
Climate Change Mitigation Policies

AEA Continuing Education
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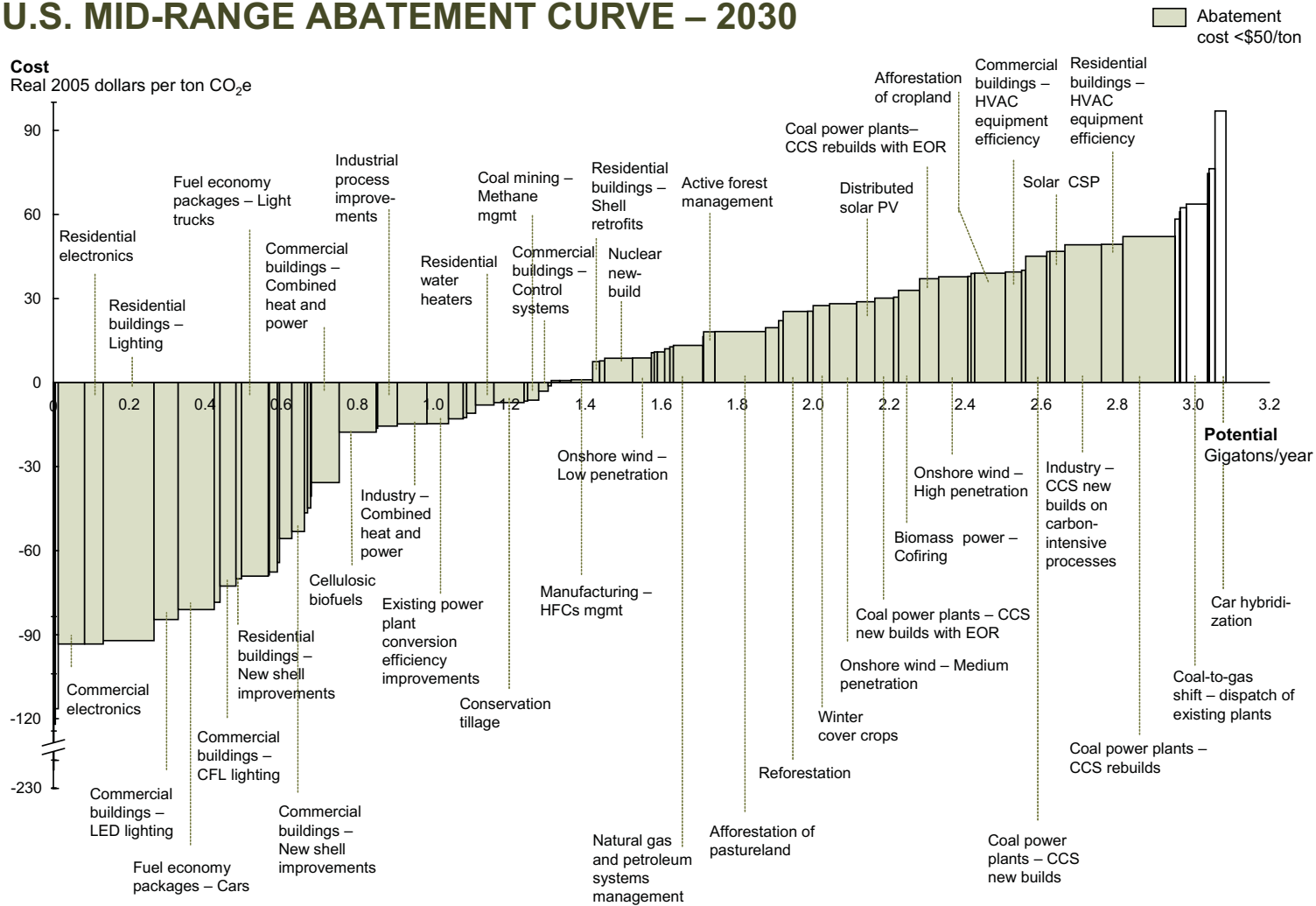
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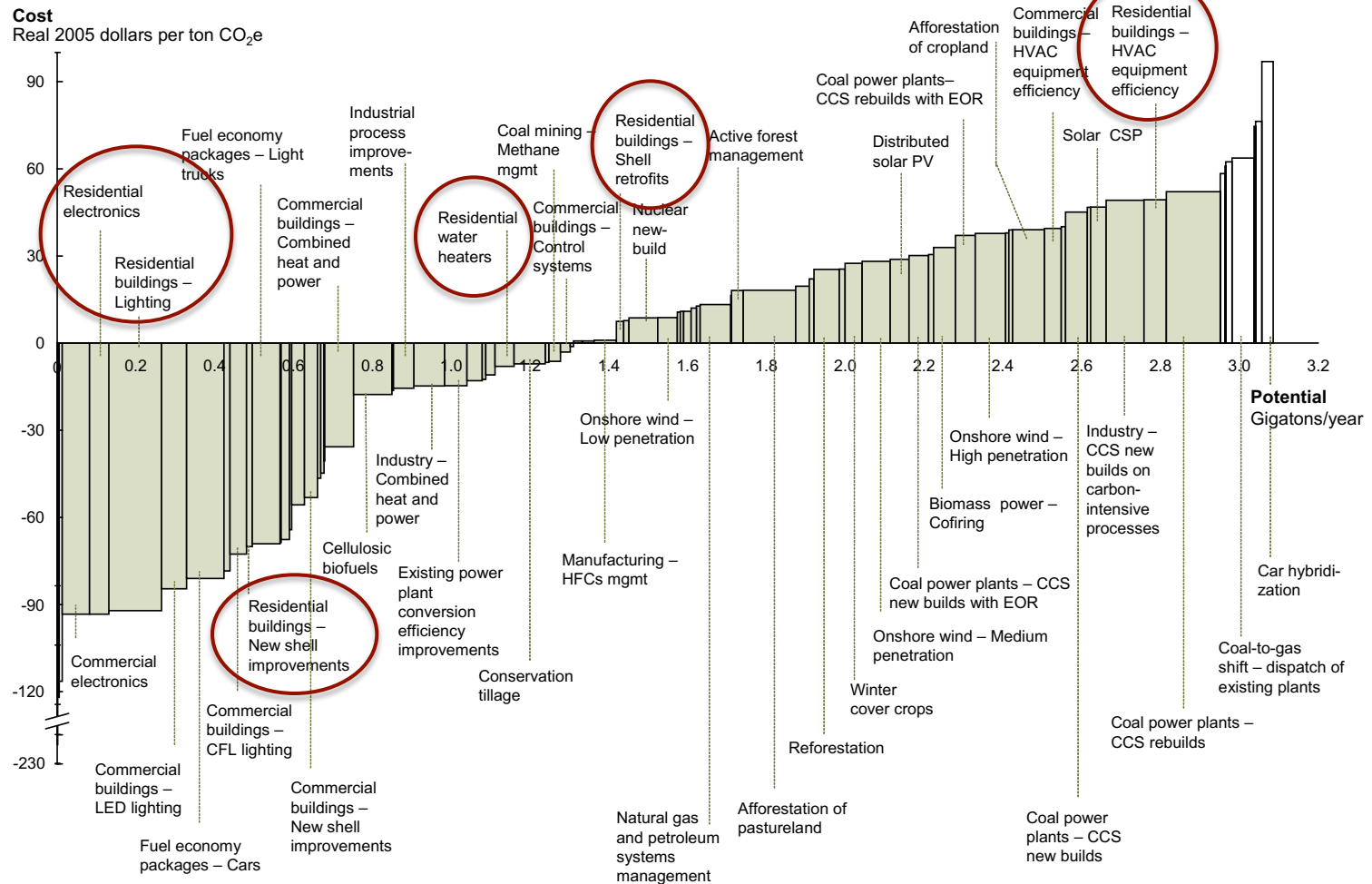
An overview of mitigation policies

1. Gillingham and Stock (2018)

U.S. MID-RANGE ABATEMENT CURVE – 2030



U.S. MID-RANGE ABATEMENT CURVE – 2030



The real world is a hodgepodge

- The economists' ideal of a carbon tax doesn't exist in a meaningful way in the real world (yet). Instead, we see an assortment of climate change mitigation policies, with a wide range of costs
 - Examples: automobile fuel economy standards, gasoline taxes, mandating generation from renewables, etc.
- By arranging the available set of policies in increasing cost order, we can trace out the marginal abatement cost ("MAC") curve
 - Engineering costs vs economic costs

Engineering costs for the power sector

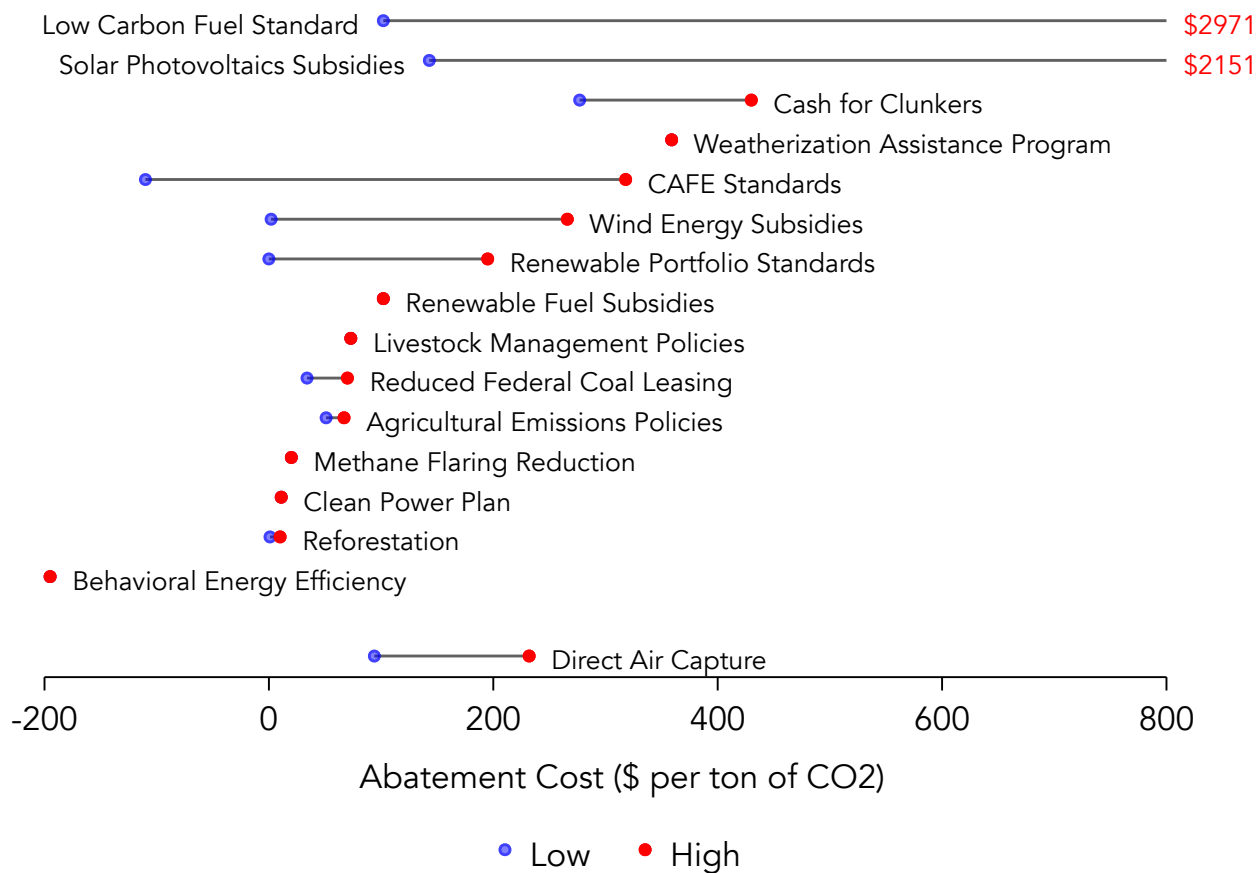
These estimates compare the cost per ton of CO₂ abated by replacing electricity generated by an existing coal-fired power plant with electricity generated by a cleaner alternative

<i>Technology</i>	<i>Cost estimate (\$2017/ton CO₂)</i>
Onshore wind	24
Natural gas combined cycle	24
Utility-scale solar photovoltaic	28
Natural gas with carbon capture and storage	42
Advanced nuclear	58
Coal retrofit with carbon capture and storage	84
New coal with carbon capture and storage	95
Offshore wind	105
Solar thermal	132

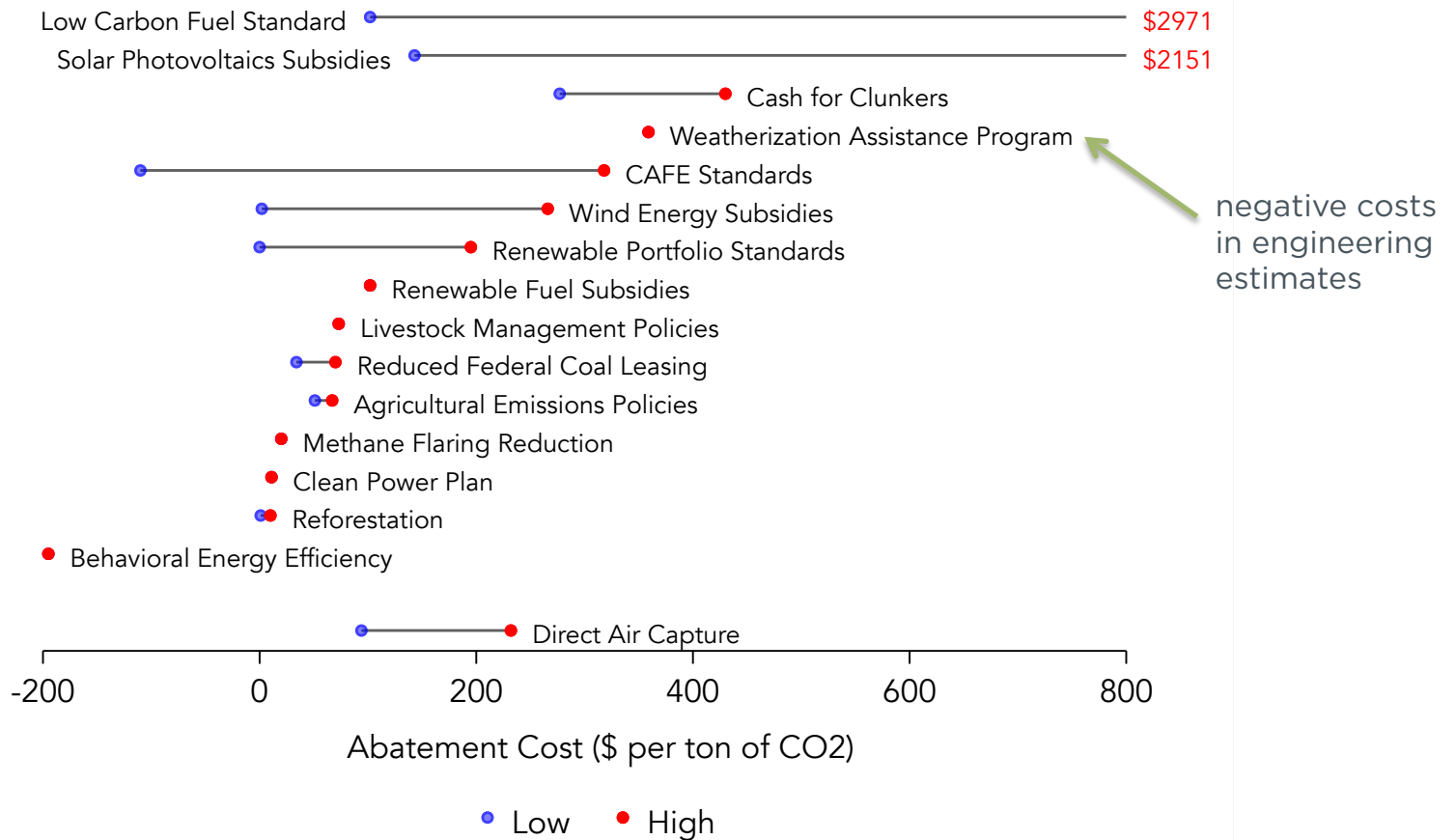
Limitations of engineering costs

- Uncertainty around cost estimates, due to:
 - Emerging/new technologies
 - Regional variations
- More importantly, these are the costs of *switching* technologies, which differ from the costs of a policy designed to encourage technology switching
 - Engineering cost estimations do not incorporate behavioral responses or any indirect emissions
- Economics literature is focused on the costs of interventions/policies

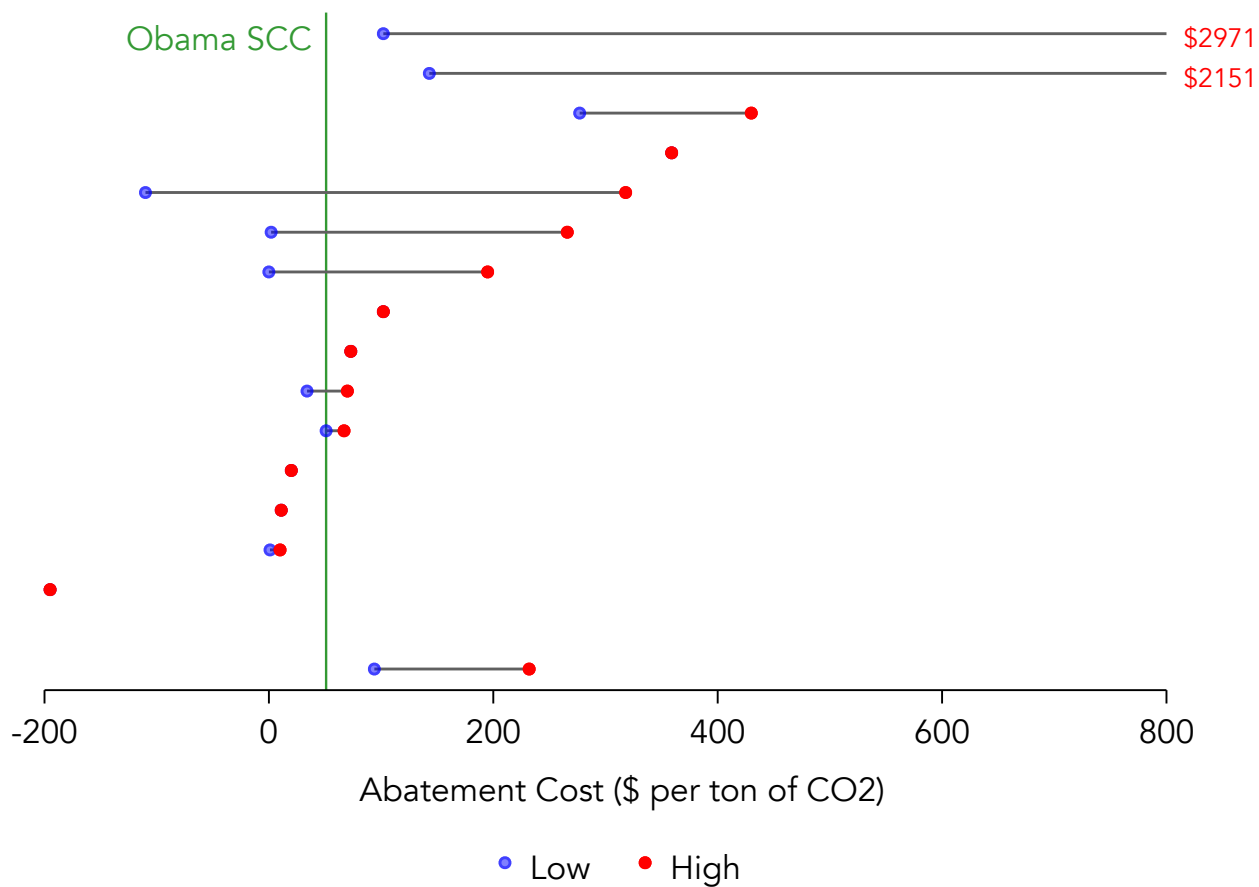
Cost of abatement



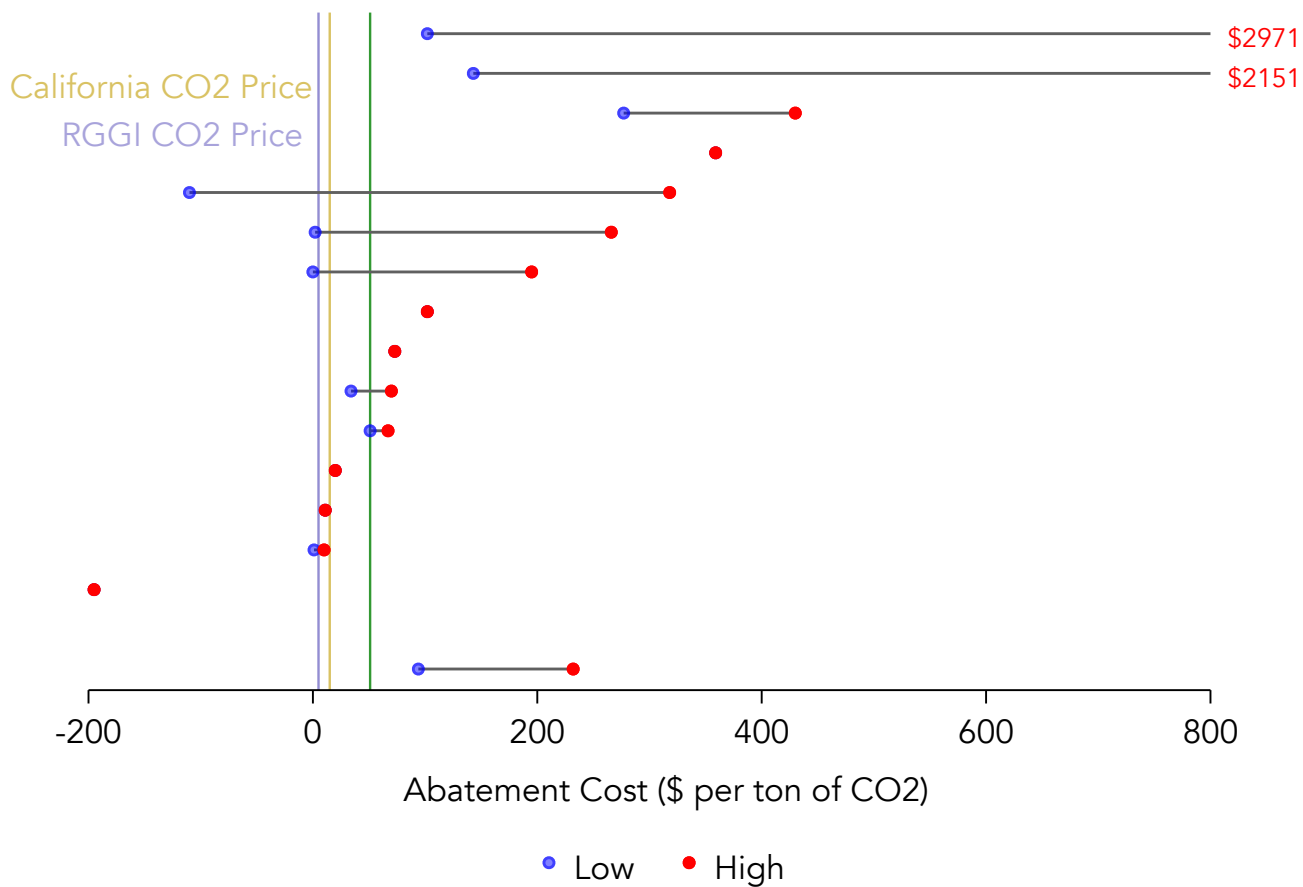
Cost of abatement



Cost of abatement



Cost of abatement



Static vs dynamic costs

- Most existing economic analyses focus on static costs, which is defined as the costs incurred today to reduce short-run emissions
- Static costs ignore the dynamic implications of actions today for future mitigation, which can be very significant
 - Example: Solar panels and electric vehicles

Case study: solar panels

- Early panel purchases (from mid 2000s) were very expensive and account for some of the high photovoltaic cost estimates
- From 2010 to 2015, the price of solar photovoltaic panels fell by two-thirds, while annual global panel installations grew by 250 percent
- Timing and recent research suggest that the early push in demand, stimulated by deep government subsidies, helped to drive down the price of solar panels
 - Current investment in R&D to reduce future costs
 - Learning-by-doing
 - Economies of scale
- There are also important geographical spillovers. For example, early German and Californian subsidies reduced solar costs for the rest of the world

Case study: electric vehicles

- The static costs for CO₂ reductions from electric vehicles are high
 - The optimal EV subsidy in many US states is actually negative, after accounting for emissions from electricity generation
- From a dynamic perspective, EV support may still make sense
 - The grid is evolving and getting cleaner
 - The forces at play for reducing solar panel costs also apply to EVs
 - Recent data suggest that recent EV models have lower costs and greater battery range, which underscores rapid technological improvements
- EVs exhibit a network effect, where demand today leads to more charging stations which in turn lowers the cost of owning an EV in the future

→ Key Challenge is that we rarely evaluate policies and instead rely on engineering analyses and projections

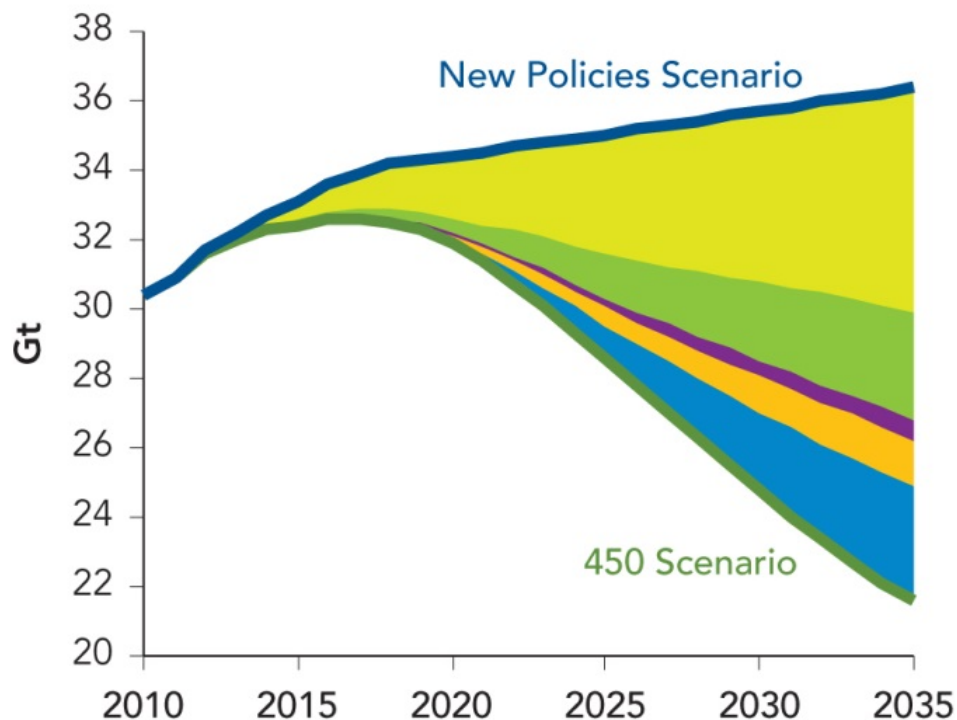
Do energy efficiency investments deliver? Evidence from the weatherization assistance program

1. Fowlie, Greenstone, Wolfram (2018)

Motivation:

Energy efficiency is part of every GHG mitigation plan

GHG Mitigation Scenarios



	Abatement	
	2020	2035
Efficiency	72%	44%
Renewables	17%	21%
Biofuels	2%	4%
Nuclear	5%	9%
CCS	3%	22%
Total (Gt CO₂)	2.5	14.8

Sources: IEA World Energy Outlook (2011)

Energy efficiency “gap”

- Improving energy efficiency can reduce costs for consumers (net of upfront investments) and help the environment
- Yet, households and firms routinely overlook these apparently cost effective investments in energy efficiency
- What’s going on?
 - Common theories make use of market failures (e.g. asymmetric information, split incentives problems) and behavioral explanations (e.g. myopia, bounded attention)

Three research objectives

- Conduct a large-scale field experiment designed to measure the real-world returns on investments in residential energy efficiency improvements
- Construct valuation measures that account not only for energy savings, but also consumers' valuation of warmer indoor temperatures
- Assess the rate of return on investments in energy efficiency from both a private and social perspective



Conceptual framework

- Returns on investment in energy efficiency are realized through two main channels:
 - Reductions in energy expenditures
 - Potentially, an increase in consumption of energy service in response to reduced cost
- A simple theoretical framework underlies our approach to measuring value associated with each

Federal weatherization assistance program (WAP)

- The largest residential energy efficiency program in the country
- Weatherization retrofits (including insulation, furnace replacement, infiltration reduction) are provided for free to eligible households
- An estimated 7 million U.S households have participated in the program
- Average expenditure/hh cannot exceed \$6,500
- Participating households receive a free energy audit/survey of building envelope characteristics
- Audit data used to calibrate a detailed building simulation model (NEAT)
- In order for a measure to be implemented, the “cumulative” savings:investment ratio must be 1 or greater



Source:
<http://www.princegeorgescountymd.gov/>

Study location: Michigan

- Michigan's cold winters and large low income population make it one of the "most deserving" recipients of WAP funding
- Michigan received over \$200 M in ARRA funding to support weatherization assistance between 2011 and 2013

Research design

- To estimate the causal impacts of weatherization we need a credible estimate of counterfactual household energy consumption
- We take two complementary strategies:
 - Randomized encouragement design (“RED”): Instrument for program participation using a randomly assigned encouragement intervention
 - Quasi-experimental design: Use data from all applicant households across five Michigan counties

Data

Two overlapping groups of households:

- Experimental sample of 34,161 households assigned to the encouraged or control groups
- Quasi-experimental sample: 7,304 WAP applicants
- 1,773 households lie in the intersection of our experimental and quasi-experimental sample

Three key data sources:

- Monthly energy consumption (natural gas and electricity) data from partner utility: 2008-2014
- Application and efficiency audit data obtained from implementing agencies
- Novel household survey on indoor temperature and thermostat settings

Data: WAP program

From all households that applied for weatherization assistance from Feb 2011 to May 2012, we have collected:

- Detailed demographic information
- Household energy audit data
- Engineering estimates of baseline energy use, installation costs, and energy savings
- Work order/job report information

Visual overview of our experiment

Start with a sample of 34,161
presumptively eligible households

Visual overview of our experiment

Randomly assign 25 percent to an “encouragement” treatment N= 8,648	Simply observe the control group N=25,513
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Randomized encouragement design (RED)

A RED is well-suited to this context:

- Non-random selection into energy efficiency treatment can introduce bias
- Mandatory assignment/direct manipulation of participation status is not practical/desirable/feasible
- The effects of both participation and outreach/encouragement are of policy interest
- We expect that an encouragement intervention will significantly affect probability of treatment

Key RED identifying assumptions

- **Unconfoundedness:** Satisfied (in expectation) by design
- **SUTVA:** Energy consumption at household i is affected by the weatherization status of household i but not the participation decisions of other households
- **Exclusion restriction:** Encouragement intervention affects potential outcomes only through effect on program participation
- **Monotonicity:** There are no defiers (i.e. households for whom our encouragement *reduces* the likelihood of participation)

Our encouragement intervention

- We issued an RFP to identify a firm specializing in grassroots mobilization and outreach
- Fieldworks LLC has extensive experience with designing communication strategies and managing neighborhood canvassing operations
- Michigan-based Fieldworks staff helped us develop a persuasive recruit-and-assist strategy, cut turf, hire local people from the community, support staff on the ground, and manage field operations

Encouraging households to get weatherized

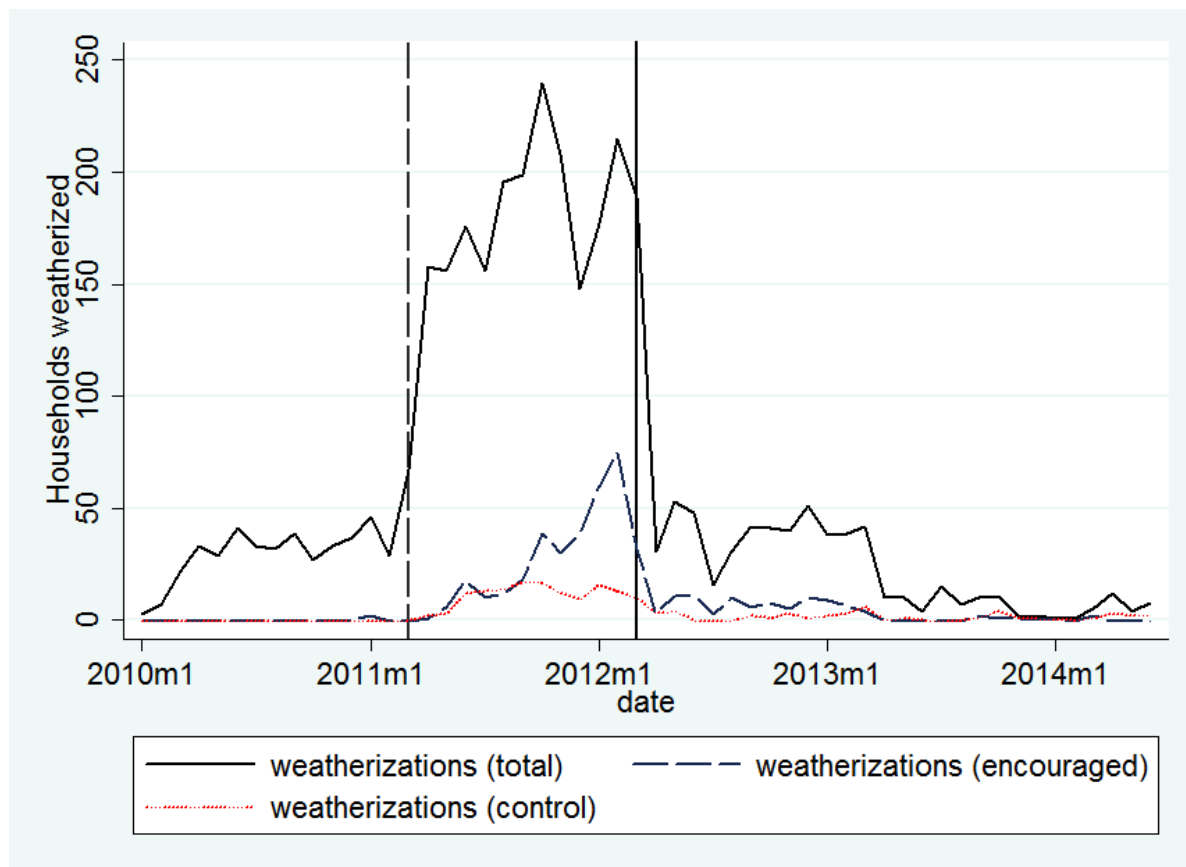
Randomized Encouragement Intervention	
Encouraged group (households)	8,648
Initial home visits	6,694
Robo-calls	23,500
Personal calls	9,171
Follow-up appointments	2,720
Average cost/encouraged hh	\$55.00

Notes: The table summarizes efforts to encourage a group of Michigan households to take up weatherization assistance. These households were selected randomly from a subpopulation of households who were located in the service territory of our partner utility and presumptively eligible based on ex ante available income information

Returns on encouragement effort

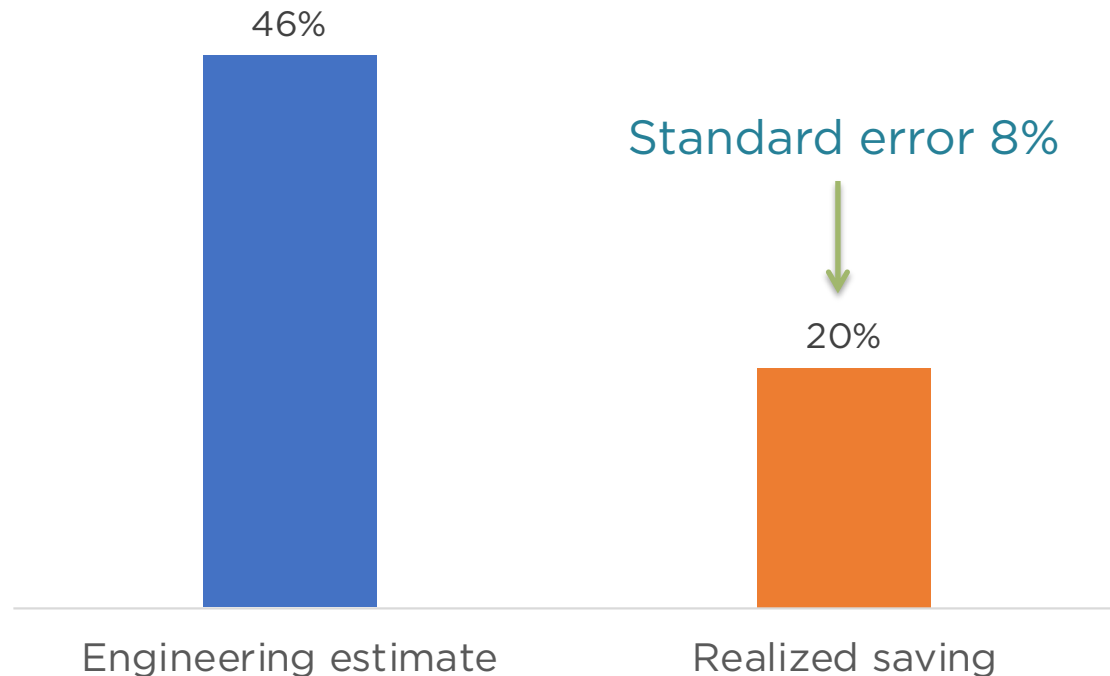
	Application	Efficiency audit	Weatherization complete
Base rate	0.02** (< 0.01)	0.01** (< 0.01)	0.01** (< 0.01)
Encouragement	0.13** (< 0.01)	0.05** (< 0.01)	0.05** (< 0.01)
Households	28,888	28,888	28,888

Weatherizations per month



Notes: Aggressive encouragement campaign ran March-May 2011. Enrollment campaign ran May 2011-Feb 2012

Weatherizations reduced energy consumption



... but not by as much as ex-ante engineering estimates had predicted.

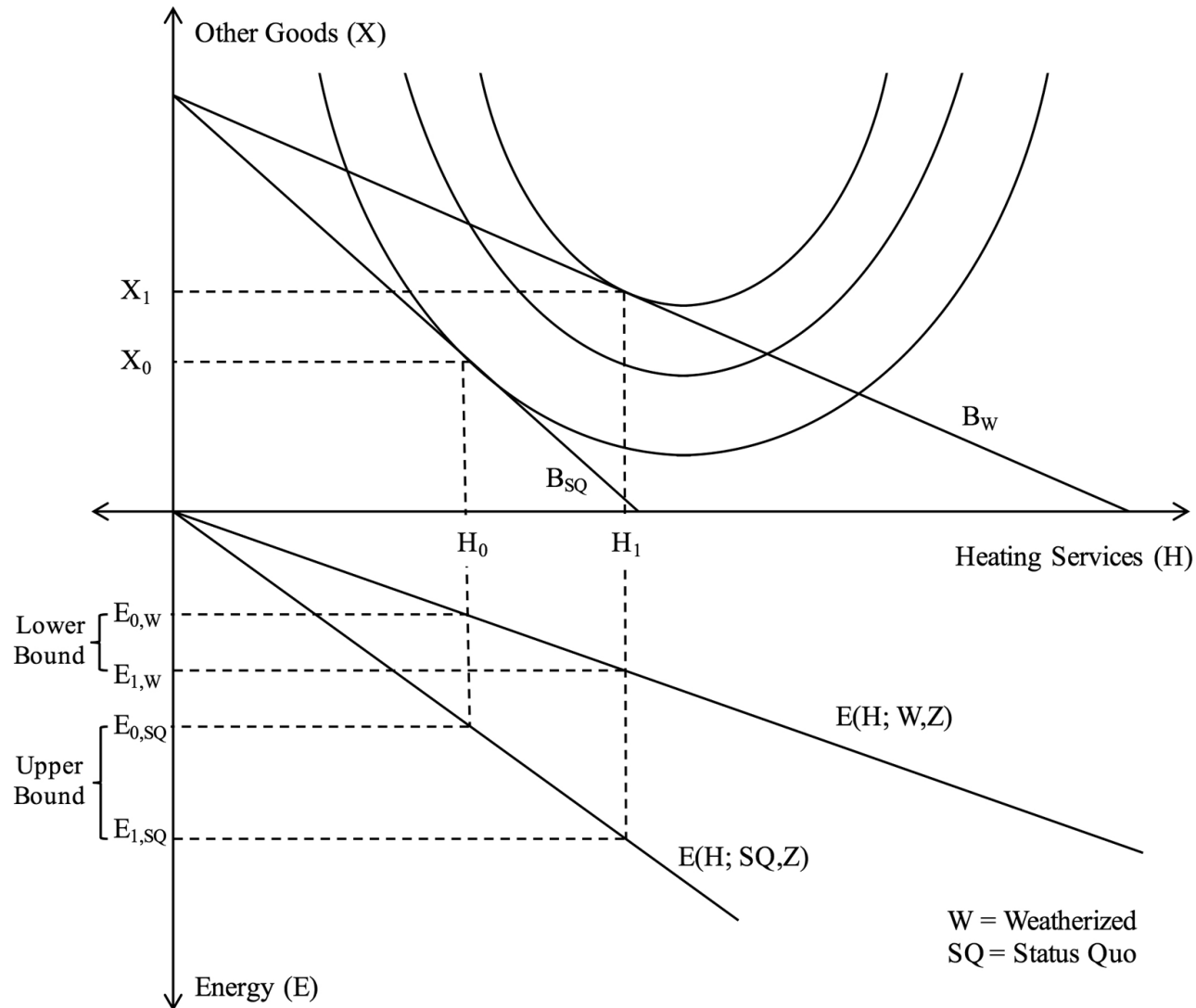
Investments were not cost-effective on average

Present value of discounted savings based on RED savings estimates

Time horizon	Real discount rate		
	3%	6%	10%
10 years	\$1,983	\$1,711	\$1,428
16 years	\$2,920	\$2,349	\$1,819
20 years	\$3,459	\$2,666	\$1,979

Average investment in efficiency measures: \$4,585

Rebound effect: theory



Rebound effect: Findings from an indoor temperature survey

	Thermometer		Thermostat	
	(1)	(2)	(3)	(4)
Indoor temperature response to weatherization				
Base temperature	72.36** (0.95)	72.17** (1.25)	69.26** (0.96)	68.96** (1.37)
Weatherized home	0.57 (0.41)	0.67 (0.44)	−0.57 (0.29)	−0.57 (0.32)
Heating degree days	−0.16** (0.03)	−0.15** (0.04)	0.04 (0.03)	0.05 (0.04)
Propensity score weights?	N	Y	N	Y
<i>R</i> -squared	0.02	0.02	0.01	0.01
Observations	1,359	1,359	899	899

Estimated returns on energy efficiency investments

Time horizon	Ex ante (NEAT) projections (1)	Empirical estimates (2)
Panel A: Private internal rate of return		
10 years	7.0%	−10.6%
16 years	11.9%	−2.3%
20 years	13.0%	0.21%
Panel B: Private internal rate of return, adding the avoided emissions damages		
10 years	11.4%	−7.6%
16 years	15.5%	0.1%
20 years	16.4%	2.3%
Panel C: Social internal rate of return		
10 years	−3.9%	−17.8%
16 years	3.1%	−7.8%
20 years	5.0%	−4.6%

Estimated returns on energy efficiency investments

Time horizon	Ex ante (NEAT) projections (1)	Empirical estimates (2)
Panel D: CO ₂ abatement cost, 3% discount (\$/ton CO ₂)		
10 years	\$85	\$322
16 years	\$38	\$201
20 years	\$22	\$161
Panel E: CO ₂ abatement cost, 7% discount (\$/ton CO ₂)		
10 years	\$117	\$404
16 years	\$71	\$285
20 years	\$56	\$248

Conclusions

- Energy efficiency is a tough sell to low-income consumers, even if it's free
- WAP reduces energy consumption, but not as much as engineering models predict
- We find no evidence of a “rebound effect,” so this does not reconcile field and engineering estimates
- Engineering models may systematically overstate savings

Do renewable portfolio standards deliver?

1. Greenstone and Nath (WP)

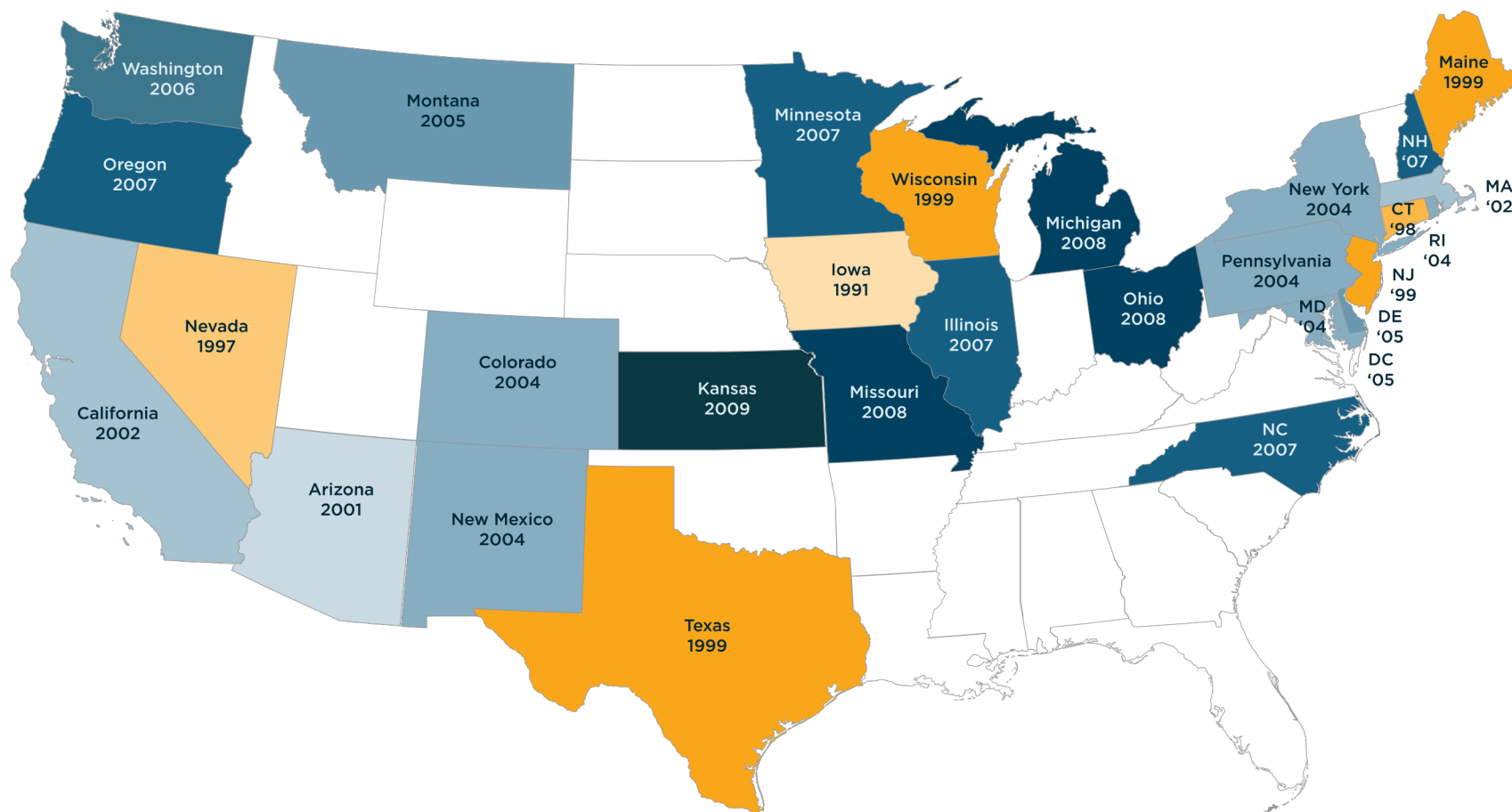
Does the cost per ton of CO₂ abated matter?

- To meet its Paris (2025) commitments, US needs to reduce CO₂ emissions by 2.35 billion tons from 2020 through 2025

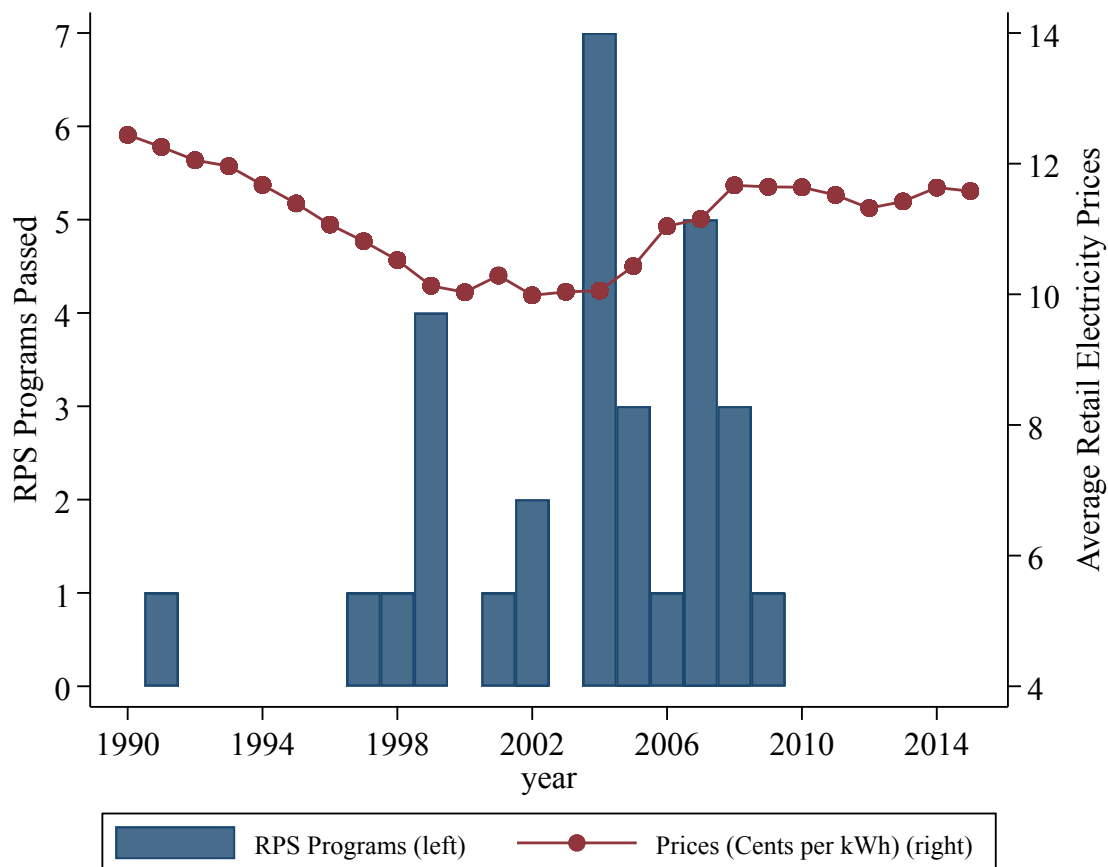
Does the cost per ton of CO₂ abated matter?

- To meet its Paris (2025) commitments, US needs to reduce CO₂ emissions by 2.35 billion tons from 2020 through 2025
- Given current prices, in 2019 dollars, how much would it cost?

Renewable portfolio standards, by year of passage



Number of RPS Programs Newly Passed into Law, by Year



Data: state and REC-region datasets

- Our main dataset is a state-level panel from 1990 to 2015 with data on RPS programs, electricity prices, generation and pollutant emissions
 - We believe this is the most comprehensive dataset ever compiled on RPS programs and their potential outcomes
 - Sources include EIA, EPA, FERC, state program websites, LBNL, DoE, DSIRE, and AQLI
- To account for cross-border spillovers in generation and pollution, we aggregate the state-level dataset to the REC-region-level
 - We sum up sales, generation and capacity
 - We take a weighted mean of state-level characteristics such as price, dummies for control programs, etc, with state-level generation as the weight

Data: robustness and mechanisms

- To better capture the geographical boundaries of electricity markets, we also create an ISO-level panel dataset
 - An independent system operator is responsible for balancing power in real-time across a geographical area
 - We take utility-level data and match each utility to the set of ISOs to which it delivers power
- To uncover mechanisms through which RPS programs can influence consumer prices, we compile two more state-level panel datasets from:
 - Utilities' self-reported financials
 - Generator-level data on prime movers and fuel types, including a designation for peaker generation

Summary statistics on RPS programs

Number of RPS states: 29

Median year of passage: 2004

Percent of RPS programs that include:

Wind 100%

Solar 100%

Biomass 100%

Landfill gas 100%

Hydro 90%

Geothermal 77%

Ocean/Tidal 63%

Net req after 7 years:

Mean 2.2%

(Minimum, Maximum) (0.0%, 12.9%)

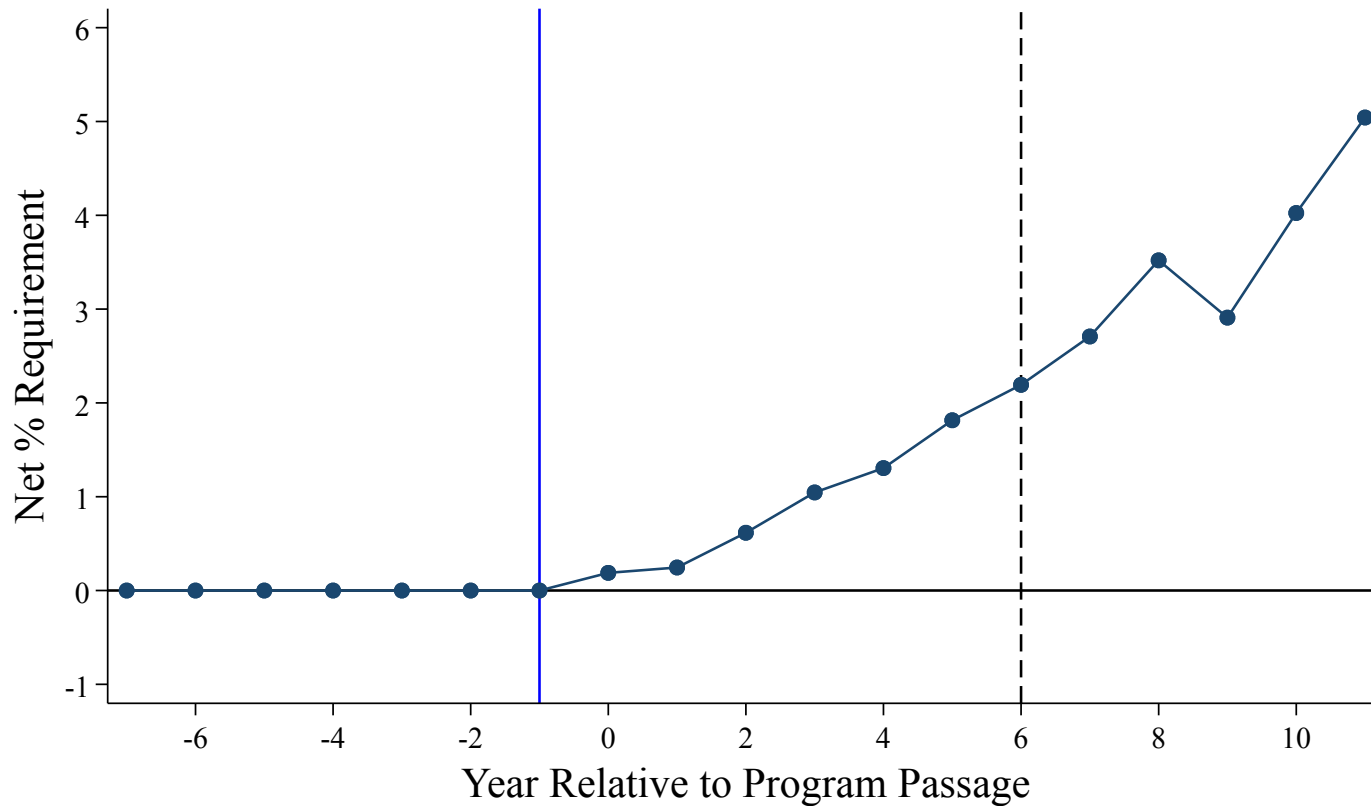
RPS emissions¹:

% of US total 19.5%

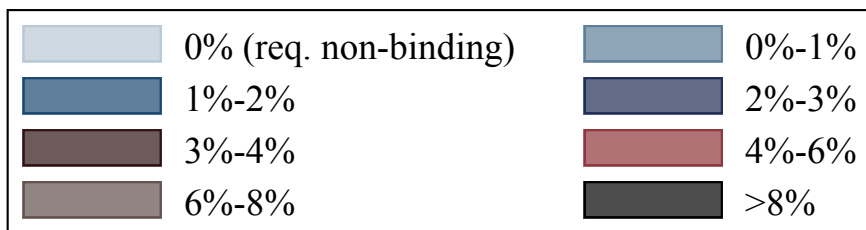
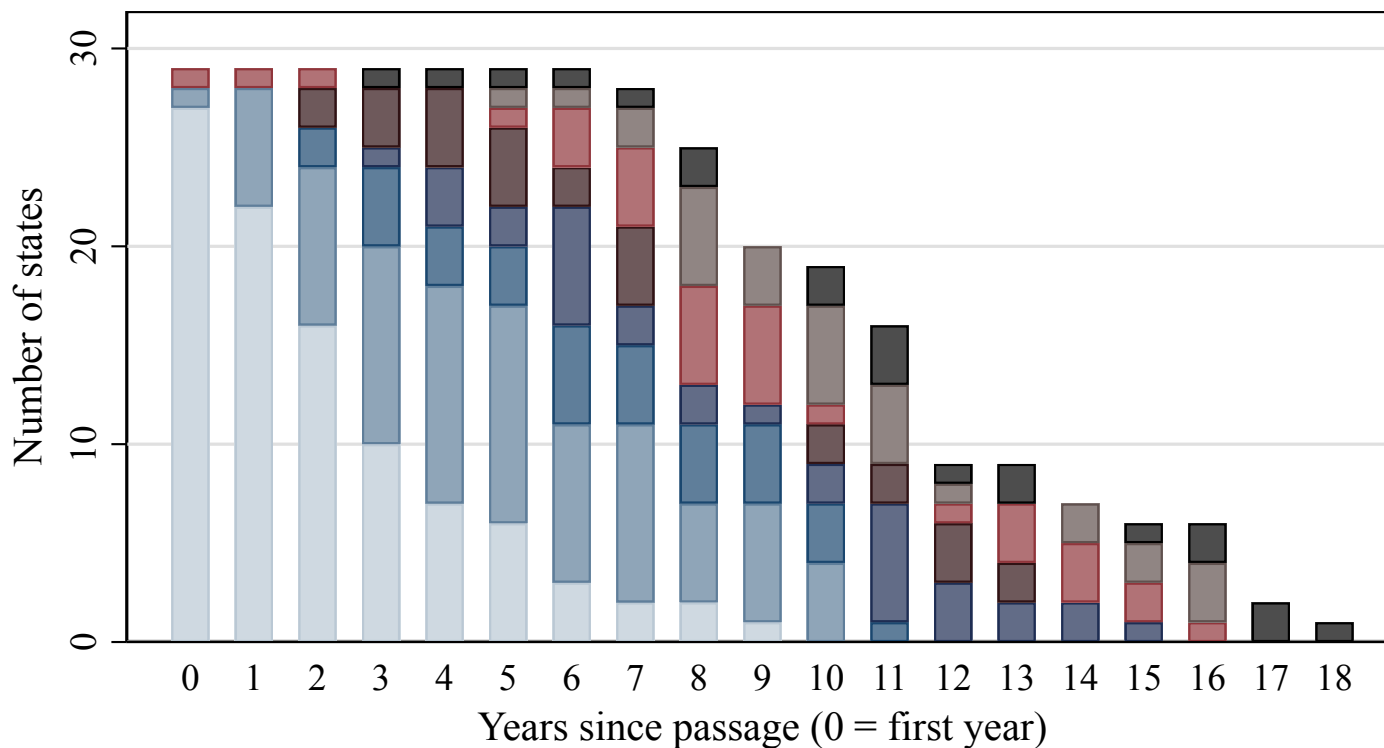
% of US electricity 55.9%

¹ As a point of comparison, Cap-and-Trade programs (RGGI and CA) cover 9.1% of total US CO₂ emissions

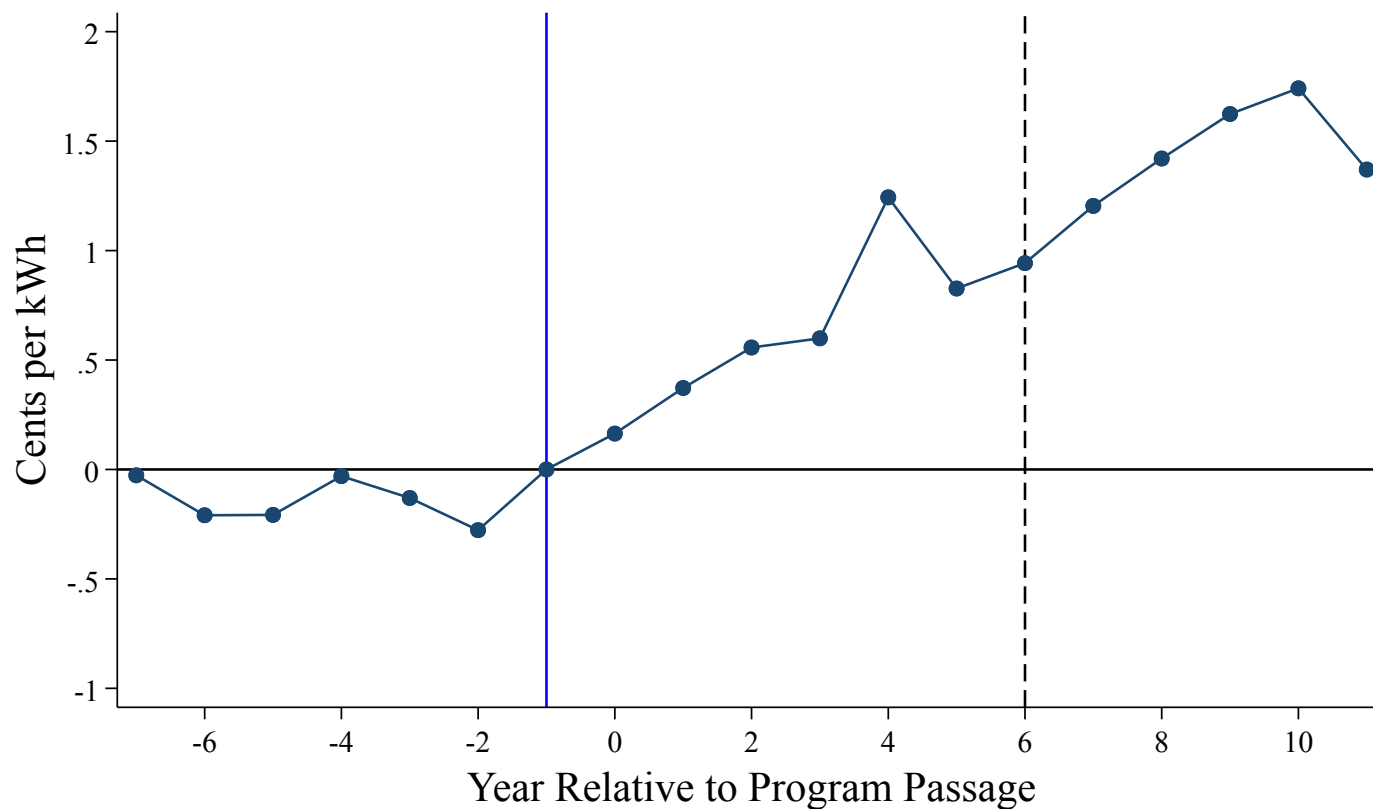
Result #1: RPS mean net requirements



RPS net renewable requirements distribution



Result #2: RPS effect on electricity prices



Result #2: RPS effect on electricity prices

	Average Retail Price	
	(1a)	(1b)
<i>Panel A: 7 Post-Passage Years, Balanced Sample</i>		
Mean Shift (δ_3)	0.72 (0.44)	0.36 (0.23)
Trend Break (β_3)		0.14 (0.09)
Effect of RPS 7 years after passage ($6\beta_3 + \delta_3$)		1.22** (0.58)
<i>Panel B: 12 Post-Passage Years, Unbalanced Sample</i>		
Mean Shift (δ_3)	0.78 (0.49)	0.39 (0.28)
Trend Break (β_3)		0.14** (0.07)
Effect of RPS 12 years after passage ($11\beta_3 + \delta_3$)		1.91** (0.77)
Mean at $\tau = -1$	11.4	11.4
State FE	Yes	Yes
Year FE	Yes	Yes
Other Programs	Yes	Yes
N	1300	1300

Result #3: RPS effect on CO₂ intensity

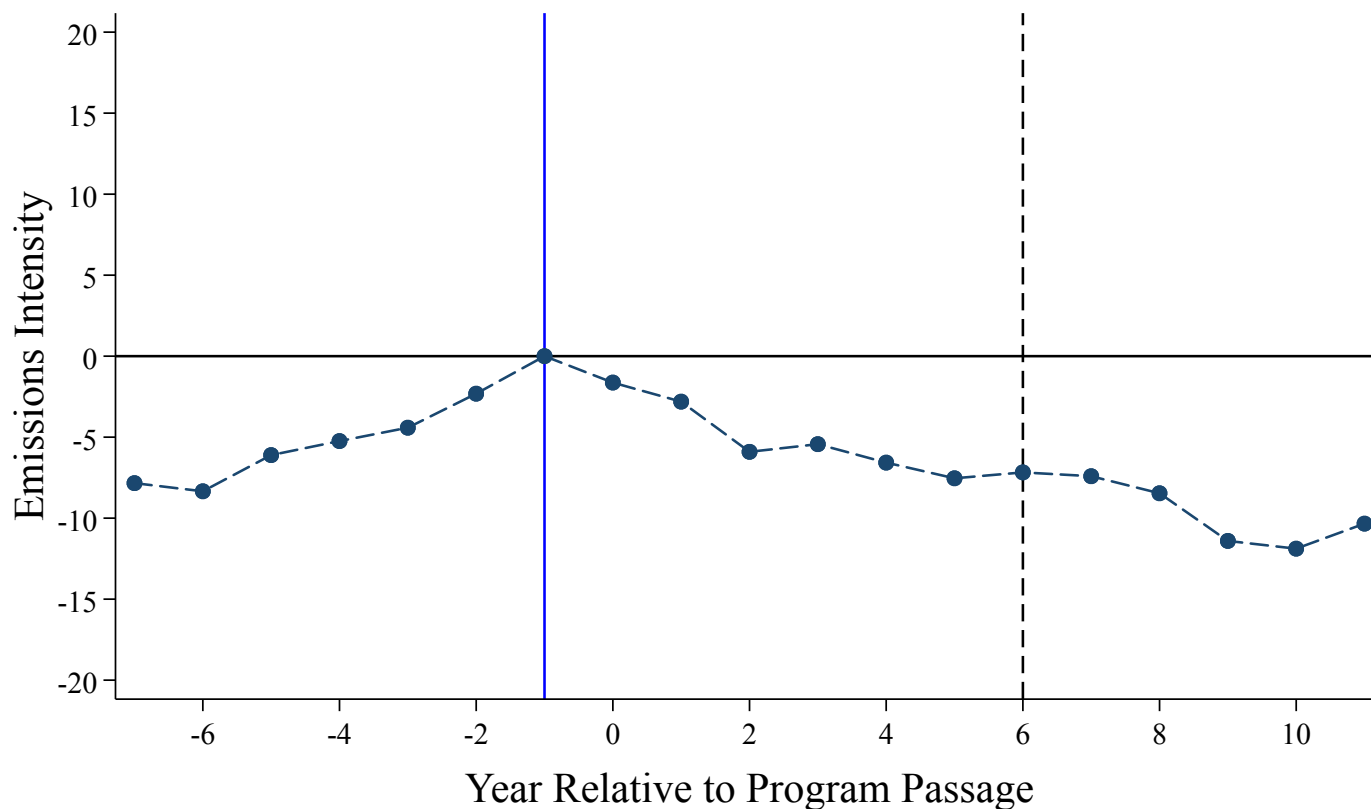
- We define CO₂ intensity as emissions (in mt) divided by generation (in MWh)
- To capture cross-state spillovers, we use a weighted mean to aggregate the intensity to the REC-region-level, using state-level generation as the weight

Result #3: RPS effect on CO₂ intensity

	CO ₂ Intensity (1)
<i>Panel A: Unweighted</i>	
Effect of RPS 7 years after passage ($6\beta_3 + \delta_3$)	-8.37** (3.55)
Effect of RPS 12 years after passage ($11\beta_3 + \delta_3$)	-17.68*** (5.71)
<i>Panel B: Weighted</i>	
Effect of RPS 7 years after passage ($6\beta_3 + \delta_3$)	-16.87** (7.30)
Effect of RPS 12 years after passage ($11\beta_3 + \delta_3$)	-26.84** (10.08)
Mean at $\tau = -1$	64.24
Region FE	Yes
Year FE	Yes
Other Programs	Yes
N	312

Notes: “weighted” refers to using state count as regression weight; “unweighted” has no regression weight

Result #3: RPS effect on CO₂ intensity



Notes: these estimates come from using the REC-region-level dataset, which is aggregated from the state-level dataset. We furthermore use state count as the regression weight in this specification

Cost per ton of CO₂ abatement

	Cost per ton abated (regression weight: state count)	Cost per ton abated (regression weight: none)
Cumulative effect in first 7 years	\$75	\$204
7 years after legislation (29 RPS states)	\$68	\$136
12 years after legislation (16 RPS states)	\$69	\$105

Calculation methodology: we take the estimated impact of RPS on CO₂ intensity and scale by the actual generation 7 (or 12) years after legislation to get the counterfactual total reduction in CO₂. To get the total cost for this reduction, we take the estimated price impact of RPS on end-consumers and scale by the actual quantity of electricity sales 7 (or 12) years after legislation. The abatement cost per ton is calculated as the total cost (in \$) divided by the total reduction (in mt)

It is critical to know the real world costs of these different approaches to CO2 abatement

