Using a Natural Experiment in California to Estimate the Demand for Electric Vehicles in Low- and Middle-Income Households

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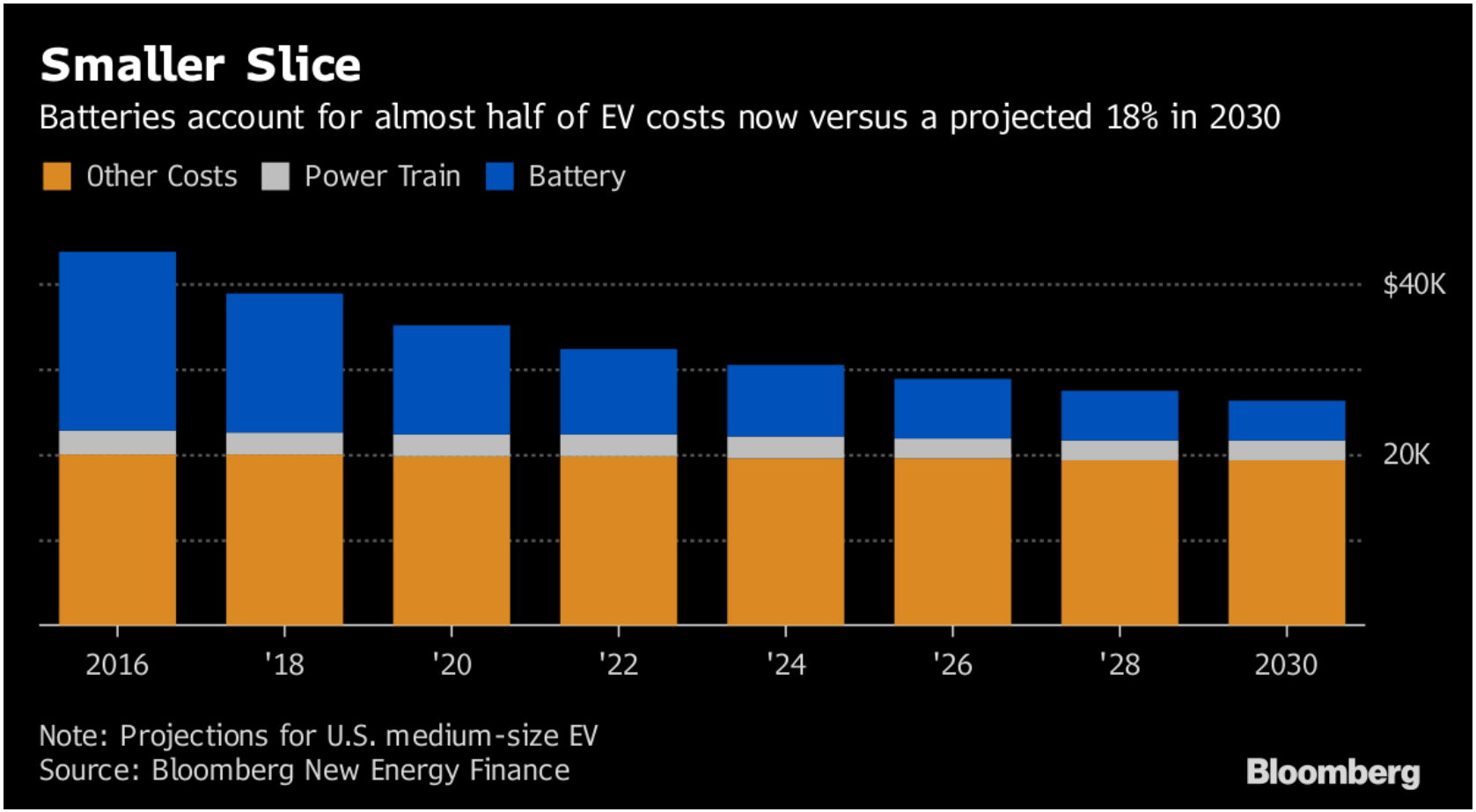
Context

EVs are not cost competitive due primarily to battery costs

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



Motivation

Widespread government stimulus for EVs, but effects difficult to measure

- Existing programs may not provide a good guide as to the costs or impacts of large-scale program
  - Incentives are not exogenously assigned
  - Historically, vehicle subsidies are disproportionately claimed by high-income households (Borenstein and Davis (2015))
- Identification can be challenging
  - Selection
  - Additivity
- Pass-through may influence cost-effectiveness
  - Sallee (2011), Gulati et al (2017)

Research Questions

- What is the incidence of EV vehicle incentives?
- What is the elasticity of demand with respect to these incentives?
- What are the public costs of meeting transportation sector electrification goals?

Our Research Strategy

- We exploit a novel feature of the Enhanced Fleet Modernization Program (EFMP) in California that:
  - offers generous incentives (up to \$9,500 per vehicle),
  - is means-tested, targeting households $<$ 400% FPL, and
  - provides quasi-random variation in incentives provided to different locations within California.

- Exploit the features of the program to:
  1. Estimate pass-through of EFMP incentives
  2. Estimate elasticity of demand for EVs
     - ★ Policy-relevant subpopulation: low- and middle-income households

Outline

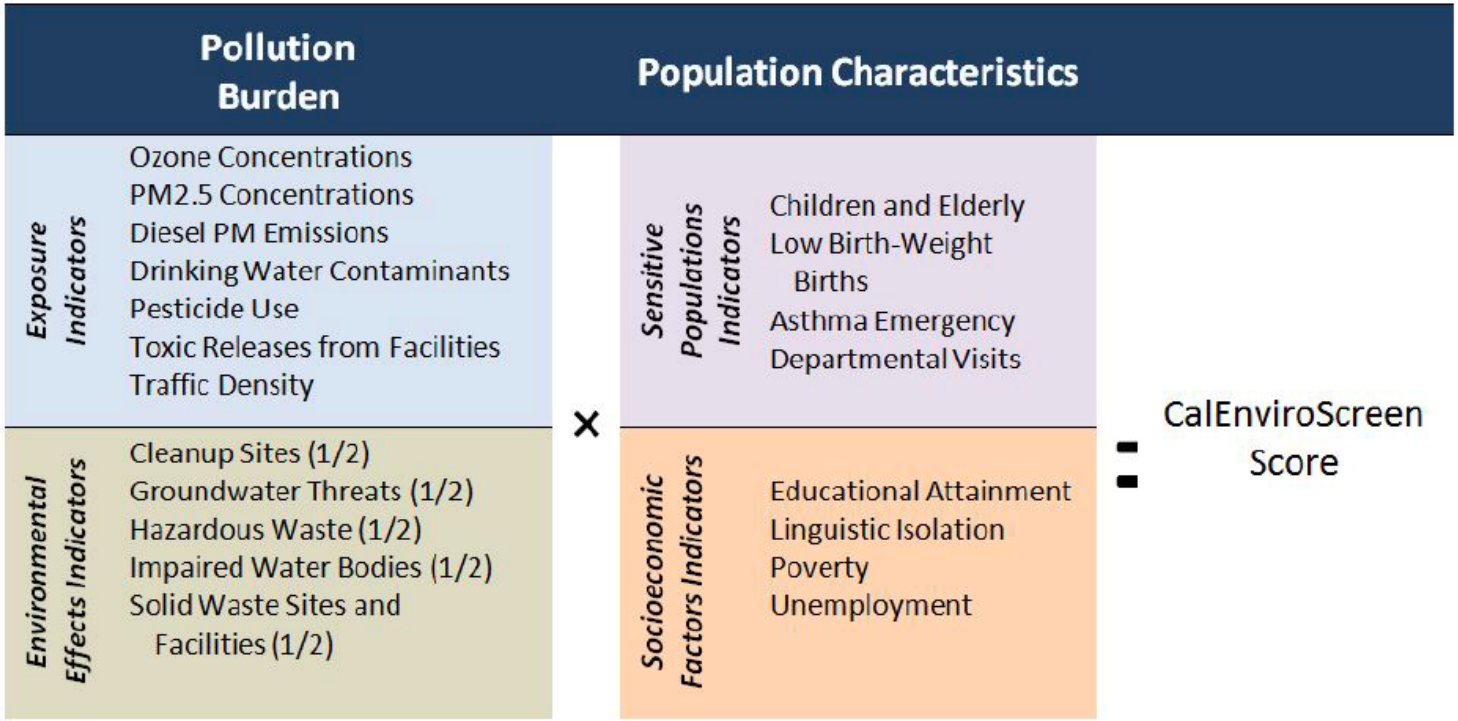
- The EFMP program
- Data
- Empirical approach & results
- Discussion

The Enhanced Fleet Modernization Program

- Initially a vehicle retirement program
- We study the pilot retire-and-replace program in South Coast AQMD, San Joaquin AQMD (started Q3-2015)

- Important program features:
  1. Pilot program is only available to buyers living in SC and SJV AQMDs
  2. Means-tested. Limited to households below $< 400\%$ of FPL
     - ★ \$97,200 for a family of 4
  3. Consumers in "disadvantaged-communities" (DACs) receive a "plus-up" that roughly double the value of the incentive

How is plus-up eligibility determined?



- Census tracts are ranked based on a CalEnviroScreen score
- The top quartile are classified as "disadvantaged"
- Plus-up eligibility is defined at the zip-level based on whether the zip contains a "disadvantaged" census tract.
- We refer to these zips as DACs.

Other features of EFMP

Other Program Requirements:

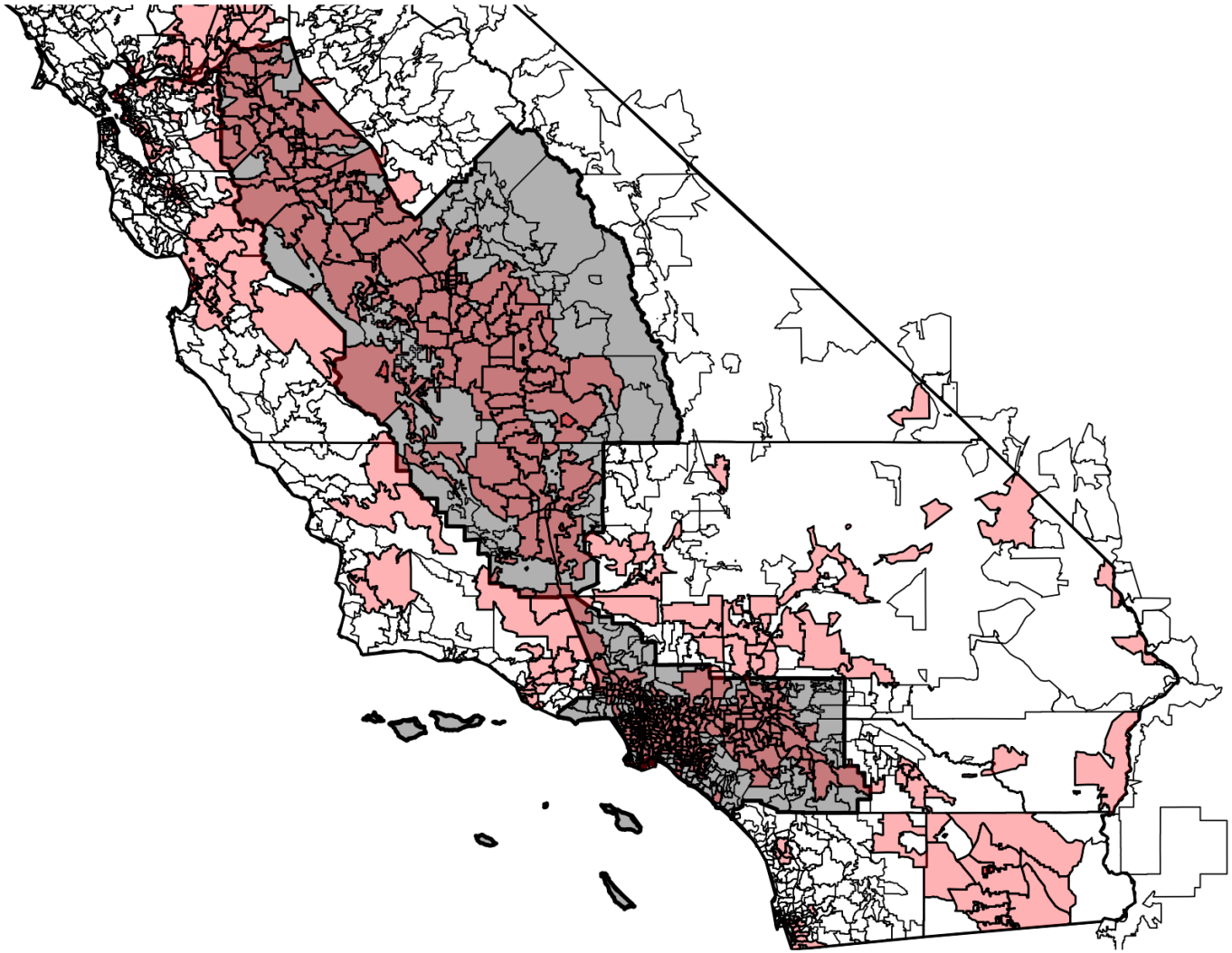
- Applicants must retire an operational, registered, high-emitting vehicle
  - Fails smog check
  - "The vehicle is able to drive forward a minimum distance of ten (10) yards under its own power"
  - "All doors are present"
  - Full Retirement Criteria
  - Vehicle Age at Retirement
- Must apply in advance of retire-replace
- Dealerships must pre-register
  - Pre-negotiated pricing on replacement vehicles
  - Limits on dealer financing arrangements

Maps of Treatment Eligibility

Figure: San Joaquim Valley and South Coast AQMDs

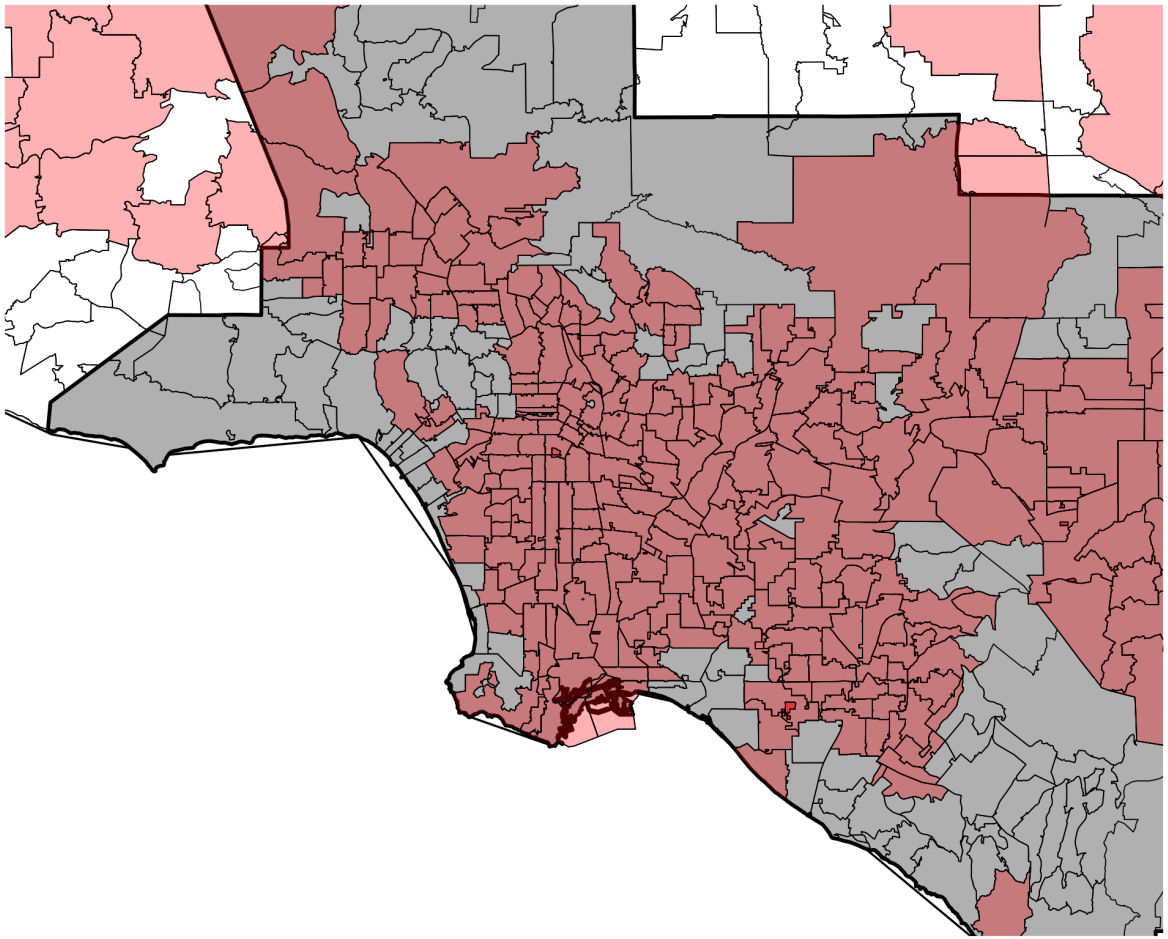
Maps of Treatment Eligibility

Figure: California Zip Codes by DAC Status



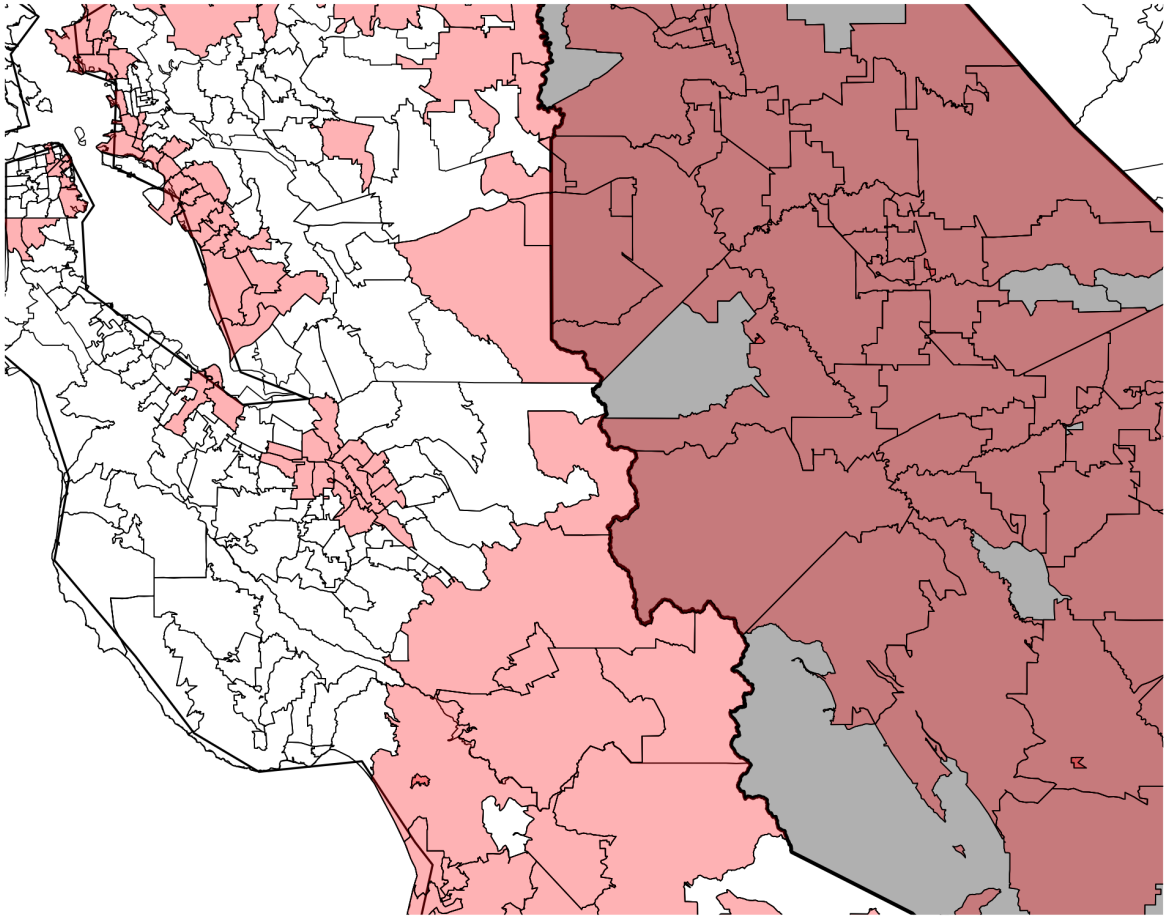
Maps of Treatment Eligibility

Figure: Los Angeles Zip Codes by DAC Status



Maps of Treatment Eligibility

Figure: San Jose Zip Codes by DAC Status



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Data Sources

- Transaction data
  - All New and Used BEV / PHEV sales in California
    - ★ Random sample of hybrid vehicles
  - We observe VIN, date, sale price, dealership, buyer zip
  - We also observe (but don't use currently) some demographics, lease dummy
  - We map each buyer zip to AQMD and DAC designations
  - *Source: DMV*

- EMFP rebate data
  - Zip-year-quarter-vehicletype-new/used level
    - ★ Make, model-year
  - Count and average EFMP and EFMP plus up incentives received
  - *Source: California Air Resources Board*

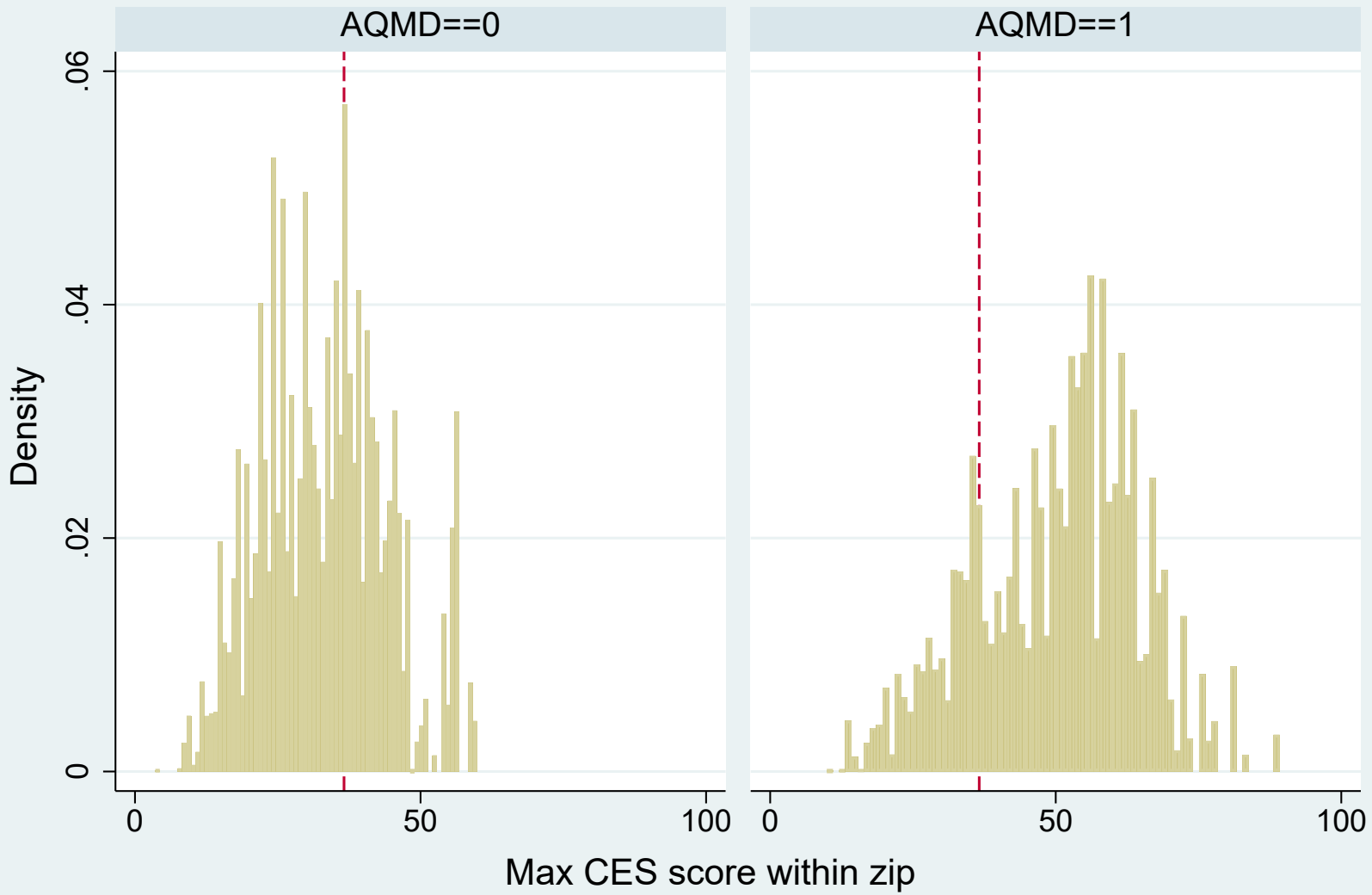
Program Incentives

Income	EFMP Category	ICE		Hybrid		PHEV/BEV
		20+ MPG	35+ MPG	20+ MPG	35+ MPG	
$<$ 225% FPL	Base	\$4,000	\$4,500	\$4,000	\$4,500	\$4,500
$<$ 300% FPL	Base	\$0	\$3,500	\$0	\$3,500	\$3,500
$<$ 400% FPL	Base	\$0	\$0	\$0	\$0	\$2,500
$<$ 225% FPL	Plus-up	\$0	\$0	\$2,500	\$2,500	\$5,000
$<$ 300% FPL	Plus-up	\$0	\$0	\$0	\$1,500	\$4,000
$<$ 400% FPL	Plus-up	\$0	\$0	\$0	\$0	\$3,000

- For EVs: approximately \$12.6 million allocated under EFMP base, \$9.3 million allocated under "plus-up."

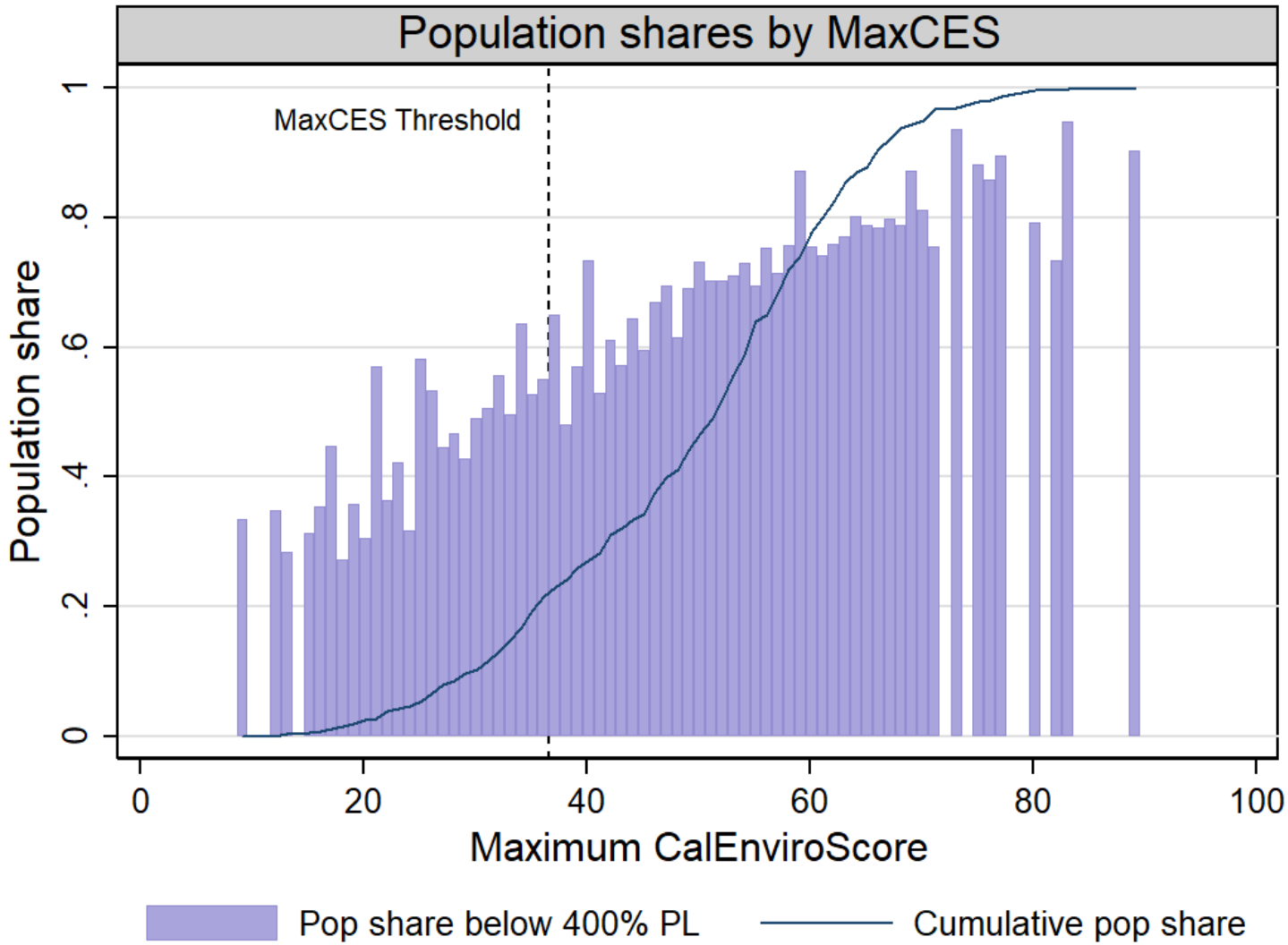
FPL Income Thresholds

Data Description



Note: graph plots the population distribution by zip-level CES score.
Vertical line corresponds to the DAC cutoff.

Data Description



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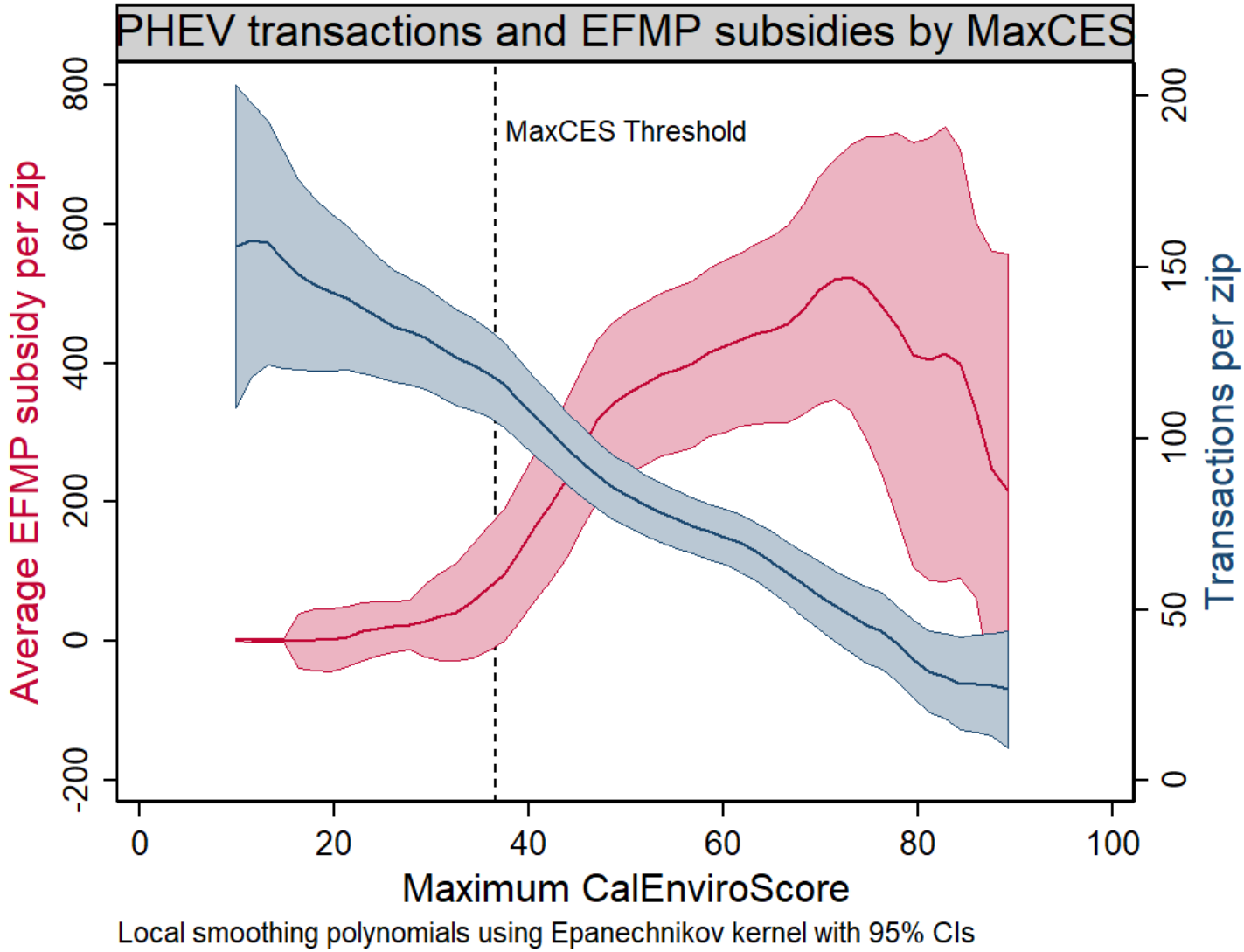

Identification strategies

Most natural options

- Regression discontinuity
  - AQMD=1
  - Zips near MaxCES threshold
  - Post period only
  - *Important action away from discontinuity*
- Triple-difference
  - AQMD=1 vs AQMD=0
  - Zips with DAC=1 vs DAC=0
  - Pre vs Post

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Empirical Approach

We employ a triple-difference estimator

- Pre/Post, AQMD = 1/0, DAC = 1/0
- We think of EFMP as a continuous treatment variables (λ) assigned at the zip, quarter, vehicle-type, N/U level
  - "Fraction EV purchases that receive j-type EFMP subsidy"
    - ★ Similar to Abadie 2005 and Burlig et al 2017

- i = buyer, z = zip, k = type (e.g., New PEV), t = qtr-yr

$$\lambda_{zkt} = \frac{\sum_i \mathbf{1}(Subsidy_{izkt} > 0, zip_i = z, type_i = k, time = t)}{\sum_i \mathbf{1}(zip_i = z, type_i = k, time = t)}$$

Variables of Interest

- $\overline{Subsidy}^{Total}_{zkt} = \overline{Subsidy}^{Base}_{zkt} + \overline{Subsidy}^{PlusUp}_{zkt}$
  - where $\overline{Subsidy}^{j}_{zkt} \equiv \frac{\sum_i Subsidy^{j}_{izkt}}{\sum_i \mathbf{1}(\text{zip}=z,\text{type}=k,\text{time}=t)}$
  - Average subsidy across all EV purchases in zip z at time t
- $BuyPrice_{izkt} \equiv SellPrice_{izkt} - \overline{Subsidy}^{Total}_{zkt}$.

Regression Variables

- DAC Indicator: $\mathbf{1}_D = \mathbf{1}(i \in DAC_z = 1)$
- AQMD Indicator: $\mathbf{1}_A = \mathbf{1}(AQMD_i \in \{SCAQMD, SJVAQMD\})$
- Post Indicator: $\mathbf{1}_P = \mathbf{1}(t \geq 2015Q3)$
- X_i: transaction level covariates
  - E.g. odometer, lease indicator, make-model-modelyr

Triple-Difference Specifications: Price

- Triple-difference weighted by fraction of adopters (λ_{zkt}):

$$BuyPrice_{izkt} = \alpha_1 \lambda_{zkt} \mathbf{1}_D \mathbf{1}_A \mathbf{1}_P + \beta X_i + \nu_{tD} + \gamma_z + \mu_k + \epsilon_{izkt} \quad (1)$$

  - α_1: Average decrease in buy price for plus-up recipient

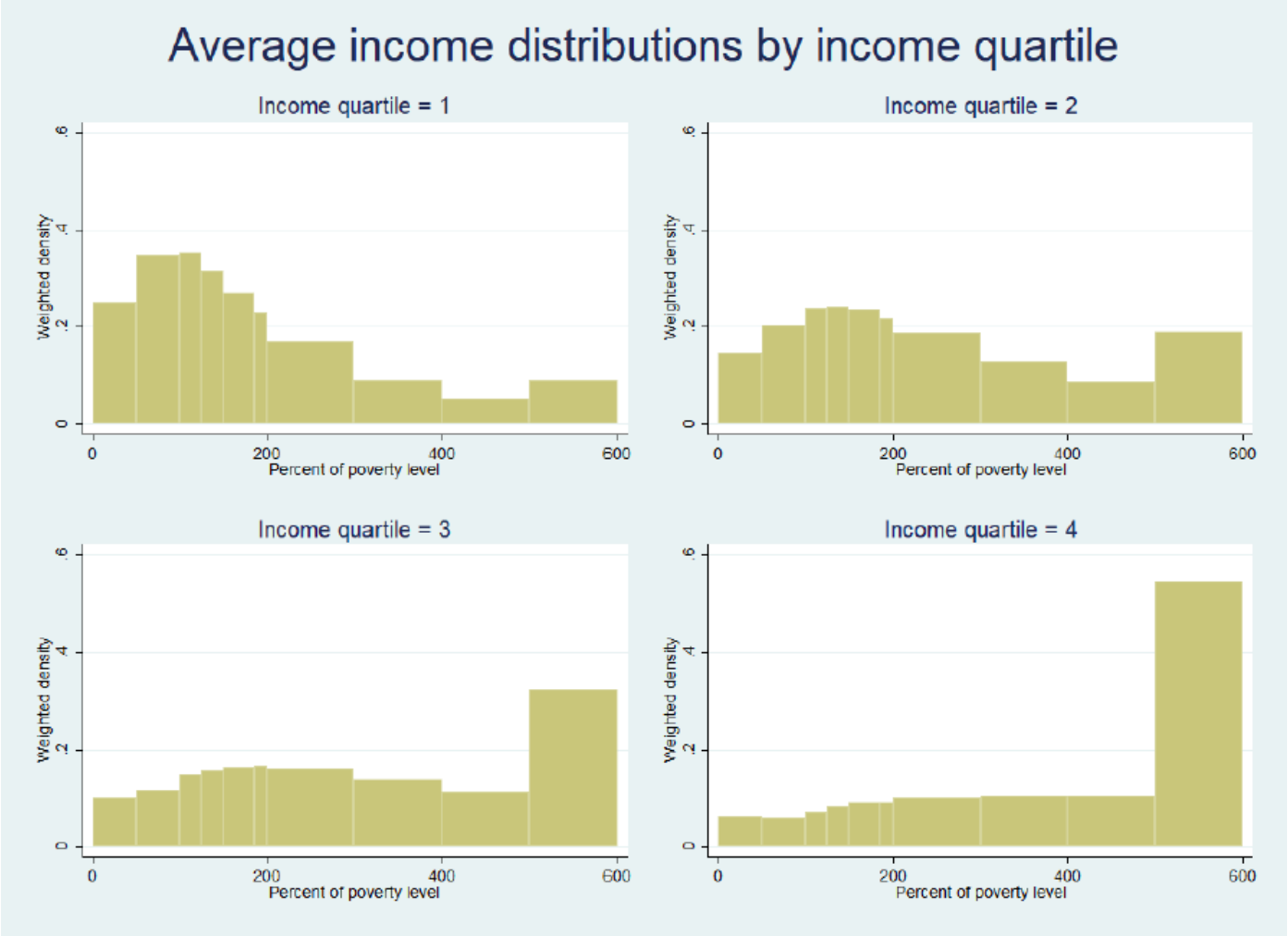
- Continuous treatment in average subsidy level:

$$BuyPrice_{izkt} = \alpha_1 \lambda_{zkt} \overline{Subsidy}_{zkt}^{Total} + \beta X_i + \nu_{tD} + \gamma_z + \mu_k + \epsilon_{izkt} \quad (2)$$

  - $\alpha_1 = 0 \rightarrow$ Dealer fully-captures subsidy,
  - $\alpha_1 = -1 \rightarrow$ Buyer fully-captures subsidy

Instrument for λ_{zkt}

Fraction of income-eligible households by zip: Census



Preliminary Results: Price

Table: Pass-through and EFMP Incentives

	New		Used	
	(1) BuyPrice	(2) BuyPrice	(3) BuyPrice	(4) BuyPrice
% EFMP PU	-3,298.0***		-5,835.8***	
	(899.1)		(661.5)	
Avg. Total EFMP Subsidy		-1.00***		-0.99***
		(0.071)		(0.092)
Observations	318,949	318,949	37,429	37,429
R-Squared	0.89	0.89	0.52	0.52

Controls: zip, DAC-by-Quarter, MMMYr, and lease FEs.

Clustering at zip level. ***, **, and * denote 99, 95, and 90 percent significance.

Triple-Difference Specifications: Quantity

Aggregate to zip level

- Again, weight by fraction of adopters (λ_{zkt}):

$$ln(Q)_{zkt} = \alpha_1 \lambda_{zkt} \mathbf{1}_D \mathbf{1}_A \mathbf{1}_P + \nu_{tD} + \gamma_z + \mu_k + \epsilon_{zkt} \tag{3}$$

  - α_1: Average percent change in quantity for zip going from 0 to 100% EVs eligible for subsidy

- Continuous treatment in average subsidy level:

$$ln(Q)_{zkt} = \alpha_1 \lambda_{zkt} \overline{Subsidy}_{zkt}^{Total} + \nu_{tD} + \gamma_z + \mu_k + \epsilon_{zkt} \tag{4}$$

  - α_1: Average percent increase in EV adoption per \$1,000 in additional subsidy

Preliminary Results: Quantity (logs)

Table: Sales and EFMP Incentives

	New		Used	
	(1) logQ	(2) logQ	(3) logQ	(4) logQ
% EFMP PU	0.48***		0.65***	
	(0.18)		(0.031)	
Avg. Total EFMP Subsidy ('000s)		0.0033		0.043***
		(0.014)		(0.0030)
Observations	83,440	83,440	83,440	83,440
R-Squared	0.73	0.73	0.45	0.45

Controls: zip, DAC-by-Quarter FEs.

Clustering at zip level. ***, **, and * denote 99, 95, and 90 percent significance.

Subsidy (Price) Elasticity of Demand

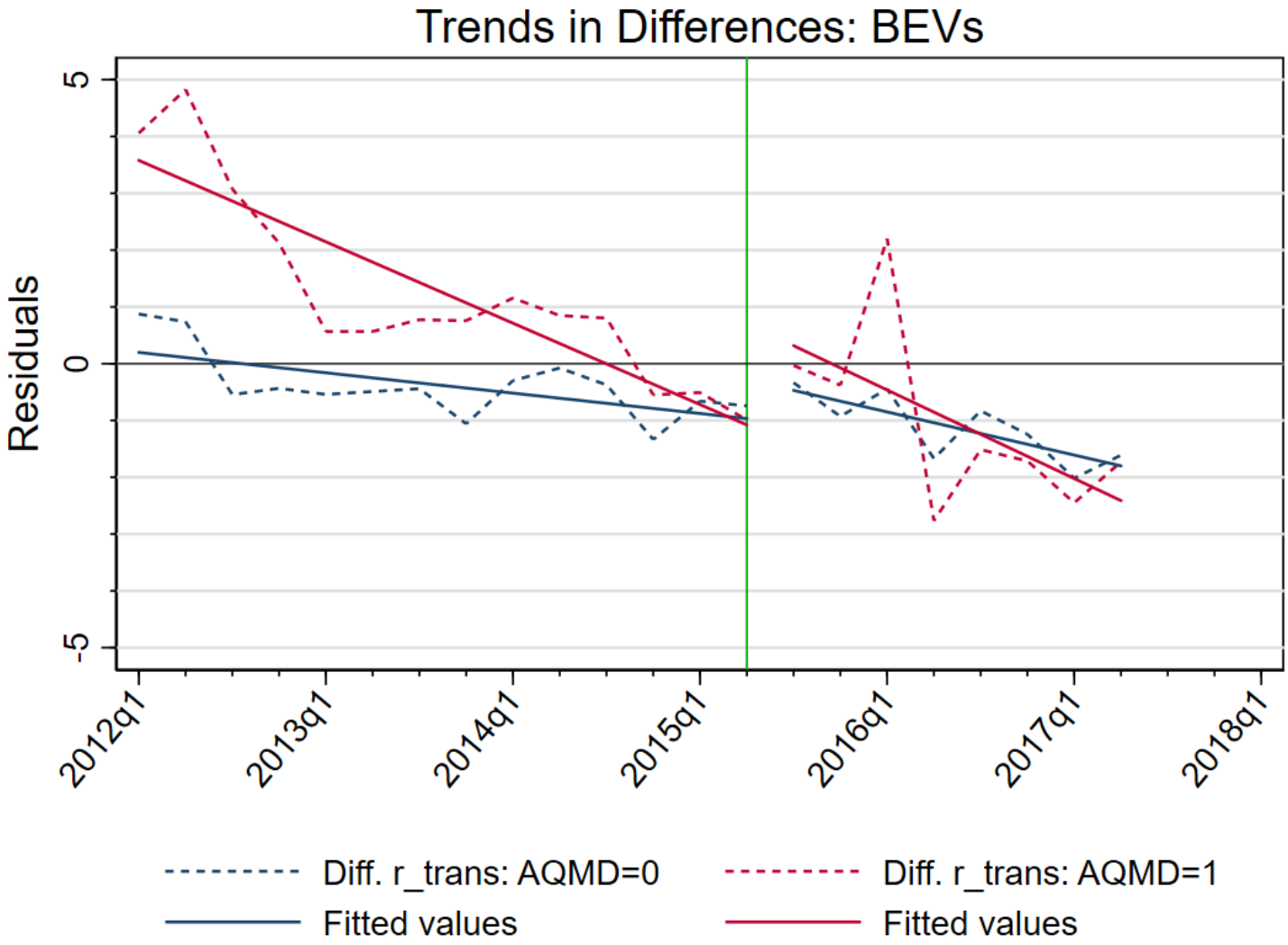
Extremely preliminary (do not cite/use for policy)

$$\mathcal{E} = \frac{exp(0.48) - 1}{-3,298/34,712} = -6.5$$

- High, but not too far from, say, BLP elasticities
- EVs are a small market segment
- Targeted outreach campaign?

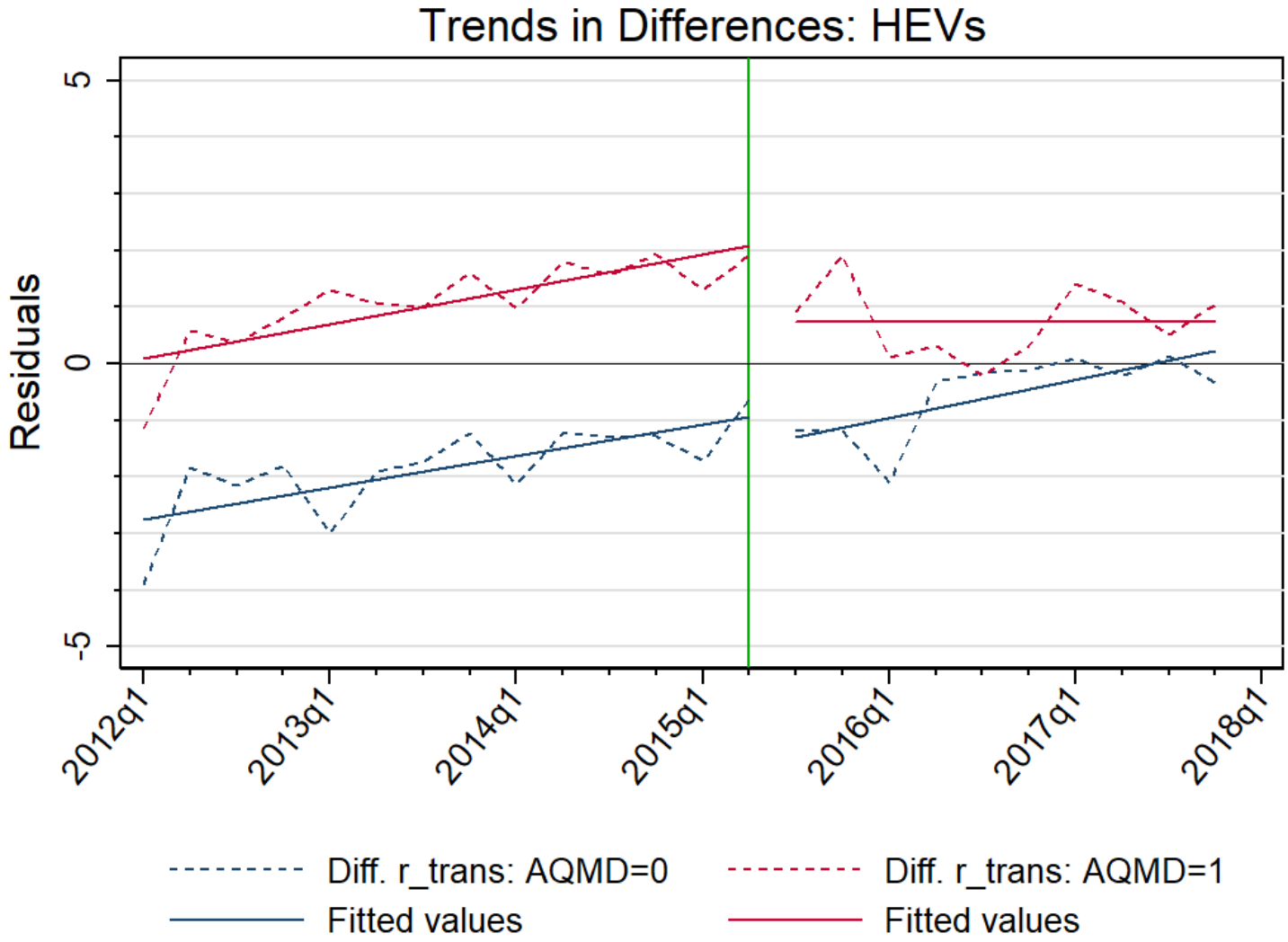
Diagnostics: Parallel Trends?

$Q^k_{t,DAC=1} - Q^k_{t,DAC=0}$ in $AQMD = 1$ vs $AQMD = 0$



Diagnostics: Parallel Trends?

$Q^k_{t,DAC=1} - Q^k_{t,DAC=0}$ in $AQMD = 1$ vs $AQMD = 0$



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Summary & Discussion

- Complete subsidy pass-through to consumers, on average
  - Pre-negotiated prices are an interesting policy feature
- Demand is price elastic in DACs
  - EFMP is stimulating EV adoption
- Cost effectiveness?

Next steps

- Economics
  - Matching
  - Falsifications (e.g. SUVs) and placebos
  - Pollutant benefits
  - Counterfactual: which cars weren't bought?
  - EFMP as demand-side IV for charging infrastructure
- Policy
  - Reconciliation with stated CA EV penetration goals
  - Is proposed $3 billion funding allocation enough/desirable?

Thank You

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Appendix

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
    Check out Dave's new car!
  - 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

Summary Statistics

	EFMP-Eligible AQMD		EFMP-Ineligible AQMD	
EFMP Time Period	Pre-	Post-	Pre-	Post-
New PHEVs	3,485	3,808	3,233	3,426
Used PHEVs	256	1,007	260	875
New BEVs	2,837	3,634	5,018	4,755
Used BEVs	135	639	209	961
Mean Purchase Price	$34,535	$35,815	$34,611	$36,379
EFMP Subsidy per Recipient	$0	$3,805	$0	$0
EFMP Subsidy per EV	$0	$162	$0	$0
EFMP Plus-up Subsidy per Recipient	$0	$3,275	$0	$0
EFMP Plus-up Subsidy per EV	$0	$139	$0	$0

- Cross section and time series variation

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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Program Incentives

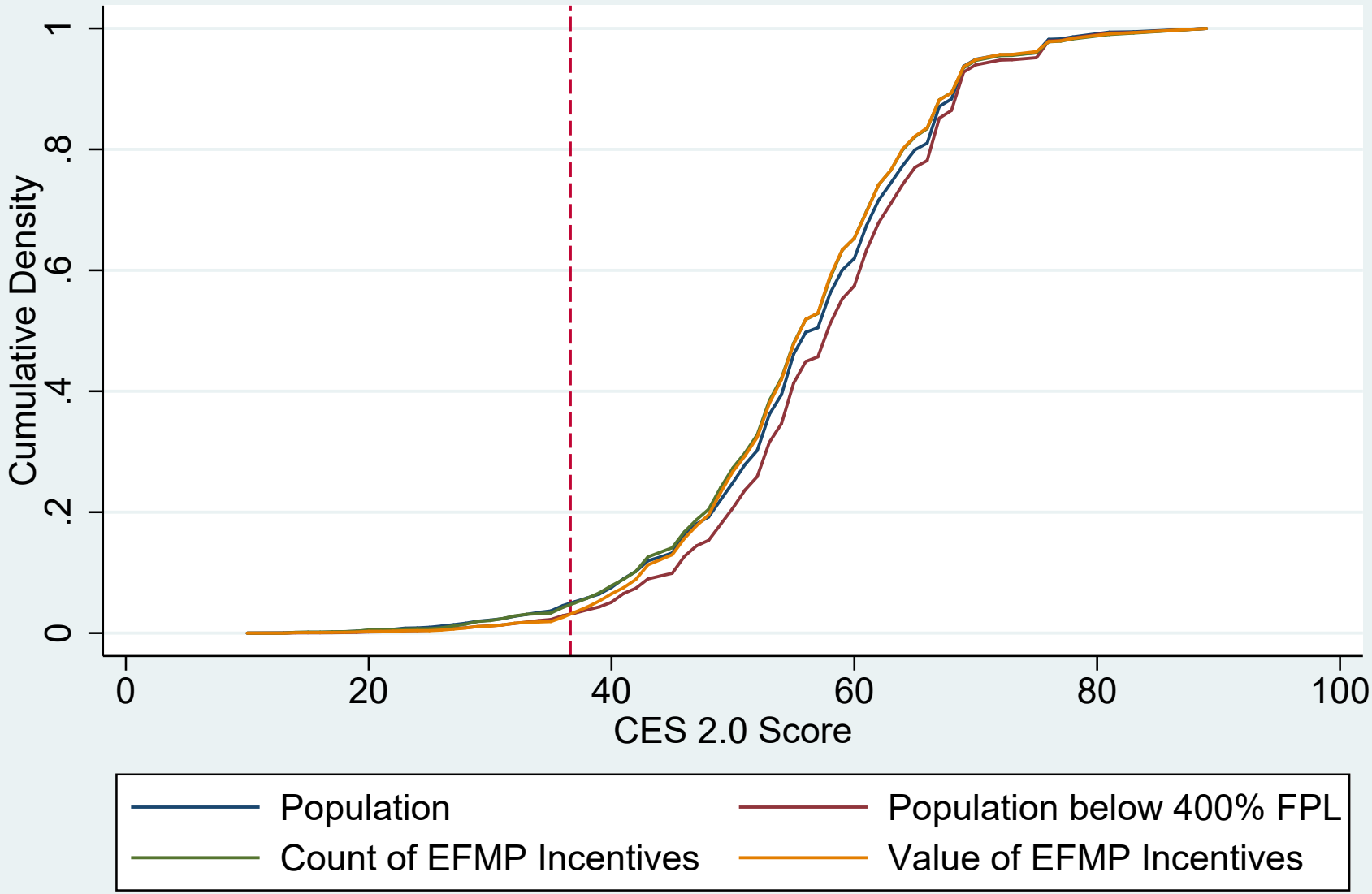
Income Bins	DAC==0	DAC==1	Total
0%-225% FPL	3.9	87.0	90.9
225%-300% FPL	0.3	6.6	6.9
300%-400% FPL	0.0	2.1	2.1
Total	4.2	95.8	100.0

Cells denote percentage of number of total subsidies allocated to Income Bin X DAC

- Through 2017, $\sim 3,000$ EVs received a subsidy payment under EFMP, $\sim 2,500$ "plus-up".
- Most subsidies go to low-income households in DAC zips

Data Description

95% of incentives go to zips with MaxCES below 70



Toyota Mirai: "The Future"

Toyota Mirai: "The Future"

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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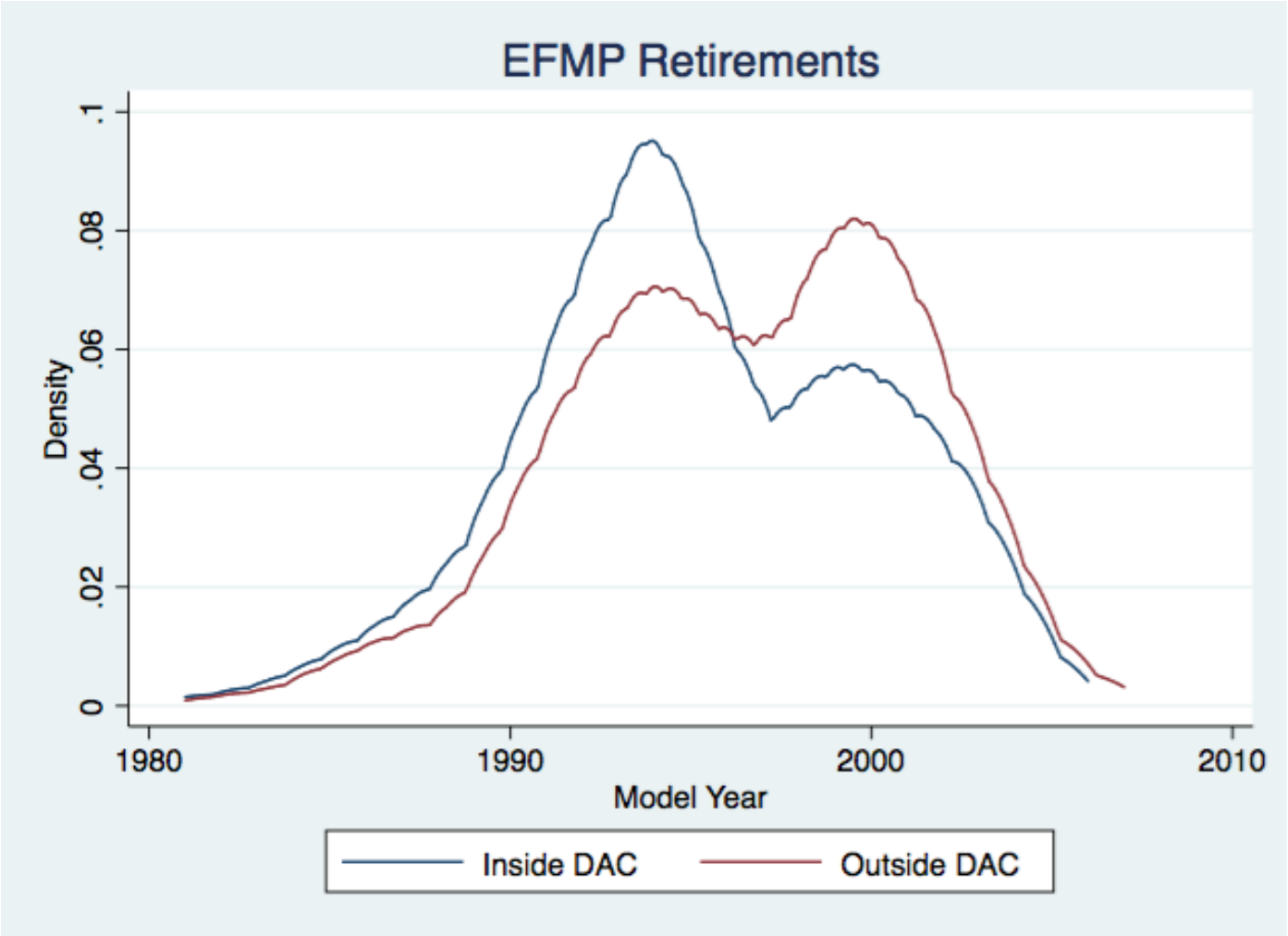
Histograms of retirement ages



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