Subsidizing Mass Adoption of Electric Vehicles: Quasi-Experimental Evidence from California

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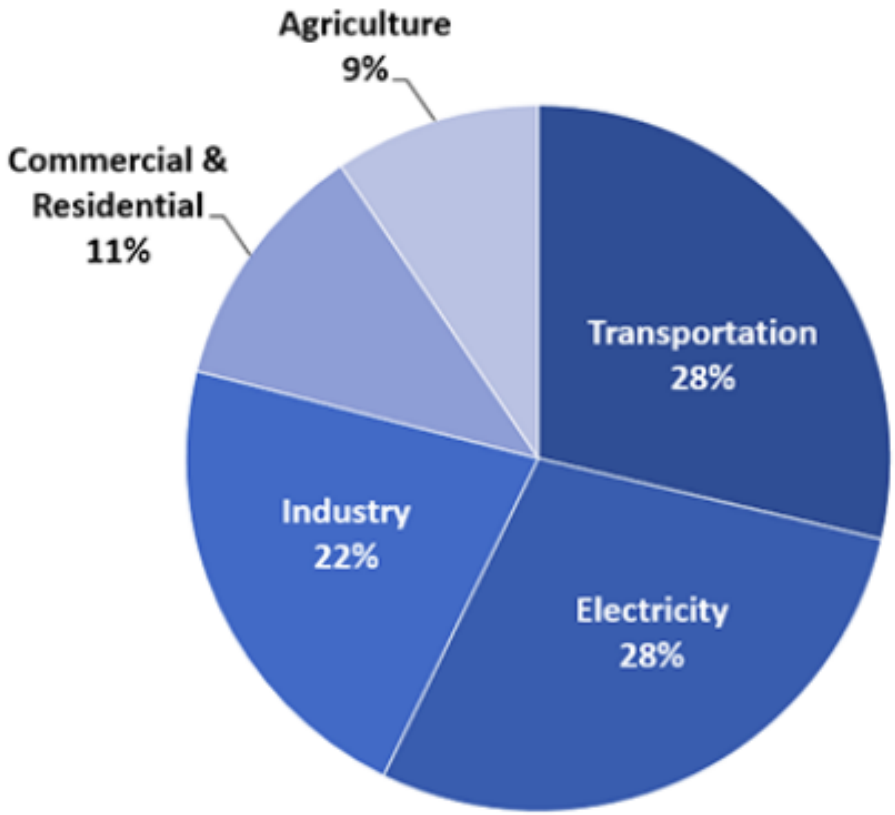
May 3, 2019

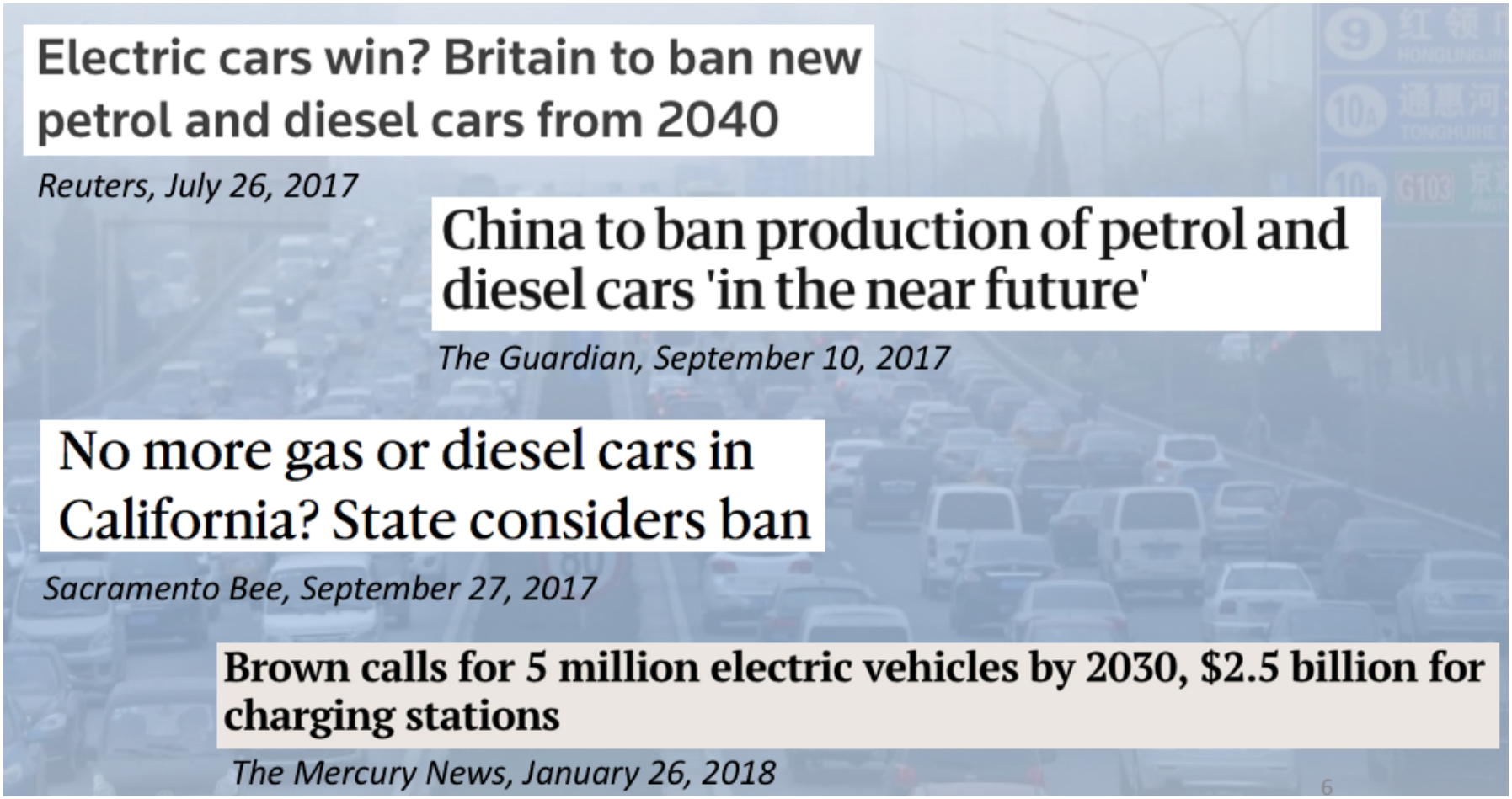
Context: Transportation Emissions

Figure: US GHG Emissions by Sector (EPA 2016)



Context: Ambitious Targets

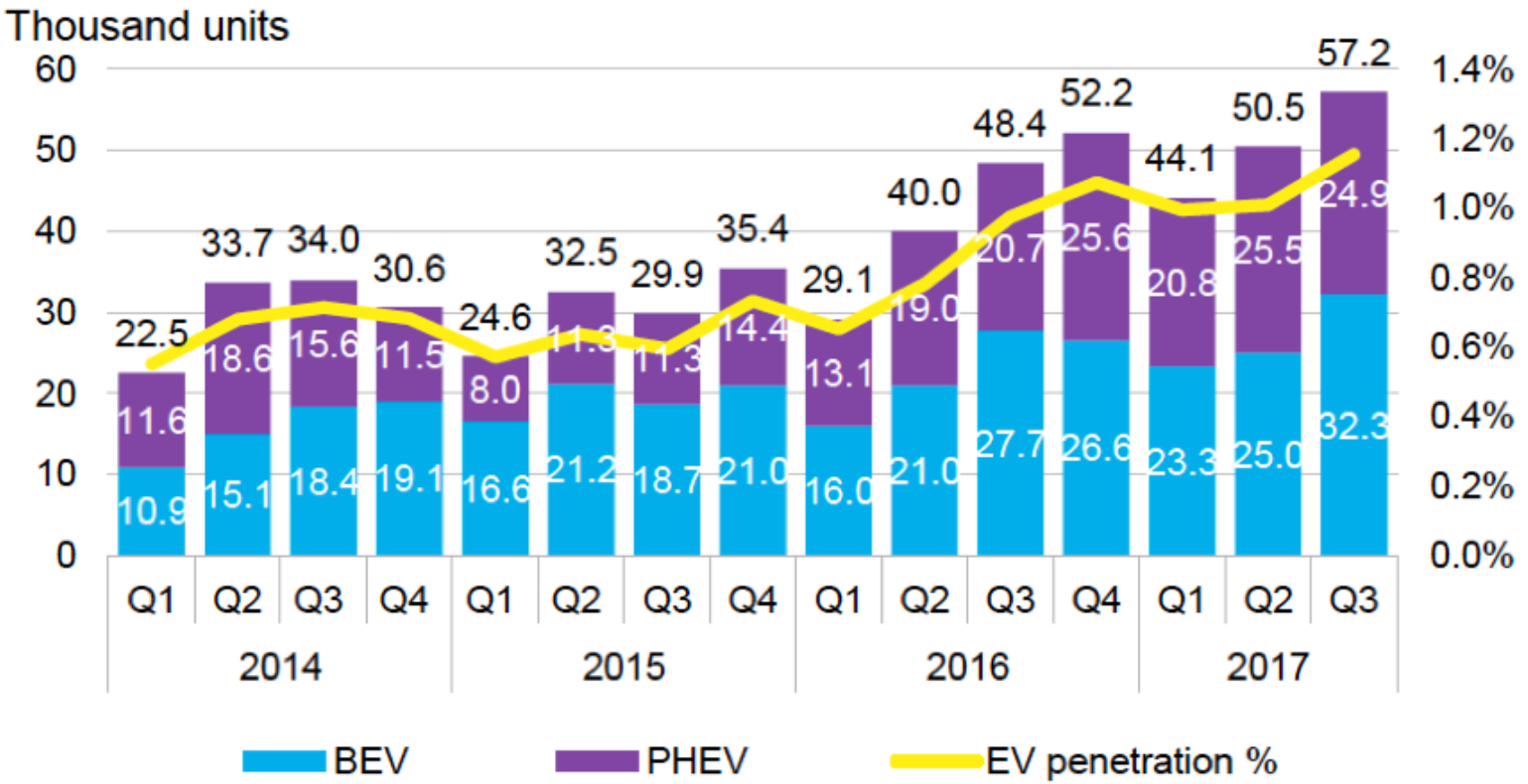
Do bold proclamations reflect genuine policy objectives?



Context: EVs are a growing share of the fleet

EVs are a small but growing share of the light vehicle fleet

Figure: North America BEV and PHEV sales

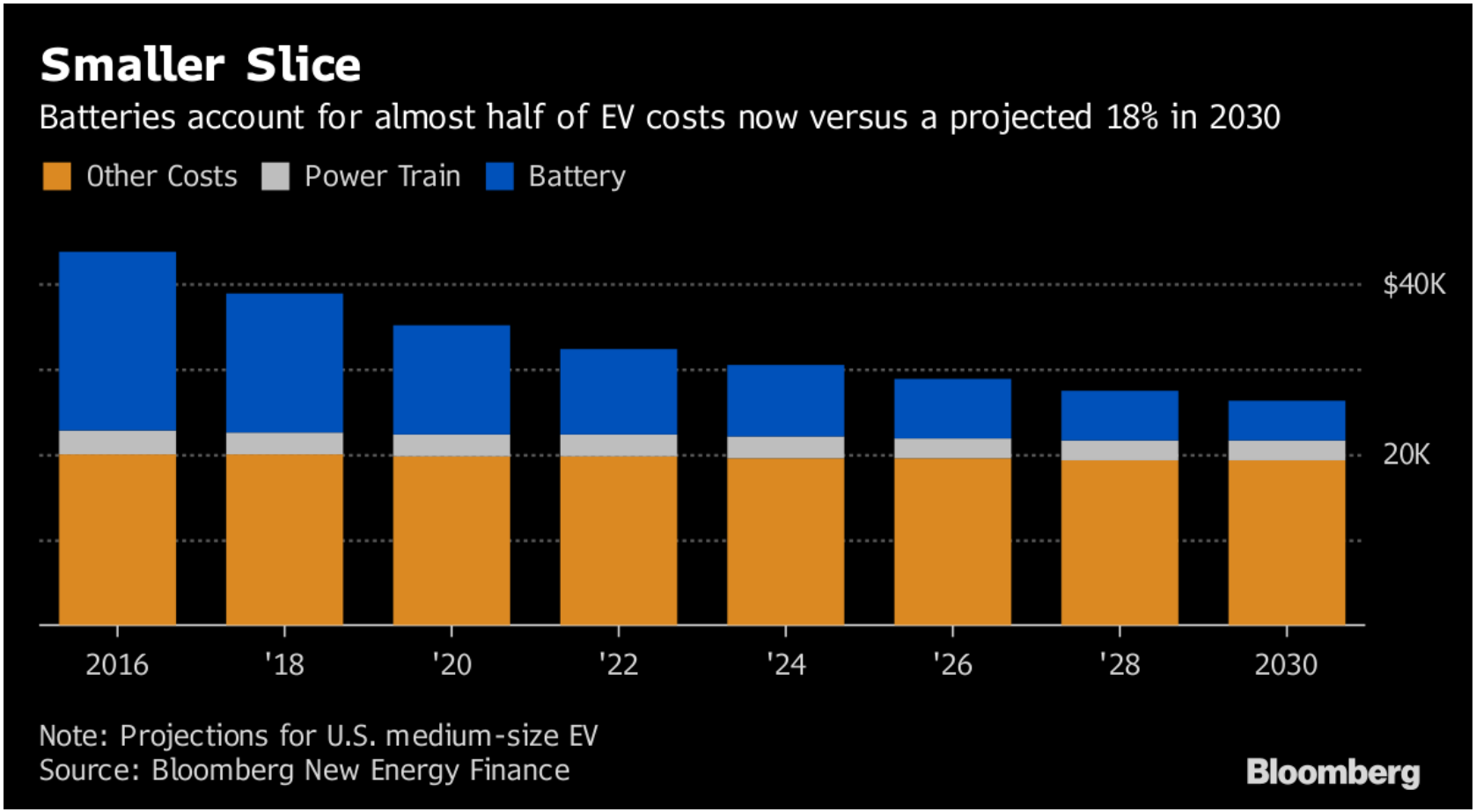


Source: Bloomberg New Energy Finance, MarkLines, automakers, vehicles registration agencies.

Context: EVs are costly

Primarily due to battery costs

- Invoice price of Nissan Leaf is $30,000 vs $14,000 for Nissan Versa



Context: EV stimulus entails substantial costs

- California has set a target of:
  - 1.5 million EVs in CA by 2025; 5 million by 2030
  - Reduce transportation emissions by 50% by 2030
  - CA has spent $388 million on EV incentives via the Clean Vehicle Rebate Project (CVRP) since 2010
  - Recent CA proposal would allocate another $3 billion.
- US federal tax credit for EVs: up to $1.5 billion per manufacturer

Yet, existing programs might not provide a good guide

- Ambitious targets require large scale adoption, but:
  - Vehicle incentives are endogenously assigned (Gallagher and Muehlegger (2011), and many others)
  - Past incentives disproportionately accrue to high-income, early-adopting households (Borenstein and Davis (2015))
  - Pass-through of incentives may be less than full, impacting program cost-effectiveness (Gulati et al (2017))

We study a program that addresses these issues

- The Enhanced Fleet Modernization Program (EFMP):
  - provides quasi-random variation in incentives in CA,
  - is means-tested, targeting households $<$ 400% FPL, and
  - offers generous incentives which we match to transaction prices

- We exploit features of the program to answer:
  1. What is the incidence of EV vehicle incentives?
  2. What is the elasticity of demand with respect to these incentives?
  3. What are the public costs of meeting California's transportation sector electrification goals?

Outline

- **Background on the EFMP program**
- Empirical approach & results
- Policy Discussion & Extensions

Enhanced Fleet Modernization Program

- EFMP was originally a vehicle retirement program
- In Q3 - 2015, CA began a pilot that paired retirements to generous replacement incentives. Other CA Incentives

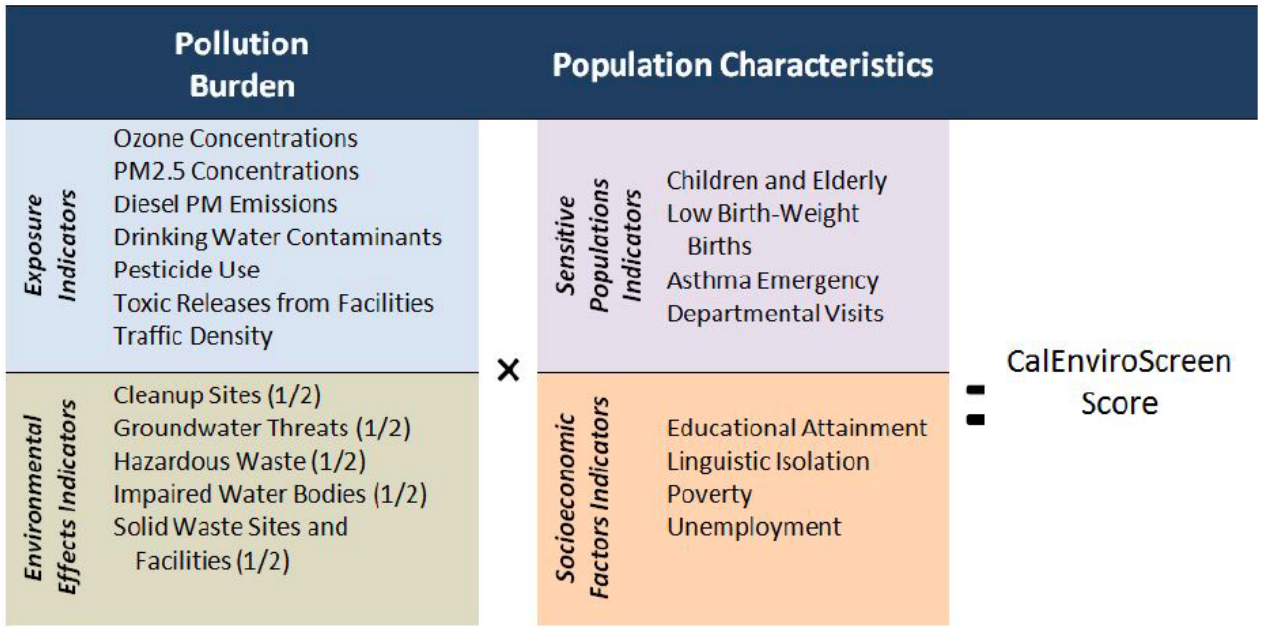
- Important program features for our analysis:
  1. Pilot program limited to South Coast and San Joaquin Air Districts (AQMDs)
  2. Consumers in "disadvantaged-communities" (DACs) receive a "plus-up" that roughly doubles the replacement incentive
  3. Means-tested. Limited to households below $<$ 400% of FPL
  4. Applies to both new and used vehicles.

EFMP Pilot Regions

Figure: San Joaquim Valley and South Coast AQMDs

How are disadvantaged communities defined?

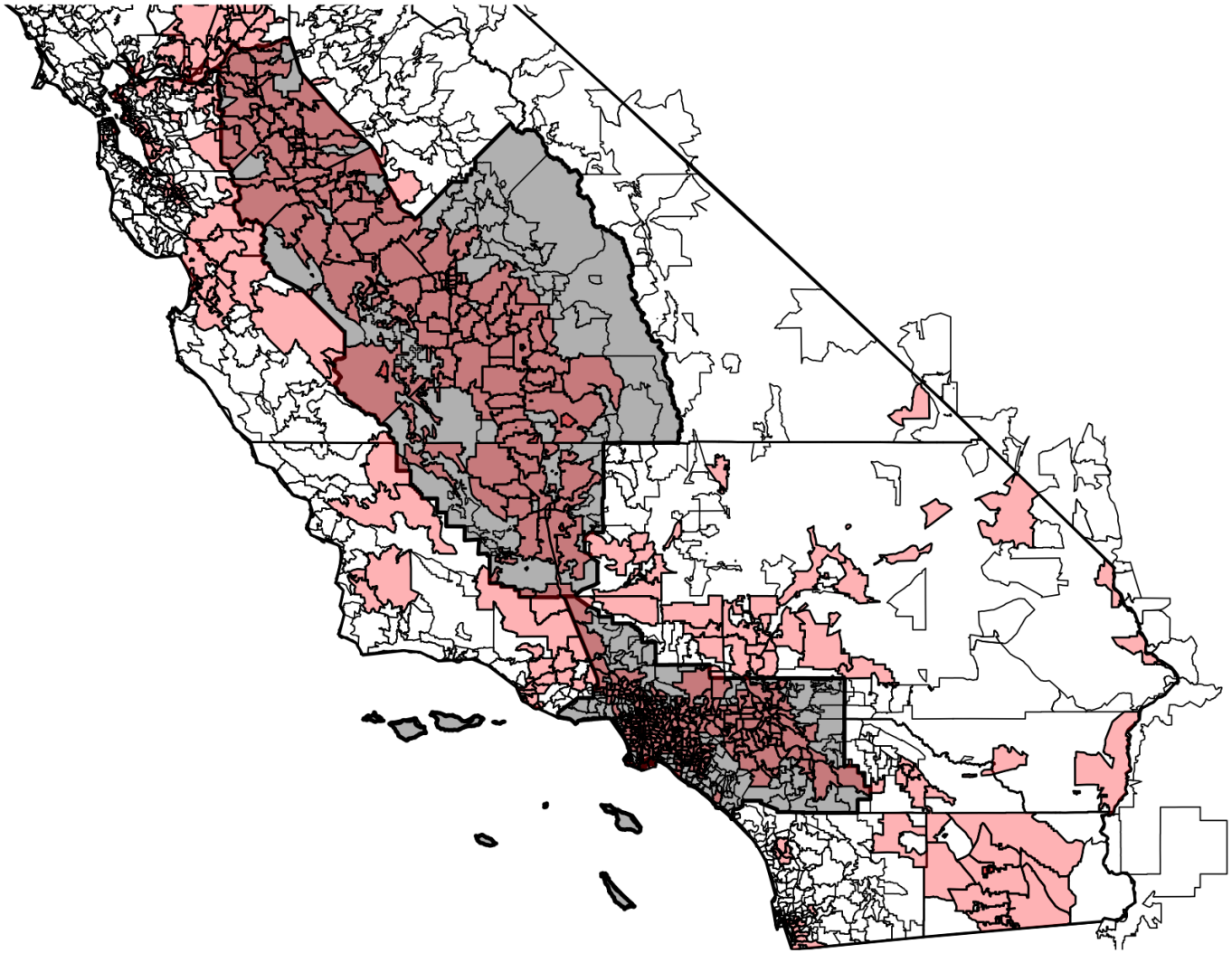
- CAL EPA ranks census tracts by a CalEnviroScreen score



- The top quartile are classified as "disadvantaged"
- If a zip code contains a "disadvantaged" census tract, the zip is "disadvantaged".
- We refer to these zips as *DACs*.

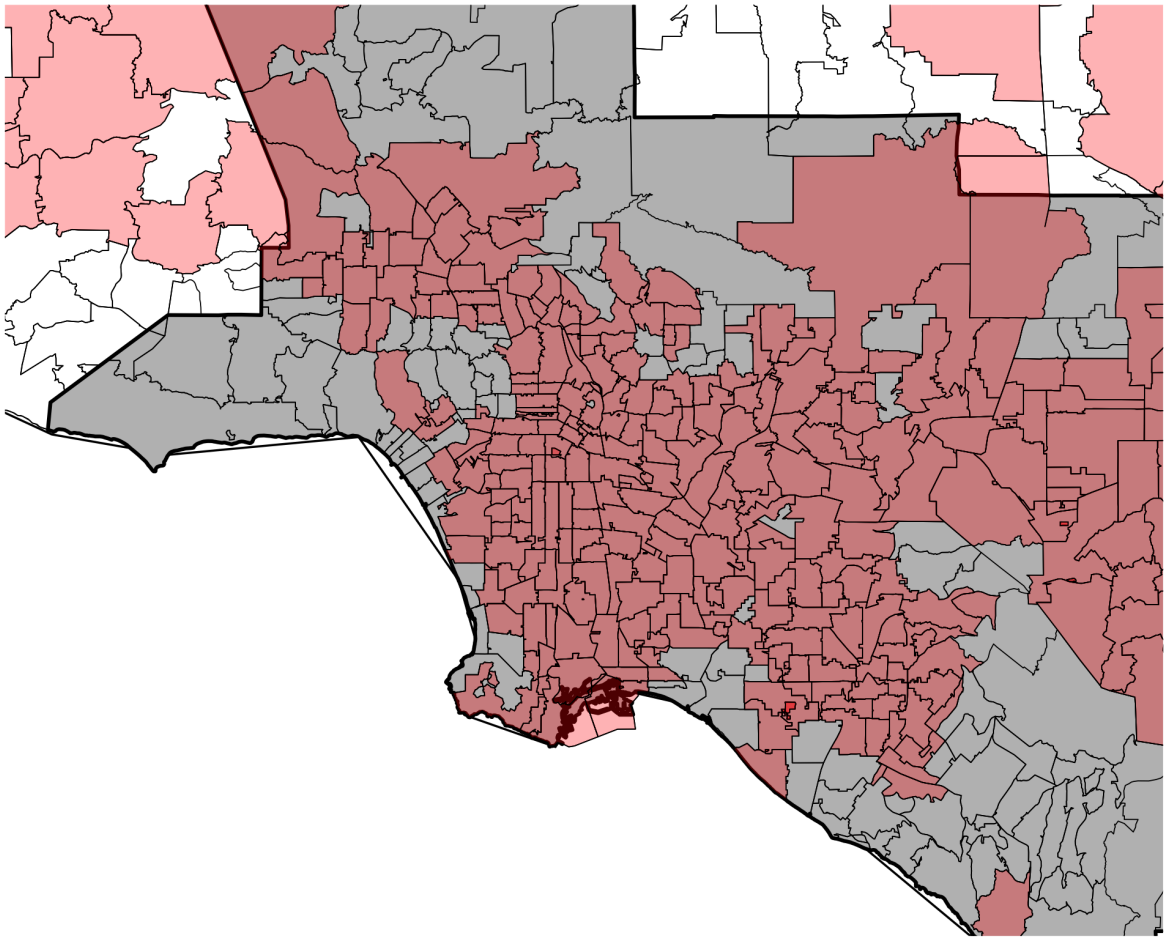
Maps of Treatment Eligibility

Figure: California Zip Codes by DAC Status



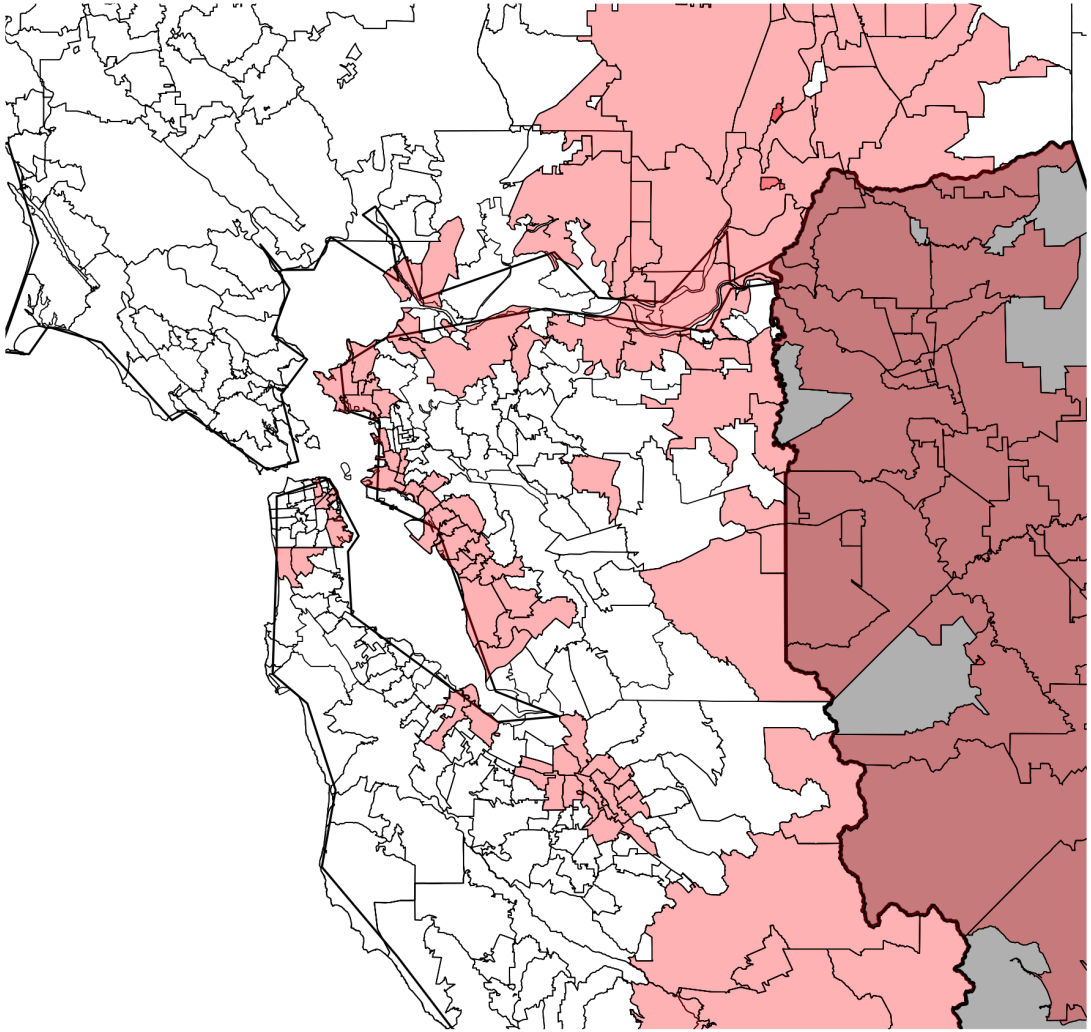
Maps of Treatment Eligibility - Los Angeles

Figure: Los Angeles Zip Codes by DAC Status



Maps of Treatment Eligibility - San Francisco

Figure: San Francisco Zip Codes by DAC Status



Means-testing targets lower income households

Income	Subsidy	Fraction of Rebates
$<$ 225% FPL	\$5,000	90.9%
225-300% FPL	\$4,000	6.9%
300-400% FPL	\$3,000	2.1%

- Cells denote percentage of number of total subsidies allocated to Income Bin X DAC
- 400% of FPL for a 4-person HH = \$97k

FPL Income Thresholds

Other features of EFMP

1. Applicants must retire an operational, registered, high-emitting vehicle Full Retirement Criteria
   - Fails smog check
   - "The vehicle is able to drive forward a minimum distance of ten (10) yards under its own power"
   - "All doors are present"
2. Must apply in advance of retire-replace
3. One rebate per household
4. Dealerships must pre-register
   - Pre-negotiated, "no-haggle" pricing on replacement vehicles
   - Limits on dealer financing arrangements

Data Sources

- Transaction data *(Source: DMV)*
  - All New and Used BEV / PHEV sales in California
  - We observe VIN, date, sale price, dealership, buyer zip, lease, odometer
  - We map each buyer zip to AQMD and DAC designations
- EFMP rebate data *(Source: California Air Resources Board)*
  - Rebate-level data
  - We observe vehicle type, owner zip, quarter, new/used
  - We do *not* observe VIN (for now)
  - We aggregate to the zip-year-quarter level
  - Count and average of incentives received

Outline

- The EFMP program
- **Empirical approach & results**
- Policy Discussion & Extensions

Overview of empirical strategy

Main goal: estimate subsidy elasticity of demand for EVs (ε)

$$\varepsilon = \frac{\%\Delta Q}{\%\Delta P}$$

For this we need to retrieve % ΔQ and % ΔP

- Intuition: compare purchase patterns in zip codes exposed to subsidy to patterns in (conditionally) identical zip codes not exposed to the subsidy
- "Triple difference" approach: AQMD 1/0, DAC 1/0, Pre/Post

3 Empirical Considerations

Discussed at length in paper

1. Compositional effects, E.g.
   - Approx. 80% of statewide purchases are ”new” vehicles
   - Approx. 20% of EFMP purchases are ”new” vehicles
2. Some difficult-to-compare zips
   - Robustness: nearest-neighbor matching
3. Scaling of results
   - Mainly a technicality, but this is why we use an IV strategy
   - See paper for details

Results: Price

$5,000 subsidy reduces buyer price by $5,000

Table: Sales and EFMP Incentives

Panel A

	(1) OLS	(2) Unmatched IV	(3) Preferred IV	(4) Zip Q LOO	(5) AQ*DAC Q LOO	(6) Shift-share IV
% EFMP Transactions	-4042.2**	-4378.9***	-4992.2***	-4873.9***	-5198.3***	-2995.9
	(1601.2)	(1081.6)	(1267.8)	(1342.0)	(940.0)	(4619.2)
Observations	22600	25139	22600	22600	22600	22600
R-Squared	0.11	0.13	0.11	0.11	0.11	0.11

Panel B

	(1) OLS	(2) Unmatched IV	(3) Preferred IV	(4) Zip Q LOO	(5) AQ*DAC Q LOO	(6) Shift-share IV
Avg. PU Subsidy	-0.79**	-0.89***	-0.99***	-0.97***	-1.05***	-0.58
	(0.32)	(0.22)	(0.25)	(0.27)	(0.19)	(0.95)
Observations	22600	25139	22600	22600	22600	22600
R-Squared	0.11	0.13	0.11	0.11	0.11	0.11

Controls: zip, DAC-by-Quarter FEs.
All columns based on matched samples.
Clustering at zip level. ***, **, and * denote 99, 95, and 90 percent significance.

Results: Ln(Quantity)

Every $1,000 of subsidy increased demand by 15%

Table: Sales and EFMP Incentives

Panel A

	(1) OLS	(2) Unmatched IV	(3) Preferred IV	(4) Zip Q LOO	(5) AQ*DAC Q LOO	(6) Shift-share IV
% EFMP Transactions	0.36***	0.72***	0.76***	0.77***	1.31***	1.44*
	(0.067)	(0.097)	(0.12)	(0.12)	(0.12)	(0.80)
Observations	27554	34477	27554	27554	27554	27554
R-Squared	0.89	0.90	0.89	0.89	0.89	0.89

Panel B

	(1) OLS	(2) Unmatched IV	(3) Preferred IV	(4) Zip Q LOO	(5) AQ*DAC Q LOO	(6) Shift-share IV
Avg. PU Subsidy	0.073***	0.15***	0.15***	0.15***	0.26***	0.30*
	(0.014)	(0.020)	(0.024)	(0.025)	(0.024)	(0.16)
Observations	27554	34477	27554	27554	27554	27554
R-Squared	0.89	0.90	0.89	0.89	0.89	0.89

Controls: zip, DAC-by-Quarter FEs.
All columns based on matched samples.
Clustering at zip level. ***, **, and * denote 99, 95, and 90 percent significance.

Outline

- The EFMP program
- Empirical approach & results
- **Policy Discussion & Extensions**

How much will 1.5 million EVs by 2025 cost?

	Baseline Growth Rate in EVs (2018-2025)			
	10%	12%	14%	16%
Elasticity = 2.4				
Implied required change in Buy Price	N/A	$ (17,475)	$ (11,737)	$ (7,532)
Cumulative Subsidy Bill ($ Billions)	N/A	$ 22.5	$ 15.1	$ 9.7
Elasticity = 3.9 (preferred)				
Implied required change in Buy Price	$ (15,659)	$ (10,658)	$ (7,158)	$ (4,593)
Cumulative Subsidy Bill ($ Billions)	$ 20.1	$ 13.7	$ 9.2	$ 5.9
Elasticity = 7.8				
Implied required change in Buy Price	$ (7,909)	$ (5,383)	$ (3,615)	$ (2,320)
Cumulative Subsidy Bill ($ Billions)	$ 10.2	$ 6.9	$ 4.7	$ 3.0

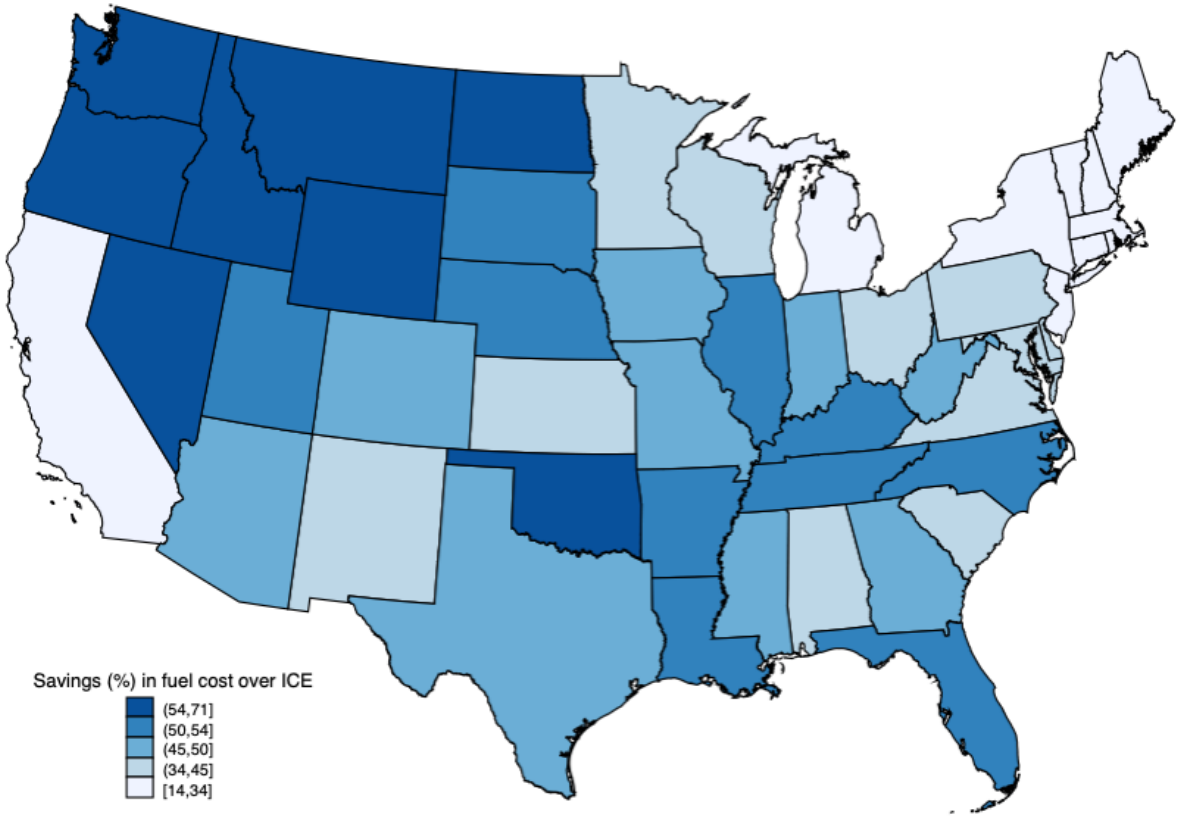
Notes: Estimates assume that 10% of the EV fleet is retired or exported each year starting in 2020 and a weighted-average (over new and used) EV price of approxiately $26,000. There are 333,000 EVs assumed to be in the fleet at the beginning of 2018. By our estimates, the zero-subsidy growth rate of California EVs in 2015, 2016 and 2017 were 28.9, 21.6 percent and 18.5 percent respectively. "N/A" reflects subsidies that exceed 100 percent of the assumed value of the car.

Caveats

- Generalizability: EFMP is a pilot program, trade-in necessary
- Total subsidy includes federal incentives (or ZEV mandates)
- Assumed new vehicle program with $26k entry EV.

Extensions: P&P Economics of EVs

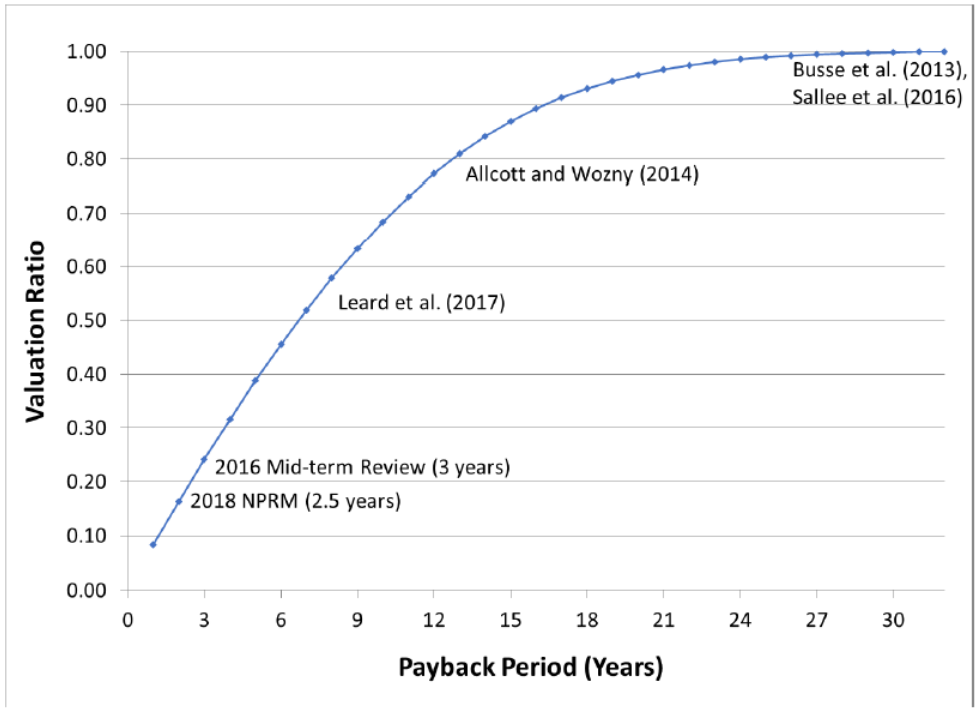
Figure: Percent savings of Leaf vs. Versa



- Locations vary with respect to the operational savings of an EV.
  - Lowest EV savings in MA = \$106 per 12k miles (14%)
  - Highest EV savings in WA = \$625 per 12k miles (71%)

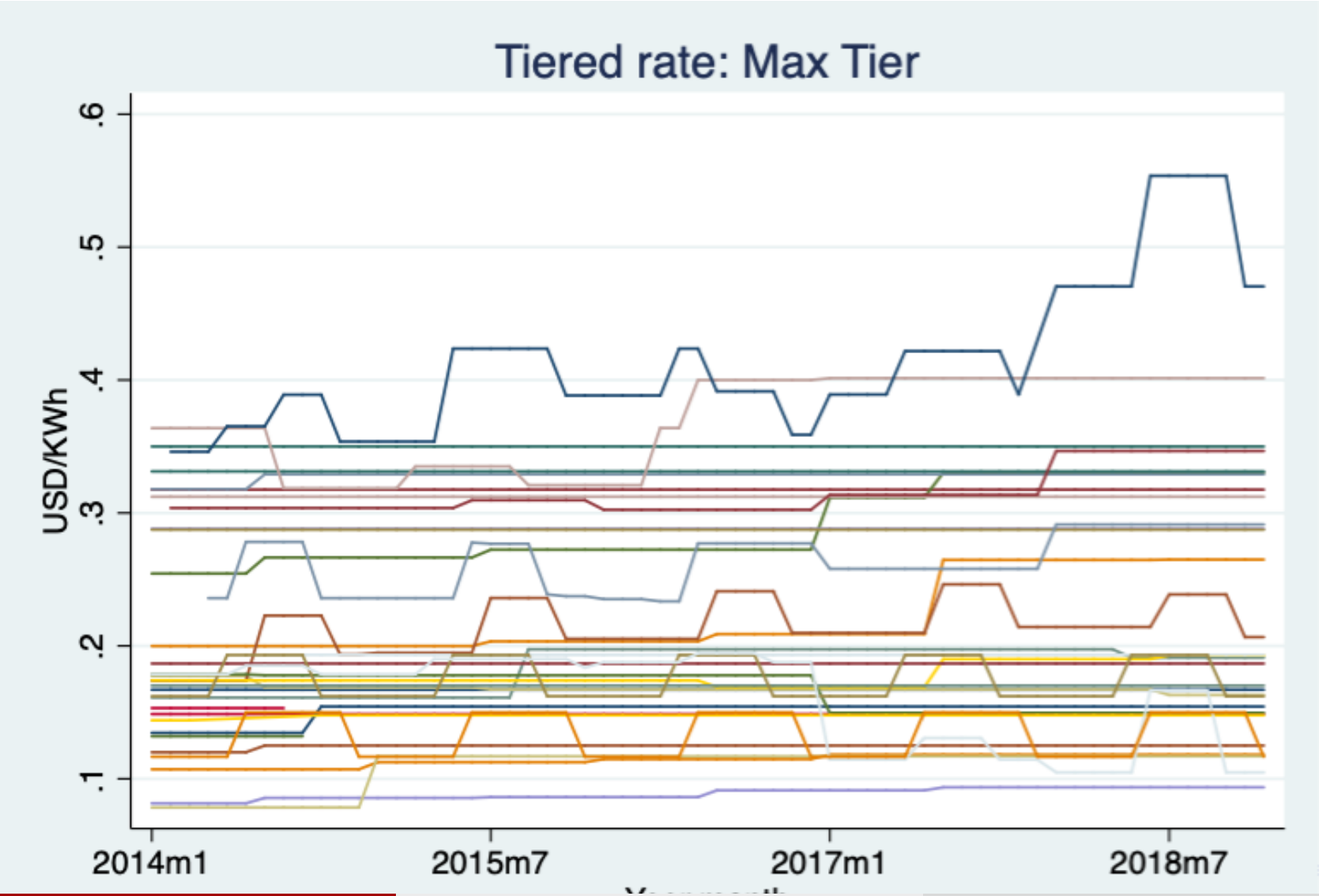
Do Consumers Value EV Savings?

- Evidence suggests consumers internalize the majority of future fuel costs when they buy a car



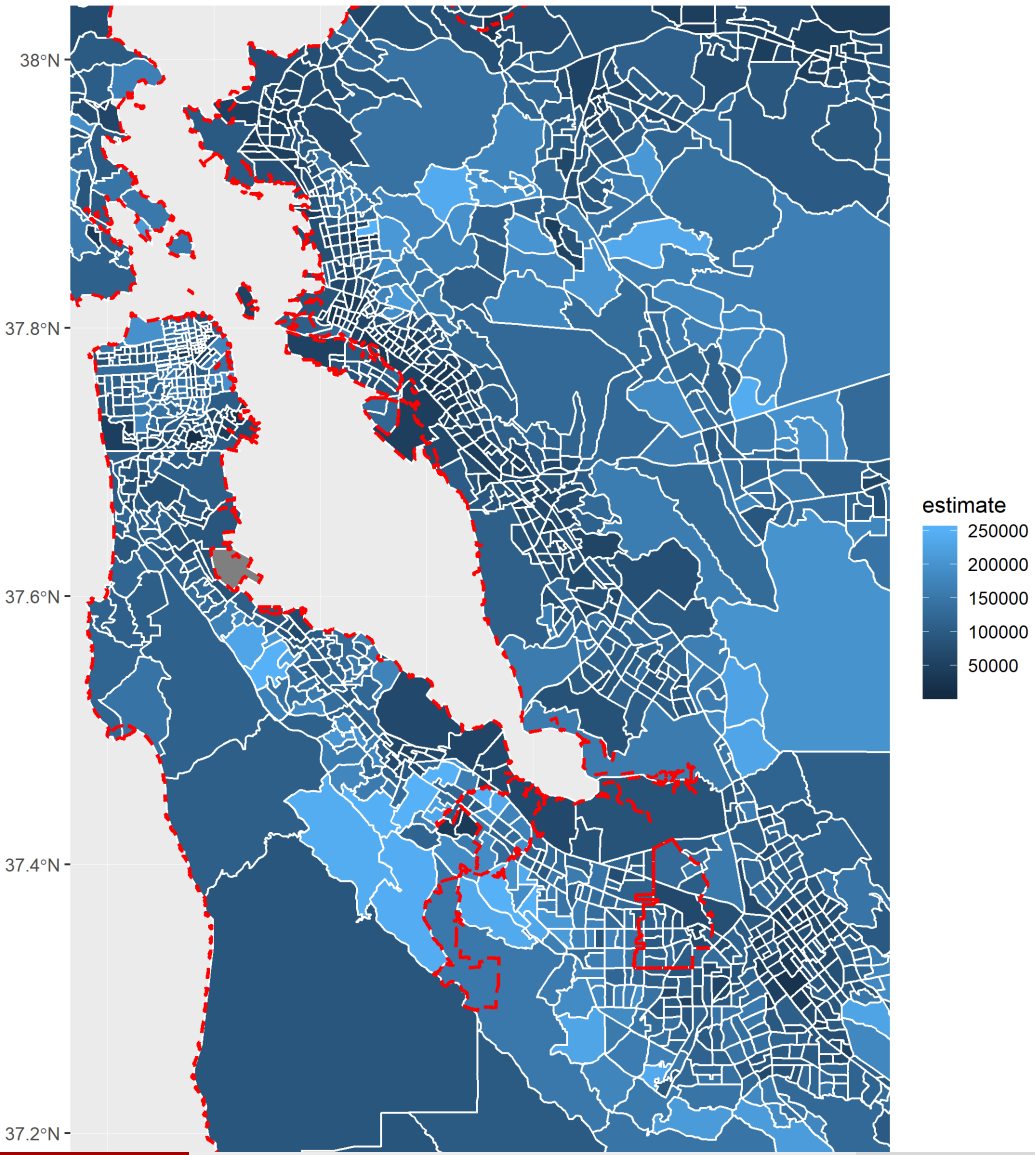
Do Consumers Value EV Savings?

- Massive differences in electricity price across locations (CA)



Do Consumers Value EV Savings?

Exploit proximity of utilities in densely-populated areas



Summary & Discussion

- Subsidies appear to be very effective
  - Close to complete subsidy pass-through to consumers
  - Stimulate substantial demand growth
- Nonetheless, the subsidy bill is large and growing
  - $9 - $14 billion to achieve 1.5 million EVs by 2025 in CA
- Other structural obstacles to EV adoption are not well understood
  - Tension between solar/EE aspirations and EV goals
  - Ongoing work:
    - ★ "Do consumers value operational savings in EV purchase decisions?" (Bushnell, Muehlegger & Rapson)
    - ★ "Private and Public Economics of EVs" (Rapson & Muehlegger)

Thank You

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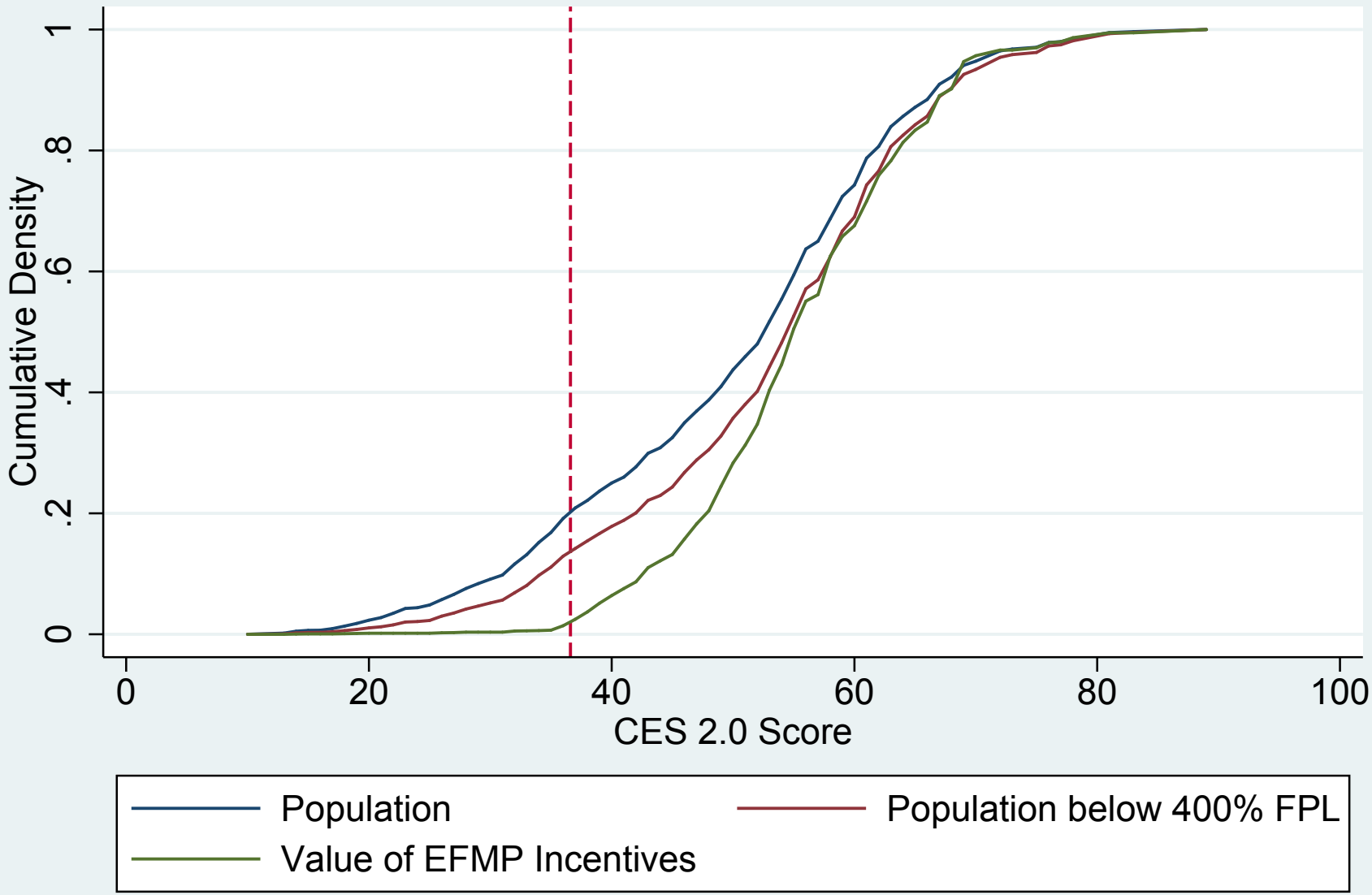
Appendix

Data Description



Note: The graph plots the cumulative distributions of population, population below 400% of FPL, Value of EFMP incentives within AQMD==1.

Other CA vehicle incentive programs

- Clean Vehicle Rebate Program (CVRP):
  - State-wide
  - $1,500 for PHEVs, $2,500 for BEVs, $5,000 for fuel cell vehicles
  - Means-testing (PHEVs and BEVs) after March 2016.
    - ★ Before March 29, 2016: None
    - ★ March 29, 2016 - Oct. 31, 2016: $250k (single) - $500k (joint)
    - ★ After Nov. 1, 2016: $150k (single) - $300k (joint)
  - Low-income bump ($< 225\%$ FPL)
    - ★ Before March 29, 2016: None
    - ★ March 29, 2016 - Oct. 31, 2016: $1,500
    - ★ After Nov. 1, 2016: $2,000
- Commercial / municipal fleet incentives
- ZEV mandate

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EFMP Income Eligibility Thresholds

Table 1 - Eligibility for EFMP or Plus Up is based on the following household income limits.

Persons in family/household	Percent of Federal Poverty Level		
	225%	300%	400%
1	$26,730	$35,640	$47,520
2	$36,045	$48,060	$64,080
3	$45,360	$60,480	$80,640
4	$54,675	$72,900	$97,200
5	$63,990	$85,320	$113,760
6	$73,305	$97,740	$130,320
7	$82,642	$110,190	$146,920
8	$92,002	$122,670	$163,560
For families/households with more than 8 persons, add $4,160 for each additional person.			

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Retirement Vehicle Criteria

VEHICLE RETIREMENT – Equipment and Operational Requirements

After approval of an application and prior to being accepted for retirement, the vehicle must pass equipment and operational inspections performed on the items listed below at a BAR-contracted Dismantler.

Vehicle Equipment Requirements

- ☐ All doors are present.
- ☐ The hood lid is present.
- ☐ The dashboard is present.
- ☐ The windshield is present.
- ☐ At least one side window glass is present.
- ☐ The driver's seat is present.
- ☐ At least one bumper is present.
- ☐ The exhaust system is present.
- ☐ All side and/or quarter panels are present.
- ☐ At least one headlight, one taillight, and one brake light are present.

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Retirement Vehicle Criteria

Vehicle Operational Requirements

- The vehicle is driven under its own power to a BAR-contracted dismantler site.
- The vehicle's engine starts readily through ordinary means without the use of starting fluids or external booster batteries.
- The drivability of the vehicle is not affected by any body, steering, or suspension damage.
- The vehicle is able to drive forward a minimum distance of ten (10) yards under its own power.
- The interior pedals are operational.

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Data Description

	Non-participating AQMDs		Participating AQMDs (South Coast/San Joaquin)	
	non-DAC	DAC	non-DAC	DAC
Panel A: Subsidy and Transaction Data				
EV Sales, Pre	60,789	26,993	31,524	39,424
EV Sales, Post	85,677	29,840	45,316	63,692
EV Sales Per Capita (per 000 pop), Pre	5.729	3.971	7.916	2.345
EV Sales Per Capita (per 000 pop), Post	8.075	4.390	11.38	3.789
Count of EFMP EV trans., Pre	0	0	0	0
Count of EFMP EV trans., Post	0	0	29	1330
EFMP Frac. of Sales, Pre	0	0	0	0
EFMP Frac. of Sales, Post	0	0	0.000640	0.0209
Mean Sales Price ($), Pre	37,391.4	33,964.5	38,516.7	34,470.5
Mean Sales Price ($), Post	39,110.1	35,997.8	41,596.1	36,544.0
Mean Subsidy ($), Pre	0	0	0	0
Mean Subsidy ($), Post	0	0	2.008	191.2
Panel B: Zip-level Covariates				
Frac. HHs $<$ 225% of FPL	0.332	0.423	0.271	0.466
Frac. HHs 225-300% of FPL	0.109	0.123	0.0932	0.125
Frac. HHs 300-400% of FPL	0.116	0.115	0.111	0.114
Frac. zips in SCAQMD	0	0	0.860	0.684
Population (MMs)	10.61	6.798	3.983	16.81

Data Description