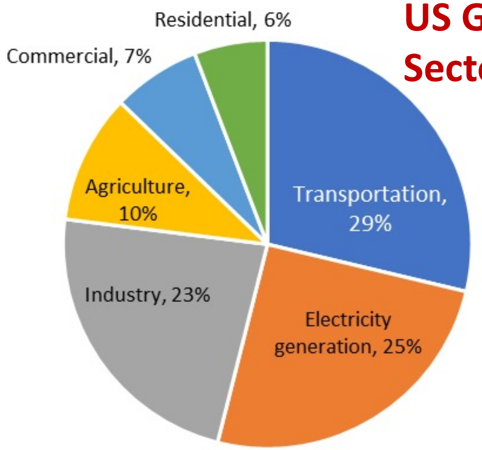
Accelerating Electrification:

Policies for Decarbonizing the US Light Duty Vehicle Fleet

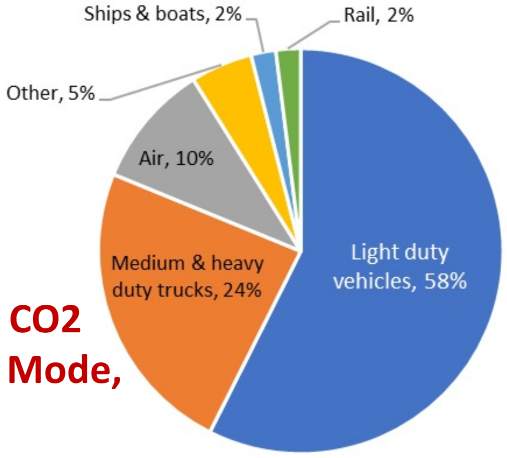
Cassandra Cole, Harvard University
Michael Droste, Harvard University
Chris Knittel, MIT
Shanjun Li, Cornell
James H Stock, Harvard University

Thanks to Jim Archsmith, Sarah Armitage, Ken Gillingham, Erich Muehlegger, and David Rapson for helpful conversations.

Will the EV transformation step on the gas?



US GHG Emissions by Sector, 2019

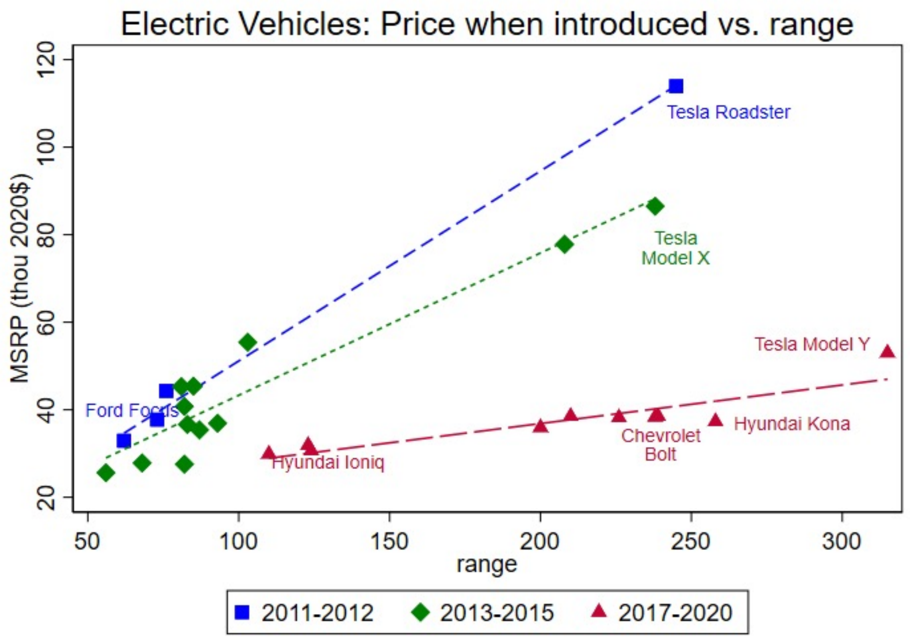


US Transport CO2 Emissions by Mode, 2019

EV LDV sales share projections, 2021

Actual 2021H1: ~2.6%

Source	share	Policy
EIA (2/21)	2.2%	Jan. 2021 reference case
Bank of America (6/21)	20%	$7500 tax credit
IHS Markits (8/21)	37%	Jan. 2021
Bident target (8/21)	50%	??



Things are moving fast…

- **CA, NY** to require 100% ZEV LDVs by 2035
- **Rivian** IPO
- **COP26: Global end to new ICEs by 2040, in "leading markets" by 2035**
  - Signed by Ford, GM, Mercedes-Benz, Volvo, Jaguar Land Rover, BYD + 30 countries + Uber:.
  - But not Toyota, Nissan-Renault, Volkswagen,…
  - And not US, China, Germany, South Korea, Japan,…

But

- **Bloomberg Green (11/16/21) on Bipartisan Infrastructure Deal:**

  Take, as the prime example, the fact that the infrastructure law authorizes $7.5 billion to build a nationwide network of charging stations for electric vehicles. That's an important step, but few analysts think that alone will inspire an adequate number of Americans to switch from combustion-engine cars to electric vehicles. That motivation will require the $7,500 electric-car purchase credit that is in the BBB.

Sources: EPA Greenhouse Gas Inventory, EIA AEO 2021, Gillingham & Stock (2018, updated)

This paper: Policies for electrification of LDVs

Effect of short-run, longer run policies in the LDV area

- Effect on: EV sales, fiscal cost, fiscal efficiency (inframarginal component), cost per ton
- Lots of uncertainty! Incorporated via MC simulations

Policies examined

Stage 1 policies

- Charging station subsidies
  - Bipartisan Infrastructure Deal has $7.5B for charging infrastructure
- EV POS rebate (refundable tax credit, assignable to dealer)
  - BBB: <=2026: $7500 + $4500 if final assembly in US + $500 if US battery through 2026; >=2027, must be assembled in US
- eRINs
- Carbon tax

Stage 2 policies

- ZEV mandate through Clean Air Act + ICE fuel economy standards through EPCA 2005

Existing LDV and fuels policies

- US Federal: CAFE/SAFE, RFS, BBTC, EVTC, [eRIN]; IDC, EOR,…
- US states: LCFS, TCI, ZEVs
- Elsewhere, ICE bans: Norway (2025), UK (2030), California (2035), France (2040),…

This is work in progress…

LDVs: Overview of analytics

LDV model

- Key elements:
  - Discrete choice model of EV demand (by cars, SUVs+)
    - Focus is BEVs
  - Private charging station buildout (differentiate Level 2, Level 3 chargers)
- Multiple equilibria
- Parameter values drawn from literature
  - Key references: Zhou & Li (2017, 2018), Springel (2020), Archsmith, Muehlegger, & Rapson (2021); also see Holland, Mansur, Yates (AEJ-EP forthcoming)
- Prices & costs in 2020 $'s
- Address (massive) uncertainty by Monte Carlo simulation
- Policies detailed later…
- Cost estimates focus on $/ton of policies
  - total system costs = EVs – ICEs + O&M differential + charging stations + power system upgrades (all gross of federal support)

LDVs: Model

Consumer demand

- Two categories of vehicles: cars or SUVs (which includes light trucks & vans)
- Within category, choose EV vs. ICE
- Demand depends on relative price, charger availability (Level 2, Level 3), and other attributes/tastes

$$s_t^{car} = Logistic\left(\alpha^{car} + \beta_P \ln P_t^{car} + \beta_{N2} \ln\left(N_{t-1}^{L2} / Q_{t-1}\right) + \beta_{N3} \ln N_{t-1}^{L3} + \psi_t\right)$$

$$s_t^{SUV} = Logistic\left(\alpha^{SUV} + \beta_P \ln P_t^{SUV} + \beta_{N2} \ln\left(N_{t-1}^{L2} / Q_{t-1}\right) + \beta_{N3} \ln N_{t-1}^{L3} + \psi_t\right)$$

where

s_t^{car} = EV share of new car sales in year t

$P_t^{car} = P_t^{car,EV} / P_t^{car,ICE}$ = full perceived user cost relative price for cars

Q_t = stock of EVs

N_t^{L2} = number of Level 2 chargers

ψ_t = attribute drift

η_P = price elasticity $= (1 - s^{car})\beta_P$ (and same for charger elasticity)

$s_t = \sigma^{car} s_t^{car} + \sigma^{SUV} s_t^{SUV}$ = EV share of LDVs

Notes: Based on Springel (2020), with the following modifications: (a) Springel uses price, I use log price. (b) Springel estimates demand at the vehicle model level, this aggregates to (EV, ICE) × (car, SUV); (c) Springel doesn't differentiate among charging station level; I differentiate between Level 2 &3. Here L2 is treated on a per-vehicle basis, L3 is treated on geographic density (or equivalently per road-mile) basis. Springel and Zhou-Li (2017) use ln(N) specifications. (d) I follow Archsmith et al (2021) and introduce the term ψ_t to capture attribute and taste drift (modeled here as a random walk). (e) I model consumer choice in year *t* as depending on (observed) charging stations in year *t*-1, while charging stations are built on an as-needed basis.

Private-sector charging station provision

Separately model L2 and L3 chargers because of different costs and different saturation values

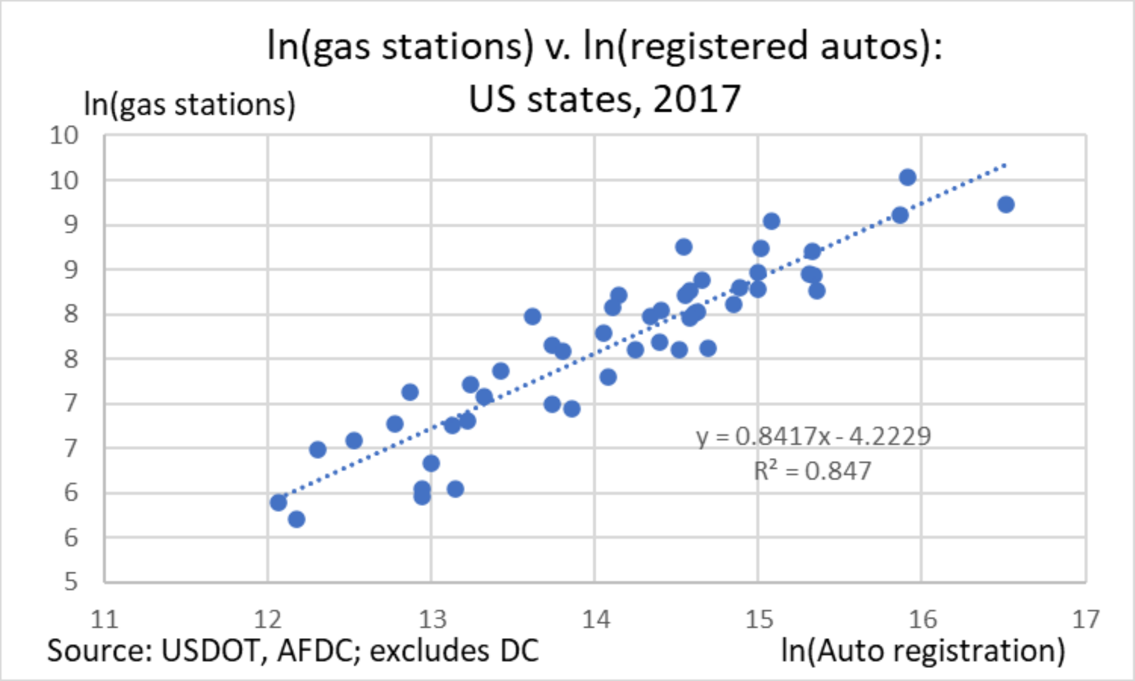
$$\ln N_t^{L2} = \kappa^{L2} + \gamma \ln Q_t - \gamma \ln \tilde{C}_t^{L2}$$
$$\ln N_t^{L3} = \kappa^{L3} + \gamma \ln Q_t - \gamma \ln \tilde{C}_t^{L3}$$

where

$$\tilde{C}_t^{L2} = C_t^{L2} - (1+r)^{-1} C_{t+1}^{L2}$$

C_t^{L2} = installed cost of a Level 2 charger

Source: Zhou & Li (2018-US), Springel (2020)



Stock/flow accounting

- LDV scrappage rate = 1/11.5
- Charging station scrappage rate 10%/year

Calibration

κ_2 : calibrate so full-penetration public Level 2 plugs/EV ratio = 0.1 (US 2019: ~0.04; Norway: ~0.03)

κ_3 : calibrate so full-penetration public Level 3 stations/EV = current gas stations/2 = 60k

$$C_t^{L2} = C_{2020}^{L2}\left(.5 + .5e^{-0.02(y-2020)}\right), C_{2020}^{L2} = \$2k$$

$$C_t^{L3} = C_{2020}^{L3}\left(.5 + .5e^{-0.02(y-2020)}\right), C_{2020}^{L3} = \$500k \ (10 \ @ \ \$50k)$$

LDVs: Parameterization & MC

Model:

$$s_t^{car} = \exp\left(\alpha^{car} + \beta_P \ln P_t^{car} + \beta_{N2} \ln\left(N_{t-1}^{L2} / Q_{t-1}\right) + \beta_{N3} \ln N_{t-1}^{L3} + \psi_t\right)$$

$$\ln N_t^{L2} = \kappa^{L2} + \gamma \ln Q_t^{EV} - \gamma \ln \tilde{C}_t^{L2}$$

Demand:

$$\eta_P \sim N\left(-2.5, 0.5\right) \text{ at EV share } 33\%$$

$$\eta_{N2} = \eta_{N3} \sim N(0.37, 0.1) \text{ at EV share } 33\%$$

$$\psi_t = \mu + \psi_{t-1} + \zeta_t \text{ , } \mu \sim N\left(.02\beta_P, .005\left|\beta_P\right|\right), \zeta_t \sim N(0, 2\mu)$$

References:

η_P: Springel (2020): -1.5 to 2.0; Xing et al (2019): -2.7; Li (2019): -1.3; Muehlegger & Rapson (2018): -3.9; Archsmith, Muehlegger, & Rapson (2021) simulation values -1, -2 -3

η_{N2}: Springel (2020): -0.418 (SE = 0.038) mean in random coefficients model @ ~12% market share (2014)

Technology: ICE, SUV price model based on Lutsey & Nicholas (ICCT (2019)) + Clinton, Knittel, and Metaxoglu (2020).

- Full user cost = initial vehicle cost + valuation factor × O&M costs
- Manufacturing cost breakdown from Lutsey & Nicholas (2019).
- Valuation factor.
  - References, all for ICEs: Gillingham, Houde, & van Bentham (forthcoming): 0.16-0.39; Allcott & Wozny (2014): 0.72; Grigolon, Raynaert, and Verboven (2018): 00.91; Leard, Linn, and Zho (2019): 0.54 and <0.30; Goldberg (1998): near 1.
  - We use the Allcott & Wozny approach: consumer discount rate of 15% & valuation factor = 1
- Battery prices: -16% per year 2007-2019; project N(-.09,.02), with $50/kWh floor
- *EV* (mi/kWh): 3.2 (cars – Chevy Bolt), 2.0 (SUVs & lt trucks – *Car & Driver* estimate for F150 Lightening)

LDVs: Parameterization & MC

Table 1: Benchmark Parameter Values and Sources

Name	Value	Notes
A. Vehicle Demand Parameters		
η_p	-2.5	Price elasticity of EV demand at initial market share s_0 (see text)
η_2	0.37	Elasticity of EV demand w.r.t. level-2 charging
η_3	0.37	Elasticity of EV demand w.r.t. level-3 charging
ρ_c	0.1072	Charging station (annual) exit rate; BEA depreciation rate for general industrial equipment
ρ_v	$\frac{1}{11.5}$	Vehicle (annual) scrappage rate; Based on Polk data average age of vehicles on the road
$\bar{Q}$	17	FRED light weight vehicle sales, millions annually
ψ_g	-	Calibrated: drift in unobserved EV attributes and tastes
B. Charging Station Supply Parameters		
γ	0.671	Elasticity of charging station supply with respect to EV stock
C_0^2	4,000	Level 2 charging station cost in 2020 ($), 2 ports (see text)
C_0^3	200,000	Level 3 charging station cost in 2020 ($), 4 ports (see text)
ζ	-0.04	Charging station cost growth (see text)
r	0.03	Annual discount rate
κ_2	-	Calibrated: full penetration L2/EV ratio = 0.1
κ_3	-	Calibrated: full penetration EVs/L3 ratio = 150k 4-plug chargers
C. Price Forecast Parameters		
e_{car}	3.2	Mi/kWh EV car avg: Chevy Bolt, adjusted down for cold weather
e_{suv}	2	Mi/kWh EV suv/lt truck average
f_{car}	27.5	EPA estimate of real-world fuel economy for cars
f_{suv}	22.4	EPA estimate of real-world fuel economy for SUVs
v	2,924,053	Million vehicle miles traveled (VMT) for LDVs, 2019; FHWA
B_g	-0.09	Battery cost growth (see text)
v_g	-0.0091	Growth of VMT (AEO 2021 reference case)
Gas prices	-	Energy Information Administration Annual Energy Outlook 2021

LDVs: Odds & ends

Model limitations

- National – no regional heterogeneity in tastes, charger buildout, etc.
- Only 2 vehicles, only 2 drive trains (!)
- Exogenous technical change (no induced, no LBD)
- No expectational channels
- Functional form assumptions

Odds & ends

- Specification details
  - Baseline attribute drift calibrated to have substantial but long-run incomplete EV penetration
  - Oil price path from AEO 2021 + random AR(1) departure estimated 1990-2021
  - Power sector marginal emissions rate and incremental costs from added EV load:
    - Main case: TPS from ReEDS (Stock-Stuart (2021)):
      - 80% emissions reduction, relative to 2005, by 2030; 90% by 2035; 100% by 2050
    - No-policy alternative: current power sector marginal emissions rate (Holland, Kotchen, Mansur, Yates (2021))
  - VMT growth from AEO 2021 reference case
- Costs
  - System costs = additional power system costs, vehicle costs, & liquid fuel costs
  - Total costs = system costs + federal share (set marginal cost of public funds = 1, cf. Hendren & Sprung-Keyser (2020))
- Simulations span 2021-2060, 2021 fixed at (estimated) 2021 initial conditions
- Discount rate: 3% real
- Monte Carlo to capture uncertainty over prices (oil, batteries, vehicles, chargers), elasticities, & attributes/tastes

Policies

Baseline

- ICE fuel efficiency (new ICE LDVs):
    - 2021-2022: SAFE
    - 2023-2026: Revised 2023 and Later Proposed Rule (86 FR 43726)
    - 2027-2031: increase @5%
    - 2032-: increase 1.5%
- Power sector: Tradeable Performance Standard starting from status quo in 2022, 80% emissions reduction by 2030, 90% by 2035, 100% by 2050
- No new LDV policies + ignore current EV tax credit (200k per OEM cap)

A. Charging station subsidy

- Public-private cost-share starting 2022, ending when budget cap is hit or in 2030, whichever is sooner

B. EV point-of-sale rebate

- $7500 2022-2031 (refundable tax credit, ignoring domestic content bonuses)

C. Enhanced Clean Air Act regulation

- Decouple EPA (CAA) & NHTSA (EPCA) rules
- NHTSA sets ICE mpg standard, to match ICE fuel efficiency standard in baseline (i.e. no change in ICE mpg standards)
- EPA implements CAA via clean vehicle standard (ZEV standard) with tradable allowance price cap. ZEV standard. SUV ZEV standard lags car ZEV standard by 2 years. Combined standard (rounded): 2025, 6%; 2030, 50%; 2035, 77%; 2040, 92%.

D. eRIN

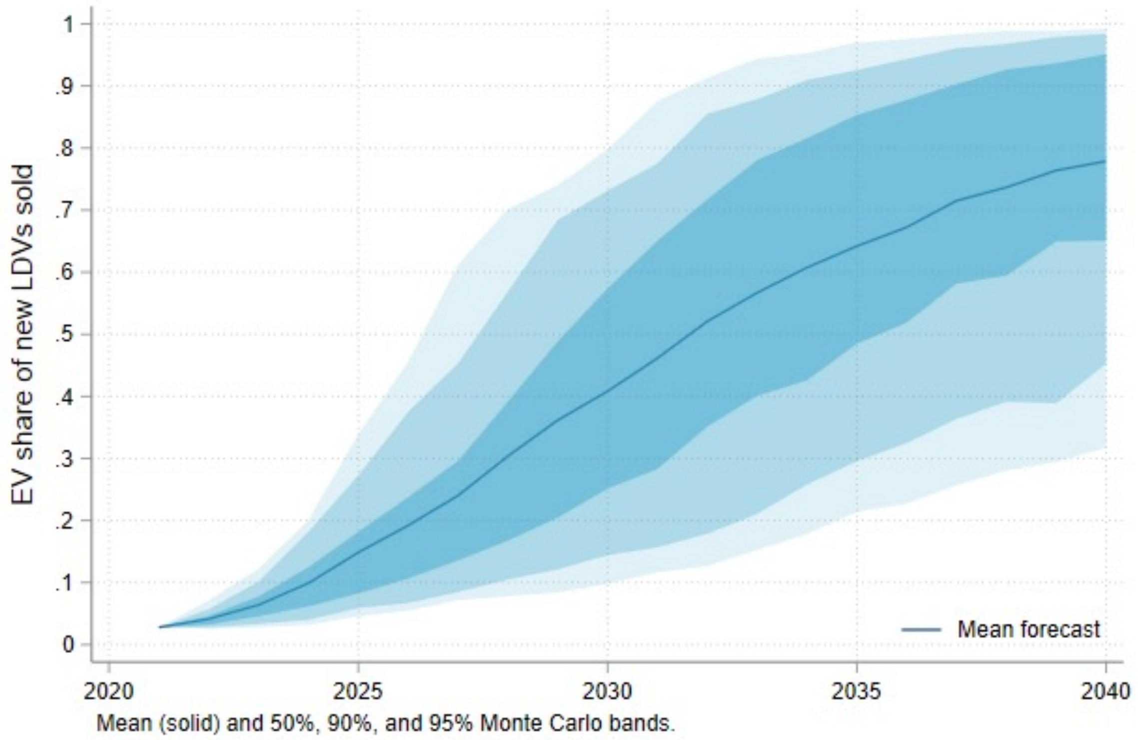
- RFS: Biogas -> electricity pathway, 2022-2032; EV owner gets quarterly check; gasoline prices rise slightly
- *Details*: third part aggregator with access to OEM vehicle data; D3 RIN @ D5 floor = $1.50; RFS energy value 10 kWh/RIN (based on ICCT 2017 methodology, updated, see EPA (2014) & ICCT (2017))

E. Carbon tax

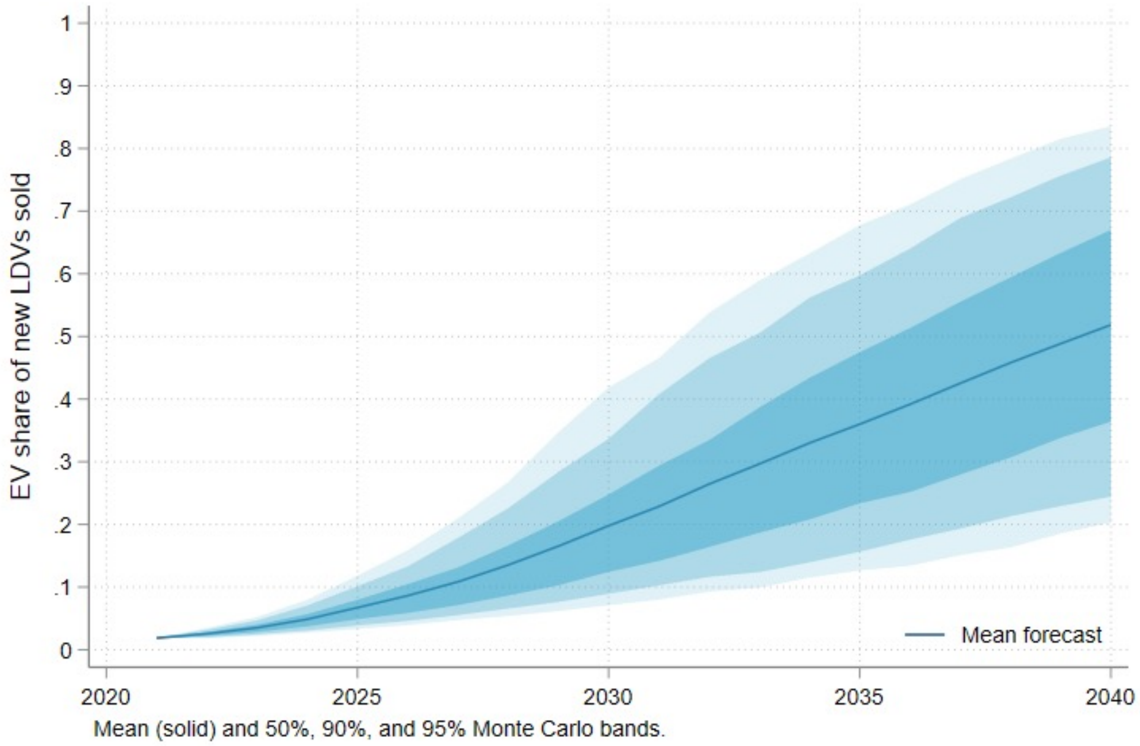
Note: assume full pass-through of government taxes/subsidies to end consumer (Mueghlegger-Rapson (2020), Knittel, Meiselman, Stock (2017),…)

Results: No-policy projections, benchmark cse

EV sales share: No new policy, IHS benchmark case



EV sales share: No new policy, low benchmark case



Results: Summary, low baseline penetration

	Policies					EV share & Emissions		
	Station cost share		EV sales rebate		ZEV permit price cap ($) (c)	EV Sales Share by 2030	Cst/ton CO2 ($/ton) (b)	ΔCO2 in 2030 (mmt)
	Percent	Budget ($B)	2022 - 2026	2027+				
0	-	-	-	-	-	0.251	-	-
A1	0.67	7.5	-	-	-	0.330	146	-35
A6	0.67	7.5	7,500	7,500	-	0.439	42	-76
A4	0.67	7.5	-	-	10,000	0.464	47	-58
A7	0.67	7.5	7,500	7,500	10,000	0.547	51	-91

Notes: Estimates are means of 1000 Monte Carlo draws over model parameters, oil price paths, and technology cost paths.

a) These are costs of tax credits provided to consumers who would have bought an EV in the no-policy (BAU) case.

b) Costs are total system costs under the policy, minus BAU total system costs, where system costs are net costs of EV-ICE production, operation, and maintenance cost, and cost of additional power system capacity required for additional EVs (computed under 80% TPS using ReEDS). Emissions are cumulative through 2060 in policy case minus BAU.

c) The ZEV standard works by setting a required ZEV sales share in a given year, with compliance by requiring tradeable ZEV credits to be retired with EPA. For example, suppose the ZEV standard is 33% EVs and the price of the tradeable allowances is $1,000; then, assuming full pass-through, the standard would reduce the EV sales price by $667 and would increase the ICE sales price by $333. If the price cap is binding in a given year, the actual ZEV share will fall short of the standard.

Results: Summary, high baseline penetration

	Policies					EV share & Emissions		
	Station cost share		EV sales rebate		ZEV permit price cap ($) (c)	EV Sales Share by 2030	Cost/ton CO2 ($/ton) (b)	ΔCO2 in 2030 (mmt)
	Percent	Budget ($B)	2022 - 2026	2027+				
0	-	-	-	-	-	0.418	-	-
A1	0.67	7.5	-	-	-	0.478	190	-34
A6	0.67	7.5	7,500	7,500	-	0.585	74	-76
A4	0.67	7.5	-	-	10,000	0.558	91	-48
A7	0.67	7.5	7,500	7,500	10,000	0.634	81	-84

Notes: Estimates are means of 1000 Monte Carlo draws over model parameters, oil price paths, and technology cost paths.

a) These are costs of tax credits provided to consumers who would have bought an EV in the no-policy (BAU) case.

b) Costs are total system costs under the policy, minus BAU total system costs, where system costs are net costs of EV-ICE production, operation, and maintenance cost, and cost of additional power system capacity required for additional EVs (computed under 80% TPS using ReEDS). Emissions are cumulative through 2060 in policy case minus BAU.

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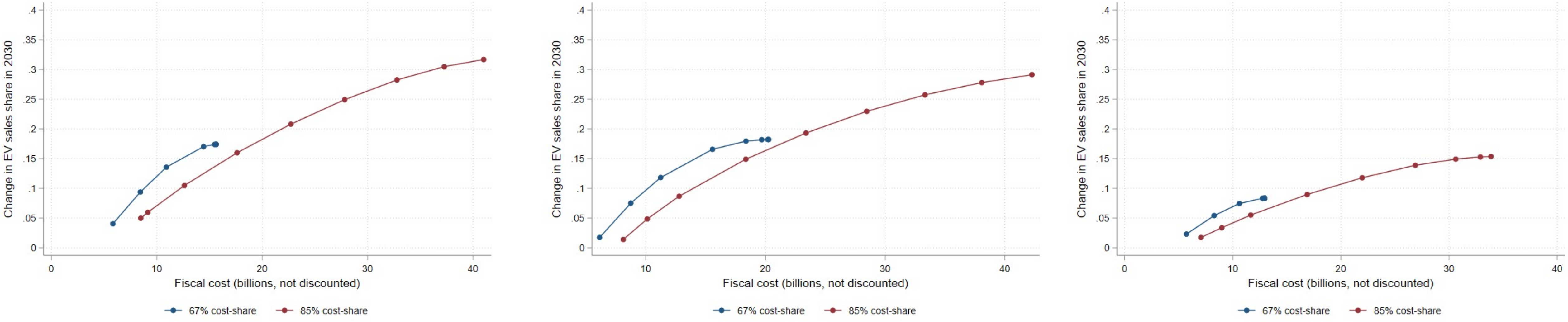
Results: Alternative policy combinations, low baseline penetration

	Policies					EV share & Emissions			Fiscal costs ($B, not discounted)			
	Station cost share		EV sales rebate		ZEV permit price cap ($) (c)	EV Sales Share by 2030	Cst/ton CO2 ($/ton) (b)	ΔCO2 in 2030 (mmt)	Total	Of which:		
	Percent	Budget ($B)	2022 - 2026	2027+						Chargers	Rebates	Inframarginal Rebates (a)
0	-	-	-	-	-	0.199	-	-	-	-	-	-
E1	0.67	7.5	6,000	3,900	-	0.338	165	-44	158	8.6	149	63
E2	0.67	15.0	5,500	3,500	-	0.436	117	-55	160	15.6	145	56
E3	0.70	25.0	5,000	3,250	-	0.462	106	-59	158	20.9	137	51
E4	0.75	28.0	5,000	2,750	-	0.485	110	-66	158	26.0	132	45
E5	0.80	30.0	4,600	2,400	-	0.510	117	-74	156	31.0	125	39
E6	0.85	40.0	3,900	2,100	-	0.554	118	-87	158	42.2	116	32
F1	0.67	7.5	6,000	3,900	10,000	0.450	64	-57	178	8.6	169	63
F2	0.67	15.0	5,500	3,500	10,000	0.517	72	-64	174	16.2	157	56
F3	0.70	25.0	5,000	3,250	10,000	0.535	77	-67	170	22.4	148	51
F4	0.75	28.0	5,000	2,750	10,000	0.547	82	-73	167	27.4	139	45
F5	0.80	30.0	4,600	2,400	10,000	0.558	87	-79	162	32.1	130	39
F6	0.85	40.0	3,900	2,100	10,000	0.586	94	-90	162	43.0	119	32

Results: EV sales share in 2030

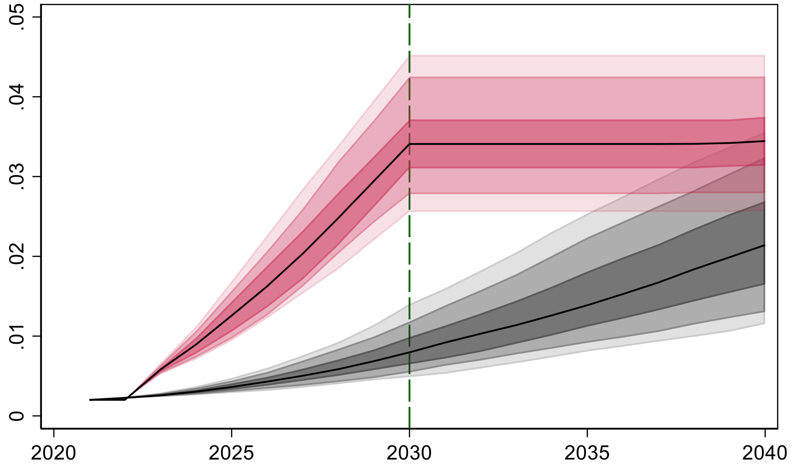
EV sales share as a function of charging station budget, charging-only policy

Left: Benchmark. Middle: High EV penetration. Right: Low charger elasticity



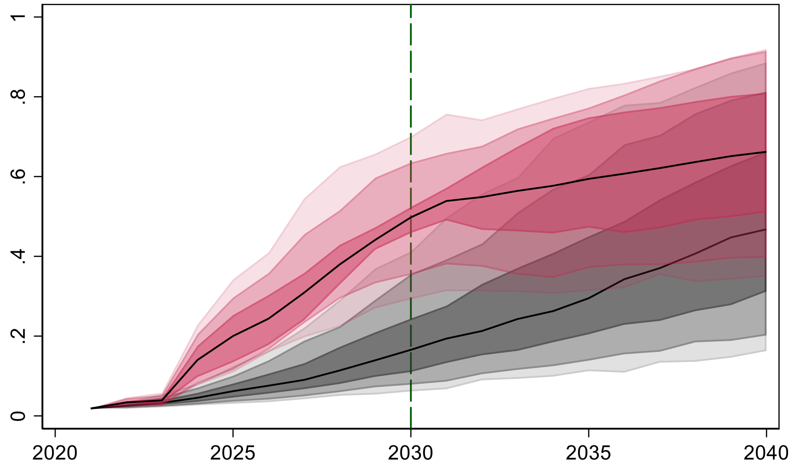
Uncertainty plots: Charging: 67%/$30B; Rebate $4k/$2.7k/40%; ZEV cap $10k (51% EV mean)

Stock of Level 3 chargers (mill)
K: D3



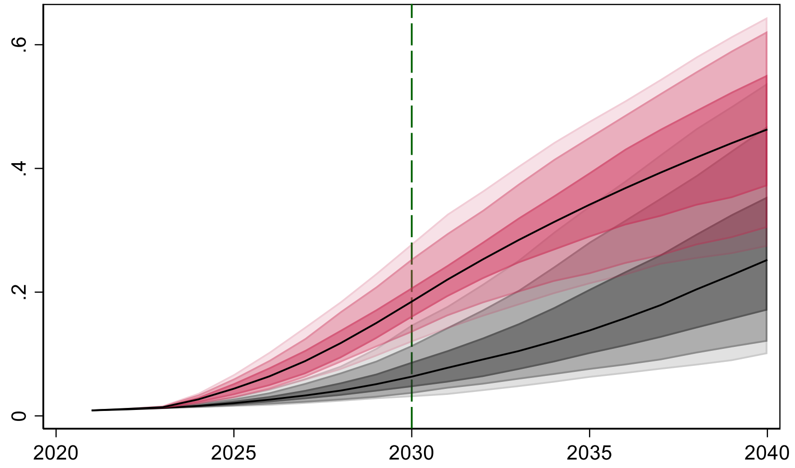
Notes: shading denotes 90%, 80%, 50% bands and median

EV share, new LDVs
K: D3



Notes: shading denotes 90%, 80%, 50% bands and median

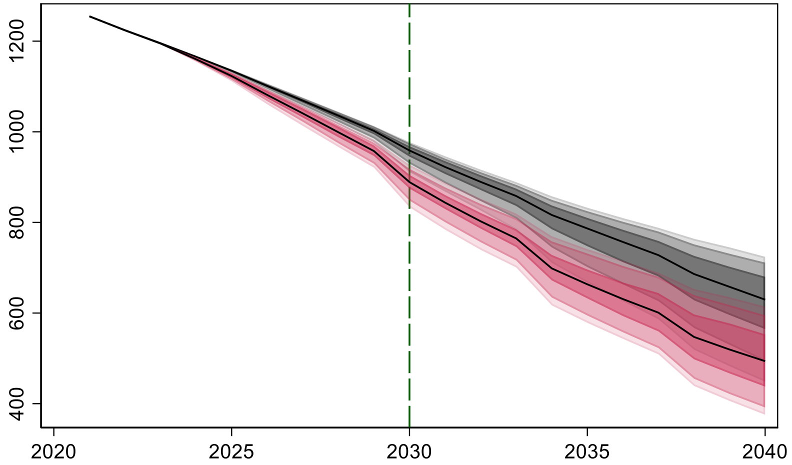
EV share, all LDVs
K: D3



Notes: shading denotes 90%, 80%, 50% bands and median

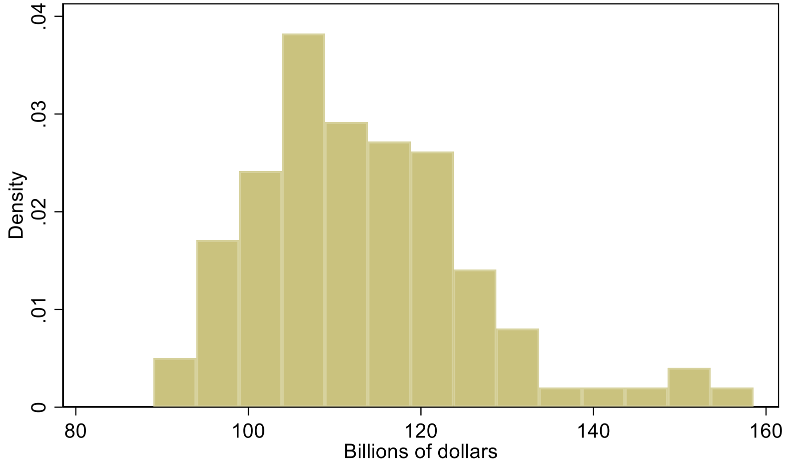
Time series plots show the mean and 5%, 10%, 25%, 75%, 90%, and 95% percentiles of the indicated variable under the no-policy BAU (gray) and policy case (red). Histograms show the value of the indicated summary variable. Uncertainty is over Monte Carlo draws.

Total CO2 emissions from LDVs (mmt)
K: D3



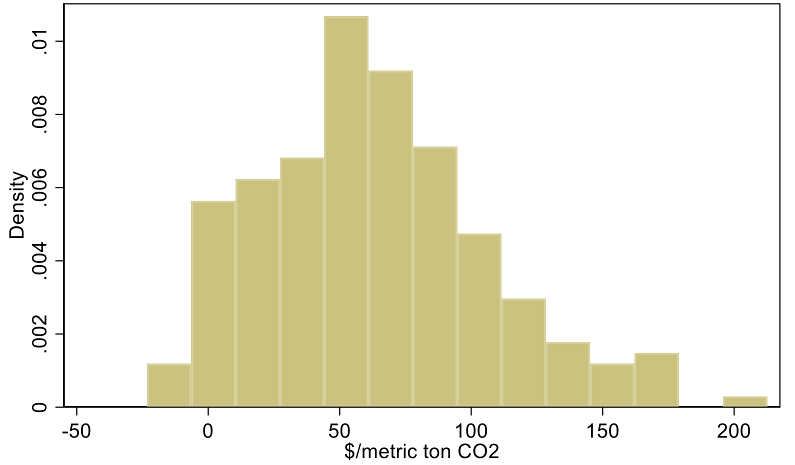
Notes: shading denotes 90%, 80%, 50% bands and median

Fiscal costs (NPV)
K: D3



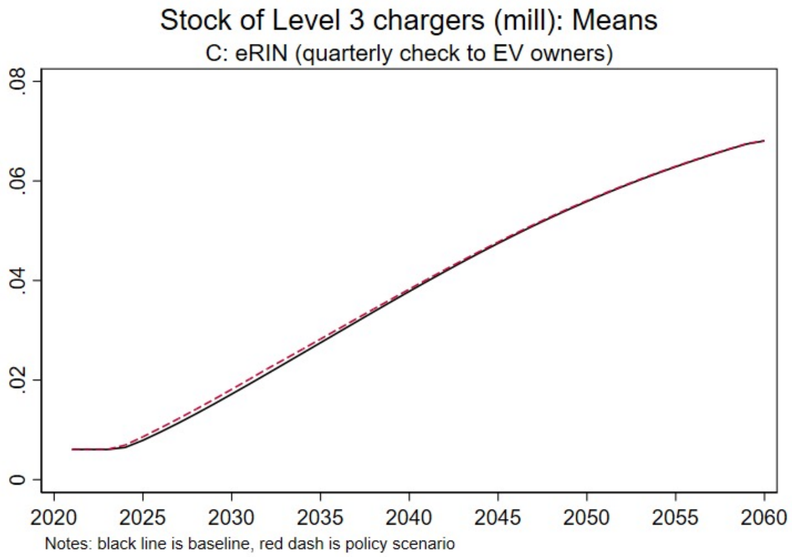
Note: Histogram shows distribution across Monte Carlo simulation draws

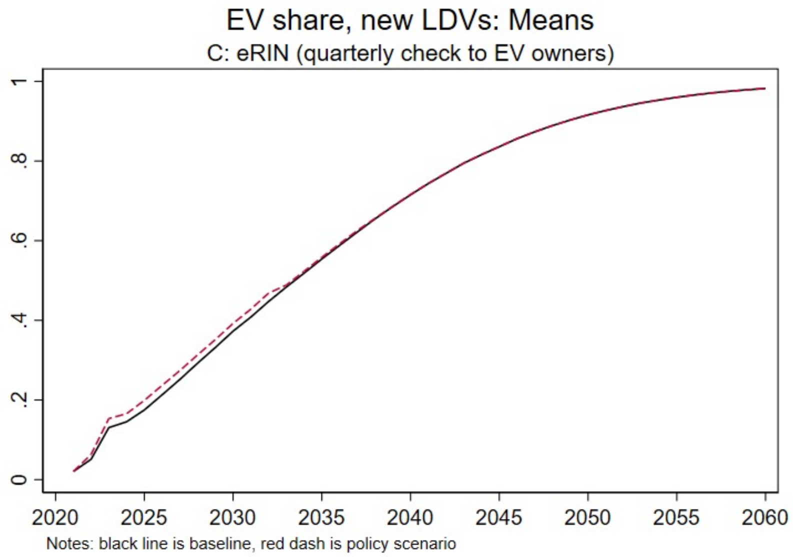
Cost per ton
K: D3

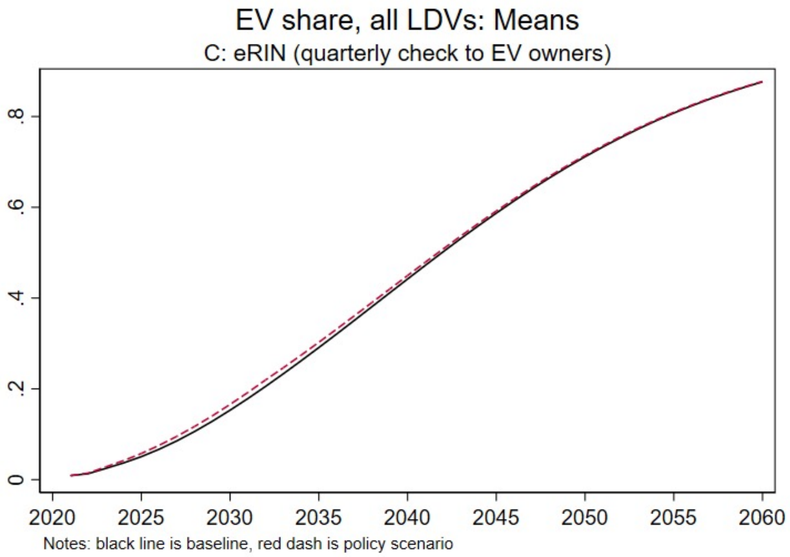


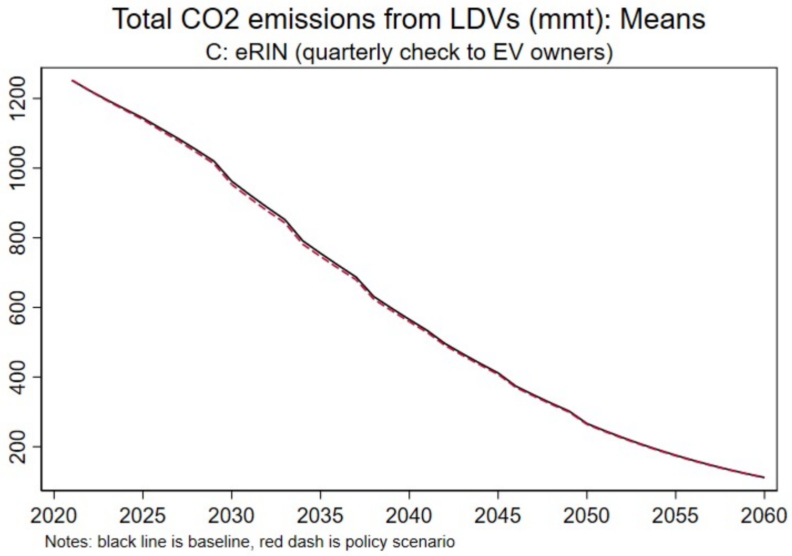
Note: Histogram shows distribution across Monte Carlo simulation draws

Results: eRIN (only)

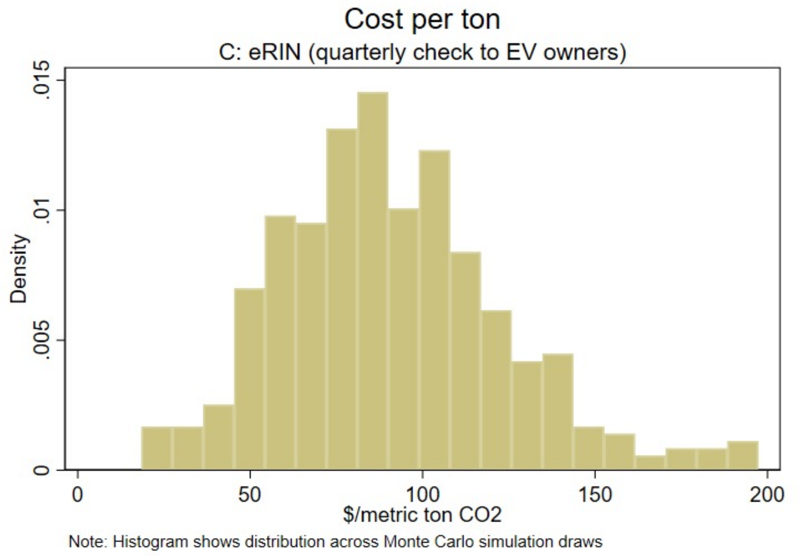




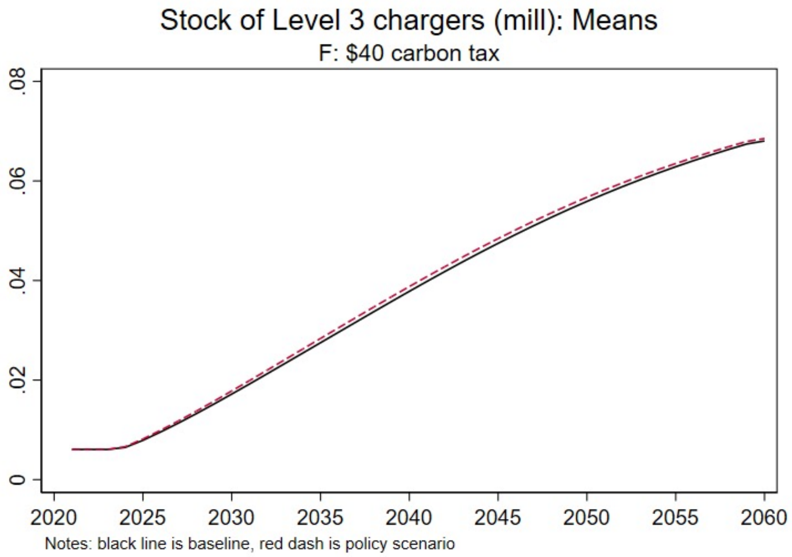


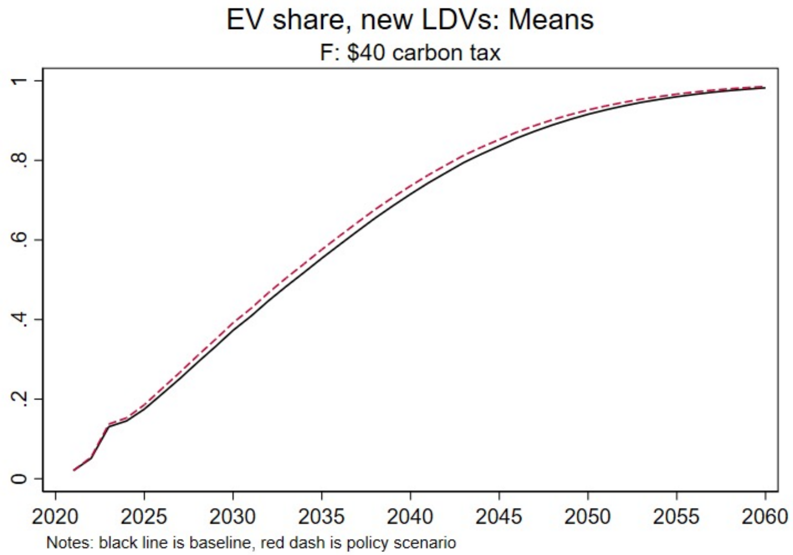


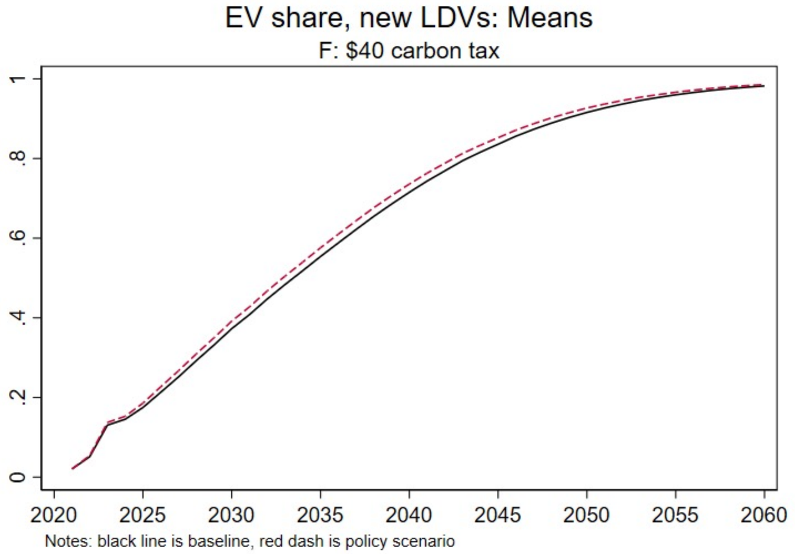
eRIN program has no direct fiscal impact

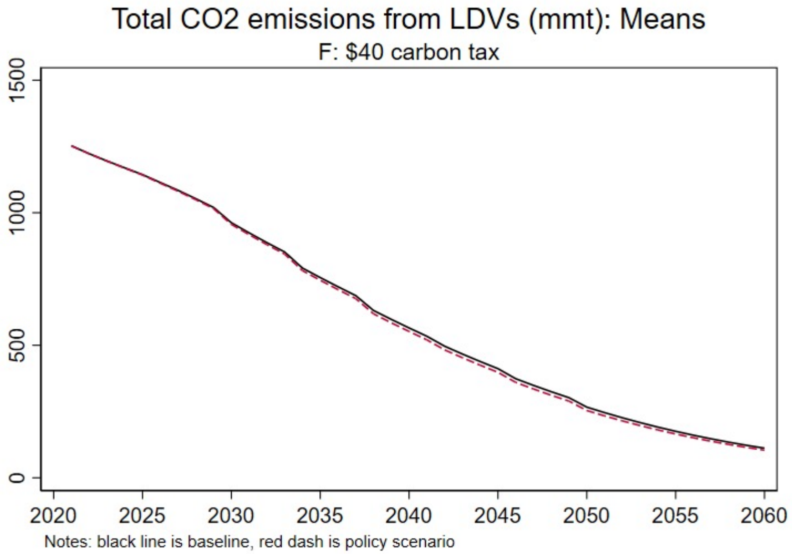


Results: $40 Carbon tax increasing at 5%/yr (only)

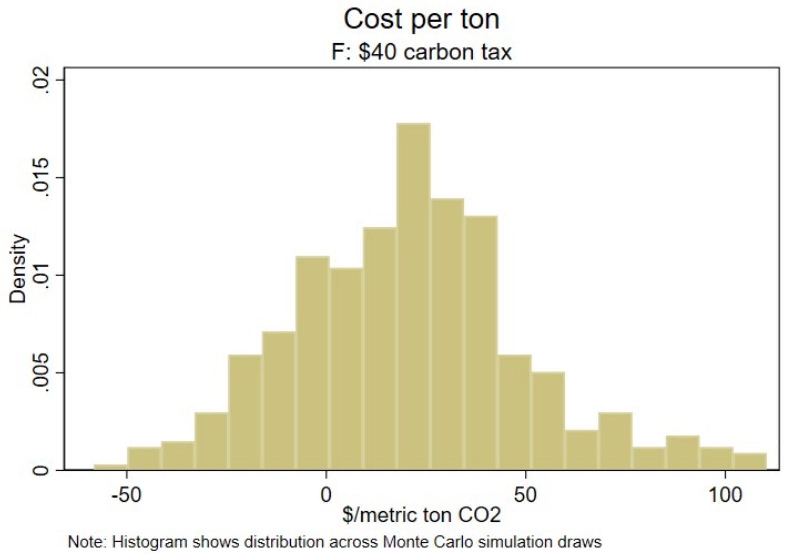








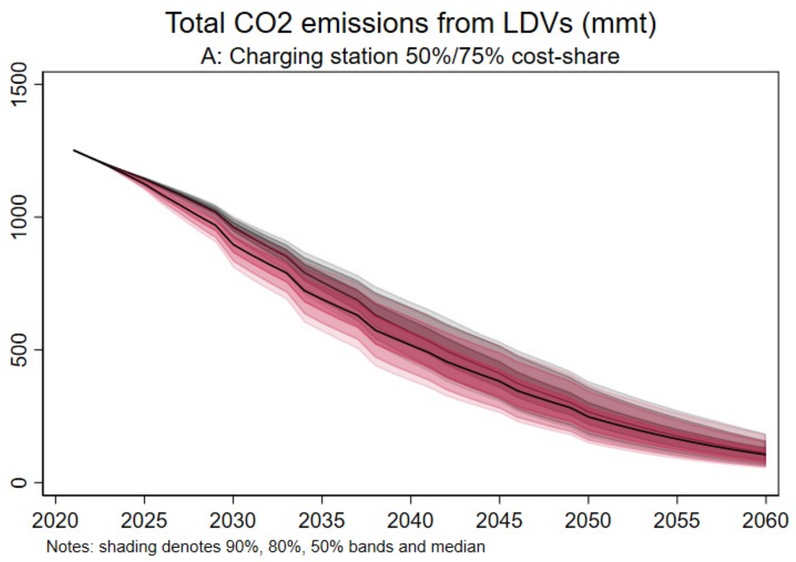
Carbon tax with revenue recycling so no net fiscal impact

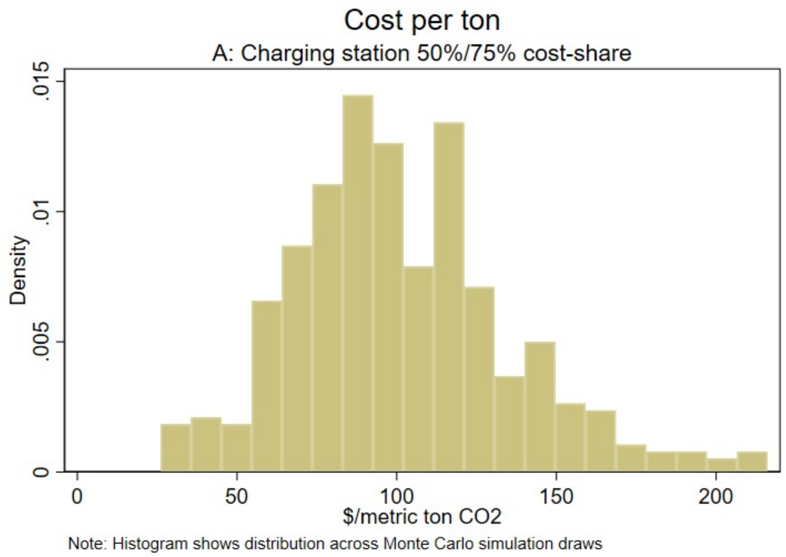


LDVs: Results – With and Without power sector policy

With power sector policy

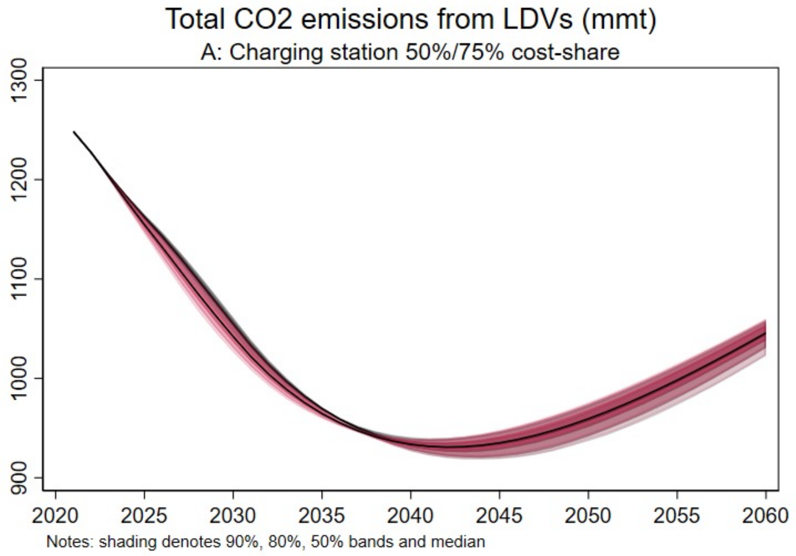
- Tradable performance standard (90% emission reduction by 2035), marginal emissions rates and costs from ReEDS (Stuart-Stock 2021)

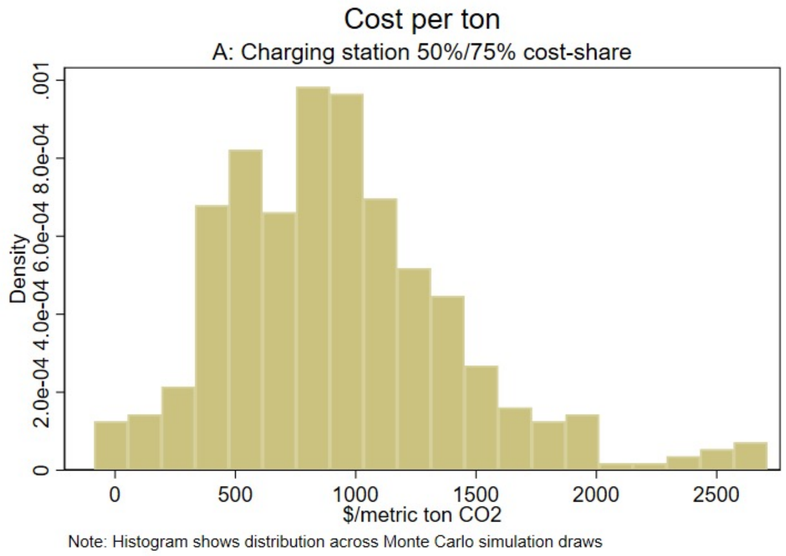




No new power sector policy

- Marginal power sector emissions from Holland et al (2021) (similar to AEO2021 NEMS)
- Marginal emissions are high because coal plants have become marginal (load-following), see NARUC (2020)





Summary

Main findings

1. Policy is very effective in expediting EV shift
2. Charging infrastructure is key
3. .. As is a cleaner power sector
4. eRINs, carbon tax barely move the needle
    - and eRINs have other problems
5. Important role for ZEV mandate
    - ZEV mandate can replicate tax wedge (without domestic content provisions), but both EV and ICE are higher than under rebate
    - ZEV mandate a feasible path towards deep EV penetration

Caveats & more work is needed…

- Charging subsidy program design
- Refine policies: first-best suite?
- Modeling:
    - EV-ICE cross-price elasticity
    - Private charging station response
    - Differentiate the Level 2 and Level 3 markets (both demand & supply)/improve modeling (Sommer & Vance [*ERL* 2021])
    - Better understanding of evolution of EV acceptance (attributes & tastes) (e.g., Archsmith et al (2021))
    - Take dynamics (expectations) more seriously?
    - Methods: out-of-sample functional form issues






Additional Slides

Discussion

Charger subsidies v. rebates

- In these simulations here, $1 in Federal charging station subsidies produces the same increment in EV share as approximately $10-$13 in EV tax rebates.
  - The main reason for this is that, at the currently-low level of charging stations, more charging stations are more valuable to the consumer than EV price reductions, using the empirically estimated parameters
  - A secondary reason is that, across the simulations reported here, just under 40% of the EV tax credits (on average across the policy cases) are inframarginal transfers to individuals who would have purchased an EV under the no-policy BAU scenario.
  - Because of this differential effect, increasing the charger budget while holding the rebate program constant can substantially reduce fiscal costs, because the increased number of chargers expedites the date at which the sales share hits the 50% trigger for sunsetting the rebate program.

- The charger subsidy rates reported in the tables depend on a specific model of charger supply. There is very little evidence, however, on the charger industry, so specific cost-shares are highly uncertain. One implementation approach would be to begin the program at a certain cost-share, say 50%, accept applications, and adjust the cost share as appropriate.

- Additional challenges of charging station policy
  - Provide incentives to maintain the stations
  - Provide incentives to maximize EV adoption ≈ maximize use
    - Lessons from the USDA blender infrastructure partnership

Point-of-sale rebates

- The rebate can be more cost-effective and targeted than the universal rebate considered here by:
  - Making the rebate only available to first-time EV buyers (like the first-time homebuyer tax credit). (This raises enforcement/compliance challenges however.)
  - Price cap on vehicle eligibility. (Because our model has only 1 EV it cannot model vehicle eligibility). If this were done it would be appropriate to have a phase-out schedule to avoid cliffs, and possibly to have different price caps based on chasis (car, light truck).

- The modeling assumes that the point-of-sale rebate is salient and fully passed through to the consumer. The modeling does not address the specific mechanism. Alternative mechanisms would be a point-of-sale instant rebate to the consumer that can be applied to the purchase, or a dealer rebate that can be applied to the purchase. In theory, both should have the same effect as they would both apply directly to the transaction and would both be highly salient. A refundable tax credit has additional frictions and would be expected to be somewhat less effective.

Discussion

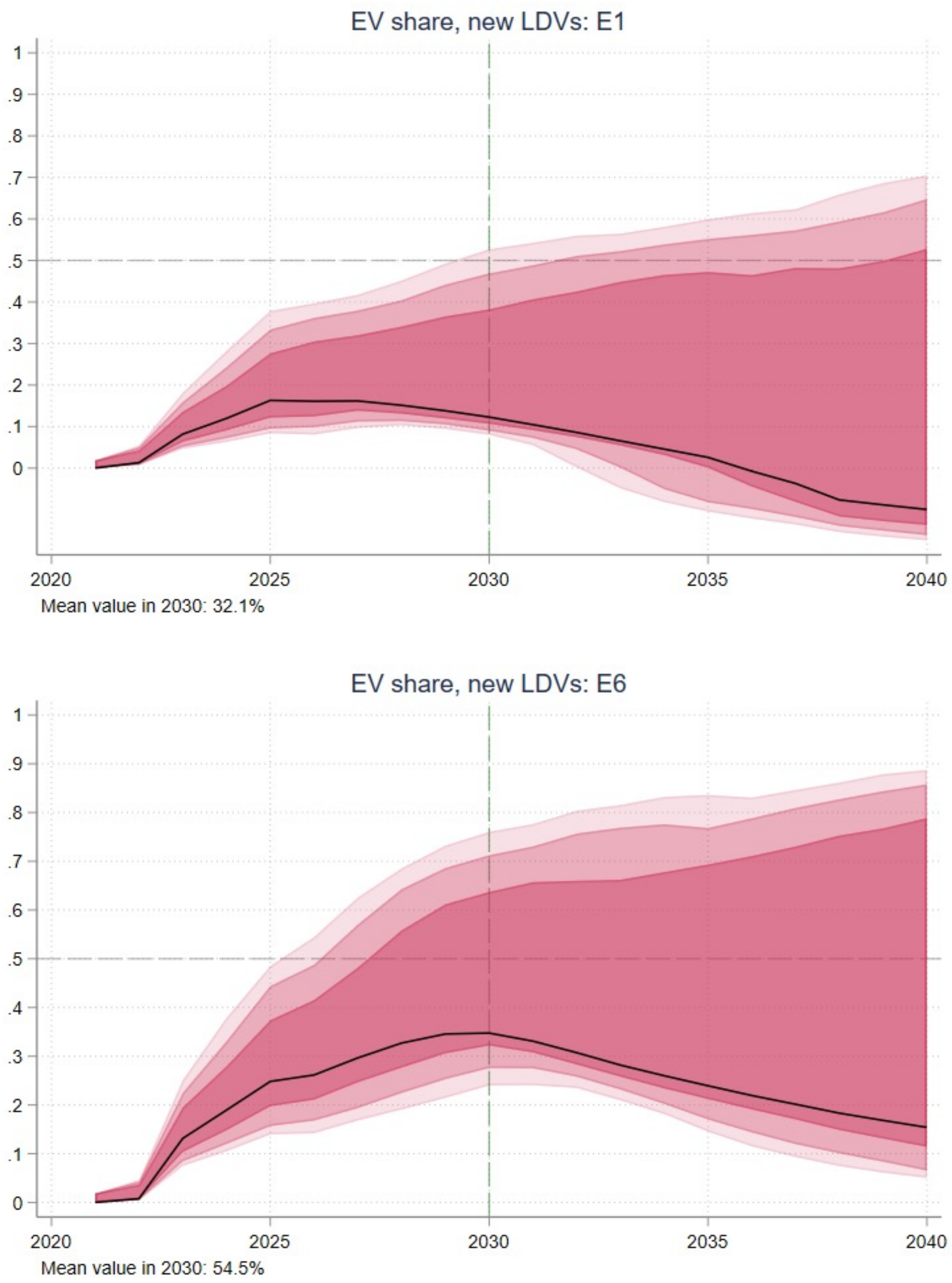
CAA ZEV standard

- The CAA ZEV standard modeled here separates the current joint DOT/EPA fuel economy standards into two regulations: DOT regulation of ICE fuel economy for ICEs, and EPA regulation of emissions under the CAA. EPA is modeled as implementing this regulation as a clean vehicle standard (or ZEV standard). The DOT ICE mpg regulation is assumed to be binding. The EPA standard may or may not be binding, depending on developments in the EV market including price, range, recharging time, charger availability, performance, and consumer acceptance.

- The simulations show that emissions regulation plays an important and complementary role to the fiscal policies.
  - A CAA ZEV standard provides a backstop in the event that EV penetration faces headwinds such as battery cost declines that are slower than expected or low oil prices.
  - A ZEV standard reduces costs of the rebate program because share threshold for the rebate sunset is hit sooner. The ZEV standard slightly increases the costs of the charging subsidy program because, as more vehicles are sold, charger supply increases.
  - A ZEV mandate encourages investment in EV technology (ZEV more generally) instead of in improving efficiency of ICEs, which can be regulated under EPCA, potentially lightly.

- The ZEV standards are modeling as taking effect in the late 2020s, when EV costs have dropped below ICE costs in most draws. As a result, the ZEV standards tend to have low costs per ton. The higher costs per ton of other programs, such as the charger buildout, is a consequence of their promoting EV sales when EVs are still relatively expensive.

Results: Change in EV sales share in 2030, relative to no-policy case



Change in EV sales share, benchmark parameters

Top:

67% cost-share, $7.5B; $6000/$3900 credits

Bottom:

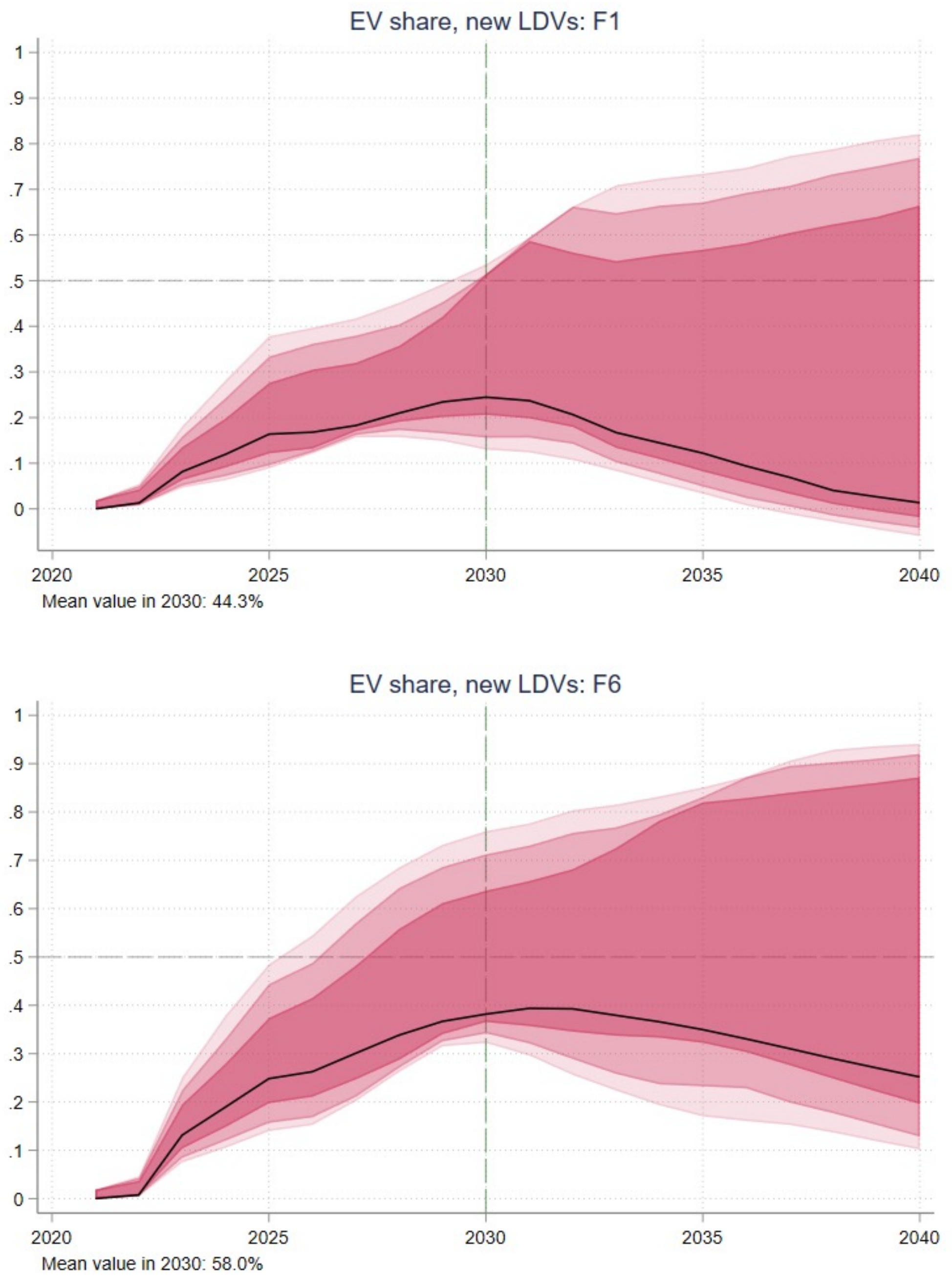
85% cost-share, $40B; $3900/$2100 credits

Left:

No ZEV policy

Right:

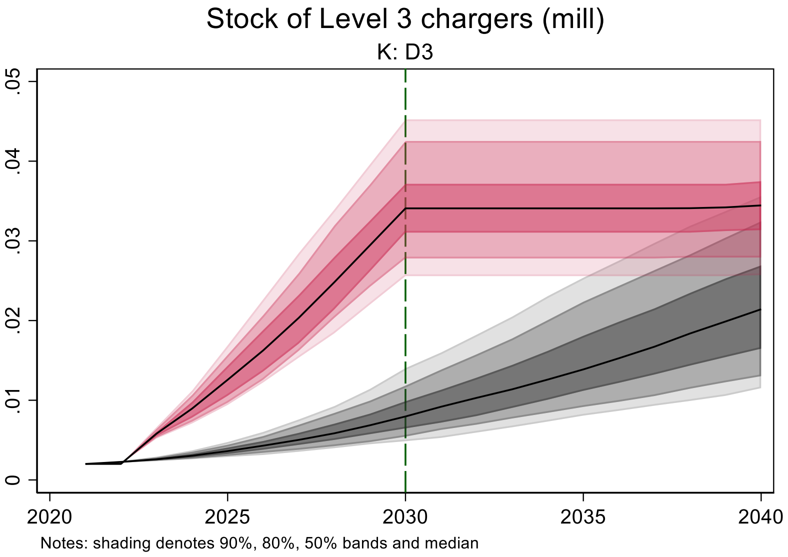
ZEV policy, $10k price cap

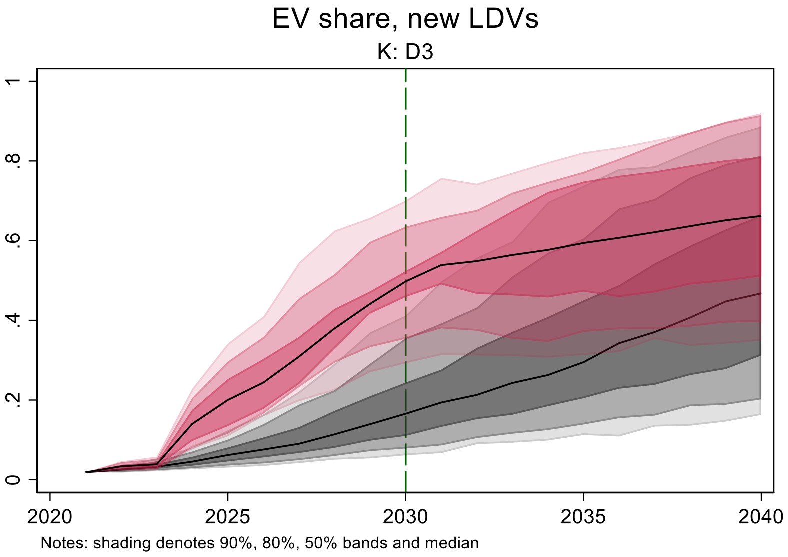


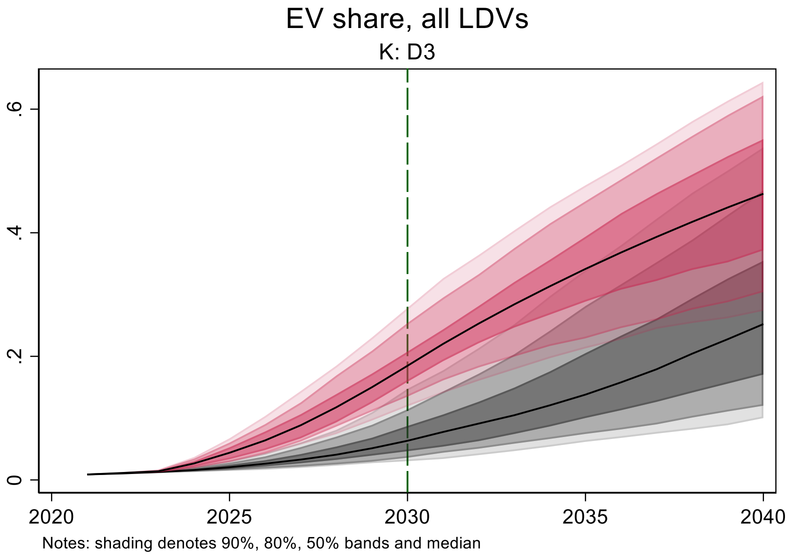
Results: Alternative policy combinations, IHS baseline penetration case

	Policies					EV share & Emissions			Fiscal costs ($B, not discounted)			
	Station cost share		EV sales rebate		ZEV permit price cap ($) (c)	EV Sales Share by 2030	Cst/ton CO2 ($/ton) (b)	ΔCO2 in 2030 (mmt)	Total	Of which:		
	Percent	Budget ($B)	2022 - 2025	2026+						Chargers	Rebates	Inframarginal Rebates (a)
0	-	-	-	-	-	0.374	-	-	-	-	-	-
E1	0.67	7.5	6,000	3,900	-	0.500	288	-47	182	9.0	173	94
E2	0.67	15.0	5,500	3,500	-	0.594	144	-61	179	16.1	163	80
E3	0.70	25.0	5,000	3,250	-	0.629	138	-66	176	23.7	152	73
E4	0.75	28.0	5,000	2,750	-	0.645	143	-73	173	28.1	145	64
E5	0.80	30.0	4,600	2,400	-	0.659	149	-80	167	31.9	135	54
E6	0.85	40.0	3,900	2,100	-	0.694	154	-92	163	42.9	120	43
F1	0.67	7.5	6,000	3,900	10,000	0.551	112	-54	193	9.0	184	94
F2	0.67	15.0	5,500	3,500	10,000	0.627	116	-66	186	16.5	169	80
F3	0.70	25.0	5,000	3,250	10,000	0.659	121	-71	182	24.4	158	73
F4	0.75	28.0	5,000	2,750	10,000	0.670	127	-77	178	28.8	149	64
F5	0.80	30.0	4,600	2,400	10,000	0.679	132	-83	170	32.5	138	54
F6	0.85	40.0	3,900	2,100	10,000	0.708	141	-94	165	43.4	122	43

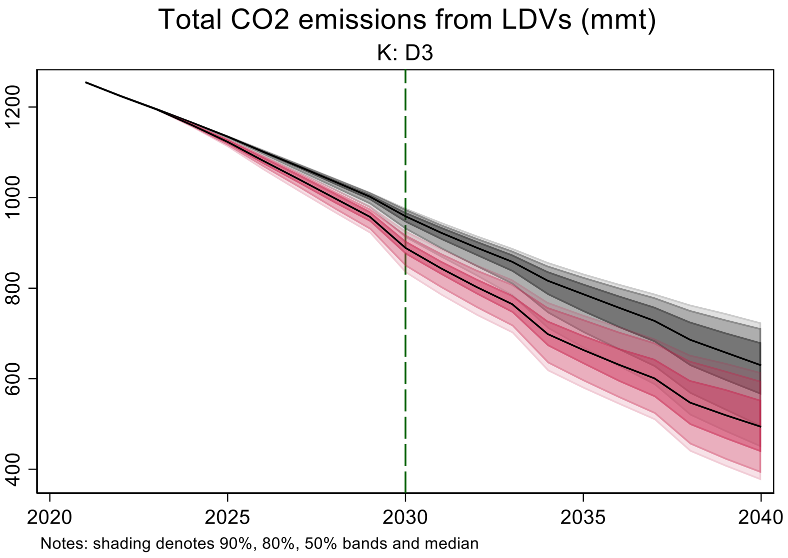
Uncertainty plots: Charging: 67%/$30B; Rebate $4k/$2.7k/40%; ZEV cap $10k (51% EV mean)

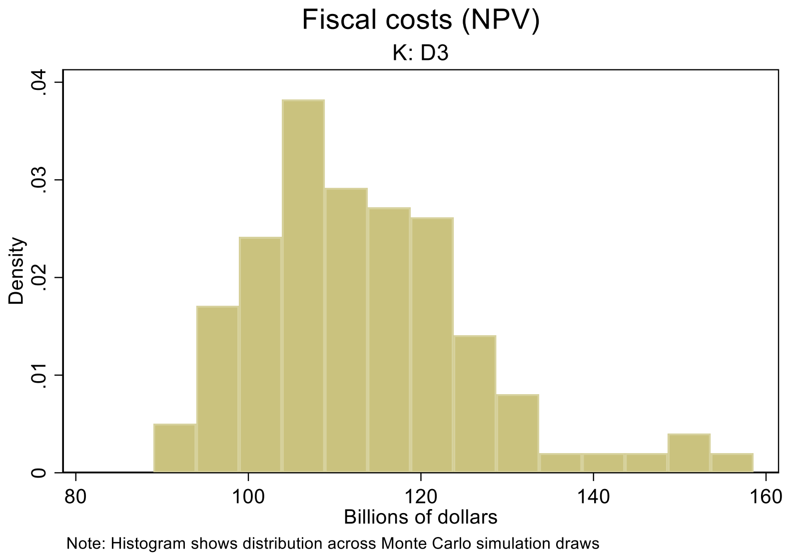


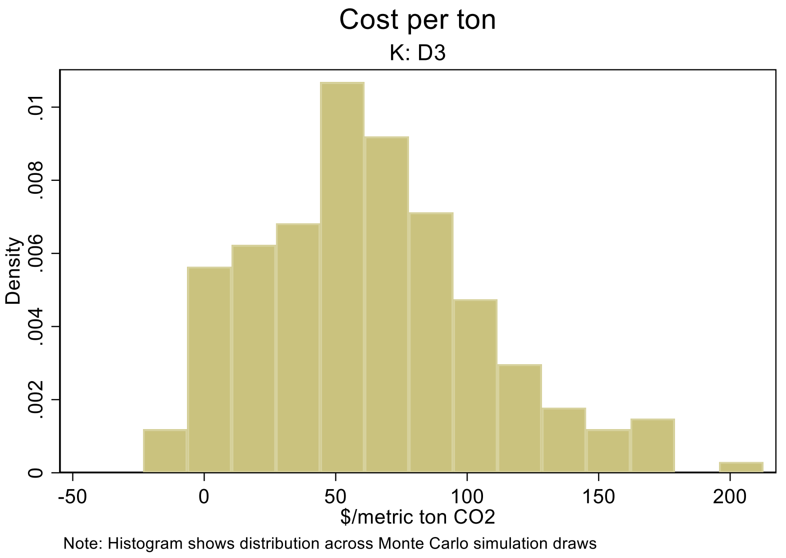




Time series plots show the mean and 5%, 10%, 25%, 75%, 90%, and 95% percentiles of the indicated variable under the no-policy BAU (gray) and policy case (red). Histograms show the value of the indicated summary variable. Uncertainty is over Monte Carlo draws.







Results: J. 50%/75% charging station cost-share + Enhanced CAA standards ($15k cap)