ECON 8000/9000 Empirical Energy Econ

Topic 12: Introduction to Topics on EVs

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April 6, 2026

Outline

- Introduction to Topics on EVs
- Example 1: Gillingham, van Benthem, Weber, Saafi, & He (2023) AEA P&P
- Example 2: Burlig, Bushnell, Rapson, & Wolfram (2021) AEA P&P
- Examples 3-4: Student Presentations: Bushnell, Muehlegger, & Rapson (2025) NBER WP + Nehiba (2024) JEEM
- Example 5: Bailey, Brown, Myers, Shaffer, & Wolak (2025) AER: Insight
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Introduction to Topics on EV

Some terminology: Vehicle types by fuel types

- ICEVs: Conventional vehicles on fossil fuels with internal combustion engine (ICE)
  - Gasoline vehicles (GVS), or called petrol vehicles in Europe
  - Diesel vehicles
  - Hybrid vehicles (on either gasoline or diesel)
- Electric vehicles (EVs)
  - Battery electric vehicles (BEVs) typically with 100-500 miles battery range
  - Plug-in hybrid vehilces (PHEVs) typically with $<$ 50 miles battery range
- Alternative fuel vehicles (AFVs)
  - Before EV adoption took off, both EVs and Hybrid are all considered AFVs
- Rare: Fuel cell electric vehicles (FCEVs)
  - They convert hydrogen gas to electricity. Very small market share.
  - e.g., Toyota Mirai and Honda Clarity
  - Depends on market/country, fuel cell may be considered as EV

Introduction to Topics on EV

Some terminology: Measure energy efficiency using operating energy cost DPM

- Dollar-per-mile (DPM) for ICEVs
  - $dpm = \frac{fp}{mpg}$ or $dpm = fp \cdot gpm$
  - fp: fuel price in dollar-per-gallon
  - mpg: fuel economy of a vehicle in miles-per-gallon
  - gpm: fuel consumption rate of a vehicle in gallon-per-mile
- Dollar-per-mile (DPM) for BEVs
  - $dpm = ep \cdot epm$
  - ep: electricity price in dollar-per-kwh
  - epm: electricity consumption rate of a vehicle in kwh-per-mile
- Dollar-per-mile (DPM) for PHEVs
  - Compute DPM under BEV mode and ICEVs mode
  - Weight the above two using fraction of miles typically run on each mode on average
  - Can use manufacturer reported fraction, or follow ICCT (2022)

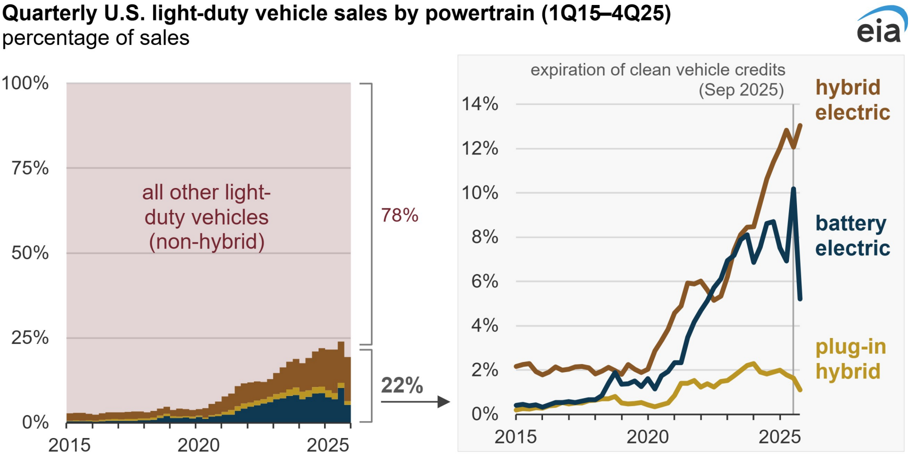
Introduction to Topics on EV

Some new considerations for EV market that are not present in ICEV market

- Consumer preference for battery range (a new attribute)
- Consumer preference for charging speed (a new attribute)
- Consumer preference for charging network + free charging spots
- Two-sided market consideration: EV adoption & charging station entry
- Early EVs market pre-predominately higher income groups as they are also luxury vehicles
- No more on-road emission! (That's why they are called zero-emission-vehicles!)
- But ZEVs are not zero emissions. Emission will then come from electricity generation
  A spatial redistribution of emissions and local health impact
- Electricity consumption and smart charging
- Different regulations and incentives
  - ICEVs historically comply to fuel economy standards, CAFE by EPA and GHG emission standards by NHTSA
    Now a firm with both ICEVs and EVs can use EVs to help compliance
  - Certain states have ZEV standards: 17 states
  - EV subsidies and incentives at federal and local level

Fast Facts and Discussions

1. EV uptake: Trends of market share



Source: US EIA

Fast Facts and Discussions

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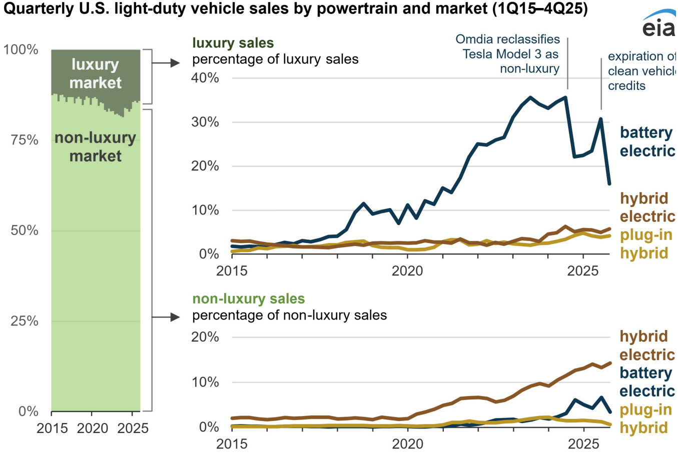
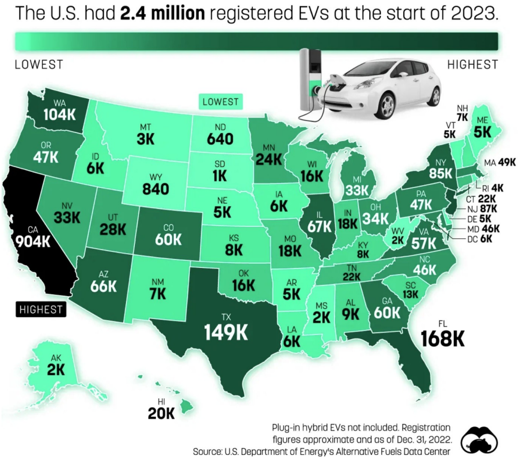


Source: US EIA

Fast Facts

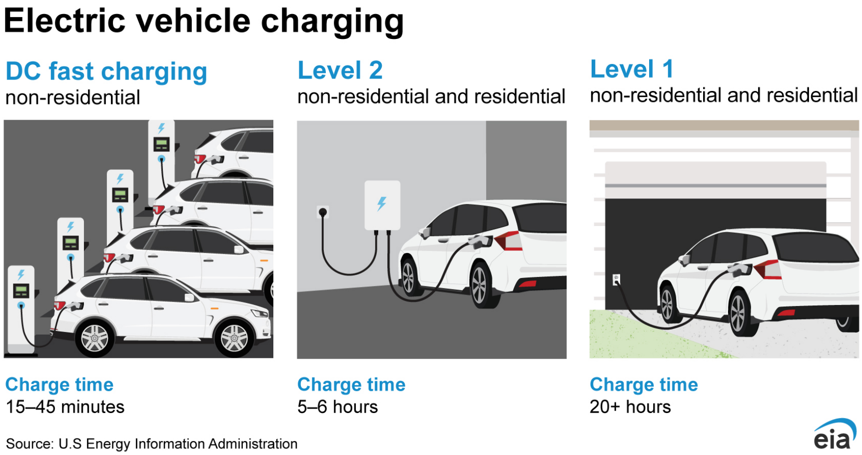
1. EV uptake: Spatial distribution



Source: US EIA

Fast Facts and Discussions

2. Potential Barrier: Charging Speed and Network



Source: Veronoi

Fast Facts and Discussions

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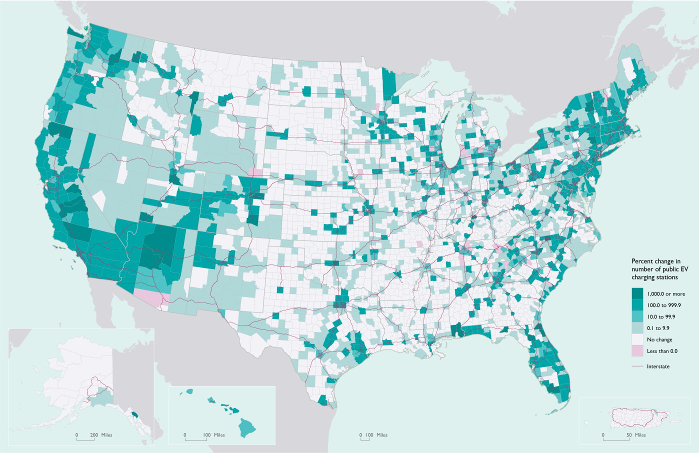
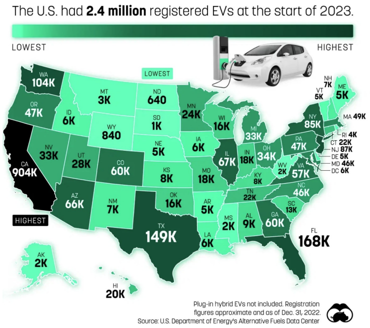


Source: EV Charging Density by BTS of DOT

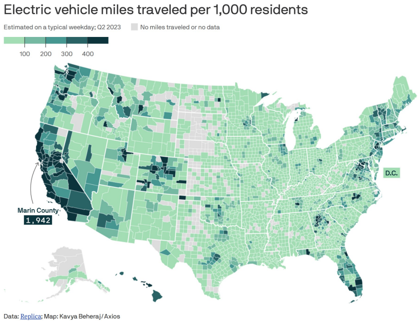
Fast Fact and Discussions

3. Potential Pollution and Climate Net Benefit

Left: EV adoption



Right: EV VMT



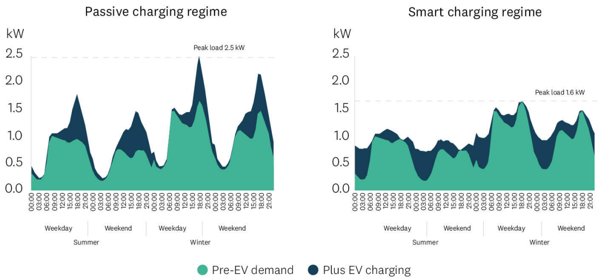
Potential net-gains depends on

- Where EV purchases replace ICEV purchases
- How much these EVs get driven (VMT)?
- Where are these EV driven?
- When and where these EVs are charged (implication for emissions from electricity generation)?

Fast Fact and Discussions

4. Potential Unintended Consequences on Electricity Market + Smart Charging

Household demand under passive and smart charging regimes

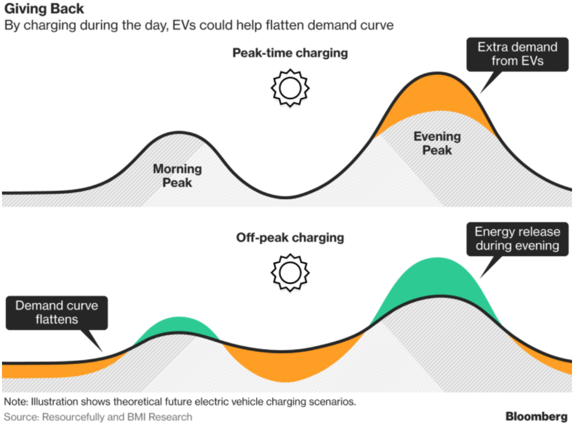


Source: Concept Consulting, 2018

- Extra electricity demand
- Specifically during late hours
- An emerging technology of smart-charging: Contingent on how good AI algorithm is in automating charging by location & time

Fast Fact and Discussions

4. Smart Charging



- Potentially shift charging away from peak hours during the evening and early morning
- Potentially help use daytime renewable energy better (they have a curtailment issue)

Typical Research Questions

Questions that don't involve a serious demand estimation

- Correlative question: What are typical determinants impacting EV demand?
- How do fuel & electricity price variations affect EV adoption?
- How do fuel & electricity price variations affect EV VMT?
- How does the charging network affect EV adoption & usage?
- How does the variation in electricity prices throughout the day affect EV charging time?
- What's the pass-through of EV subsidies?
- Effectiveness of adoption subsidies: Does EV subsidy increase marginal adoption or are they captured by always-adopters?
- Effectiveness of usage incentives: E.g., discounted charging from utility or local gov't
- How does EV charging affect electricity consumption and create burdens on the grid?
- How does EV adoption and charging affect emissions?
- What are the local economic impacts of charging stations (positive & negative)?

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Gillingham, van Bentham, Weber, Saafi & He 2021

AEA P&P "Consumer Acceptance of EV: Microdata on Every New EV Sales in US"

Research Question:

- This is a correlational study to document some patterns
- Q: If we look at demographics, what are the key determinants of EV adoption & acceptance? What types of EVs do we observe get adopted?

Data

- All new vehicle registrations from 2014 to 2020

Key trends and factors

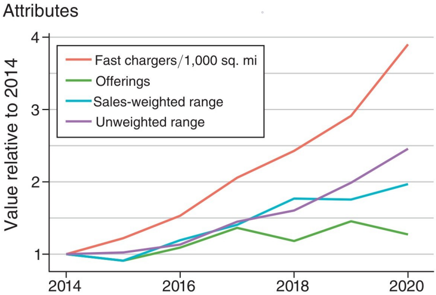

Figure 1. EV Trends for the Period 2014–2020

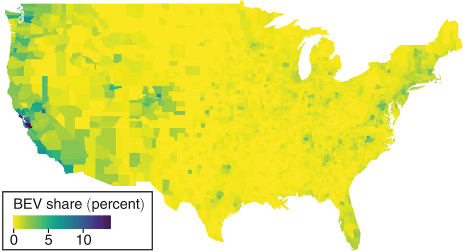

Figure 2. County-Level Market Share of Battery Electric Vehicle Sales in 2020

- Attribute: EV range, fast-charging capability
- Spatial uptake: (i) rural/urban split, (ii) locations with ZEV policies

Key determinant/barriers: Income

TABLE 1—REGRESSION OF EV/PHEV ADOPTION ON DEMOGRAPHICS

	(1)	(2)	(3)
Time	0.006	0.007	0.007
	(0.002)	(0.002)	(0.002)
Single-family home	−0.008	0.001	−0.000
	(0.003)	(0.002)	(0.002)
Urban	0.024	0.007	0.005
	(0.011)	(0.003)	(0.003)
Income \$100,00–\$200,000	0.019	0.014	0.011
	(0.007)	(0.005)	(0.004)
Income \$200,000+	0.044	0.039	0.032
	(0.013)	(0.011)	(0.009)
Single-family home × Urban	−0.018	−0.002	−0.002
	(0.012)	(0.005)	(0.005)
Graduate degree			0.006
			(0.001)
High school diploma			−0.012
			(0.004)
Less than high school			−0.019
			(0.008)
Some college			−0.010
			(0.004)
State fixed effects	No	Yes	Yes
Mean	0.023	0.023	0.023
Observations	58,654,169	58,654,169	58,654,169

Note: Dependent variable is a dummy for EV or PHEV.

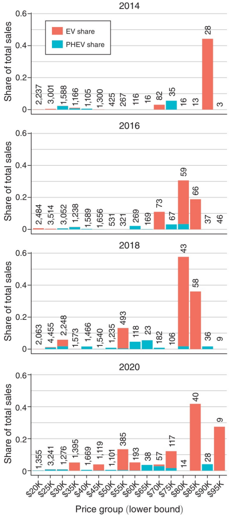

FIGURE 3. EV AND PHEV SHARES OF TOTAL VEHICLE SALES IN PRICE RANGE BRACKET, 2014–2020

Key determinants/barriers: Very limited segments

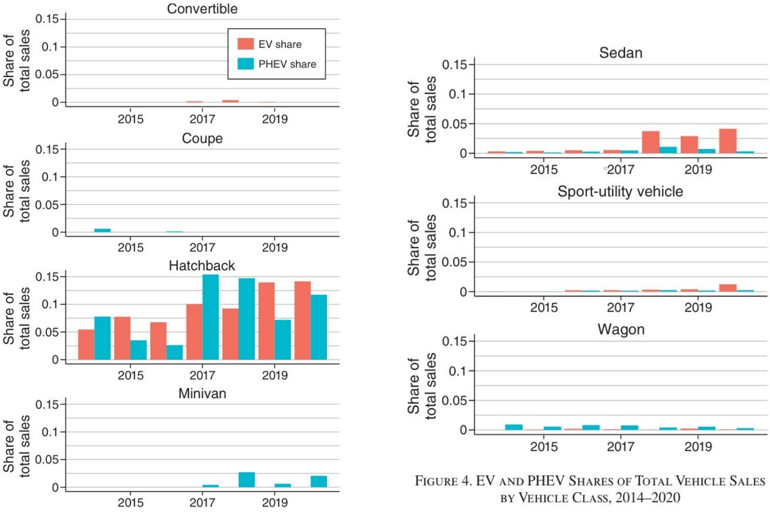

Figure 4. EV and PHEV Shares of Total Vehicle Sales by Vehicle Class, 2014–2020

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Burlig, Bushnell, Rapson, & Wolfram (2021)

AEA P&P "Low energy: Estimate EV electricity use"

Research Question and Data:

- RQ: How does EV adoption affect electricity consumption at different times of the day?
- Data: PG&E metering data, California DMV

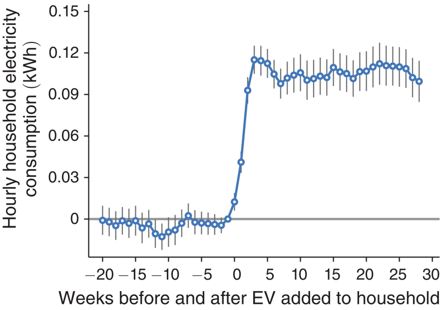
Approach: For household i in a week of the same t in hour-of-day h, estimate

$$Y_{ith} = \beta EV_{it} + \gamma Solar_{it} + \alpha_i + \delta_t + \varepsilon_{ith} \tag{1}$$

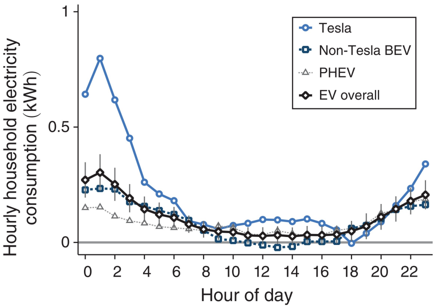
- Y: electricity consumption (kwh)
- Control: if a household has installed solar PV
- Identification: assume household i does not shift energy use across hours in a day

Results

Left: Event Study version of Eq(1)



Right: Allow β_h to vary by h in Eq(1)



- Magnitude: Δ3 kwh per day increase for EV adoptors, relative to mean at 6-10 kwh per day
- Elevated usage during peak hours

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Student Presentations

Bushnell, Muehlegger, & Rapson (2025) NBER WP:

- "Energy Price and EV Adoption"
- RQ: How does variation in fuel price and electricity price affect EV adoption?

Nehiba (2024) JEEM:

- "EV Usage, Pollution Damages, and the Electric Price of Driving"
- RQ: How does electricity price affect VMT, then ergo, pollution distribution?

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Bailey, Brown, Myers, Shaffer & Wolak (2025)

AER:I "EV and the Energy Transition: Unintended Consequences of TOU Pricing"

- For this paper, we will do a demo of making slides with Notebook LM
- I usually recommend a two-step approach
  - Step one: Ask Notebook LM to summarize the study into a deck of slides. Then you can write prompts, ask for clarification and supply some additional "sources" to perfect your deck of slides. Each iteration will take quite 10-ish minutes.
  - Optional step two: You can load the slides that Notebook LM makes for you into a different AI tool, e.g., ChatGPT, Claude, etc, and ask the AI to generate Latex code that you can copy & paste into Overleaf.
- Suitability:
  - Teach a standard set of topics for undergraduate electives. You can load relevant news, policy discussion, or simple studies that are undergrad-friendly
  - Make a deck of slides for your own research. The downside is Notebook LM doesn't generate a long deck of slides, but the slides it generates can also help you think of framing, motivation, and give you ideas regarding how to improve clarity
- Try this at your next presentation!

Bailey et al. (2025) AER:I

Iteration 1

- Prep step: Load the PDF of Bailey et al. (2025) into "Source" for Notebook LM
- Prompt *"In this chat, I would like to create a demo slides deck for Bailey et al. (2025) to show Ph.D. students how to use Notebook LM for their own studies. I will ask you to make slides, save them, then ask you for modifications, in a few iterations."*
  - Output 1: Deck V1a
  - Output 2: Deck V1b
- Pro + issues:
  - Pro: Good overview of the market if the market or policy is a bit foreign to you
  - Downside: A lot of factual errors and hallucinations. Also, the deck reads like a manifesto rather than a deck that explains a study

Bailey et al. (2025) AER:I

Iteration 2

- Prep step: crop figures, tables, and equations that are important to the study and load them into "Source" for Notebook LM to consider
- Prompt *"I have now added (i) key equation (1), (ii) figures 1-3, (iii) tables 1-2 into the source. Please revise the deck. Be clear (1) what is the experiment design, (2) what are the two key variables they look at and why the yare important to look at, (3) how authors specify their estimation so that they can go after their research question, and (4) present the main results (aka Table 2 and Figure 3) and discuss implications.*
  Also, the original slides have a lot of factual errors. For example, the total sample size is not 150; the total number of EVs is 202, with 62 EVs in control, 70 in TOU, and 70 in smart charging. I know there are 32 existing EVs, could you investigate if the main results include them or not, if so, where did the authors state so?"
- Prompt *"Also, add how the transformer works in this research so that students understand. For example, what do transformers do and why the authors need to create "virtual" transformers."*
- Output
  - Intermediate chat responses
  - New Deck: V2
  - Much better deck but needs more work

Bailey et al. (2025) AER:I

Iteration 3

- Prompt *"This is much better. Please revise in the following ways. 1. The title should be the same as the study, list all authors journal name (AER:I) and year), 2. After title page, on the first page, summarize their main research question, also explain why it is important to study them, 3, you can modify the current pages 2-3 into page 3-4 that further explains although TOU may correct some distortions that flat price creates, TOU also creates additional unintended challenges, 4 next using 1-2 pages explain data and design, then to show balance test, it is better to insert the table than create your own page 5. Next, when presenting empirical spec, do not omit the "..."; those are important FEs and controls. Please note that what they are in the same slides, also spell out what subscript i,d,h are; otherwise, the original page 6 is fine. 6. No need for page 7 now that the experimental spec page will be improved. Then explain how the 2nd outcome relates to the transformer and how that works in this study. For the main results, present Table 2 and Figure 3 separately. Make sure Table 2 is directly inserted. Then on the slide somewhere, also remind what betas are summed together as you are doing so."*
- Prompt *"There is no need to mention elasticity as it is not the main result. You can go ahead and make slides. On the last page, explain some key insights as well as some tradeoffs that were studied in this paper.*
  Now on the last page, call it "Discussion". The discussion will include the following questions without answers. These are the opening questions I will discuss with students: Q1: How do the results depend on the algorithm of smart/managed charging? Q2: Why do you think people quit (in addition to the reasons offered by the authors)? Q3: How does the objective function of smart-charging management matter here? Q4: Do smart charging objectives function compared to the social planner's objective in maximizing total private surplus? How does this relate to Q2? Q5: Centralization vs. decentralization?."
- Output: V3, almost ready

Bailey et al. (2025) AER:I

Iterations 4-5

- Prompt *"The motivation on page 2 is fine, but that is mostly a big-picture question. The specific research question is how different types of charging pricing and systems affect when where EV users charge their vehicles. Then you can go into the big question you raised. When you raise that question, offer two solutions on the market, one is the TOU as a conventional solution that economists offered as a pricing tool, and then the second one is the managed charging. Then explain why TOU has some flaws, highlight potential (i) EV charging hours that can be created by incentivizing ppl to move to off-peak, which can create a shadow-peak, then (ii) this effect can be even worse considering the spatial correlation of such behavior. On page 4, it simply compares what 3 types of pricing as a matter of fact. The 3 rows you created are mostly your opinion. To introduce the study, just present, as a matter of fact, how the three pricing methods are implemented in general. Page 5 is great. Also, mention that transformers are hypothetical and were defined so that 2-3 EVs can be charged at the same time. Page 6, don't use the word "prove", just mention that they passed the balance test. Page 7 is great. Could you highlight beta 1 and beta 6 in one color, and beta 2 and beta 7 in another? Add a data page before the equation that lists yvars and xvars, then insert page 8 to explain what capacity violation means. No need to list page 8 after page 7 now that we explained that before the equation. For page 9, split into one slide that looks into kWh, and another that looks into constraint violation. Last page, use bullet, remove 1-5 as the questions have numbers already."*
- Prompt *"Could you add the previous version page 5 (aka experiment design) before the current page 5, i.e., explain experiment assignment first. Then add current page 7 to explain 7 var, then use current page 5 to explain the transformer. Also page 9 -12 need to insert actual figures and tables that I gave you, not to create them yourslef"*
- Output: V4-V5, almost ready

Suggestions

- Cost/capacity management: Each iteration will burn some of your tokens. So if you can (i) make all requests in one go, instead of multiple iterations, and (ii) provide all "sources" needed, then the free version should be good enough. Also, you can give them some sample slides you read in the past and like for the basic structure.
- Tradeoff: 10-12 slides so some requests may crowd out other requests
- Good use: Slides deck or reports that summarize the paper
- Other use for undergrad teaching: Load your teaching slide and make some quizzes

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Muehlegger & Rapson (2022) JPubE

"Subsidizing low- and middle-income adoption of EVs: Quasi-experiment evidence from California"

Research Question: What is the effect of EV subsidies of the Enhanced Fleet Modernization Program (EFMP)?

- EFMP: A retire-and-replace subsidy since 2015
  → a bit like cash-for-clunker but for new EV adoption → takes place in 2 Air Quality Management Districts (AQMDs)
- Importance: EV adoption has been concentrated amongst the higher-income population, and subsidies have been quite regressive. → Raise issues on both (i) effectiveness ground and (ii) distributional ground
- Consumers in a disadvantaged community (DAC) receive a higher subsidy
  DAC = the top quartile in terms of socio-economic disadvantages e.g., poverty, unemployment

Approach and data

- DID and tripple DID
- California DMV data 2012-2018
- Program participation and rebate data
- Transactional-level data of new and used EV purchases

Program Design: EFMP

Figure A1: EFMP Eligibility Flowchart

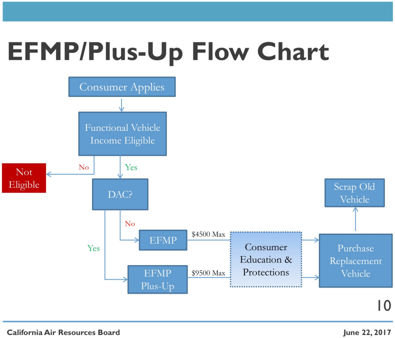
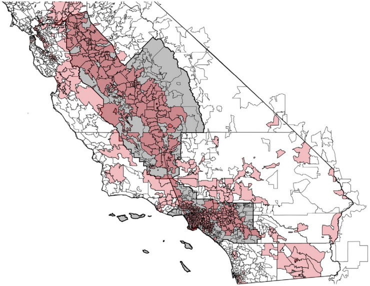


Table 1
EFMP Incentive Schedule for BEVs and PHEVs.

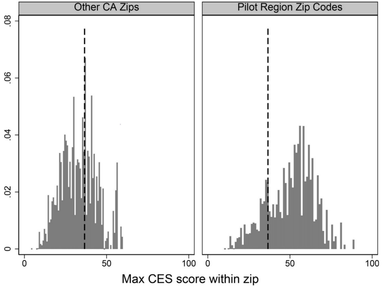
Income	EFMP Category	PHEV/BEV
$<$ 225% FPL	Base	$4,500
225–300% FPL	Base	$3,500
300–400% FPL	Base	$2,500
$<$ 225% FPL	Plus-up	$5,000
225–300% FPL	Plus-up	$4,000
300–400% FPL	Plus-up	$3,000

Participating Locations & External Validity

Participating AQMDs are slightly lower income



South Coast and San Joaquin Valley AQMDs. Note: The figure maps zip codes in California and the boundaries of the two of pilot program. Disadvantaged zip codes are shaded red. The area of two participating AQMDs are shaded gray.



Average Income and Max-CES Score. Note: Left histogram presents the distribution of zip-level maximum CES scores for non-pilot regions. Right histogram tribution of zip-level maximum CES scores for the pilot regions. The dashed vertical line corresponds to the disadvantaged community CES score cutoff of

Empirical Model + Main Results

Direct Regression for Demand Elasticity with IV. For zipcode z in quarter t, estimate

$$Y_{zt} = \beta X_{zt} + \gamma_z + \nu_t + \varepsilon_{zt} \tag{4}$$

- Y: Inverse hyperbolic since of EV quantity in z at t
- X: Residual subsidy-inclusive price in z at t (de-meaned already by vehicle)
- β: Demand elasticity for targeted consumers
- IV: Average eligible subsidy in z based on FPL eligibility
- Q1: Source of identification?

Table 6
Demand Elasticity of Electric Vehicles - Full Subsidy.

	(1)	(2)	(3)
	DinD	Matched DinD	DDD
Upper Bound	−3.10	−3.83	−2.83
	(0.51)	(0.94)	(0.47)
Direct Estimate (IV)	−2.10	−2.16	−2.14
	(0.46)	(0.57)	(0.47)
Lower Bound	−0.86	−0.57	−0.33
	(0.22)	(0.30)	(0.22)

Table 6 presents elasticity estimates obtained from Eq. 15 using the "upper-" and "lower-"bound estimates from Table 5 in the top and bottom rows, respectively. Standard errors for these two rows are calculated via bootstrap (N = 200 samples drawn with replacement at the zip-code level). The middle row of Table 6 ("Direct Estimate (IV)") presents our preferred estimates of the demand elasticity, which arise from estimating Eq. 16.

- Demand elasticity ≈ -2.1 from EV incentives to EV adoption for mid- & low-income hh

Other Regressions: Two-step for Elasticity

Step 1 Regression: A pass-through regression. For zipcode z in quarter t, estimate

$$Y_{zt} = \beta_1 \lambda_{zt} + \gamma_z + \nu_t + \varepsilon_{zt} \tag{1}$$
$$Y_{zt} = \beta_{PT} S_{zt} + \gamma_z + \nu_t + \varepsilon_{zt} \tag{2}$$

- Y: residual subsidy-inclusive price
- λ: fraction of vehicles subsidized in z at t
- S: average per-vehicle subsidy in z at t.
- Robustness: synthetic control
- Robustness: use θ_{At} and η_{Dt} (AQMD- and DAC-specific trend) instead of γ_z

Step 2 Regression: Quantity regression with the same IV

$$Y_{zt} = \beta_Q T^{\omega}_{zt} + \gamma_z + \theta_{At} + \eta_{Dt} + \varepsilon_{zt} \tag{3}$$

- Y: Inverse hyperbolic quantity of EV in z at t
- T: weighted average subsidy per EV under EFMP in z at t in two ways in 1k USD
  - High version: fraction of hh under 400% of federal poverty line (FPL)
  - Low version: fraction of hh purchased EV under EFMP

Step 3: Infer Elasticity

- Elasticity $\varepsilon_d = \frac{\beta_Q \cdot P}{\beta_{PT}}$

Additional Pass-through Results + Quantity Results

Table 4
Pass-Through and EFMP Incentives - Full Subsidy.

	(1)	(2)	(3)	(4)	(5)	(6)
	DinD	Matched DinD	Triple Diff	DinD	Matched DinD	Triple Diff
% EFMP Transactions	−8005.0***	−6993.3***	−7900.6***			
	(1348.3)	(1582.1)	(1343.3)			
(mean) avgsubsidy_total				−0.85***	−0.73***	−0.84***
				(0.15)	(0.17)	(0.15)
Observations	12495	16415	25139	12495	16415	25139
R-Squared	0.12	0.096	0.14	0.12	0.096	0.14

The dependent variable is average residual subsidy-inclusive price in a zip*quarter, after conditioning on Make*Model*Model-year*Year of Sale fixed effects. Columns (1), (2), (4) and (5) include time and zip fixed effects. Columns (3) and (6) include time*AQMD, time*DAC and zip fixed effects. Standard errors are clustered by zip code.

Table 5
EV Sales and EFMP Incentives - Full Subsidy.

	(1)	(2)	(3)	(4)	(5)	(6)
	DinD	Matched DinD	Triple Diff	DinD	Matched DinD	Triple Diff
Lower Bound	0.028***	0.016**	0.011			
	(0.0057)	(0.0070)	(0.0067)			
Upper Bound				0.12***	0.13***	0.11***
				(0.011)	(0.013)	(0.010)
Observations	15801	19458	34477	15621	19278	34297
R-Squared	0.87	0.87	0.90	.	.	.
First-stage F-stat				170.2	120.7	168.9
Hansen Test p-value				0.64	0.33	0.89

The dependent variable is the inverse hyperbolic sine of sales in a zip*quarter. Control variables in all specifications are zip and quarter-of-sample fixed effects. Standard errors are clustered by zip code. Columns 1, 2 and 3 are OLS regressions for the unmatched Differences-in-Differences, the matched Difference-in-Differences and the Triple-differenced specifications, respectively. Columns 4, 5 and 6 present IV estimates of columns 1 through 3 using our preferred instrument described in Section 4.1.

Main Elasticity Results Again with Bounds

Table 6
Demand Elasticity of Electric Vehicles - Full Subsidy.

	(1)	(2)	(3)
	DinD	Matched DinD	DDD
Upper Bound	−3.10	−3.83	−2.83
	(0.51)	(0.94)	(0.47)
Direct Estimate (IV)	−2.10	−2.16	−2.14
	(0.46)	(0.57)	(0.47)
Lower Bound	−0.86	−0.57	−0.33
	(0.22)	(0.30)	(0.22)

Table 6 presents elasticity estimates obtained from Eq. 15 using the "upper-" and "lower-"bound estimates from Table 5 in the top and bottom rows, respectively. Standard errors for these two rows are calculated via bootstrap (N = 200 samples drawn with replacement at the zip-code level). The middle row of Table 6 ("Direct Estimate (IV)") presents our preferred estimates of the demand elasticity, which arise from estimating Eq. 16.

- How is elas = -2.1 compared to early adopters?
- EV papers on earlier market (2010-2015) typically estimate EV demand elasticity -0.9 to -2
- Typical vehicle demand report elasticity -1.5 to -7
- It is indeed the case that earlier adopters' estimates are less elastic, and adopters in mid- and lower-income groups are slightly more elastic. But still not very elastic compared to typical vehicle demand
- What does that tell you about the later adopter?
- What do these results tell you about potential (i) effectiveness and (ii) regressivity of EV subsidies?

Outline

- Introduction to Topics on EVs ✓
- Example 1: Gillingham, van Benthem, Weber, Saafi, & He (2023) AEA P&P ✓
- Example 2: Burlig, Bushnell, Rapson, & Wolfram (2021) AEA P&P ✓
- Examples 3-4: Student Presentations: Bushnell, Muehlegger, & Rapson (2025) NBER WP + Nehiba (2024) JEEM ✓
- Example 5: Bailey, Brown, Myers, Shaffer, & Wolak (2025) AER: Insight ✓
- Example 6: Muehlegger & Rapson (2022) JPubE ✓
- Example 7: Holland, Mansur, Muller, & Yates (2016) AER

Holland, Mansur, Muller, & Yates (2016) AER

"Are there environmental benefits from driving EV? The importance of local factors"

Research Question and Objective:

- Can we do a sophisticated accounting exercise to study the distributional effect of driving (and ergo charging) EV across various locations in the US?
- Estimate the marginal effect of charging on emissions at various power plants?
- What do these estimates imply about the optimal place-based EV subsidy?

Conception idea: Emissions from ICEVs vs EVs

- Emissions from internal combustion engine vs. emissions a combination of renewable and coal- and gas-fired combustion turbines
- What do these estimates imply about the second-best place-based EV subsidy?

Holland et al. (2016) AER

Approach

Module 1: Convert EV Charging to Emissions at plant X time level

- Correlation between hour-specific load to emissions from power plants
- You have seen an application in Nehiba (2024)
- Here they estimate βs separately for 9 NERC regions

Module 2: Convert Emissions to Damages using AP4 from Nicholas Muller

- Muller's Air Pollution Emission Experiments and Policy analysis (APEEP) model
- Later editions of APEEP are AP2, AP3, AP4 (Link to APEEP models)
- A spatial accounting model started in Muller, Mendelsohn, & Nordhaus (2011) AER
- Input: emissions at different locations from various industries (power plants, various kinds of manufacturing)
    - They need Δ emissions, not just emissions.
    - Δ emissions = emissions EVs create - counterfactual ICEVs emissions avoided
- Model allows: pollutant transport and deposition
- Output: air pollution damages, such as health effects and crop yields

Holland et al. (2016) AER

Other things go into the accounting

ICEVs Emission Rate and Emissions

- This is important to compute counterfactual ICEVs emissions avoided
- Emission rate (e.g., CO_2, SO_2, NO_x) can be directly converted from fuel economy (MPG) using an engineering estimate
- They use various common sources for the engineering conversion factor
- To map emission rate to emissions, need to use VMT estimate from the EPA

What is the counterfactual ICEV vehicles

- Use the second-choice data from the MaritzCX consumer survey
- Instead of computing the diversion ratio and response matrix from estimating a discrete-choice demand model, simply use the stated preference as an estimate
- Why? A good discrete choice should be able to match the stated preference of the second choice

Empirical model

Correlate electricity use to emissions

For power plant i hourly emission at time t

$$y_{it} = \sum_{h=1}^{24} \sum_{j=1}^{J(i)} \beta_{ijh} Hour_h Load_{jt} + \phi_{mh} + \varepsilon_{it} \tag{1}$$

- $Load_{jt}$: electricity load in each plant i's interconnection
    - Ideally they want to observe $Load_{ijt}$
    - For each of 3 interconnections, there are a few NERC region j (except TX)
    - Use hourly load at NERC region
- ϕ_{mh}: month-in-the sample FE X hour-of-day FE (36 X 24 of them)
- β_{ijh}: Marginal emission factors
- How is this connected to EV charging?
    - EV charging will shock the $Load_{jt}$ part by different $Hour_h$

Empirical model

Damage estimate from Eq(1)

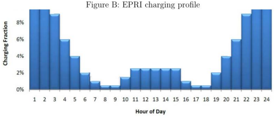
TABLE 1—MEAN DAMAGES IN CENTS PER MILE BY ELECTRICITY DEMAND REGION FOR A 2014 FORD FOCUS ELECTRIC VEHICLE FOR DIFFERENT CHARGING PROFILES

Region	EPRI	Flat	Hr 1–4	Hr 5–8	Hr 9–12	Hr 13–16	Hr 17–20	Hr 21–24	VMT (%)
California	0.69	0.75	0.65	0.78	0.78	0.84	0.82	0.64	11
WECC w/o CA	1.03	0.92	1.18	0.98	0.84	0.76	0.73	0.99	11
ERCOT	1.28	1.21	1.50	1.41	1.10	1.07	1.05	1.16	7
SPP	2.24	2.74	2.07	4.91	2.30	2.89	2.39	1.89	4
FRCC	2.48	2.14	3.21	2.36	2.25	1.39	1.53	2.11	6
SERC	2.75	2.67	2.75	2.26	2.72	2.96	2.63	2.71	22
NPCC	3.11	2.75	4.19	3.75	1.61	2.12	2.49	2.35	9
RFC	3.64	3.55	3.42	3.38	3.83	3.06	3.43	4.15	17
MISO & MRO	4.29	3.52	5.63	3.91	3.03	2.57	2.32	3.69	14
Total	2.59	2.41	2.90	2.56	2.28	2.15	2.12	2.46	100

Notes: The regions are ordered by the damage per mile under the EPRI charging profile. The EPRI charging profile is illustrated in Figure B in online Appendix F; the flat charging profile assumes charging is equally likely across hours; and other profiles assume charging occurs only in the indicated hours. Damages (in cents per mile) are weighted across counties by passenger vehicle VMT. California is the California ISO; WECC w/o CA is the Western United States excluding California; ERCOT is Texas; SPP is Kansas and Oklahoma; FRCC is Florida; SERC is the Southeast; NPCC is the Northeast; RFC is the Mid-Atlantic and Midwest; and MISO & MRO is the upper Midwest. See Figure C in online Appendix H for a map of the regions.

- damages weighted across hours by EPRI charging profile

Figure B: EPRI charging profile



Source: Electric Power Research Institute (2007).

What does an EV replace?

Stated-preference from MaritzCX

24. When shopping for your new vehicle, did you consider any OTHER cars or trucks? . . . . 1 Yes 2 No *(Skip to Q28.)* con_yn

25. Please complete the following information for other vehicles you may have considered while shopping for your new vehicle.

	Model Most Seriously Considered	Second Model Considered	Third Model Considered
Make, Model, Series...... *(e.g., Honda Accord EX)*	c1_model_response c1_series_response	c2_model_response c2_series_response	c3_series_response
Model Year......	c1_myr 1930-2019	c2_myr 1930-2019	c3_myr 1930-2019
Drive type......	c1_drive 1 2WD 2 4WD/AWD	c2_drive 1 2WD 2 4WD/AWD	c3_drive 1 2WD 2 4WD/AWD
Number of doors......	c1_door 1 2 doors 2 4 doors	c2_door 1 2 doors 2 4 doors	c3_door 1 2 doors 2 4 doors
Body style......	c1_bdst_unedited 1 Coupe 6 Pickup 2 Sedan 11 Sport Utility 10 Hatch 12 Crossover 4 Convertible 13 Van 3 Wagon	c2_bdst_unedited 1 Coupe 6 Pickup 2 Sedan 11 Sport Utility 10 Hatch 12 Crossover 4 Convertible 13 Van 3 Wagon	c3_bdst_unedited 1 Coupe 6 Pickup 2 Sedan 11 Sport Utility 10 Hatch 12 Crossover 4 Convertible 13 Van 3 Wagon
Type of engine......	c1_fuel_type 1 Gasoline 3 Hybrid 2 Diesel 5 Electric 4 Plug-in Hybrid 7 Hydrogen	c2_fuel_type 1 Gasoline 3 Hybrid 2 Diesel 5 Electric 4 Plug-in Hybrid 7 Hydrogen	c3_fuel_type 1 Gasoline 3 Hybrid 2 Diesel 5 Electric 4 Plug-in Hybrid 7 Hydrogen
Did you . . . Look at dealership?......	1 Yes 2 No c1_shop	1 Yes 2 No c2_shop	1 Yes 2 No c3_shop
Test drive?......	1 Yes 2 No c1_testdr	1 Yes 2 No c2_testdr	1 Yes 2 No c3_testdr
Intend to purchase or lease?......	1 Purchase 2 Lease c1_pl	1 Purchase 2 Lease c2_pl	1 Purchase 2 Lease c3_pl
Wish to acquire new or used?......	c1_nu 1 New 2 Used 3 Certified pre-owned	c2_nu 1 New 2 Used 3 Certified pre-owned	c3_nu 1 New 2 Used 3 Certified pre-owned

*All variables in Q.26 have a prefix of c1_rnb_*

26. Please check the reason(s) why you did not select the model you most seriously considered.

1 Manufacturer's Reputation reputation
2 Vehicle Size Too Big big
3 Vehicle Size Too Small small
4 Interior Styling intstyle
5 Safety Features safety
6 Overall Quality/Reliability quality
7 Attitude of Dealer Personnel dealer
8 Seating Capacity seatcap
9 Exterior Styling extstyle
10 Engine Performance/Power power
11 Fuel Economy mpg
12 Future Trade-in/Resale Value trade
13 Price/Deal Offered price
14 Interior Roominess introom
15 Rear Leg Room rearleg
16 Cargo Capacity cargo
17 Riding Comfort comfort
18 Value for the Money value
19 Available Options/Equipment options
20 Warranty Coverage warr
21 Ease of Handling ehand
22 Country of Manufacturer country_man
23 Financing Terms/Rebate rebate
24 Lease Option Not Available lease
25 Model Not Available at Dealership model
26 Environmental friendliness environ
27 Overall Cost of Ownership cost
28 Country of assembly make_country
29 Towing Capability towing
30 Vehicle color colour
31 Didn't want fuel type not_fuel_type
32 Vehicle range range
33 Missing specific features I wanted miss_feat
34 Other other other_verbatim

27. Indicate from the list above *(1-34)* the ONE item that was MOST IMPORTANT for not selecting your most seriously considered vehicle. . . . . *(Number 1-34)* c1_rnb_most

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What does an EV replace?

Stated-preference from MaritzCX

Table C: Nissan Leaf EV: Model most seriously considered

Response	Frequency	Share
No Other Considered	31,081	61%
Chevrolet Volt *	3372	7%
Toyota Prius	2166	4%
Ford Focus Electric *	1889	4%
Toyota Prius Plug-in *	1073	2%
Tesla Model S *	903	2%
Honda Fit EV *	590	1%
BMW i3 *	502	1%
Ford C-Max Energi *	459	1%
Fiat 500 Electric *	448	1%
Kia Soul	344	1%
Mitsubishi i-MiEV *	332	1%
Ford Fusion	301	1%
Honda Accord	263	1%
Nissan Juke	249	0%
Ford Fusion Plug In Hybrid *	241	0%
Lexus CT200h	231	0%
Toyota Prius v	227	0%
Kia Soul EV *	217	0%
Audi A5	201	0%
Chevrolet Spark Electric *	200	0%
Nissan Altima	189	0%
Honda CR-V	182	0%
Toyota RAV4 EV *	181	0%
Honda Accord Hybrid	172	0%
Honda Civic	157	0%
Nissan Rogue	146	0%
Toyota Corolla	136	0%
smart fortwo electric *	136	0%
MINI Cooper Countryman	135	0%

Notes: The survey has 51,002 responses from Nissan Leaf EV purchasers. * indicates plug-in vehicles.

Net Damages

TABLE 2—SUMMARY STATISTICS OF DAMAGES AND ENVIRONMENTAL BENEFITS IN CENTS PER MILE FOR 2014 ELECTRIC VEHICLES AND SUBSTITUTE 2014 GASOLINE VEHICLES ACROSS COUNTIES

	Electric vehicle			Gasoline vehicle			Environmental benefits		
Vehicle	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Panel A. Damages and environmental benefits									
Chevy Spark	2.28	0.59	4.17	1.69	0.95	4.30	−0.60	−3.15	3.08
Honda Fit	2.30	0.60	4.20	1.93	1.13	4.83	−0.37	−3.00	3.60
Fiat 500e	2.34	0.61	4.27	1.74	0.93	4.62	−0.60	−3.26	3.33
Nissan Leaf	2.38	0.62	4.35	1.23	0.74	3.53	−1.16	−3.52	2.22
Mitsubishi i-Miev	2.42	0.63	4.41	1.69	0.95	4.30	−0.73	−3.40	3.05
Smart fortwo	2.54	0.66	4.63	1.67	0.98	4.50	−0.87	−3.57	3.13
Ford Focus	2.59	0.67	4.72	1.86	1.03	4.32	−0.73	−3.63	3.16
Tesla S (60 kWh)	2.82	0.73	5.15	2.44	1.28	5.48	−0.38	−3.78	4.28
Tesla S (85 kWh)	3.06	0.80	5.59	2.67	1.48	5.74	−0.39	−4.02	4.55
Toyota Rav4	3.58	0.93	6.52	2.09	1.20	5.02	−1.49	−5.23	3.50
BYD e6	4.35	1.13	7.94	2.09	1.20	5.02	−2.27	−6.64	3.30

	Environmental benefits			Global environmental benefits			Local environmental benefits		
Vehicle	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Panel B. Decomposition of environmental benefits into global and local environmental benefits									
Chevy Spark	−0.60	−3.15	3.08	0.35	−0.14	0.72	−0.95	−3.01	2.37
Honda Fit	−0.37	−3.00	3.60	0.52	0.02	0.89	−0.89	−3.02	2.71
Fiat 500e	−0.60	−3.26	3.33	0.32	−0.19	0.71	−0.92	−3.08	2.63
Nissan Leaf	−1.16	−3.52	2.22	−0.09	−0.40	0.28	−1.07	−3.16	1.99
Mitsubishi i-Miev	−0.73	−3.40	3.05	0.30	−0.21	0.69	−1.04	−3.20	2.36
Smart fortwo	−0.87	−3.57	3.13	0.18	−0.24	0.57	−1.06	−3.34	2.57
Ford Focus	−0.73	−3.63	3.16	0.44	−0.21	0.89	−1.17	−3.43	2.28
Tesla S (60 kWh)	−0.38	−3.78	4.28	0.83	-0.07	1.36	−1.21	−3.72	2.93
Tesla S (85 kWh)	−0.39	−4.02	4.55	0.96	0.01	1.54	−1.36	−4.04	3.02
Toyota Rav4	−1.49	−5.23	3.50	0.23	−0.51	0.81	−1.72	−4.73	2.71
BYD e6	−2.27	−6.64	3.30	−0.04	−0.88	0.65	−2.23	−5.78	2.66

Notes: Damages are from power plant emissions or tailpipe emissions of NO_x, VOCs, $PM_{2.5}$, SO_2, and CO_2. Electric vehicles assume the EPRI charging profile. Substitute vehicles are defined as the identical make where possible. The substitute vehicle for the Nissan Leaf is the Toyota Prius; for the Mitsubishi i-Miev is the Chevy Spark; for the Tesla Model S is the BMW 740 or 750; and for the BYD e6 is the Toyota Rav4. Damages are in cents per mile and are weighted across counties by VMT.

Net Damages

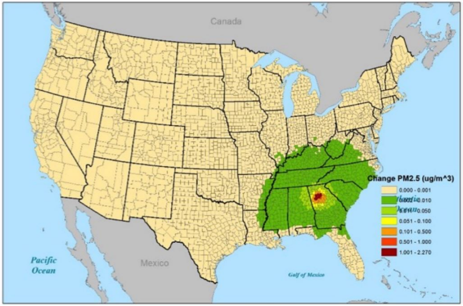
Table E: Environmental benefits (cents/mile) relative to two substitute gasoline vehicles

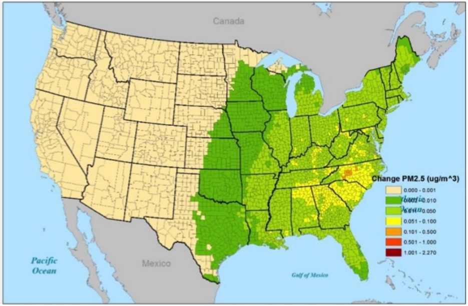
Electric Vehicle	Environmental Benefits Original Substitute	Environmental Benefits Composite Substitute
Chevy Spark EV	-.60	-0.45
Nissan Leaf	-1.16	-.92
Mitsubishi i-Miev	-0.73	-0.70
Smart fortwo electric	-0.87	-0.73
Ford Focus electric	-0.73	-1.02
Tesla Model S (85 kWhr)	-0.39	-0.54
Toyota Rav4 EV	-1.49	-1.93

Notes: Data for original substitute column is from Table 2. Composite substitute is formed by taking the weighted average of the top 10 substitutes for the relevant electric vehicle.

Net Damages

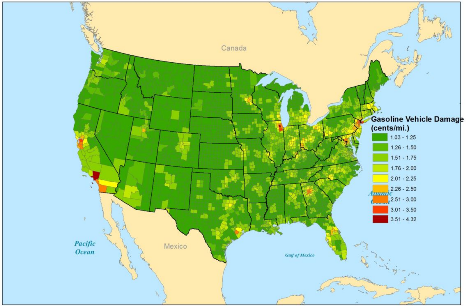
Spatial Example: Atlanta

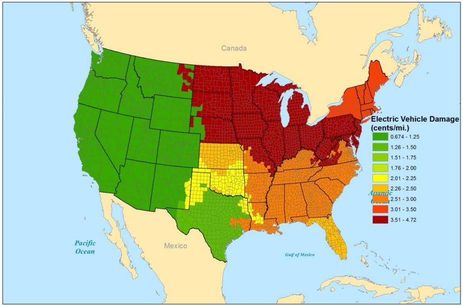




Net Damages

Spatial Distribution of Using ICEVs vs EVs





Second-best Subsidy Design

Naive vs. Accounting for Emissions from Charging