Cleaner bills, cleaner air: the environmental consequence of Renewable Portfolio Standards (RPS) policy design

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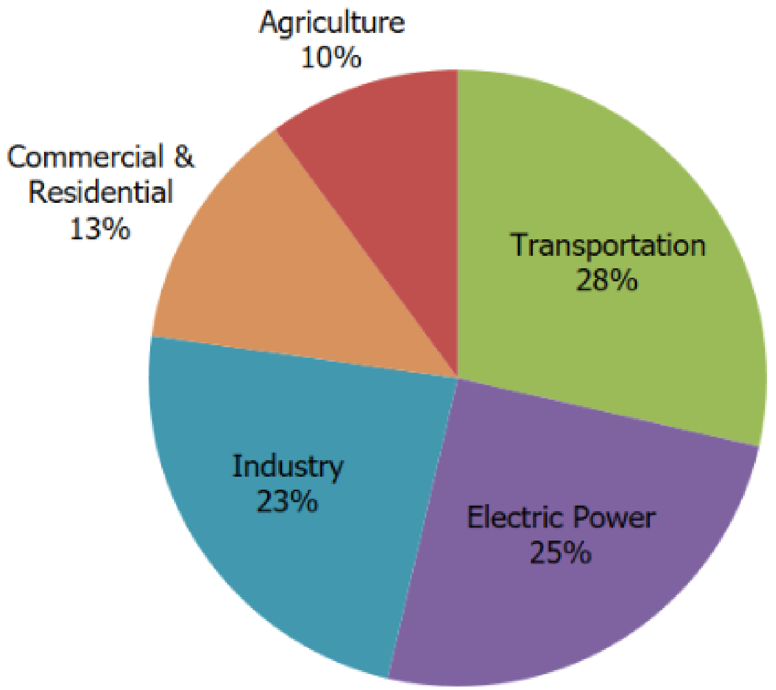
Motivation

- Climate change is one of the most important challenges facing our future
- US has been lacking a federal overarching climate policy (e.g. carbon tax) and instead implements sector-wise policies
  - Transportation: CAFE standards, LCFS
  - Buildings: energy efficiency policies, e.g. building codes, appliance standards
  - Power: **Renewable Portfolio Standards (RPS)**
- The power sector decarbonization is essential for low-carbon economy.
  - 25% of GHG emissions in 2021 (down from 32% in 2001)
  - Integrated with other sectors through electrifications (EVs, heating)

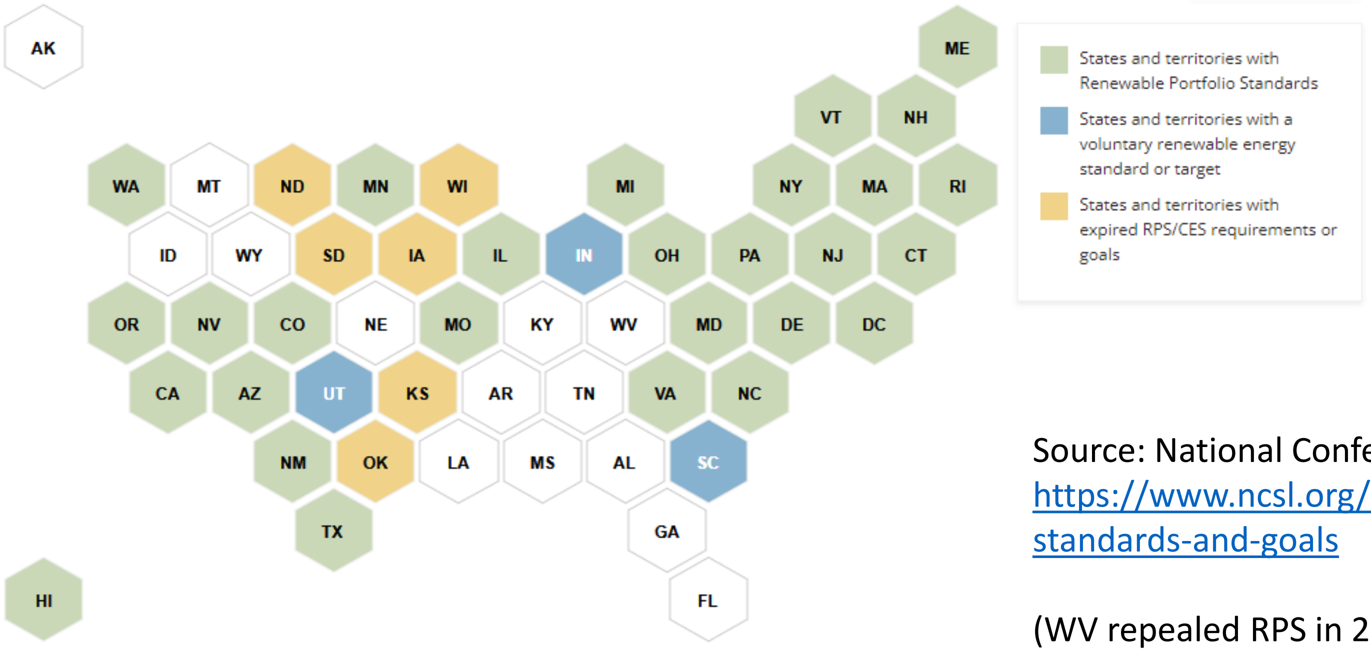


Total U.S. Greenhouse Gas Emissions by Economic Sector

Source: EPA (2021)
https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

What is Renewable Portfolio Standards (RPS)?

- RPS is a **state-level** policy that requires a specific percentage of electricity **sales** from renewable resources
  - 36 states + DC have passed RPS policies as of 2021



Source: National Conference of State Legislatures (2021). https://www.ncsl.org/energy/state-renewable-portfolio-standards-and-goals

(WV repealed RPS in 2015, MT in 2021)

What is Renewable Portfolio Standards (RPS)?

- RPS is a **state-level** policy that requires a specific percentage of electricity **sales** from renewable resources
  - 36 states + DC have passed RPS policies as of 2021
- RPS vs. Clean Energy Standard (CES)
  - “Clean Energy” can include nuclear which is non-renewable.
  - **This study treats them as the same policy.**
- Policy goals of RPS:
  - Energy independence/diversification
  - Decarbonization
  - Non-GHG pollution is generally NOT part of the legislative intent for most RPS

Empirical evidence on the impact of RPS

Recent causal evidence suggests that RPS policy:

- Increases retail electricity price by 2-11% (Upton and Snyder 2015; Greenstone and Nath, 2021; Wolverton et al. 2023)
- Decreases carbon emission by 10-25% (Greenstone and Nath, 2021)
  - RPS is relatively cost-ineffective as a climate policy: $60-300 per ton of CO2 abatement
- Small increases in renewable energy deployment (Greenstone and Nath 2023; Fullerton and Ta 2022; Feldman and Levinson 2023; Deschenes et al. 2023)
- Large reductions of in-state and out-of-state coal generation (Hollingsworth and Rudik 2019)

Less clear in the literature: environmental effects of RPS

- In theory renewable energy provides non-climate environmental benefits
- Empirical evidence is scarce, many based on simulation (Johnson and Novacheck 2015; Barbose et al. 2016; Wiser et al. 2017)
    - Model potential change in energy mix – project corresponding change in flow pollution emission
    - Co-benefit ~$1.5 billion annually
- Closest empirical evidence: Hollingsworth and Rudik (2019 JAERE):
    - Models REC demand at state/facility levels
    - Simulate pollution reduction, then monetize using Mueller et al. (2013)'s air pollution transport model
    - Co-benefits from $100,000 to over $100 million with 1% increase in nominal RPS target

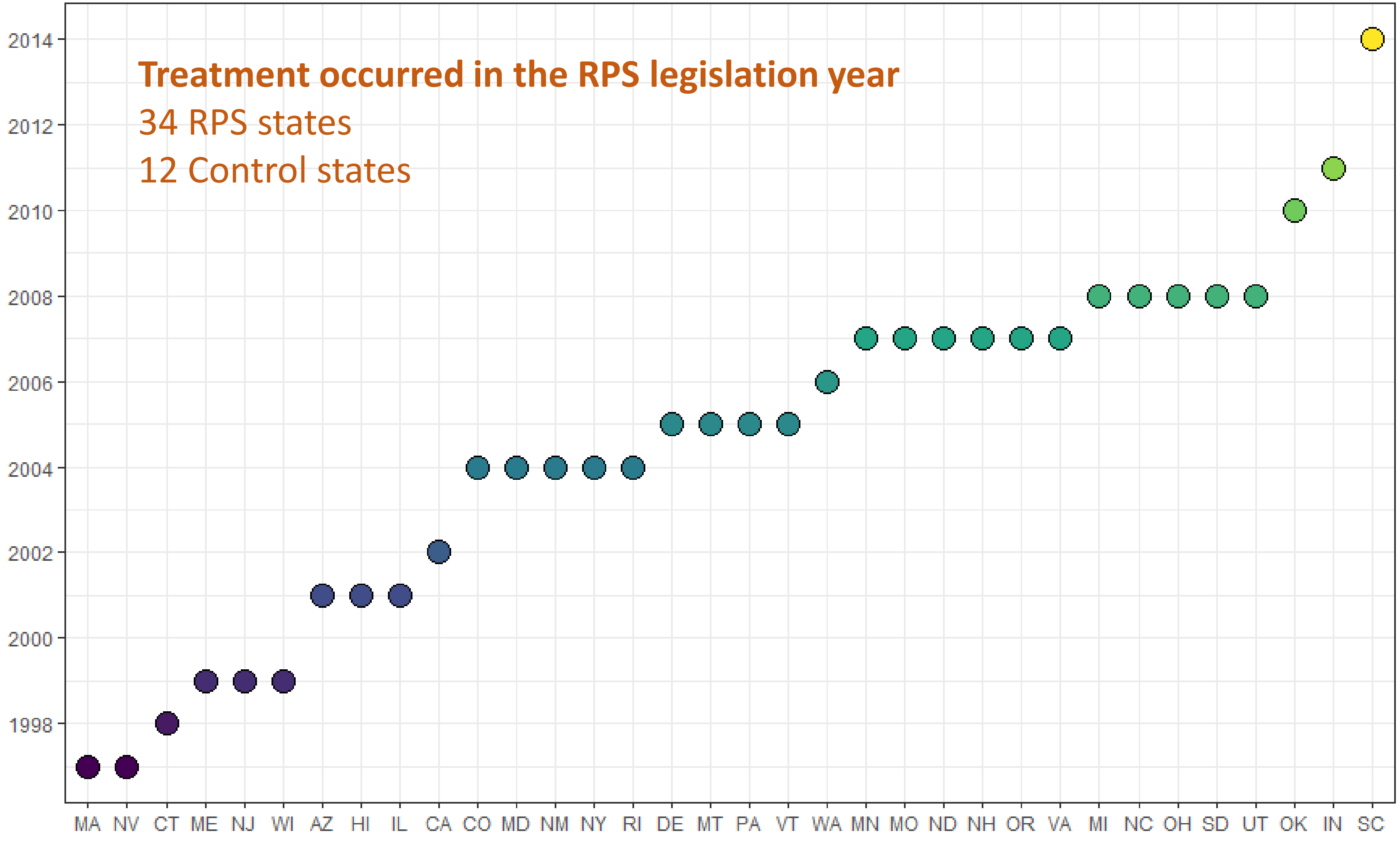
Policy design matter: the role of policy stringency

- RPS laws can differ widely from each other (Carley et al. 2012; Fischlein and Smith 2013; Bernstein and Hoffmann 2018; Carley et al. 2018) in a variety of ways:
  - Percentage requirement (nominal goal)
  - Design features: multipliers, exemptions, voluntary goals etc.
- Limited evidence that systematically documents stringency and its impacts
  - Carley et al. (2018 Nature Energy): more stringent laws lead to higher renewable adoption with a mixed quantitative-qualitative scoring system
  - DSIRE database (NC State): a database on RPS stringency but does not enable structured comparisons of technology types
  - Hong et al. (2023 NBER WP): Exempted municipal generation facilities are less constrained financially compared to commercial counterparts

What’s this study about?

- Construct a new, unified metric of RPS stringency
- Provide causal estimates on the heterogenous environmental effects of RPS associated with policy design:
  - Pooled together, on average RPS mildly reduces SO_2 emission and has negative but insignificant effects on NOx emission or ambient air quality
  - **The RPS effect differs widely by policy stringency:**
    - States with “clean” RPS laws: Large reductions in SO_2 and NO_x emission, improvement in ambient air quality
    - States with “discrepant” RPS laws: Small reduction in SO_2, no reduction in NO_x emissions, no ambient air quality improvement
- Effects driven by differential shifts in generation sources
  - States with clean RPS laws transit away from coal faster
- Forgone co-benefits are estimated to be **$12-22 billion in year 2016**

Method: DiD with Staggered Treatment



RPS states are defined as states that have passed RPS policies **1990-2018**.

Our analyses exclude 4 states that had RPS between 1990-2012:

- West Virginia repealed its RPS in 2015.
- Iowa and Texas set RPS targets in terms of renewable <u>capacity</u> levels rather than % of retail electricity sales.
- Kansas requires a percentage of <u>peak</u> electricity demand.

Method: Documenting discrepancy in policy design

- **Voluntary Goal:** States set a voluntary renewable/clean energy goal instead of a mandatory standard.
- **Excluded Sales:** RPS targets apply to only a subset of load serving entities (LSEs), and/or some obligated LSEs are allowed to exclude a portion of their load from determination of their annual procurement obligations.
- **Credit Multipliers:** Many states allow the use of credit multipliers for certain types of resources and/or allow demand-side management resources to contribute to some portion of the RPS.
- **Carbon Exemption**: States allow carbon-emitting technologies to be counted as "renewable" energy

"Excluded Sales" example: Arizona (2001)

Ariz. Admin. Code § 14-2-1618

Section R14-2-1618 - Environmental Portfolio Standard

A. Upon the effective implementation of a Commission-approved Environmental Portfolio Standard Surcharge tariff, any Load-Serving Entity selling electricity or aggregating customers for the purpose of selling electricity under the provisions of this Article must derive at least .2% of the total retail energy sold from new solar resources or environmentally-friendly renewable electricity technologies, whether that energy is purchased or generated by the seller. Solar resources include photovoltaic resources and solar thermal resources that generat electricity. New solar resources and environmentally-friendly renewable electricity technologies are those installed on or after January 1, 1997.

1. Electric Service Providers, that are not UDCs, are exempt from portfolio requirements until 2004, but could voluntarily elect to participate. ESPs choosing to participate would receive a pro rata share of funds collected from the Environmental Portfolio Surcharge delineated in R14-2-1618.A.2 for portfolio purposes tc acquire eligible portfolio systems or electricity generated from such systems.

2. Utility Distribution Companies would recover part of the costs of the portfolio standard through current System Benefits Charges, if they exist, including a re-allocation of demand side management funding to portfolio uses. Additional portfolio standard costs will be recovered by a customer Environmental Portfolio

“Credit Multipliers” example: Virginia (2007)

2021 § 56-585.2. Sale of electricity from renewable sources through a renewable energy portfolio standard program

C. It is in the public interest for utilities that seek to have a renewable energy portfolio standard program to achieve the goals set forth in subsection D, such goals being referred to herein as "RPS Goals." A utility shall receive double credit toward meeting the renewable energy portfolio standard for energy derived from sunlight, from onshore wind, or from facilities in the Commonwealth fueled primarily by animal waste, and triple credit toward meeting the renewable energy portfolio standard for energy derived from offshore wind.

D. Regarding any renewable energy portfolio standard program, the total electric energy sold by a utility to meet the RPS Goals shall be composed of the following amounts of electric energy or renewable thermal energy equivalent from renewable energy sources, as adjusted for any sales volumes lost through operation of the customer choice provisions of subdivision A 3 or A 4 of § 56-577:

“Carbon Exemption” example: Colorado (2004)

40-2-124. Renewable energy standard - definitions - net metering

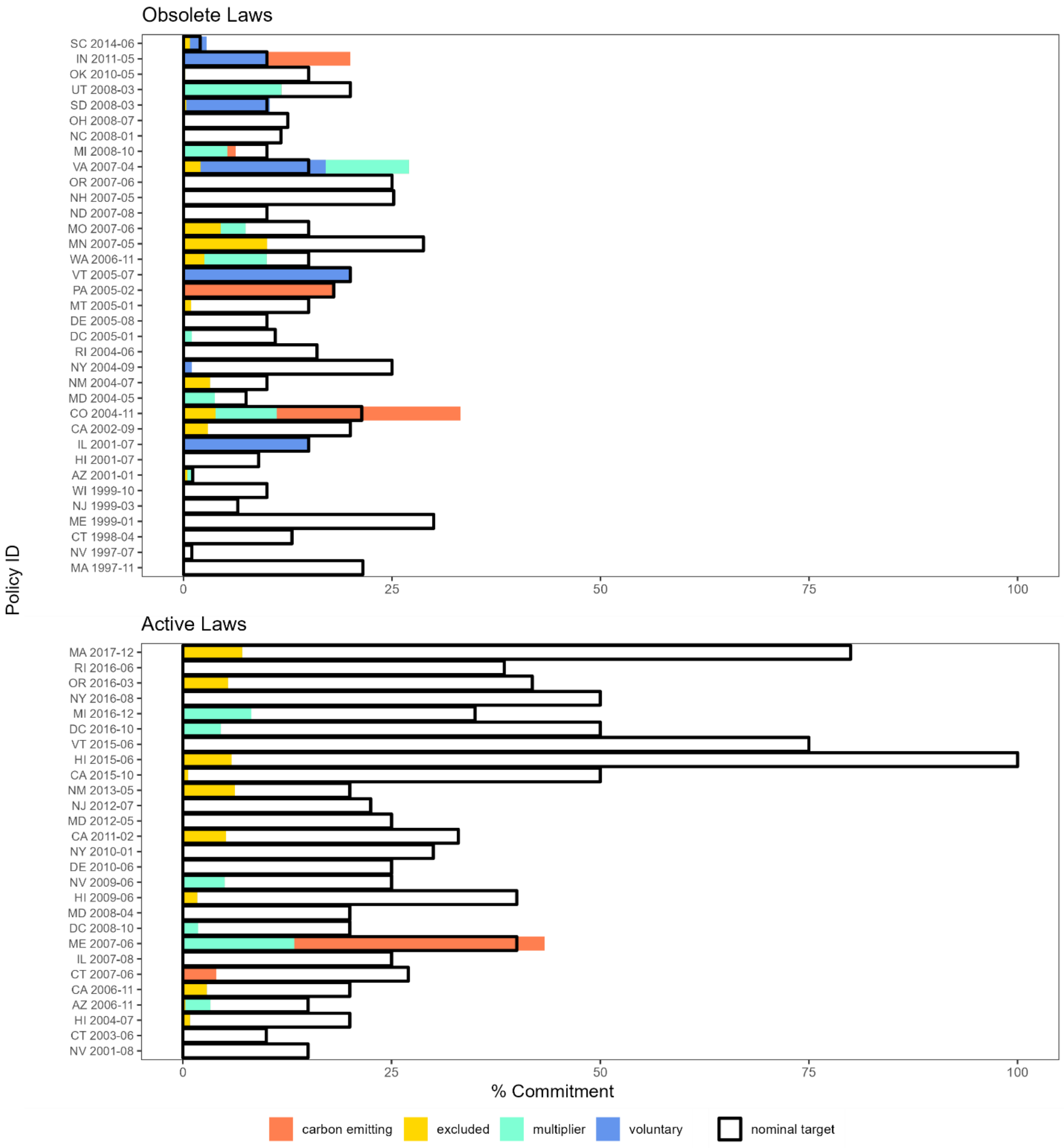
section. In accordance with article 4 of title 24, the commission shall revise or clarify existing rules to establish the following:

(a) Definitions of eligible energy resources that can be used to meet the standards. "Eligible energy resources" means recycled energy and renewable energy resources. In addition, resources using coal mine methane and synthetic gas produced by pyrolysis of municipal solid waste are eligible energy resources if the commission determines that the electricity generated by those resources is greenhouse gas neutral. The commission shall determine, following an evidentiary hearing, the extent to which such electric generation technologies utilized in an optional pricing program may be used to comply with this standard. A fuel cell using hydrogen derived from an eligible energy resource is also an eligible electric generation technology. Fossil and nuclear fuels and their derivatives are not eligible energy resources. For purposes of this section:

(II) "Coal mine methane" means methane captured from active and inactive coal mines where the methane is escaping to the atmosphere. In the case of methane escaping from active mines, only methane vented in the normal course of mine operations that is naturally escaping to the atmosphere is coal mine methane for purposes of eligibility under this section.

Method: Creating the RPS Statues Database

- We collect all RPS laws passed until 2018
- Record the **nominal goal** and the target year
- Quantify the minimum amount of renewable energy needed to achieve the nominal goal
  - Subtract four types of discrepancies from the nominal goal
  - Resulting in the **binding minimum** metric

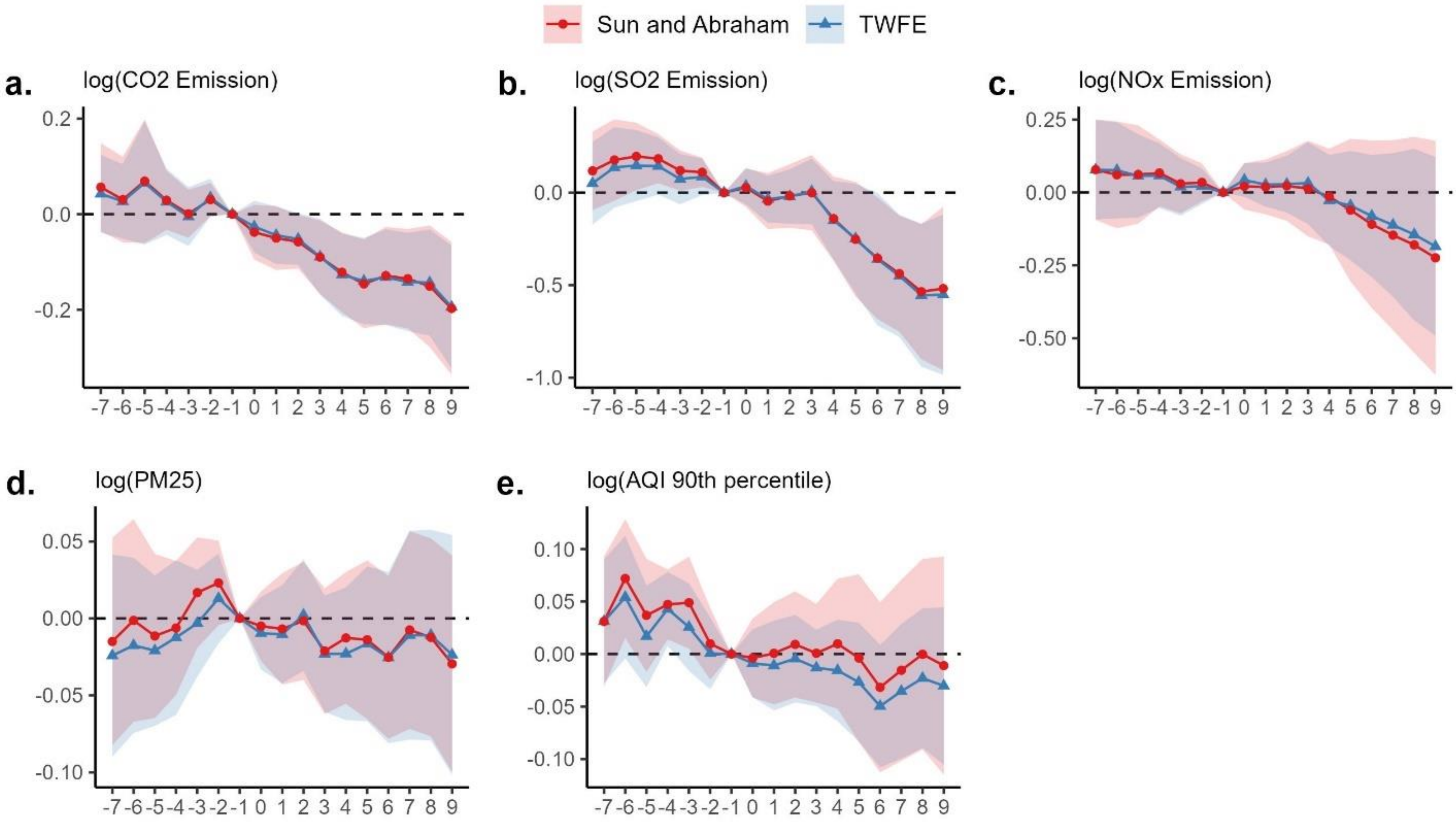


Obsolete Laws
SC 2014-06
IN 2011-05
OK 2010-05
UT 2008-03
SD 2008-03
OH 2008-07
NC 2008-01
MI 2008-10
VA 2007-04
OR 2007-06
NH 2007-05
ND 2007-08
MO 2007-06
MN 2007-05
WA 2006-11
VT 2005-07
PA 2005-02
MT 2005-01
DE 2005-08
DC 2005-01
RI 2004-06
NY 2004-09
NM 2004-07
MD 2004-05
CO 2004-11
CA 2002-09
IL 2001-07
HI 2001-07
AZ 2001-01
WI 1999-10
NJ 1999-03
ME 1999-01
CT 1998-04
NV 1997-07
MA 1997-11
0
25
50
75
100
Policy ID
Active Laws
MA 2017-12
RI 2016-06
OR 2016-03
NY 2016-08
MI 2016-12
DC 2016-10
VT 2015-06
HI 2015-06
CA 2015-10
NM 2013-05
NJ 2012-07
MD 2012-05
CA 2011-02
NY 2010-01
DE 2010-06
NV 2009-06
HI 2009-06
MD 2008-04
DC 2008-10
ME 2007-06
IL 2007-08
CT 2007-06
CA 2006-11
AZ 2006-11
HI 2004-07
CT 2003-06
NV 2001-08
0
25
50
75
100
% Commitment
carbon emitting
excluded
multiplier
voluntary
nominal target

Empirical Strategy: Difference-in-Differences

$$Y_{s,t} = \sum_{\tau} \beta_\tau 1\{t - RPS_s = \tau\} + X_{s,t} + \alpha_s + \delta_t + \varepsilon_{st}$$

- $Y_{s,t}$ is an outcome of interest for state s in year t. (e.g. emission, power generation)
- RPS_s is the first RPS legislation year of state s.
- **Fixed effects:** α_s (state) and δ_t (year).
- $X_{s,t}$ are **time-varying covariates**: state-level political indicators, gross state product per capita, natural gas price, population, share of exported energy, HDDs, CDDs, net metering programs, NOx trading programs, nonattainment status.



Two types of DD estimators are presented in the figure: (1) TWFE, two-way fixed effects estimated by OLS and (2) the robust DiD estimator proposed by Sun and Abraham (2021).

Impact of Policy Stringency in RPS Policy Design

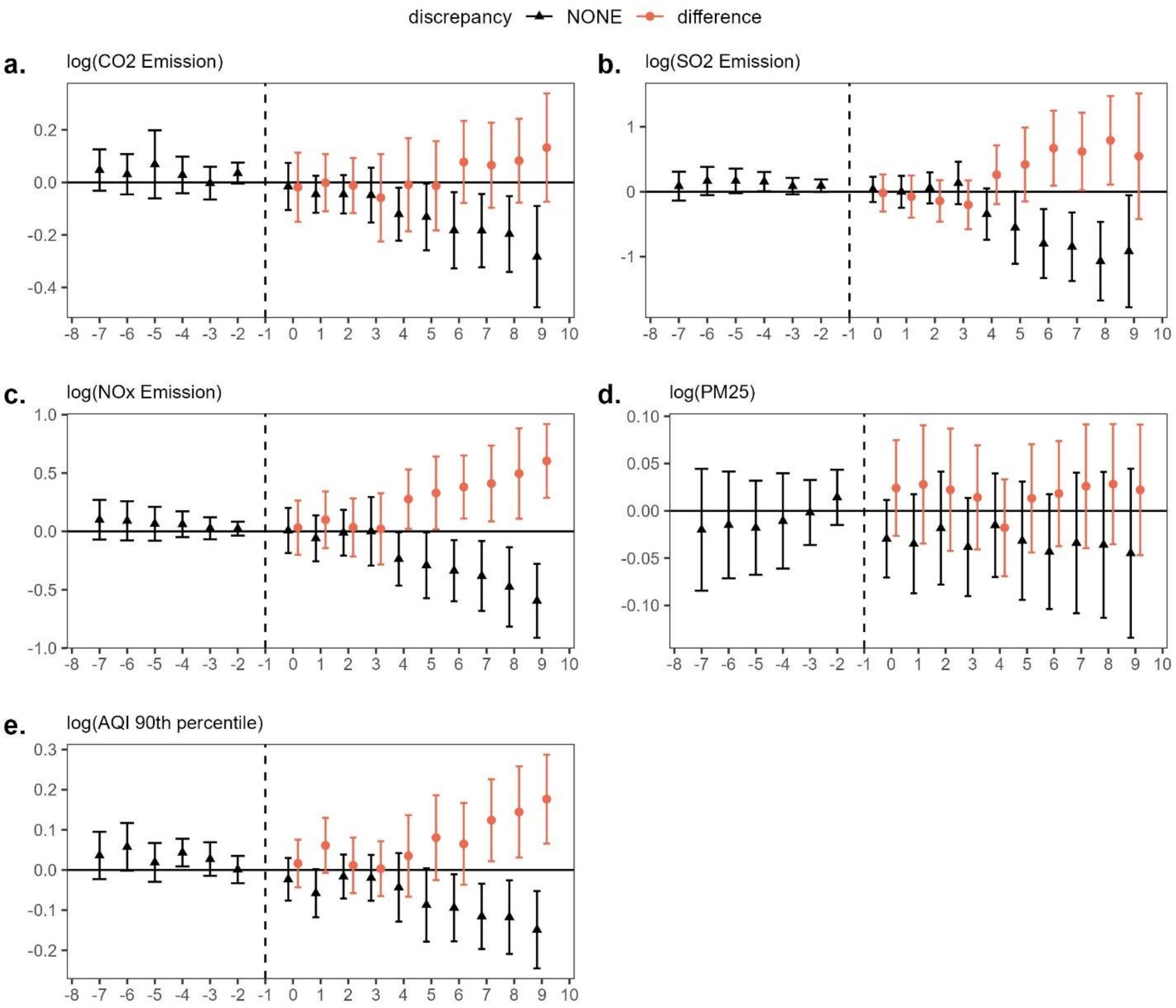
Treatment effect of
stringent RPS policy

Difference in the dynamic treatment effect due
to existence of non-stringent policy design.

$$Y_{s,t} = \sum_{\tau} (\beta_\tau + \gamma_\tau \times \boxed{Discrepancy_{st}}) \cdot 1\{t - RPS_s = \tau\} + X_{s,t} + \alpha_s + \delta_t + \varepsilon_{st}$$

Discrepancy = 1 if non-binding target was
identified in the RPS law of state *s* in year *t*

Discrepancy is due to any of the 4 policy designs:
(1) voluntary commitment, (2) excluded sales, (3)
credit multiplier, (4) carbon exemption



Difference in the dynamic treatment effect due to existence of non-stringent policy design.

Pretrend check: clean vs. discrepant RPS (Roth 2022)

Outcome	Event Study Coefficients: Control vs. Clean RPS					
	Pre-trend Test		Power Analysis (Roth 2022)			
			Positive Pretrend		Negative Pretrend	
	Pretrend Level	Pretrend Slope	Bayes Factor	Likelihood Ratio	Bayes Factor	Likelihood Ratio
log(CO2 Emission)	-0.039***	-0.017	0.119	0	0.119	0
log(SO2 Emission)	-0.064***	0.011	0.116	0.001	0.116	0.001
log(NOx Emission)	-0.01***	0.008	0.119	0.253	0.119	0
log(PM25)	-0.022***	0.018**	0.118	171,678	0.118	0
log(AQI 90th percentile)	-0.035***	0.002	0.121	0.057	0.121	0.002
% of Generation: Coal & Oil	-3.85***	0.567	0.12	0.794	0.12	0
% of Generation: Natural Gas	3.779***	-1.553***	0.119	0	0.119	0.228
% of Generation: Wind and Solar	-0.993**	0.252**	0.116	0.759	0.116	0
% of Generation: Hydro and Nuclear	0.996***	0.861	0.118	0	0.118	0
% of Generation: Other Renewable	0.002	-0.005	0.113	0	0.113	0.002
Electricity Price	0.443***	-0.07	0.121	0	0.121	0.211

Impact of RPS Discrepancy on emission

	(1) $\log(CO_2)$	(2) $\log(SO_2)$	(3) $\log(NO_x)$	(4) log(PM2.5)	(5) $\log(AQI_{90})$
Panel A: Heterogeneous Effects Associated to Policy Discrepancy					
Baseline ATT of Discrepancy-free RPS					
0-4 years post RPS	-0.053	-0.065	-0.074	-0.030	-0.054**
	(0.045)	(0.119)	(0.081)	(0.024)	(0.023)
5-9 years post RPS	-0.185***	-0.859***	-0.411***	-0.044	-0.129***
	(0.068)	(0.259)	(0.140)	(0.031)	(0.041)
≥ 10 years post RPS	-0.263***	-1.187***	-0.632***	-0.053	-0.176***
	(0.097)	(0.312)	(0.195)	(0.046)	(0.057)
ATT Differences due to RPS Policy Discrepancy					
(0-4 years) × Discrepancy	-0.048	-0.089	0.064	0.020	0.025
	(0.065)	(0.146)	(0.099)	(0.022)	(0.025)
(5-9 years) × Discrepancy	0.046	0.570**	0.412***	0.029	0.112**
	(0.081)	(0.276)	(0.144)	(0.021)	(0.045)
(≥ 10 years) × Discrepancy	0.030	0.578	0.631***	0.092***	0.172***
	(0.095)	(0.380)	(0.154)	(0.034)	(0.058)
Obs.	1334	1334	1334	924	1305
R^2	0.987	0.948	0.949	0.935	0.839

Standard errors are clustered at the state level. ***, **, * indicate statistical significance at 1%, 5% and 10%, respectively.

For clean RPS laws, in the medium run (5-9 years):

- CO_2 decreases by 16.9%
- SO_2 decreases by 57.6%
- NO_x decreases by 33.7%
- AQI90 decreases by 12.1%

For dirty RPS laws:

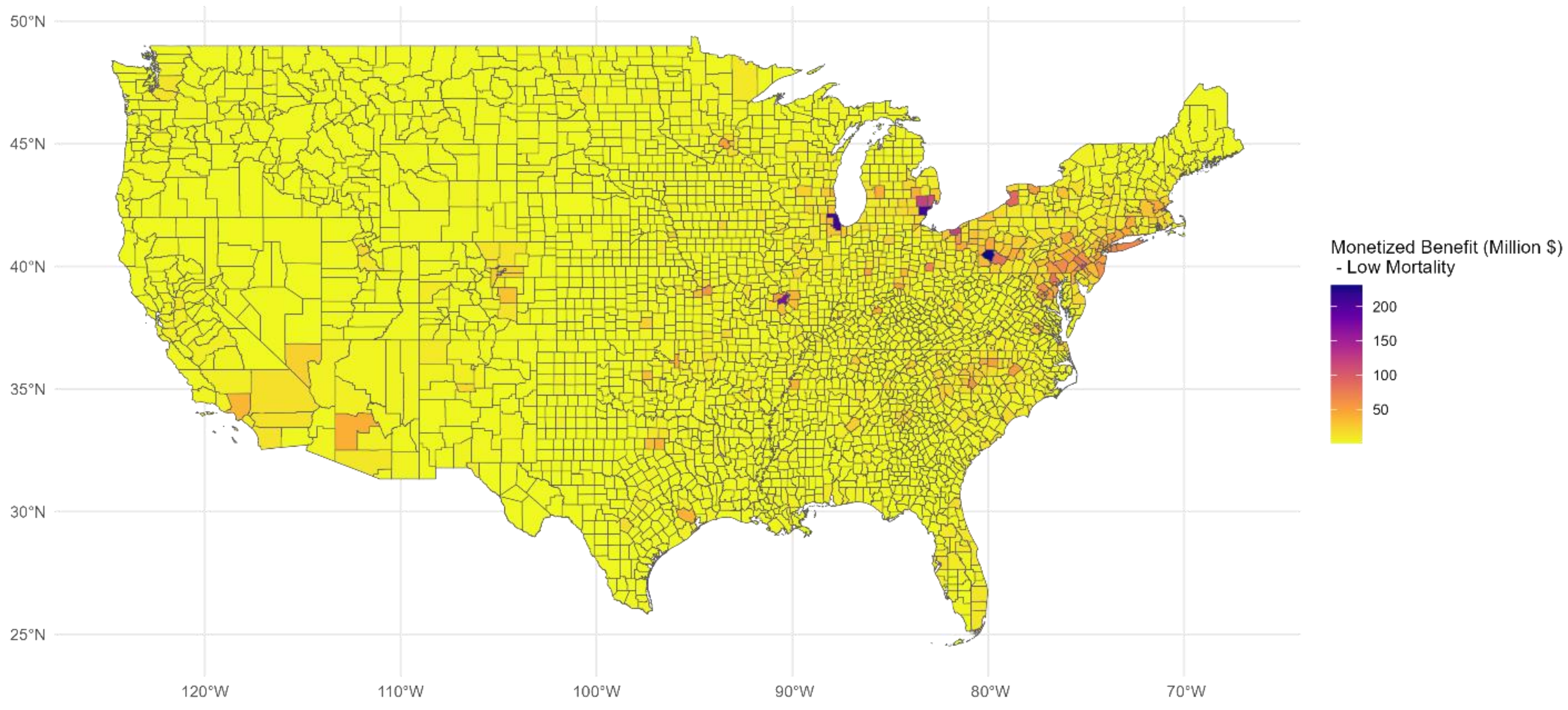
- CO_2 decreases by 12.5%
- SO_2 decreases by 25.1%
- NO_x decreases by 0.1%
- AQI90 decrease by 1.7%

Monetizing air quality co-benefits

- Medium-run estimate on foregone pollution reduction: 43.4% SO_2, 33.6% NO_x emission
- Need an integrated assessment model that handles (1) pollution transport; (2) population exposure
- EPA's CO-Benefits Risk Assessment (COBRA) tool:
  - Integrates a pollutant fate and transport model with monetized exposure estimates;
  - Allows counterfactual analysis at the state/sector level
  - Results driven by SO_2 (precursor for O_3) and NO_x (precursor for $PM_{2.5}$ and O_3)

Monetized benefit

- **Monetized foregone co-benefits due to discrepancy: $12-22 billion in 2016**
  - Had the 22 discrepant states would have adopted clean RPS policy
  - Foregone benefits cluster around population centers in Northeast and Midwest
  - Large policy spillover: more than half of the foregone benefits come from out of state
- Actual benefits from RPS: $17-34 billion
- Some benchmark numbers:
  - Cost of compliance: $3-30 billion annually
  - Benefits from decarbonization: $33 billion using SSC=$185/ton CO_2



50°N
45°N
40°N
35°N
30°N
25°N
120°W
110°W
100°W
90°W
80°W
70°W
Monetized Benefit (Million $)
- Low Mortality
200
150
100
50

What is driving the observed divergence?

	(1) Coal and Oil	(2) Natural Gas	(3) Wind and Solar	(4) Hydro and Nuclear	(5) Other Renewable	(6) Electricity Price
Panel A: Heterogeneous Effects Associated to Policy Discrepancy						
Baseline ATT of Discrepancy-free RPS						
0-4 years post RPS	-2.028	1.202	0.924	-0.733	0.009	-0.001
	(1.558)	(2.741)	(0.732)	(2.270)	(0.442)	(0.488)
5-9 years post RPS	-11.359***	7.358*	-0.011	3.884*	-0.185	0.037
	(3.537)	(3.982)	(0.968)	(2.312)	(0.389)	(0.407)
≥ 10 years post RPS	-13.365**	8.253	-1.465	6.072*	-0.082	0.405
	(5.711)	(5.591)	(1.329)	(3.058)	(0.456)	(0.570)
ATT Differences due to RPS Policy Discrepancy						
(0-4 years) × Discrepancy	-0.548	-1.283	0.477	1.820	-0.044	0.048
	(2.028)	(2.827)	(0.769)	(2.048)	(0.398)	(0.510)
(5-9 years) × Discrepancy	6.450*	-6.121	2.953**	-3.237*	-0.127	0.289
	(3.824)	(3.926)	(1.206)	(1.826)	(0.309)	(0.443)
(≥ 10 years) × Discrepancy	5.913	-4.395	4.720***	-6.548**	0.115	0.010
	(6.123)	(5.793)	(1.501)	(2.865)	(0.863)	(0.658)
Obs.	1334	1334	1334	1334	1334	1334
R^2	0.946	0.903	0.682	0.949	0.925	0.925

Summary of policy effect (using estimates of 5-9 years)	*Coal and Oil*	*Natural Gas*	*Wind and Solar*	*Hydro and Nuclear*	*Other Renewable*	*Electricity Price*
Clean RPS	-11.36%	7.36%	-0.01%	3.88%	-0.19%	0.04 ¢/kWh
Discrepant RPS	-4.91%	1.24%	2.94%	0.65%	-0.31%	0.33 ¢/kWh

RPS discrepancy due to "excluded sales" is most influential

	(1) log(CO_2)	(2) log(SO_2)	(3) log(NO_x)	(4) % polluted days	(5) Coal and Oil	(6) Natural Gas	(7) Wind	(8) Solar	(9) Hydro & Nuclear	(10) Electricity Price
5-9 years post RPS	-0.229***	-0.819***	-0.347***	-0.021**	-11.624***	8.026*	-1.173	0.117	4.695**	0.023
	(0.063)	(0.242)	(0.126)	(0.008)	(3.480)	(4.005)	(0.979)	(0.114)	(2.246)	(0.399)
ATT Differences due to RPS Law Discrepancy: 5-9 years post RPS										
(5-9 years) × exclude	0.174**	0.538*	0.382**	0.024*	7.728**	-8.774**	7.058***	-0.218	-5.976**	0.492
	(0.074)	(0.302)	(0.156)	(0.012)	(3.817)	(3.678)	(1.889)	(0.227)	(2.600)	(0.541)
(5-9 years) × voluntary	-0.194*	0.013	0.022	0.002	0.738	-1.915	1.644	-0.260**	0.0241	0.052
	(0.103)	(0.358)	(0.307)	(0.012)	(4.645)	(5.150)	(3.455)	(0.112)	(2.484)	(0.285)
(5-9 years) × multiplier	-0.006	0.310	-0.053	-0.003	2.198	0.568	-4.910**	0.171	1.141	-0.831
	(0.074)	(0.241)	(0.142)	(0.011)	(3.605)	(3.558)	(1.971)	(0.272)	(2.453)	(0.495)
(5-9 years) × carbon	0.107	0.164	0.180	0.011	-2.130	-0.358	3.933**	0.009	-1.238	0.633
	(0.089)	(0.220)	(0.136)	(0.011)	(3.742)	(3.996)	(1.760)	(0.126)	(1.682)	(0.635)
Obs.	1334	1334	1334	1305	1334	1334	1334	1334	1334	1334
R^2	0.988	0.949	0.948	0.831	0.949	0.907	0.698	0.477	0.965	0.930

Standard errors are clustered at the state level. ***, **, * indicate statistical significance at 1%, 5% and 10%, respectively.

- ***Excluded Sales:*** *RPS targets apply to only a subset of load serving entities (LSEs), and/or some obligated LSEs are allowed to exclude a portion of their load from determination of their annual procurement obligations.*
- ***Voluntary Goal:*** *States set a voluntary renewable/clean energy goal instead of a mandatory standard.*
- ***Credit Multipliers:*** *Many states allow the use of credit multipliers for certain types of resources and/or allow demand-side management resources to contribute to some portion of the RPS.*
- ***Carbon Exemption**: States allow carbon-emitting technologies to be counted as "renewable" energy*

Conclusions

- Stringency of the law could substantially affect the RPS policy outcomes → foregone co-benefits.
- Discrepancies in RPS laws in general undermine the intended RPS policy effects.
  - Less reduction in non-CO2 pollutants (SO2, NOx)
  - Less improvement in air quality
  - Smaller cuts in coal & oil generation
  - Lower growth in natural gas
  - Less generation from hydro & nuclear, but more generation from wind.
- The discrepancy policy design in “excluded sales” is most influential in altering the RPS effects.

Supplementary Slides

Contributions to Literature

- On causal identification of the heterogenous impacts of RPS
  - Previous studies mostly focused on impacts of renewable adoption, GHG emission, and price effects (Upton and Snyder 2015; Carley et al. 2018; Greenstone and Nath, 2021, etc.)
  - We document the heterogenous environmental impact of RPS (Hollingsworth and Rudik, 2019)
- Environmental federalism and policy stringency
  - We document the performance gap in policy design heterogeneity in RPS (Lyon and Yin 2010; Carley et al. 2012, 2018; Hong et al. 2023)
  - Compliment studies on hazardous wastes (Soberg and Xu 2018; Blundell et al. 2021); wetlands (Keiser et al. 2022; Aronoff and Rafey 2023); pollution monitoring and enforcement (Zhang 2018)
- Co-benefits and unintended consequences of environmental policy
  - We document large non-carbon co-benefits generated from a renewable energy policy
  - Literature on co-benefits of sulfur cap-and-trade (Stavin and Schmalensee 2013); non-point-source water pollution (Keiser et al. 2019; Weng et al. 2023);

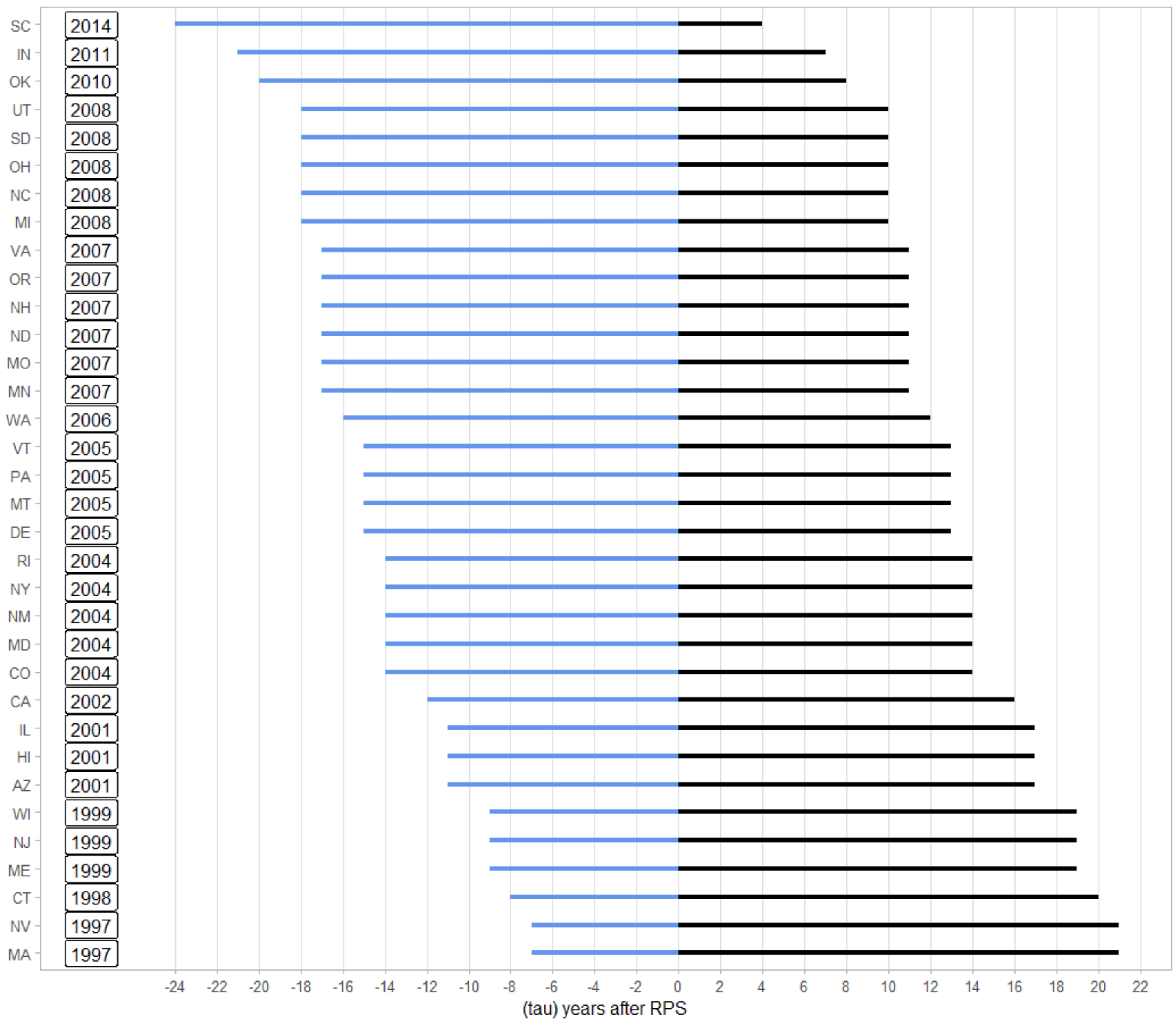
Data sample years 1990-2018

36 RPS states

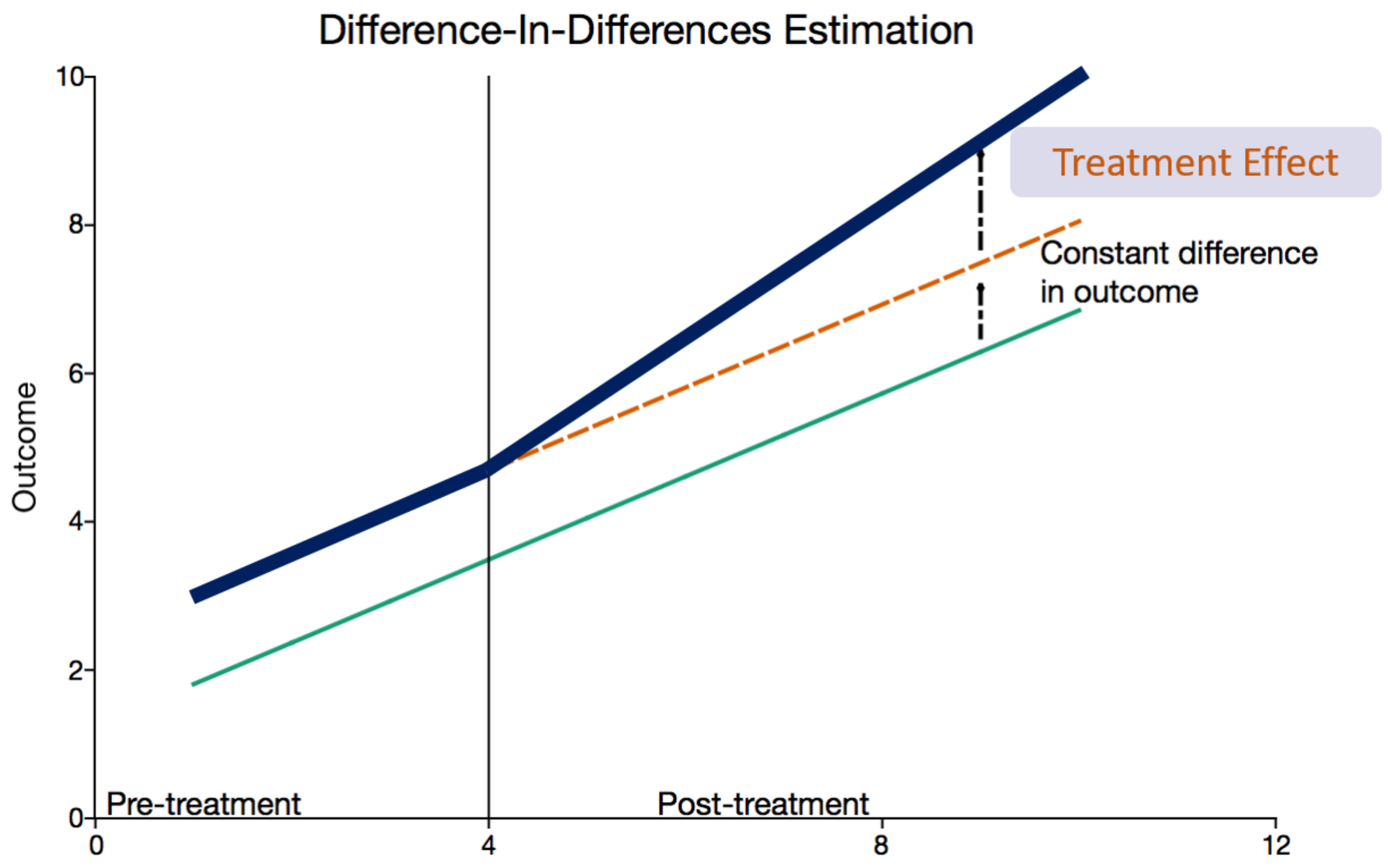
years before and after policy treatment from 1997 to 2014

range of $\boldsymbol{\tau}$ for a balanced panel:

$$-7 \leq \tau \leq 4$$



Difference-in-Differences to identify policy effect



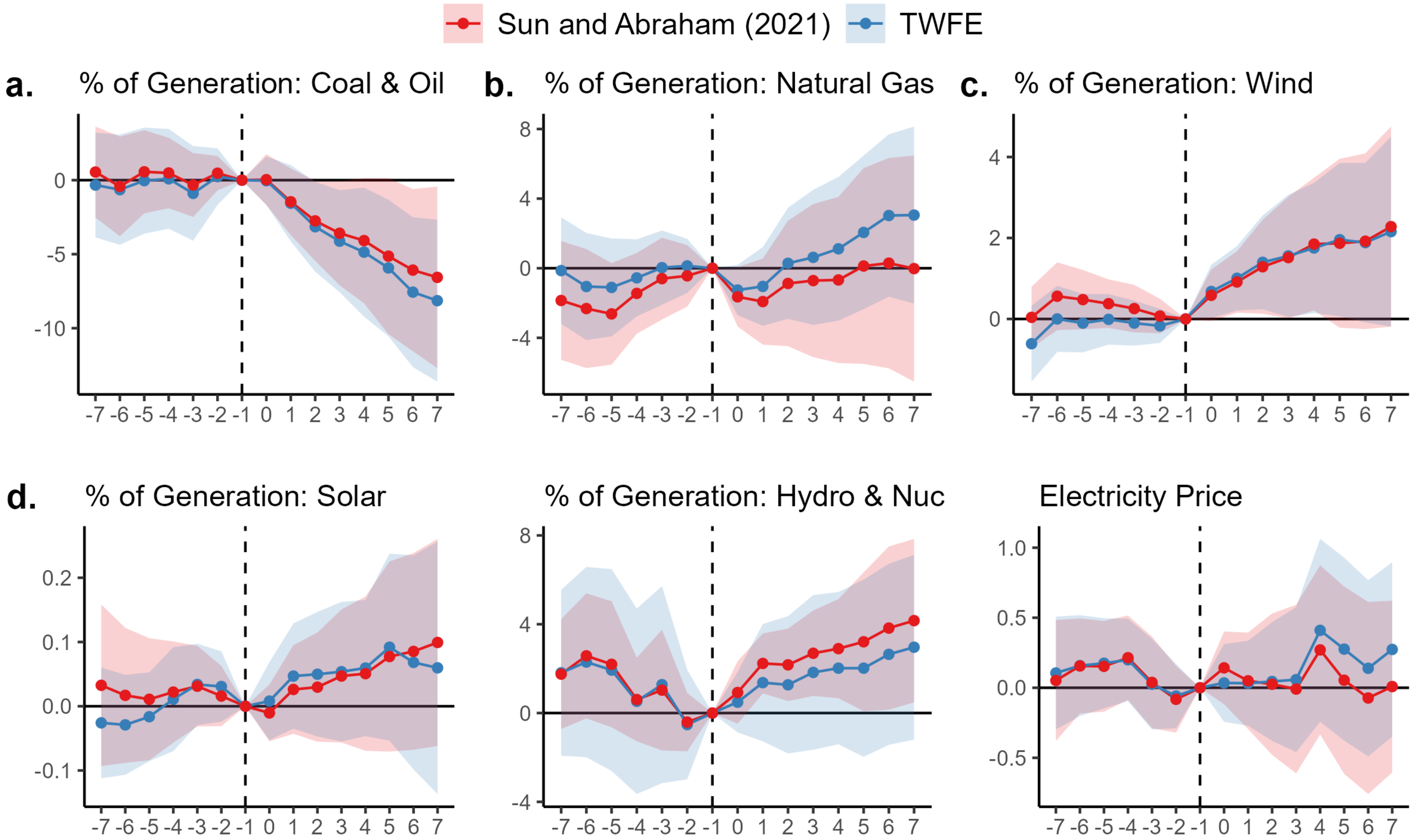
Source: https://www.aptech.com/blog/introduction-to-difference-in-differences-estimation/

Panel A: Outcome Variables

	RPS states			Control states		
	N	Mean (std dev)	Min-Max	N	Mean (std dev)	Min-Max
CO_2 (1000 metric tons)	957	37463.239 (32870.971)	6.583 – 133416.545	377	46490.424 (32388.933)	438.133 – 131543.37
SO_2 (1000 metric tons)	957	164.228 (283.856)	0.009 – 2045.983	377	201.061 (224.377)	2.559 – 892.347
NO_x (1000 metric tons)	957	78.616 (92.709)	0.148 – 535.619	377	95.194 (87.313)	1.931 – 353.547
Share of Polluted Days	957	0.051 (0.056)	0.000 – 0.369	348	0.033 (0.037)	0.000 – 0.194
% of Generation: Coal and Oil	957	46.141 (30.604)	0.033 – 96.964	377	47.48 (27.229)	0.112 – 97.564
% of Generation: Natural Gas	957	18.866 (22.573)	0.000 – 98.944	377	19.664 (21.824)	0.028 – 79.666
% of Generation: Wind	957	1.910 (4.551)	0.000 – 32.230	377	0.815 (2.803)	0.000 – 18.478
% of Generation: Solar	957	0.239 (1.105)	0.000 – 13.806	377	0.039 (0.248)	0.000 – 3.059
% of Generation: Other Renewables	957	14.663 (20.977)	0.000 – 91.360	377	13.004 (21.678)	1.258 – 98.284
Electricity Price (cents per kWh, 2015 USD)	957	10.510 (3.563)	5.098 – 34.040	377	8.442 (2.291)	5.099 – 17.726

Panel B: State-level Time-varying Covariates

	RPS states			Control states		
	N	Mean (std dev)	Min-Max	N	Mean (std dev)	Min-Max
Legislature control (DEM)	957	0.417 (0.493)	0 – 1	377	0.337 (0.473)	0 – 1
Legislature control (GOP)	957	0.336 (0.473)	0 – 1	377	0.451 (0.498)	0 – 1
State control (DEM)	957	0.229 (0.42)	0 – 1	377	0.172 (0.378)	0 – 1
State control (GOP)	957	0.231 (0.422)	0 – 1	377	0.334 (0.472)	0 – 1
Governing party (DEM)	957	0.486 (0.495)	0 – 1	377	0.377 (0.48)	0 – 1
Log(Gross State Product)	957	11.854 (1.139)	9.351 – 14.817	377	11.546 (0.923)	9.45 –13.737
Natural Gas Price ($ per 1000 ft3)	957	6.126 (3.017)	2.005 –32.39	377	5.433 (2.129)	0.479 –11.428
Log(Population)	957	15.132 (1.036)	13.244 –17.491	377	14.931 (0.942)	13.025 –16.872
Net Metering Program	957	0.639 (0.48)	0 – 1	377	0.342 (0.475)	0 – 1
% of Energy Exported	957	0.089 (0.447)	-0.840 – 2.737	377	0.169 (0.576)	-0.636 – 2.607
HDDs	957	5642.92 (2019.611)	0 – 10810	377	4317.859 (2757.045)	430 – 11702
CDDs	957	935.448 (896.818)	42 – 5213	377	1550.968 (963.582)	0 – 4156
NOx Trading Program	957	0.088 (0.283)	0 – 1	377	0.064 (0.244)	0 – 1



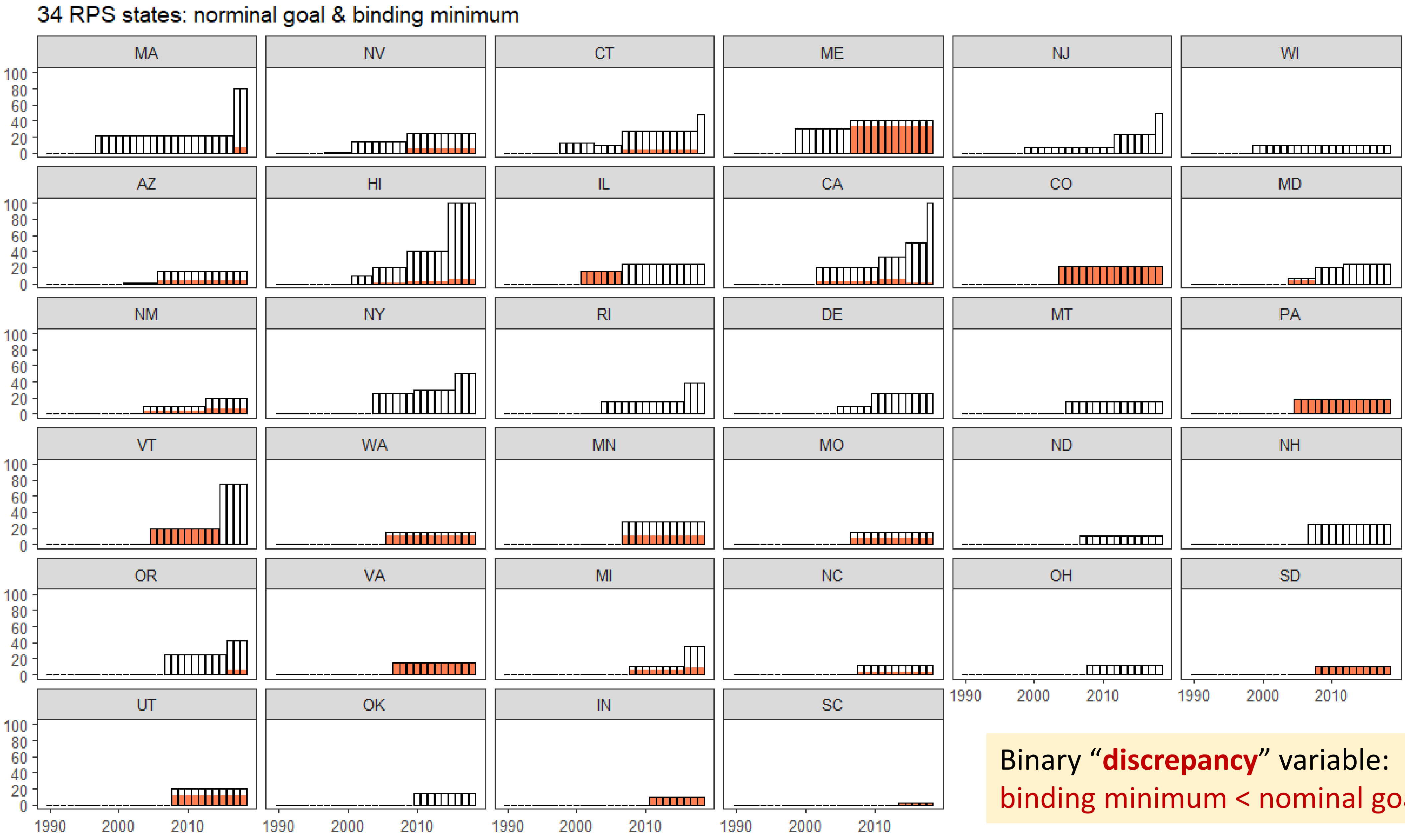
Sun and Abraham (2021)
TWFE
a.
% of Generation: Coal & Oil
b.
% of Generation: Natural Gas
c.
% of Generation: Wind
d.
% of Generation: Solar
% of Generation: Hydro & Nuc
Electricity Price
-7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7

Impact of RPS Discrepancy: 5-year average

- Following Greenstone and Nath (2022), we estimate the dynamic treatment effects summarized into 5-year periods:
  short-run (0-4 years), medium-run (5-9 years), long-run (>10 years).

$$
\begin{aligned}
Y_{s,t} = {} & \beta_1 \mathbf{1}\{0 \le \tau \le 4\} + \beta_2 \mathbf{1}\{5 \le \tau \le 9\} + \beta_3 \mathbf{1}\{\tau \ge 10\} + \\
& \gamma_1 \mathbf{1}\{0 \le \tau \le 4\} \times Discrepancy_{st} + \\
& \gamma_2 \mathbf{1}\{5 \le \tau \le 9\} \times Discrepancy_{st} + \\
& \gamma_3 \mathbf{1}\{\tau \ge 10\} \times Discrepancy_{st} + X_{s,t} + \alpha_s + \delta_t + \varepsilon_{st}.
\end{aligned}
$$

  - Partially guided by the event study graph
  - RPS targets usually become tighter over time, some with built-in soft checks (Deschenes et al. 2023)
    - 30% renewable by 2030. Interim goal of 15% by 2015, 18% by 2018, etc.

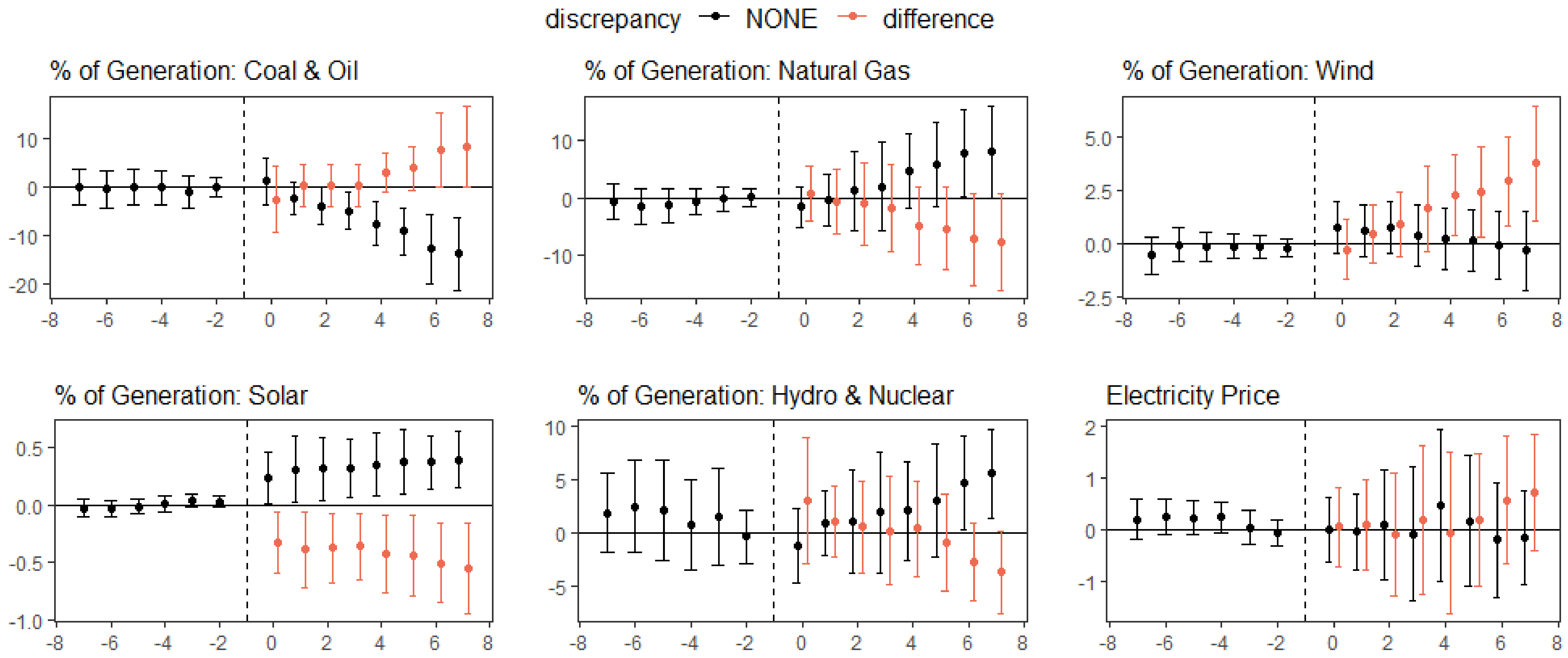


Binary "**discrepancy**" variable:
binding minimum < nominal goal

Example

- Arizona has discrepant RPS laws passed in 2001 and 2006
- Counterfactual prediction: Clean RPS laws would have led to
  - 44.6% lower SO_2 emission from electricity generation
  - 33.1% lower NO_2 emission
- With a 3% discount rate, this would lead to $171-385 million of foregone environmental co-benefit
  - Mostly from cost of mortality: $167-380 million

Difference in the dynamic treatment effect due to existence of non-stringent policy design.



What is driving the observed divergence?

Clean RPS laws lead to:

- Quick transition away from coal and oil generation
  - Driving the environmental performance of the clean RPS laws
- Partially compensated by faster growth in natural gas generation

Dirty RPS laws:

- Slower transition away from coal and oil generation (but still faster than non-RPS states)
- Small increase in wind generation

Decomposing "policy design" effect through 4 types of discrepancies

- The dynamic treatment effects are summarized into 5-year periods: short-run (0-4 years), medium-run (5-9 years), long-run (>10 years).

$$
\begin{aligned}
Y_{s,t} = {} & \beta_1 \mathbf{1}\{0 \le \tau \le 4\} + \beta_2 \mathbf{1}\{5 \le \tau \le 9\} + \beta_3 \mathbf{1}\{\tau \ge 10\} + \\
& \mathbf{1}\{0 \le \tau \le 4\} \times \left(\gamma_{e,1} E_{st} + \gamma_{v,1} V_{st} + \gamma_{m,1} M_{st} + \gamma_{c,1} C_{st}\right) + \\
& \mathbf{1}\{5 \le \tau \le 9\} \times \left(\gamma_{e,2} E_{st} + \gamma_{v,2} V_{st} + \gamma_{m,2} M_{st} + \gamma_{c,2} C_{st}\right) + \\
& \mathbf{1}\{\tau \ge 10\} \times \left(\gamma_{e,3} E_{st} + \gamma_{v,3} V_{st} + \gamma_{m,3} M_{st} + \gamma_{c,3} C_{st}\right) + \\
& X_{s,t} + \alpha_s + \delta_t + \varepsilon_{st}
\end{aligned}
$$

- **Design-specific effects** estimated by $\boldsymbol{\gamma}$ **coefficients** of the discrepancy indicators
  - Excluded sales ($E = 1$ or 0)
  - Voluntary target ($V = 1$ or 0)
  - Credit multiplier ($M = 1$ or 0)
  - Carbon exemption ($C = 1$ or 0)