Carbon pricing effects on renewables: evidence from California's electricity market

Gökhan Dilek Mònica Serrano Jordi J. Teixidó

University of Barcelona

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Summary

Motivation

- Contributing to the discussion of how effective carbon pricing in the long-run.
- Exploiting a unique opportunity to study Carbon Border Adjustment Mechanism's (CBAM) spillover effects.

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- Entropy Balanced Difference in Differences

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Results

- An average Californian county experienced 143 MW renewable capacity increase.
- 5.18 percentage point rise in California's renewable electricity share.
- Arizona and Nevada counties' renewable capacity increased by 53 MW and 107 MW respectively due to CBAM.

Outline

Motivation

- The adequacy of carbon pricing in deep decarbonization
  - Fuel-switching vs. energy transition
  - Short-term vs. long-term
- A unique case for Carbon Border Adjustment Mechanism (CBAM)
  - Preventing emission leakage
  - Unilateral policy vs. international cooperation
  - Spillover effects

Policy Framework

- Assembly Bill 32 (AB 32) legislated in 2006 in California.
- California Air Resources Board (CARB) prepared the First Scoping Plan in 2008 discussing the measures to achieve AB 32 objectives including an ETS.
- An opposition tried to suspend AB 32 in 2010.
- ETS with a CBAM for the electricity market started in January 2013.
  - CBAM is based on first deliverer approach.
  - CBAM is susceptible to emission leakage in California's case.

▸ Details

Literature and Contributions

- The *cause célèbre* of deep decarbonization (Rosenbloom et al., 2020; Patt and Lilliestam, 2018; Lilliestam et al., 2020; Tvinnereim and Mehling, 2018; van den Bergh and Botzen, 2020)
- Studies showing the emission reductions due to decrease in consumption and fuel-switching: Kim and Kim (2016), Delarue et al. (2008), Ellerman and McGuinness (2008), Wilson and Staffel (2018). Studies finding emission reduction without differentiating the cause: Andersson (2019), Bayer and Aklin (2020), Murray and Maniloff (2015), Kotnik et al. (2014). Studies finding long-term changes: Leroutier (2022).
  - **Contribution:** Providing evidence in favor of carbon pricing for long-term results.

Literature and Contributions

- California CBAM literature revolved around leakage problem: Cullenward and Weiskopf (2013), Cullenward (2014), Pauer (2018), Bushnell and Chen (2012), Bushnell et al. (2014), Xu and Hobbs (2021), and Fowlie et al. (2021), Caron et al. (2015), and Lo Prete et al. (2019)
  - **Contribution:** This study will be the first one to look at the full side of the bottle, i.e., CBAM's positive effects on the trade partners.
- There are policy-evaluation studies focusing on small-scale renewable energy adaptation policies in California: Dong and Wiser (2013), Hughes and Podolefsky (2015), Frey and Mojtahedi (2018). However, there is not any policy-evaluation study focusing on utility-scale policies in California.
  - **Contribution:** This is the first study to evaluate utility-scale electricity policies in California

Methodology and Data

- Arkhangelsky et al. (2021) syntehetic difference in differences (SDID). ▸ Details

$$Y_{it}^{*} = \alpha + \beta \mathit{CaliforniaETS}_{it}^{*} + \gamma X_{it}^{*} + \delta_{i}^{*} + \theta_{t}^{*} + \epsilon_{it}^{*} \tag{1}$$

  i: States, t: Years, *: Weighted according to SDID weights

- Difference in differences is also employed with county level disaggregated data. Entropy balancing (Hainmueller, 2012) is used to ensure the robustness of the results. Entropy balancing is a generalization of propensity score matching. ▸ Details

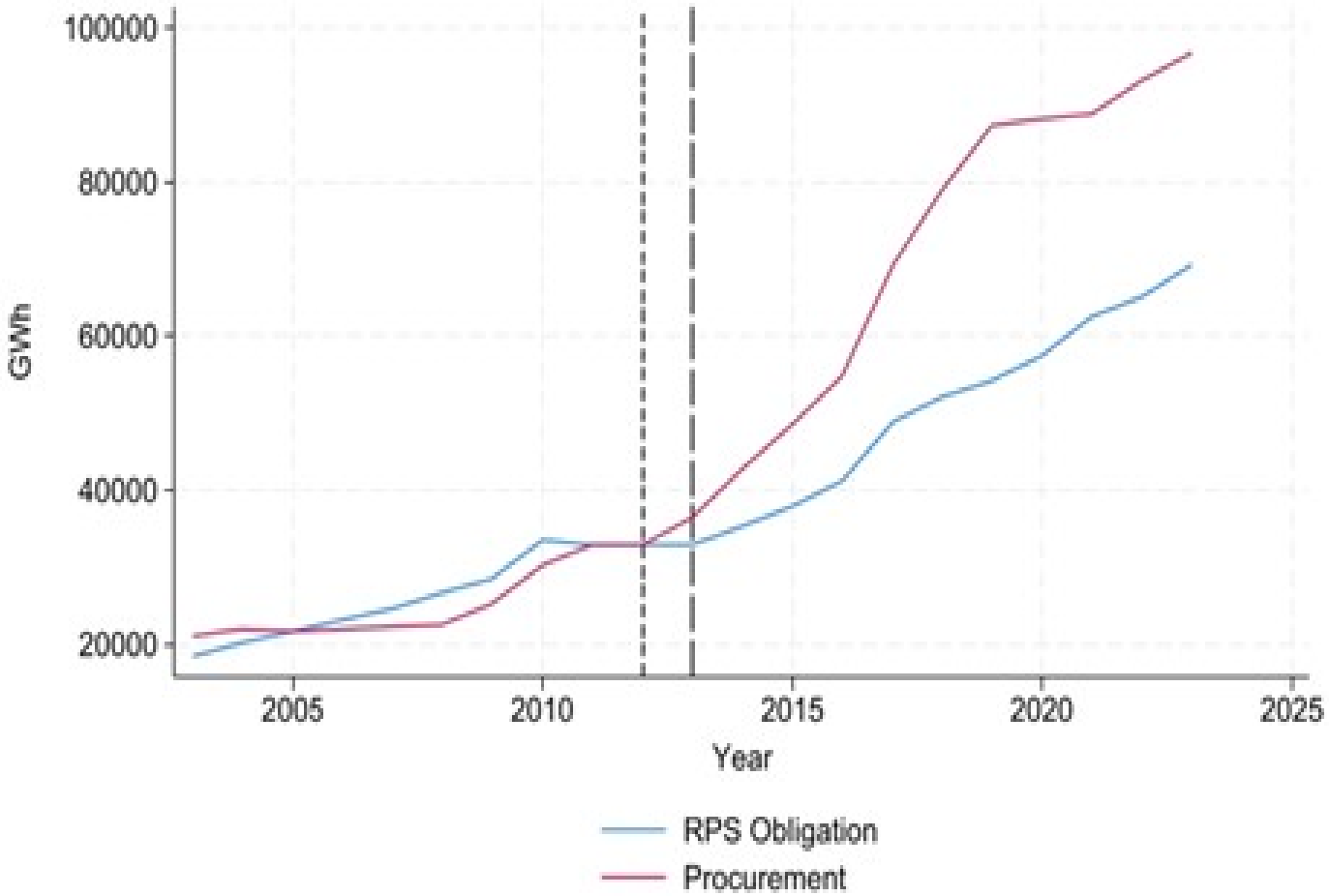
Methodology and Data

- Main data source: Energy Information Agency (EIA).
  - Electricity capacity according to generation type (solar, nuclear, coal etc.)
  - Location of electricity generator plants
- States' and counties' GDP, and industry share are from Bureau of Economic Analysis.
- Population is from Census Bureau.
- Climate indicators are from National Oceanic and Atmospheric Administration (NOAA).
- The information on the other state level environmental policies is from National Conference of State Legislatures (NCSL), Center for Climate and Energy Solutions (C2ES), and Database of State Incentives for Renewables and Efficiency (DSIRE).

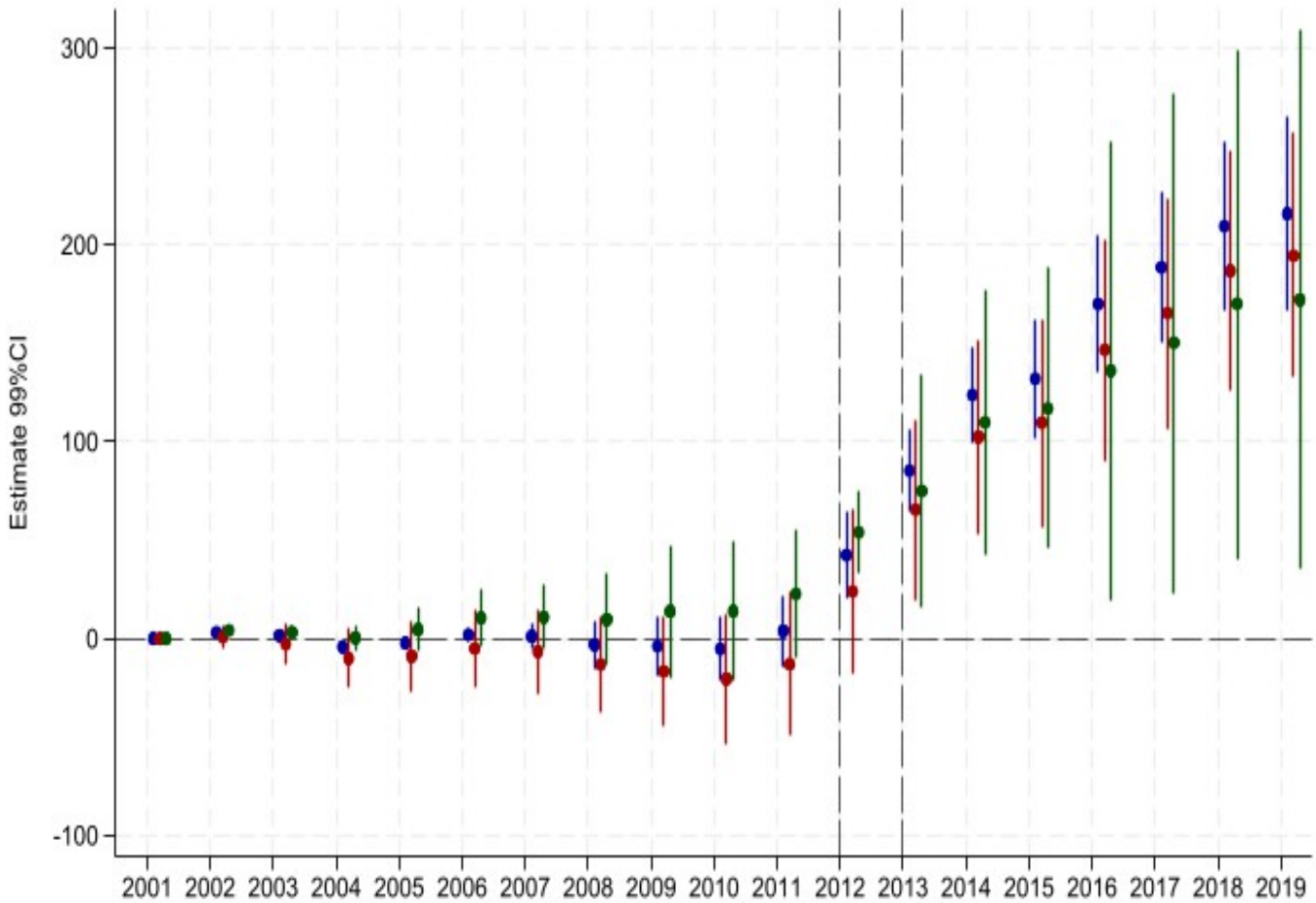
Renewable Portfolio Standards: An Identification Challange

- California introduced its RPS in 2002; however, increased its target in 2011.
- We have several answers to the potential confounding effects of RPS:
  - First, we showed that RPS does not seem to be effective in California between 2002 and 2011.
  - Second, California's renewable electricity procurement diverges from RPS target starting 2013, corresponding to the start of the cap-and-trade program.
  - Finally, we control for RPS by introducing RPS policy dummy and also by restricting the sample to "the most ambitious" RPS states.

Renewable Portfolio Standards: An Identification Challange



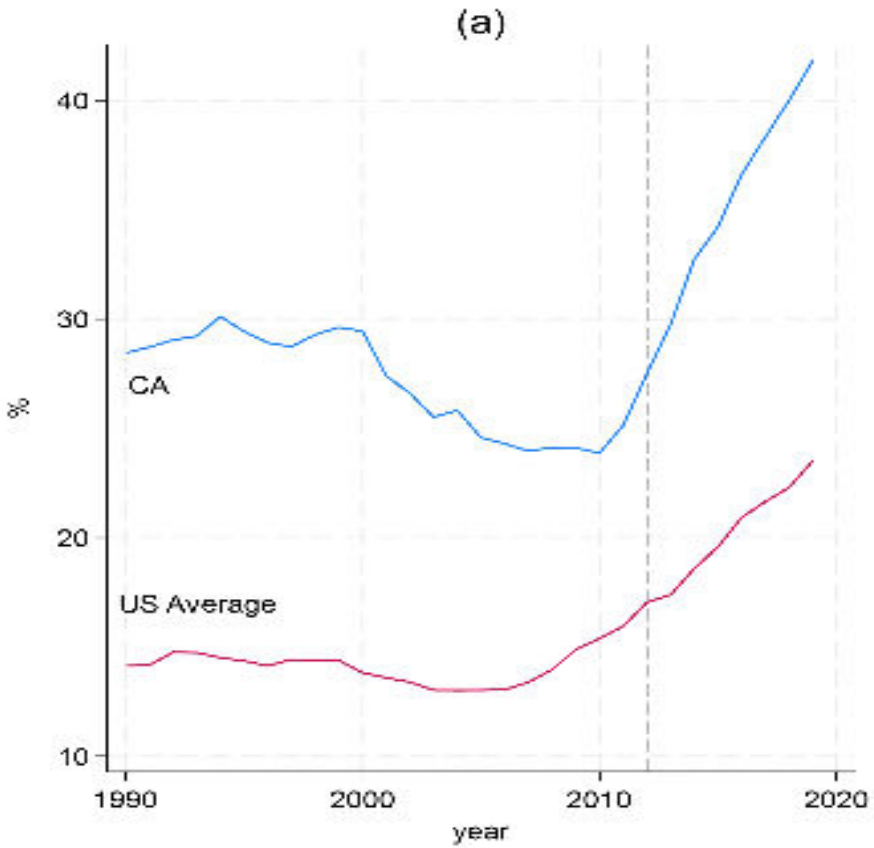
Estimation and Results

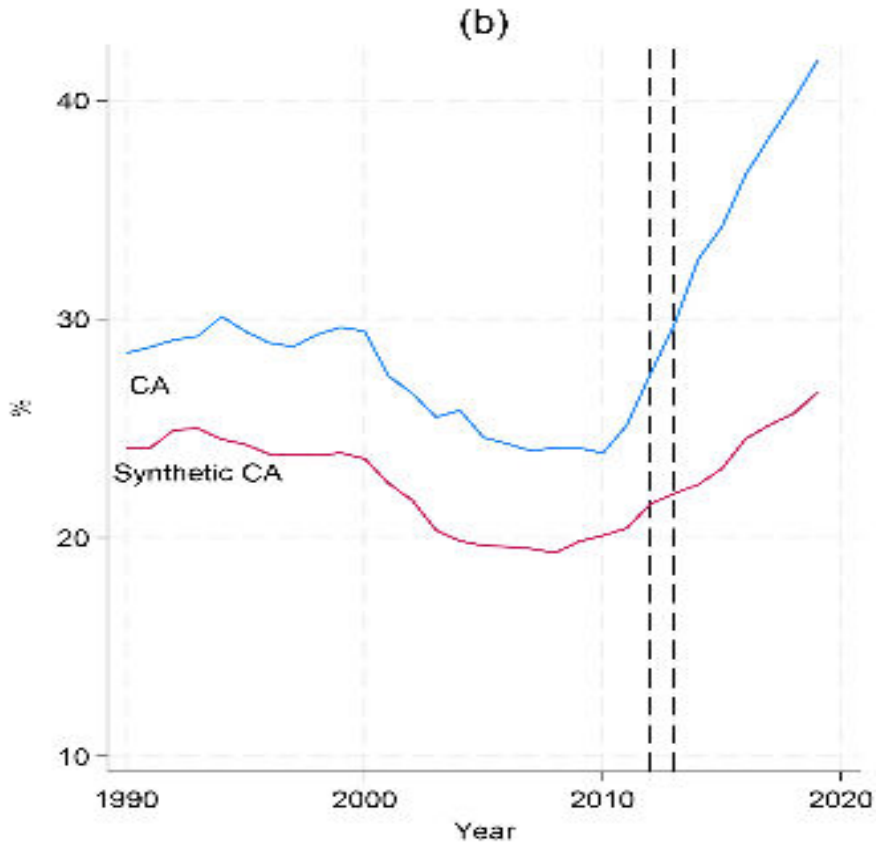


Estimation and Results

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	Renewable capacity	Renewable capacity	Renewable capacity	Renewable capacity	Renewable capacity	Renewable capacity
Cap-and-trade	159.64***	169.37***	180.54***	143.87***	156.81***	150.80***
Observations	24,016	24,016	24,016	10,127	10,127	10,127
R-squared	0.104	0.124	0.837	0.116	0.134	0.821
Number of id	1,264	1,264	1,264	533	533	533
Control covariates	No	Yes	Yes	No	Yes	Yes
Ebalance	No	No	Yes	No	No	Yes
15 RPS states	No	No	No	Yes	Yes	Yes

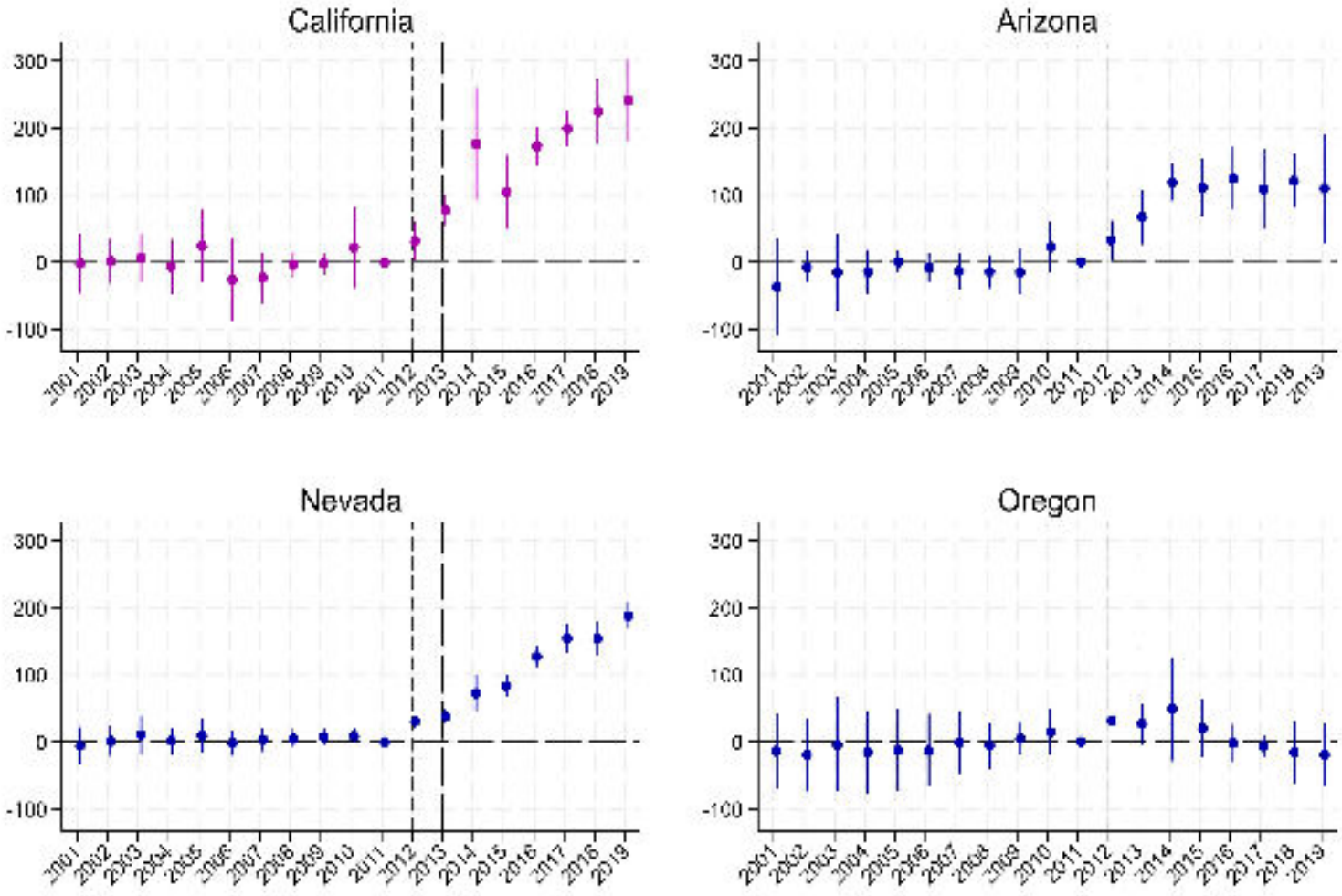
Estimation and Results





▸ ATT and P-value

Spillover Effect on the Neighbor States



Spillover Effect on the Neighbor States

Variable	(1) Renewable capacity Arizona	(2) Renewable capacity Arizona	(3) Renewable capacity Arizona	(4) Renewable capacity Nevada	(5) Renewable capacity Nevada	(6) Renewable capacity Nevada	(7) Renewable capacity Oregon	(8) Renewable capacity Oregon	(9) Renewable capacity Oregon
CBAM	146.49***	137.09***	53.09**	153.33***	138.52***	107.05***	52.01***	18.39***	8.05*
Observations	23,541	23,541	9,348	23,522	23,522	9,329	23,883	23,883	9,690
R-squared	0.942	0.939	0.923	0.94	0.885	0.858	0.943	0.953	0.95
Covariates	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Ebalance	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
15 RPS states	No	No	Yes	No	No	Yes	No	No	Yes

Discussion

- The spillover effect on the neighbors are not strong enough to cause energy mix changes.
- Still the effect is quite strong considering CBAM is an auxilary policy with a small price signal. Hence, can we attribute the totality of this effect to the price signal itself?
- Overall, this study supports two important arguments:
  - Carbon pricing can cause long-term changes. Changes beyond consumption reduction or fuel-switch.
  - CBAM can encourage trade partners to invest cleaner technologies.

Thank You!

Policy Details

- By January 1, 2008 – CARB adopts the Mandatory Reporting Regulation for GHGs to require reporting, verification, monitoring and enforcement.
- By January 1, 2009 - CARB adopts a Scoping Plan indicating how emission reductions will be achieved from significant sources of GHGs via regulations, market mechanisms and other actions.
- During 2009 - CARB staff drafts rule language to implement its plan and holds a series of public workshops on each measure (including market mechanisms).
- By January 1, 2010 - Early action measures take effect.
- During 2010 - CARB conducts series of rulemakings, after workshops and public hearings, to adopt GHG regulations including rules governing market mechanisms.
- By January 1, 2011 - CARB completes major rulemakings for reducing GHGs including market mechanisms. CARB may revise the rules and adopt new ones after January 1, 2011, in furtherance of the 2020 cap.

Back

Policy Details

- January 1, 2012 - GHG rules and market mechanisms adopted by CARB take effect and are legally enforceable.
- November 14, 2012 - CARB holds its first quarterly auction of GHG emissions allowances as part of the Cap-and-Trade program.
- January 1, 2013 - Cap-and-Trade program begins with a GHG emissions cap that will decline over time.
- September 17, 2013 - CARB issues first carbon offset credits as part of the Cap-and-Trade program.
- May 22, 2014 - CARB approves First Update to the Climate Change Scoping Plan.
- December 31, 2020 - Deadline for achieving 2020 GHG emissions cap.

Back

- SDID control unit weights minimize:

$$(\hat{w}_0, \hat{w}^{\text{sdid}}) = \min_{w_0, w} \sum_{t=1}^{T_{pre}} \left(w_0 + \sum_{i=1}^{N_{co}} w_i Y_{it} - \frac{1}{N_{tr}} \sum_{i=N_{co}+1}^{N} Y_{it} \right)^2 + \zeta^2 T_{pre} \|w\|_2^2 \tag{2}$$

- and time weights are chosen by:

$$(\hat{\delta}_0, \hat{\delta}^{\text{sdid}}) = \min_{\delta_0, \delta} \sum_{i=1}^{N_{co}} \left(\delta_0 + \sum_{t=1}^{T_{pre}} \delta_t Y_{it} - \frac{1}{T_{post}} \sum_{t=T_{pre}+1}^{T} Y_{it} \right)^2 \tag{3}$$

Back

$$\min_{w_i} \sum_{D=0} w_i + \log \frac{w_i}{q_i} \tag{4}$$

subject to

$$\sum_{D=0} w_i \times K_i = \bar{K} \tag{5}$$

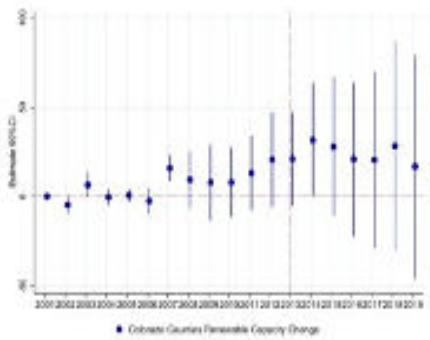
Where K is a subset of control variables and $\bar{K}$ is fixed moments of the treated units for variables K. ▸ Back

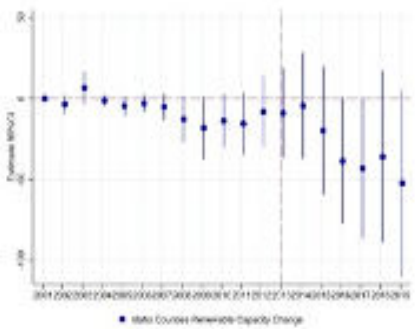
Renewable Capacity Share SDID Estimation

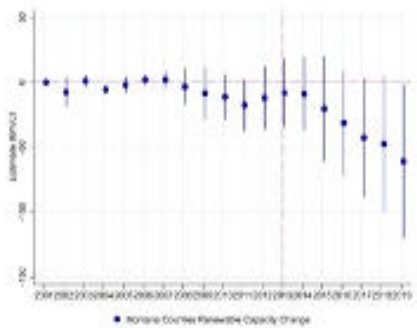
	(1)	(2)	(3)	(4)	(5)	(6)
	Renewable share	Renewable share	Renewable share	Renewable share	Renewable share	Renewable share
ATT	6.71**	6.72**	7.49***	6.98***	6.30**	5.18**
GDP per capita		✓	✓	✓		✓
kWh per capita			✓	✓		✓
Average temperature			✓	✓		✓
Precipitation			✓	✓		✓
Cooling degree days				✓		✓
Heating degree days				✓		✓
Policy indicators				✓		
15 RPS states					✓	✓

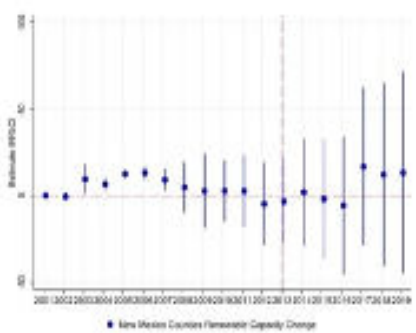
Back

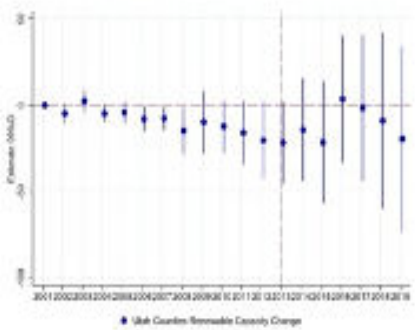
Other States

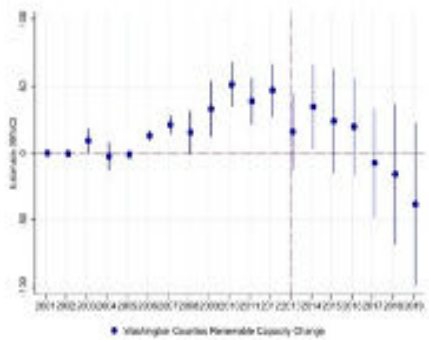


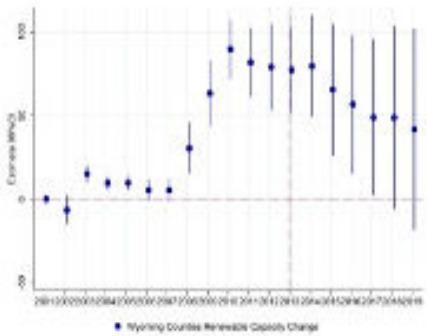




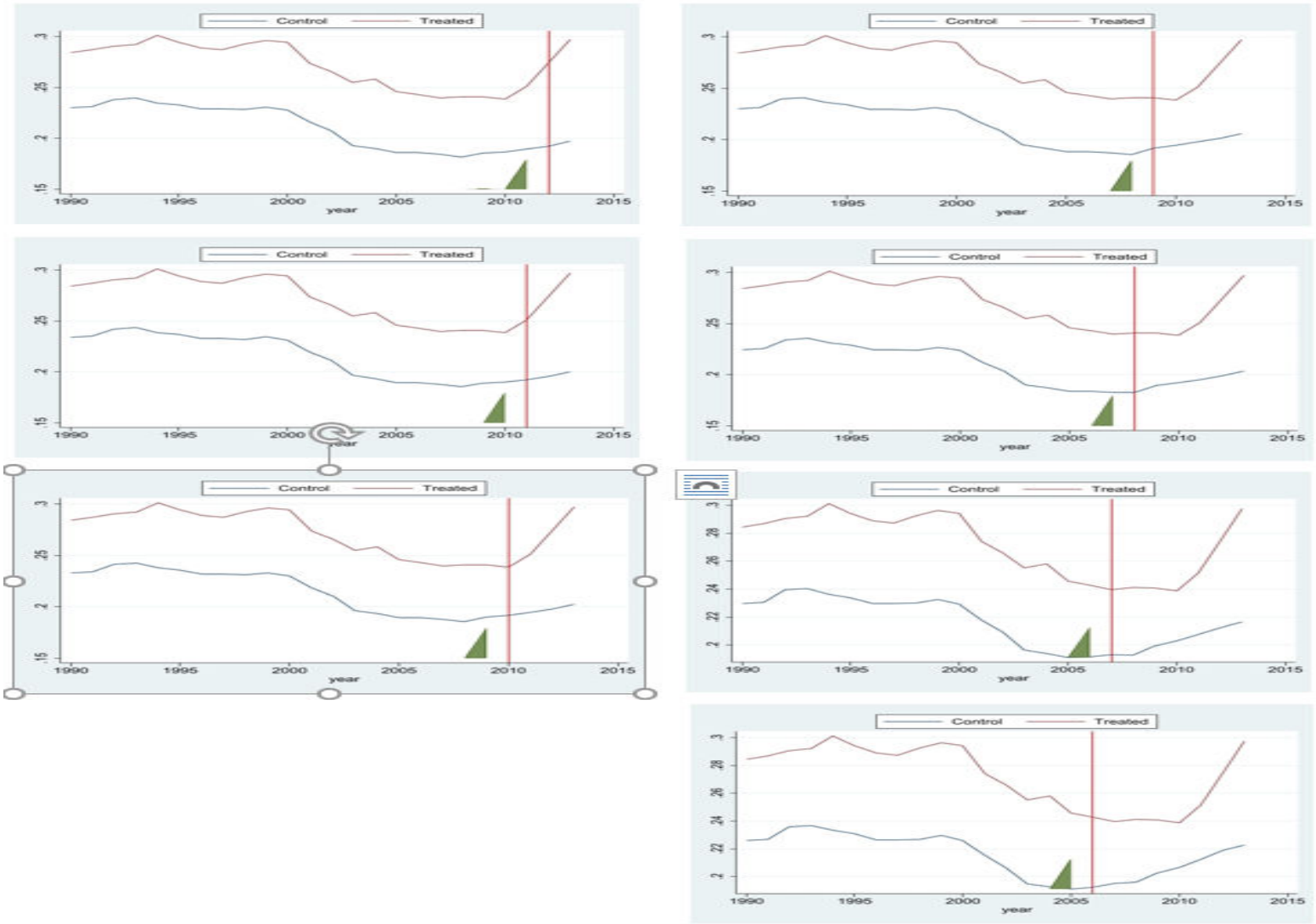








Backdating



Carbon Allowance Price