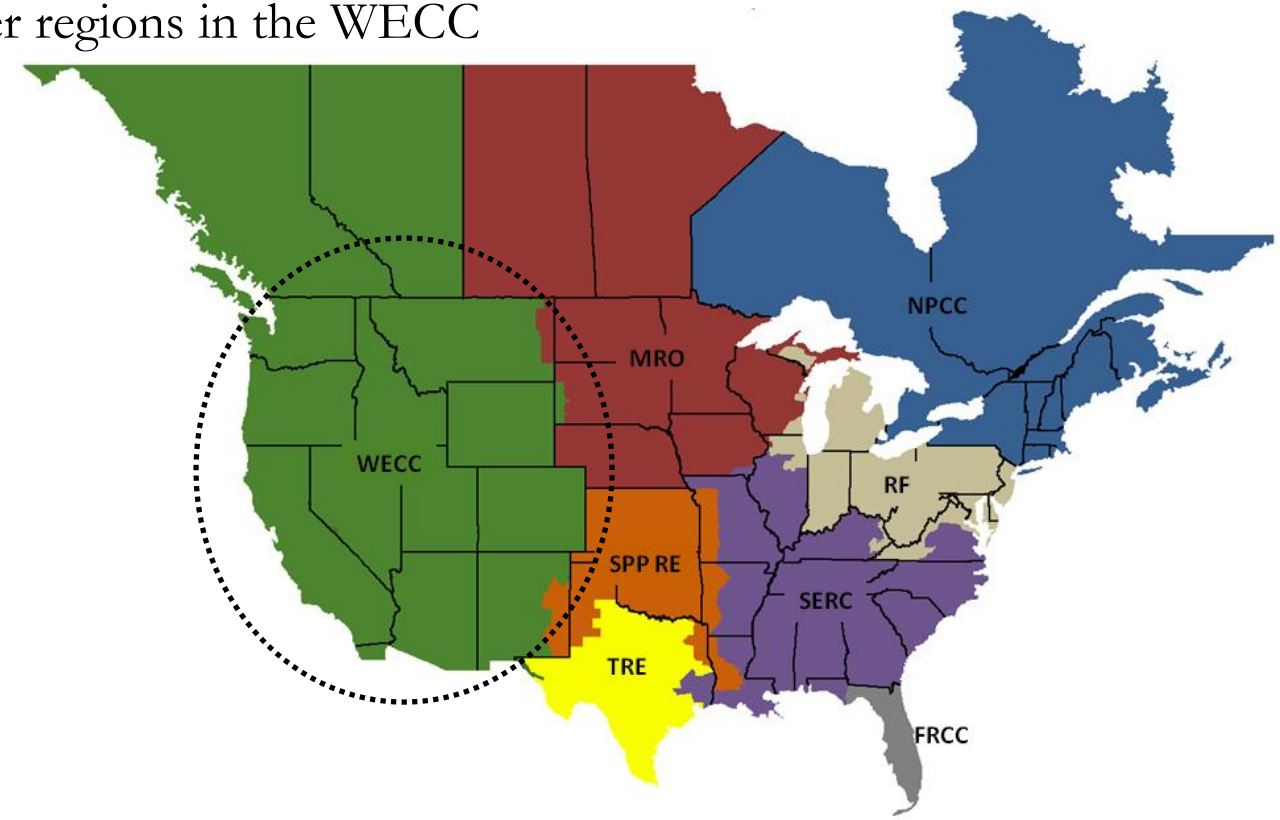
- Emission leakage in regional CO_2 cap-and-trade markets has typically been examined ex ante (Wing and Kilodziej, 2008; Chen et al., 2011; Bushnell et al., 2014; Caron et al., 2015)

- Empirical analyses are less common (Aichele and Felbermayr, 2015; Fell and Maniloff, 2015)

Objective

- This study empirically investigates the leakage effects of California's cap-and-trade program on electricity generation in the Western Interconnection

- We examine whether the policy affected production and efficiency of coal and natural gas fired power plants in California differently from other regions in the WECC



Data

- We construct a plant-level dataset including monthly observations from 2011 to 2015 on:
  - Net generation
  - Fuel consumption
  - Operating capacity
  - Power control area and location
  - CO_2 emission rates
  - Emission abatement control types and number
  - Fuel cost, as delivered to the plant (or state average fuel cost for electric power generation)
  - CO_2 prices
  - Electric load in the plant's planning area
  - Renewable and nuclear generation in the plant's state
  - Heating/cooling degree days and drought indices in the plant's climate division
  - CAISO net power imports on major transmission interfaces

Empirical strategy

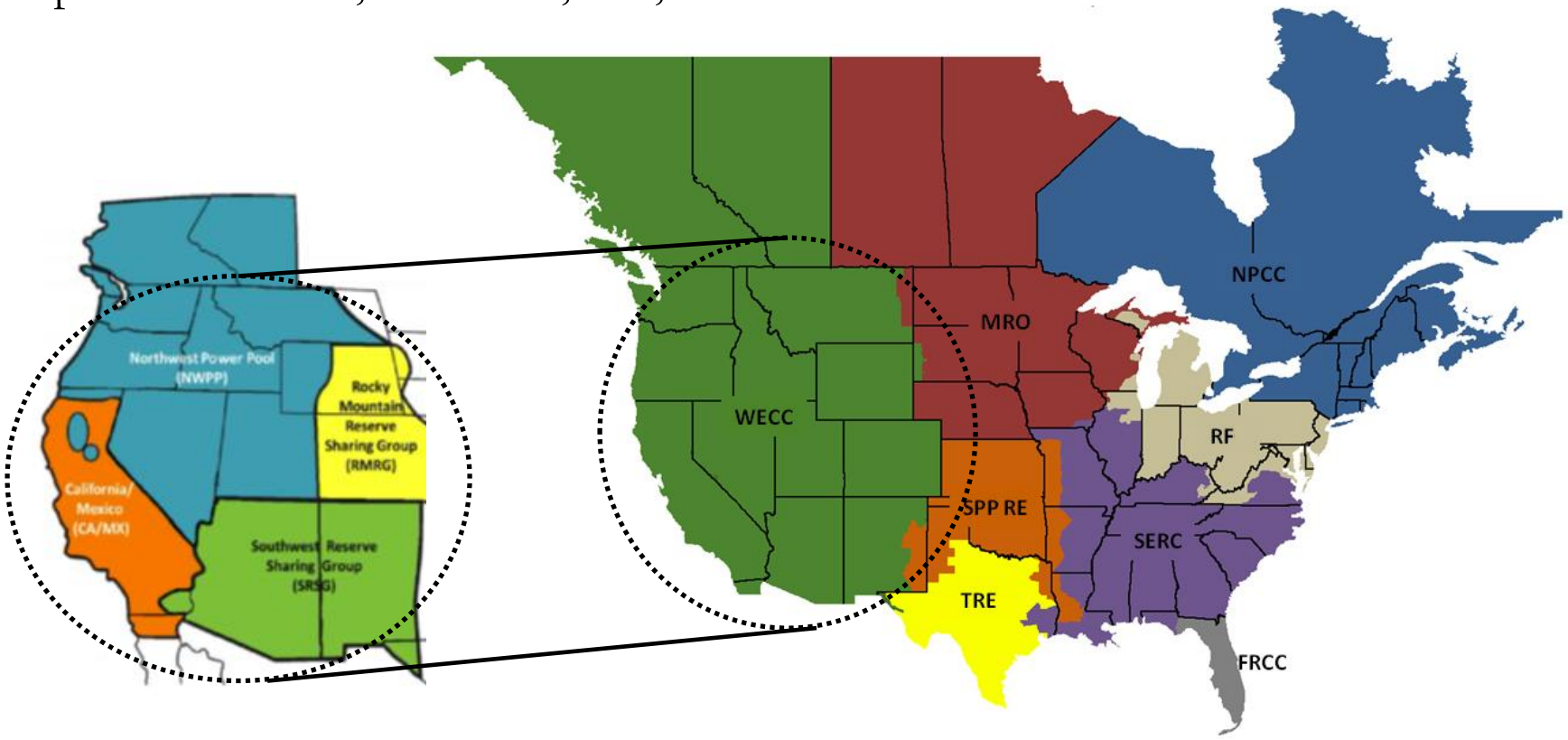
- We use a differences-in-differences approach to examine impacts of California's cap-and-trade program on capacity factors and heat rates of coal and NGCC power plants in the Western Interconnection

- To limit selection bias due to changes in group composition across time, we restrict our sample to plants that are present pre and post treatment

- We present results for two model specifications focusing on capacity factors

Empirical strategy

- **Specification 1** considers WECC sub-regions outside of California as potential leakers, and MRO, SPP, and TRE as controls



Empirical strategy

- **Specification 1**

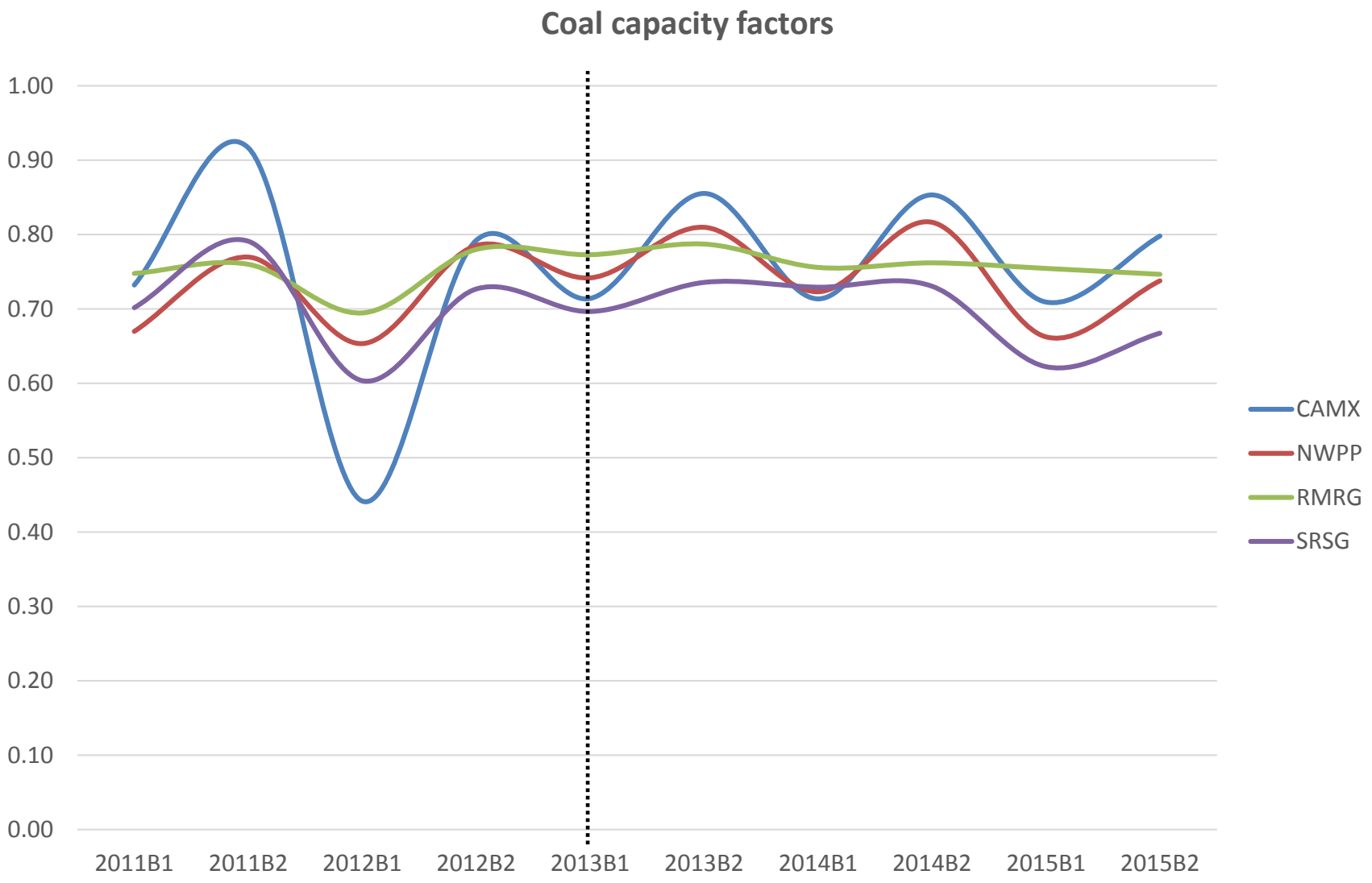
$$Y_{igt} = \delta_{CA} TREAT_{igt}^{CA} + \sum_{h} \delta_{h} LEAK_{igt}^{h} + X_{it}^{'} \underline{\beta} + \alpha_i + \gamma_t + \gamma_m + \gamma_y + SONGS_t + \varepsilon_{igt} \qquad g=1,....G$$

where i refers to power plant of generation type g and t denotes the month (January 2011 to December 2015)

Y_{igt} is capacity factor (in %) for plant i of type g

$TREAT_{igt}^{CA}$ is equal to 1 if plant i of type g is in CA, and month t is January 2013 or later

$LEAK_{igt}^{h}$ is equal to 1 if plant i of type g is in sub-region h, and month t is January 2013 or later


Coal capacity factors
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
2011B1
2011B2
2012B1
2012B2
2013B1
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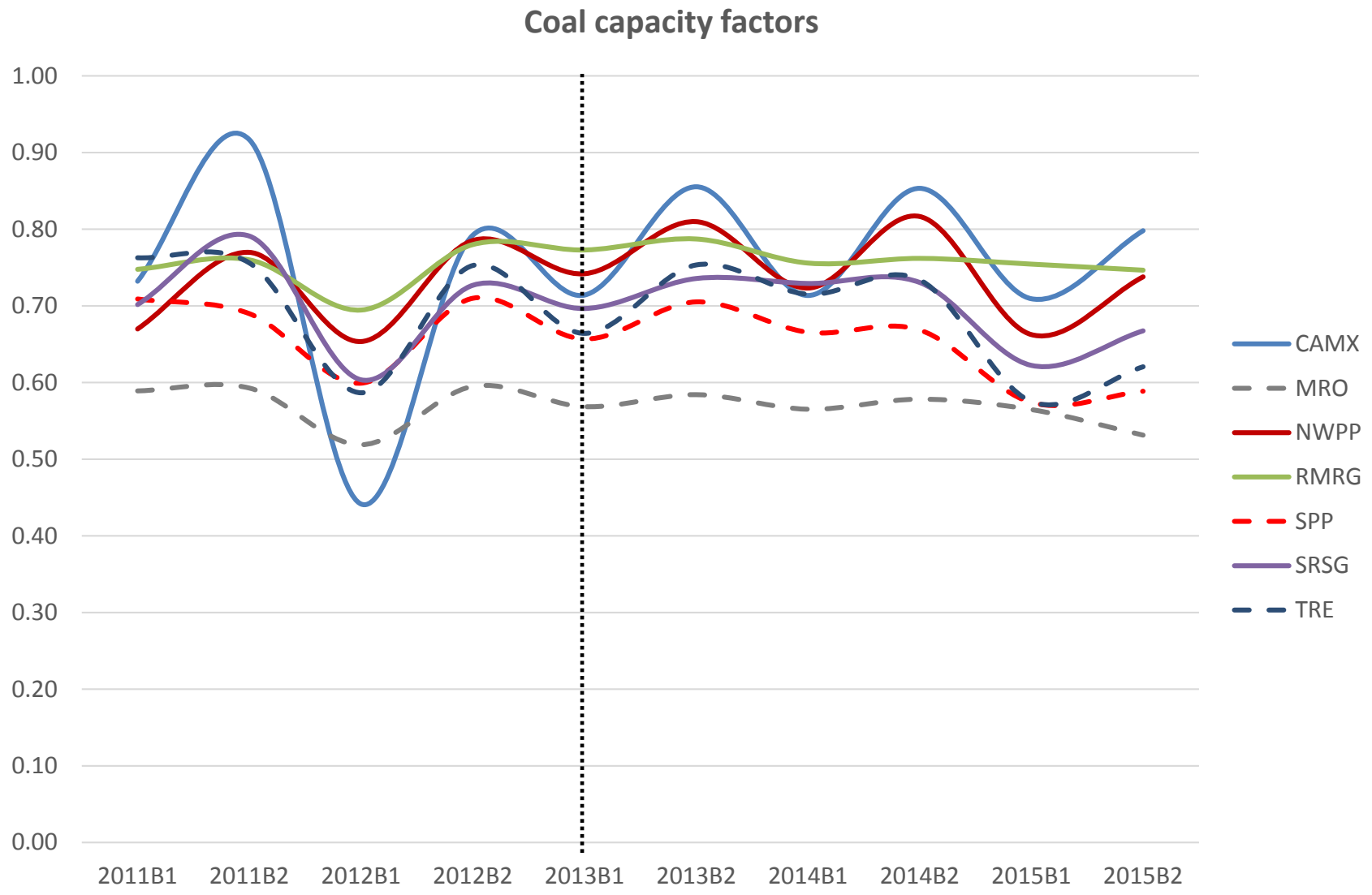
2015B1
2015B2
CAMX
NWPP
RMRG
SRSG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SPP
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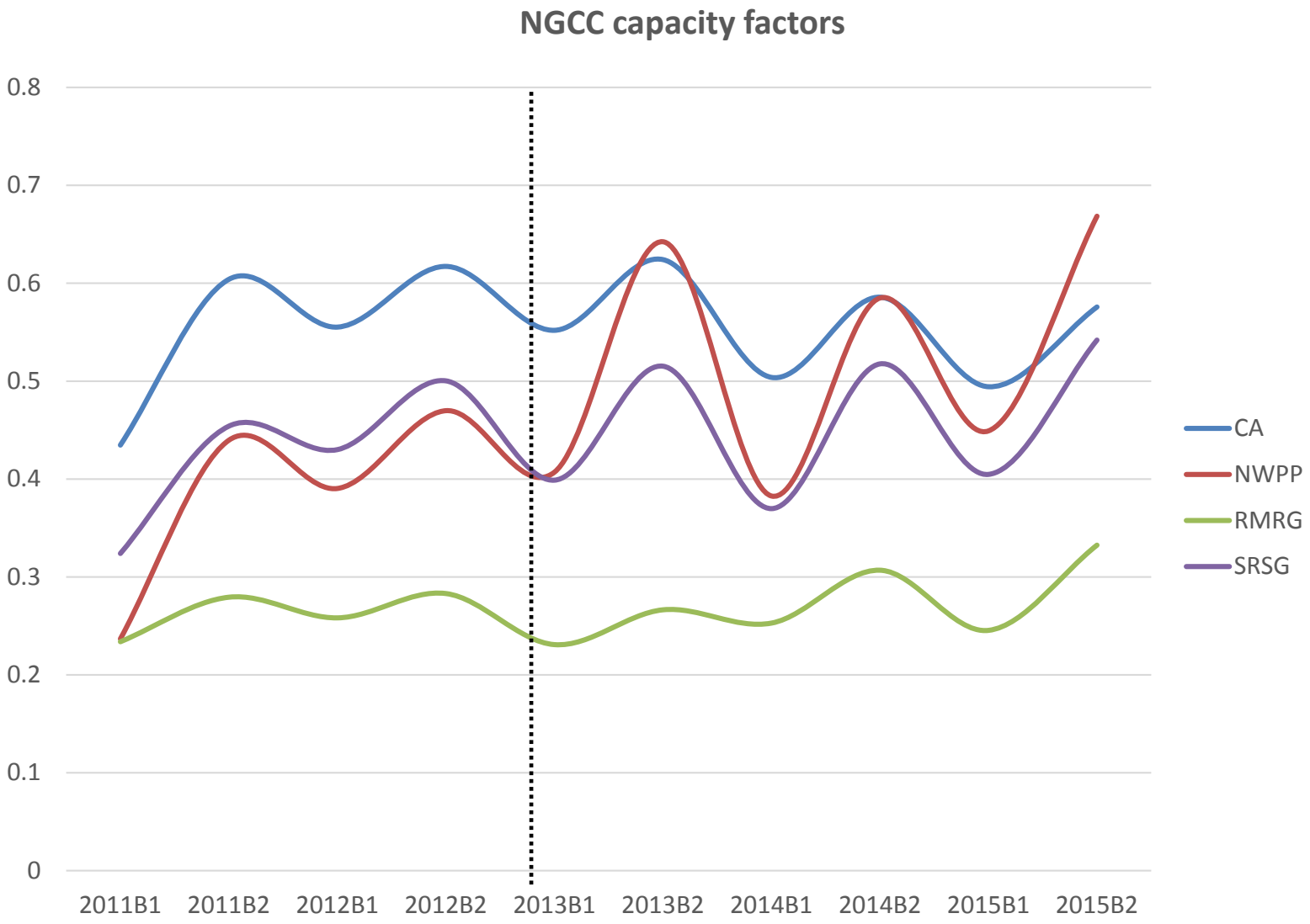
TRE


NGCC capacity factors
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0.6
0.5
0.4
0.3
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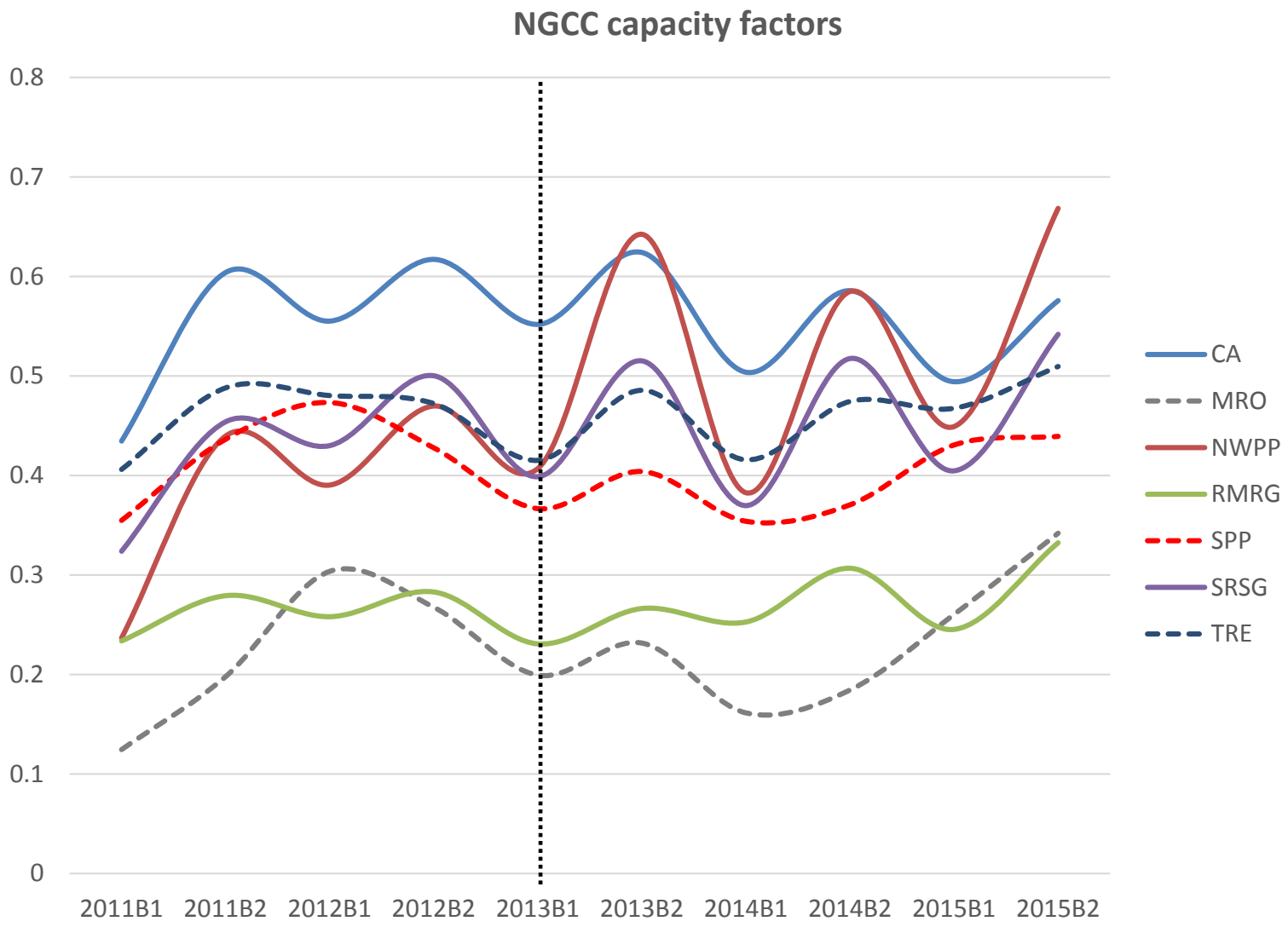
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Empirical strategy

- **Specification 1**

$$Y_{igt} = \delta_{CA} TREAT_{igt}^{CA} + \sum_{h} \delta_{h} LEAK_{igt}^{h} + X_{it}' \underline{\beta} + \alpha_i + \gamma_t + \gamma_m + \gamma_y + SONGS_t + \varepsilon_{igt} \qquad g=1,....G$$

X_{it} includes:

- ✓ Log of electric load in the plant's planning area
- ✓ Input price ratio (levels and square) for the plant
- ✓ Log of renewable generation in the plant's state
- ✓ Heating/cooling degree days in the plant's climate division

Empirical strategy

- **Specification 1**

$$Y_{igt} = \delta_{CA} TREAT_{igt}^{CA} + \sum_{h} \delta_{h} LEAK_{igt}^{h} + X_{it}' \underline{\beta} + \alpha_i + \gamma_t + \gamma_m + \gamma_y + SONGS_t + \varepsilon_{igt} \qquad g=1,....G$$

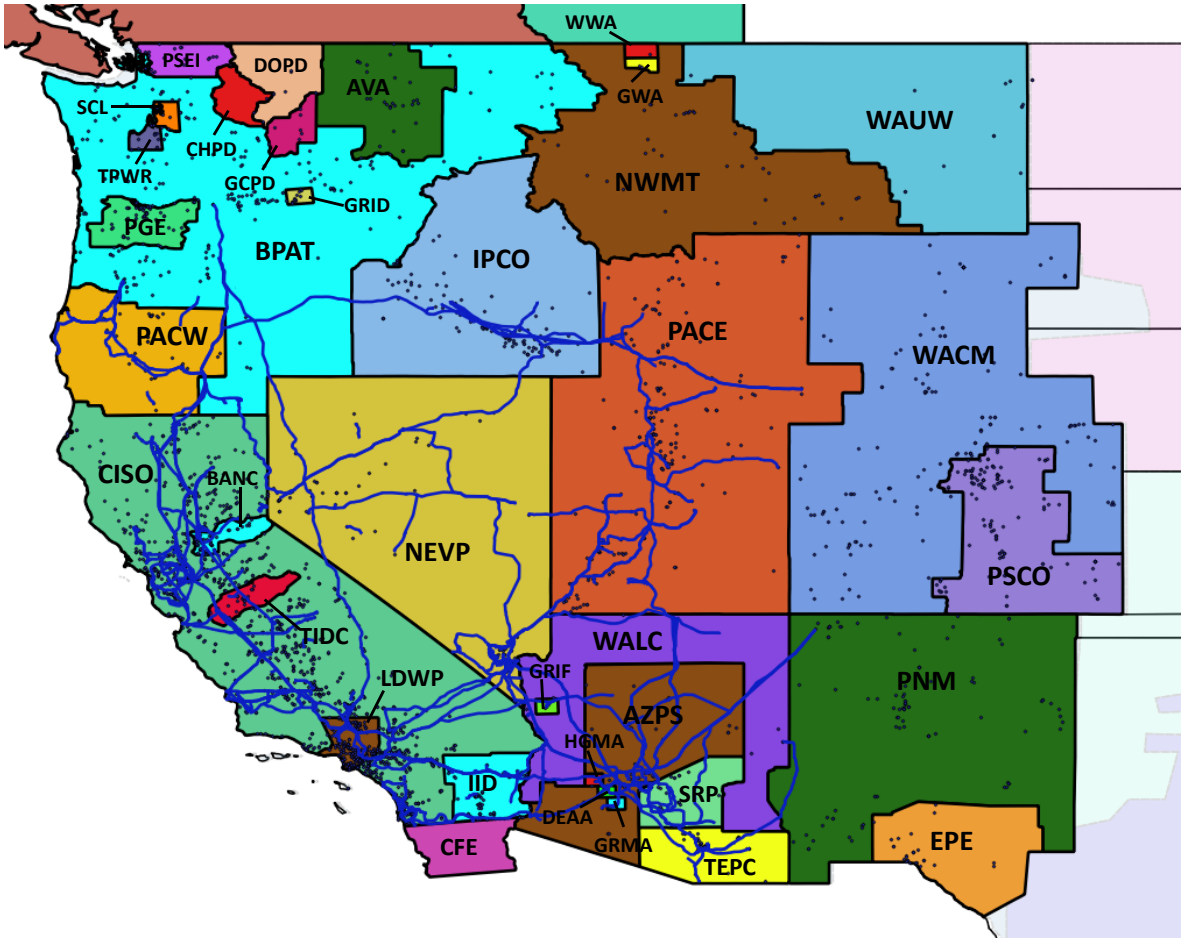
α_i are plant fixed effects

γ_t are period fixed effects
γ_m are month-by-year fixed effects
γ_y are year fixed effects

$SONGS_t$ is equal to 1 in California starting from February 2012

Empirical strategy

- **Specification 2** considers selected balancing authorities within WECC as potential leakers, and rest of WECC as control



Empirical strategy

- **Specification 2**

$$Y_{igt} = \delta_{CA} TREAT_{igt}^{CA} + \sum_{j} \delta_{j} LEAK_{igt}^{j} + \sum_{k} \delta_{k} LEAK_{igt}^{k} + \sum_{l} \delta_{l} LEAK_{igt}^{l}$$

$$+ X_{it}^{'} \underline{\beta} + \alpha_i + \gamma_t + \gamma_m + \gamma_y + SONGS_t + \varepsilon_{igt} \qquad g=1,....G$$

where *i* refers to power plant of generation type *g*, and *t* denotes the month (January 2011 to December 2015)

j, k, l refer to selected balancing authorities north, east and south of California, respectively, which:

- include a significant share of generation from plants of type *g*
- are connected to California via major transmission lines

Preliminary results

Treatment effects – capacity factors

	Coal steam		Gas CC	
	Specification 1	**Specification 2**	Specification 1	Specification2
CA	-	-	-0.04**	-0.04
CAMX	0.04***	-	-	-
NWPP	0.04***	-	0.07**	-
SRSG	0.01	-	0.02	-
RMRG	0.03	-	-0.001	-
North	-	-0.05	-	0.10***
East	-	0.04***	-	0.06***
South	-	0.01	-	-0.03

- Robust standard errors are clustered at the balancing authority level

Preliminary results

Treatment effects – capacity factors

	Coal steam		Gas CC	
	Specification 1	Specification 2	**Specification 1**	**Specification2**
CA	-	-	-0.04**	-0.04
CAMX	0.04***	-	-	-
NWPP	0.04***	-	0.07**	-
SRSG	0.01	-	0.02	-
RMRG	0.03	-	-0.001	-
North	-	-0.05	-	0.10***
East	-	0.04***	-	0.06***
South	-	0.01	-	-0.03

- Robust standard errors are clustered at the balancing authority level

Summary and future work

- Preliminary results from the capacity factor models suggest some evidence of carbon leakage from California's emission trading program
- NG combined cycles in California had a statistically significant reduction of ~4% in capacity factors since January 2013
- Displaced generation was primarily made up for by increased coal and NGCC generation in central WECC
- Implication: implementing border adjustments to address leakage post 2020 is critical
- Future work: a) model effects on efficiency more accurately; b) refine empirical approach to deal with unobserved time-varying confounders; c) estimate the scale of leakage

Thank you!

Questions?

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