Policies for Electrifying the Light-Duty Vehicle Fleet in the United States

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Introduction

Background: Decarbonization of light-duty vehicles (LDVs) is a major policy priority in the US

- LDVs generate 58% of transportation emissions in the US
- Biden administration's stated goal: 50% of new LDVs are zero-emissions by 2030
- Chicken-and-egg problem: Electric vehicle (EV) sales vs. charging stations
- Two roles for government expenditures: subsidizing EVs vs. subsidizing charging stations

Research Question

- How do the Infrastructure Investment and Jobs Act (IIJA) and the Inflation Reduction Act (IRA) impact 1) EV sales, 2) carbon emissions, and 3) government expenditures?
- How do they compare with other allocations of government dollars between charging station subsidies and EV purchase subsidies?

Research strategy

- Follow the two-sided model of the EV market from Springel (2021) and Zhou and Li (2018):
  - Standard logit discrete choice model of consumer demand for EVs vs. internal combustion engine (ICE) vehicles
  - Entry-exit model for charging station firms
- Calibrate the model using estimated parameters from relevant literature
- Implement policy simulations as reductions in the cost of either EVs or charging stations
  - Vary the size, timing, budget to implement different policies

Model: EV Demand

- Two vehicle classes (cars and light-duty trucks), with fraction of vehicles in each class held fixed over time
- Consumers choose to purchase an EV or ICE within their vehicle class to maximize utility
- Utility to consumer i from purchasing an EV in class j at time t relative to an ICE:

$$u_{ijt} = \alpha_j + \beta_p ln\left(P_{jt}\right) + \beta_2 \ln\left(N_t^{L2}/Q_{t-1}\right) + \beta_3 \ln\left(N_t^{L3}\right) + \psi_{jt} + \epsilon_{ijt}$$

$$= \bar{u}_{jt} + \epsilon_{ijt}$$

- Assuming i.i.d. type-I extreme value distribution for ϵ_{ijt}, gives rise to the EV share of vehicles in class j at time t:

$$s_{jt} = \frac{\exp(\bar{u}_{jt})}{1 + \exp(\bar{u}_{jt})}$$

Model: Charging Station Supply

- Firms choose whether to enter the market by building a level-k charging station, yielding a discounted stream of future profits:

$$V_t^k = -C_t^k + \pi_t^k + \frac{1}{1+r}\pi_{t+1}^k + \frac{1}{(1+r)^2}\pi_{t+2}^k \cdots$$

- In free entry equilibrium, firms are indifferent between entering at time t and time $t+1$, which requires:

$$\pi_t^k(N_t^k, Q_t) = C_t^k - \frac{1}{1+r}C_{t+1}^k$$

- We parameterize the charging station profit function as:

$$\pi_t^k(N_t^k, Q_t) = (exp(\kappa_k)/(N_t^k))^{\frac{1}{\gamma}} Q_t$$

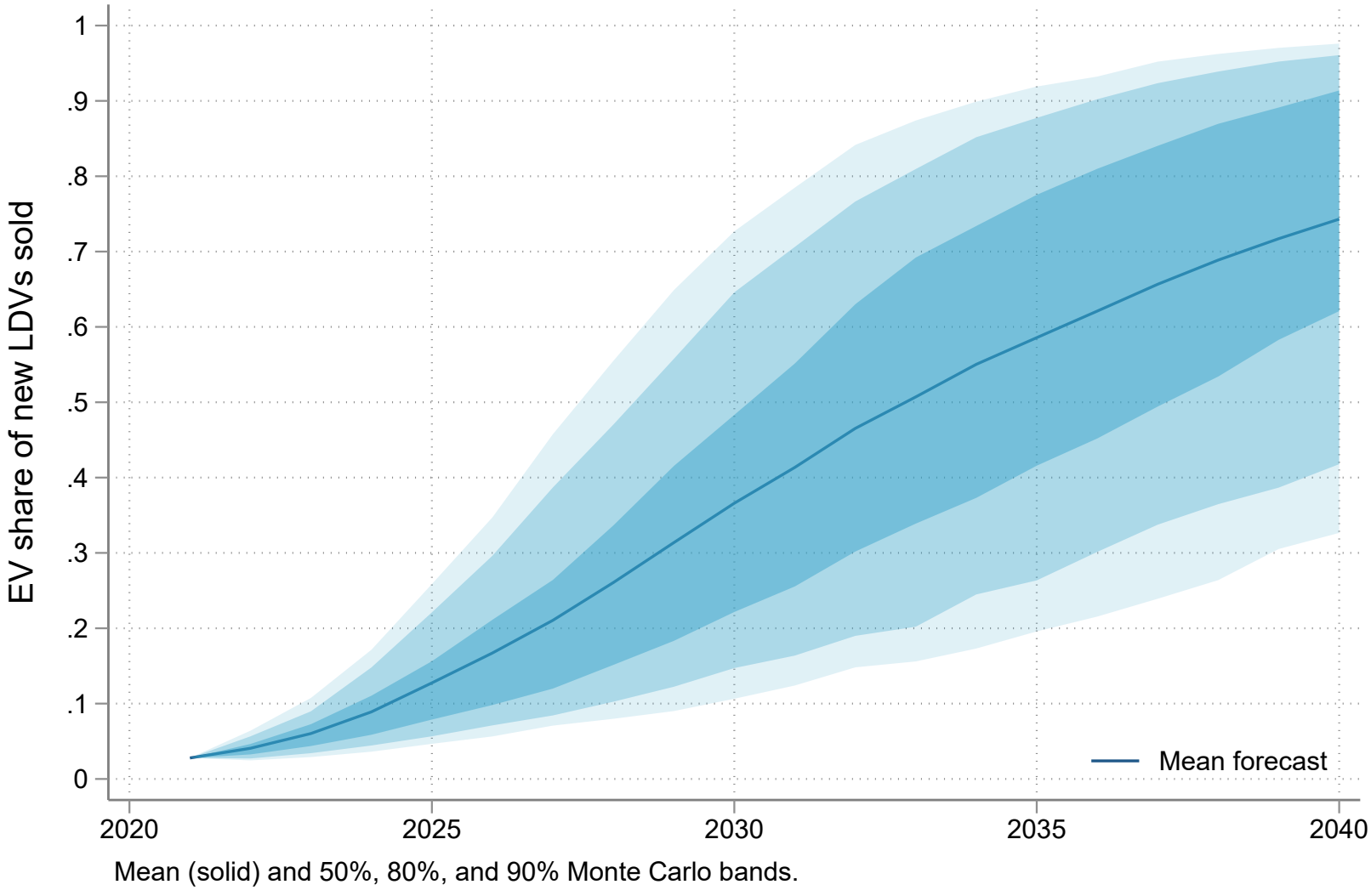
- Yielding the following equation for the supply of level-k charging stations:

$$\ln\left(N_t^k\right) = \kappa_k + \gamma \ln\left(Q_t\right) - \gamma \ln\left(\tilde{C}_t^k\right)$$

Calibration

- Calibrate our law of motion for EV preference set to match forecasted penetration of 36.6% in 2030
- Remaining parameters are drawn from relevant literature
  - Benchmark charging station elasticity: $\eta_2 = \eta_3 = 0.37$ from Springel (2021)
    - Most estimates are higher (Zhou & Li (2018), Li et al (2017)); Xing, Leard & Li (2021) is lower at 0.26.
  - Benchmark price elasticity: $\eta_P = -2.5$, approximate midpoint of estimates from Springel (2021), Zhou & Li (2017), Li (2016), Xing, Leard, & Li (2021), Muehlegger & Rapson (2019)
- Account for uncertainty: 1000 Monte Carlo draws of parameter values, assuming all parameters are independent, taking estimated variances from the literature or from the range of observed values

Baseline EV Penetration



Policy Background: The Infrastructure Investment and Jobs Act

Two direct 80% subsidy programs for EV chargers:

- $5 billion to states for subsidizing EV chargers along interstates and other major travel corridors
- $2.5 billion for alternative fuel infrastructure, with 50% in low-income locations

We treat the first as a subsidy to level-3/fast chargers, and the second as a subsidy to level-2 chargers.

Policy Background: The Inflation Reduction Act

- 30% subsidy for charging infrastructure built in census tracts which either 1) have a poverty rate of at least 20%, 2) have a median household income below 80% of the state median, or 3) are non-urban
  - 99.6% of census tracts qualify
- Tax rebate of $3750 for purchase of new EV meeting a threshold percent of battery minerals sourced from free trade agreement countries
- Additional $3750 tax rebate for purchase of new EV meeting assembly-in-North America requirements
  - Price and income caps apply; 96.1% of households have income below $300,000, threshold for married filing jointly
- Tax rebate of $4000 for purchasing a used EV from a dealer
  - Income cap of $150,000 for married filing jointly; 81.7% of households qualify

Main Results

	EV share & Emissions			Fiscal costs through 2031 ($B, not discounted)			
	EV Sales Share by 2030 (1)	Δ CO_2 in 2030 (mmt) (2)	Cost per ton CO_2 avoided (3)	Total (4)	Chargers (5)	Rebates (6)	Inframarginal Rebates (7)
0	0.366	-	-	-	-	-	-
IIJA	0.442	-31	97	6	6	-	-
IRA: charging stations	0.422	-15	90	4	4	-	-
IRA: rebates	0.490	-37	66	332	-	332	219
IRA	0.546	-54	80	382	6	376	219
IRA + IIJA	0.577	-80	95	451	11	440	219
E1	0.496	-63	94	276	9	267	160
E6	0.696	-112	118	253	43	210	94

- **IIJA**: 80% subsidy to level-3 chargers with $5 billion budget
- **IRA: charging stations**: 30% subsidy to charging stations ending after 2032
- **IRA: rebates**: $3750 rebate for EV purchase plus $4000 for used EV, implemented as $6410 to consumer and $6872 spent by government
- **E1**: 70% subsidy to charging stations with $8 billion budget, plus $4700 rebate
- **E6**: 90% subsidy to charging stations with $40 billion budget, plus $2750 rebate

Main Results

	EV share & Emissions			Fiscal costs through 2031 ($B, not discounted)			
	EV Sales Share by 2030	Δ CO_2 in 2030 (mmt)	Cost per ton CO_2 avoided	Total	Chargers	Rebates	Inframarginal Rebates
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
0	**0.366**	-	-	-	-	-	-
IIJA	**0.442**	-31	97	6	6	-	-
IRA: charging stations	0.422	-15	90	4	4	-	-
IRA: rebates	0.490	-37	66	332	-	332	219
IRA	0.546	-54	80	382	6	376	219
IRA + IIJA	0.577	-80	95	451	11	440	219
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E6	0.696	-112	118	253	43	210	94

- IIJA alone increases EV sales by 7.6 percentage points in 2030.

Main Results

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	EV Sales Share by 2030	Δ CO_2 in 2030 (mmt)	Cost per ton CO_2 avoided	Total	Chargers	Rebates	Inframarginal Rebates
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
0	**0.366**	-	-	-	-	-	-
IIJA	0.442	-31	97	6	6	-	-
IRA: charging stations	0.422	-15	90	4	4	-	-
IRA: rebates	0.490	-37	66	332	-	332	219
IRA	**0.546**	-54	80	382	6	376	219
IRA + IIJA	0.577	-80	95	451	11	440	219
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E6	0.696	-112	118	253	43	210	94

- IRA alone increases EV sales by 18 percentage points.

Main Results

	EV share & Emissions			Fiscal costs through 2031 ($B, not discounted)			
	EV Sales Share by 2030 (1)	Δ CO_2 in 2030 (mmt) (2)	Cost per ton CO_2 avoided (3)	Total (4)	Chargers (5)	Rebates (6)	Inframarginal Rebates (7)
0	0.366	-	-	-	-	-	-
IIJA	0.442	-31	97	6	6	-	-
IRA: charging stations	0.422	-15	90	4	4	-	-
IRA: rebates	0.490	-37	66	332	-	332	219
IRA	0.546	-54	80	382	6	376	219
IRA + IIJA	0.577	-80	95	**451**	11	440	219
E1	0.496	-63	94	276	9	267	160
E6	0.696	-112	118	253	43	210	94

- Benchmark estimate of IIJA & IRA costs $451 billion, vs. $10.6 billion estimated by the CBO

Main Results

	EV share & Emissions			Fiscal costs through 2031 ($B, not discounted)			
	EV Sales Share by 2030 (1)	Δ CO_2 in 2030 (mmt) (2)	Cost per ton CO_2 avoided (3)	Total (4)	Chargers (5)	Rebates (6)	Inframarginal Rebates (7)
0	0.366	-	-	-	-	-	-
IIJA	0.442	-31	97	6	6	-	-
IRA: charging stations	0.422	-15	90	4	4	-	-
IRA: rebates	0.490	-37	66	332	-	332	219
IRA	0.546	-54	80	382	6	376	219
IRA + IIJA	0.577	-80	95	451	11	440	219
E1	**0.496**	-63	94	276	9	267	160
E6	**0.696**	-112	118	253	43	210	94

- In general, the same amount of money is more effective when allocated to charging stations than to EV purchases.

Main Results

	EV share & Emissions			Fiscal costs through 2031 ($B, not discounted)			
	EV Sales Share by 2030 (1)	Δ CO_2 in 2030 (mmt) (2)	**Cost per ton CO_2 avoided** (3)	Total (4)	Chargers (5)	Rebates (6)	Inframarginal Rebates (7)
0	0.366	-	-	-	-	-	-
IIJA	0.442	-31	97	6	6	-	-
IRA: charging stations	0.422	-15	90	4	4	-	-
IRA: rebates	0.490	-37	66	332	-	332	219
IRA	0.546	-54	80	382	6	376	219
IRA + IIJA	0.577	-80	95	451	11	440	219
E1	0.496	-63	94	276	9	267	160
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- Every policy has a cost per ton abated below the most recent estimate for the social cost of carbon ($190).

Main Results

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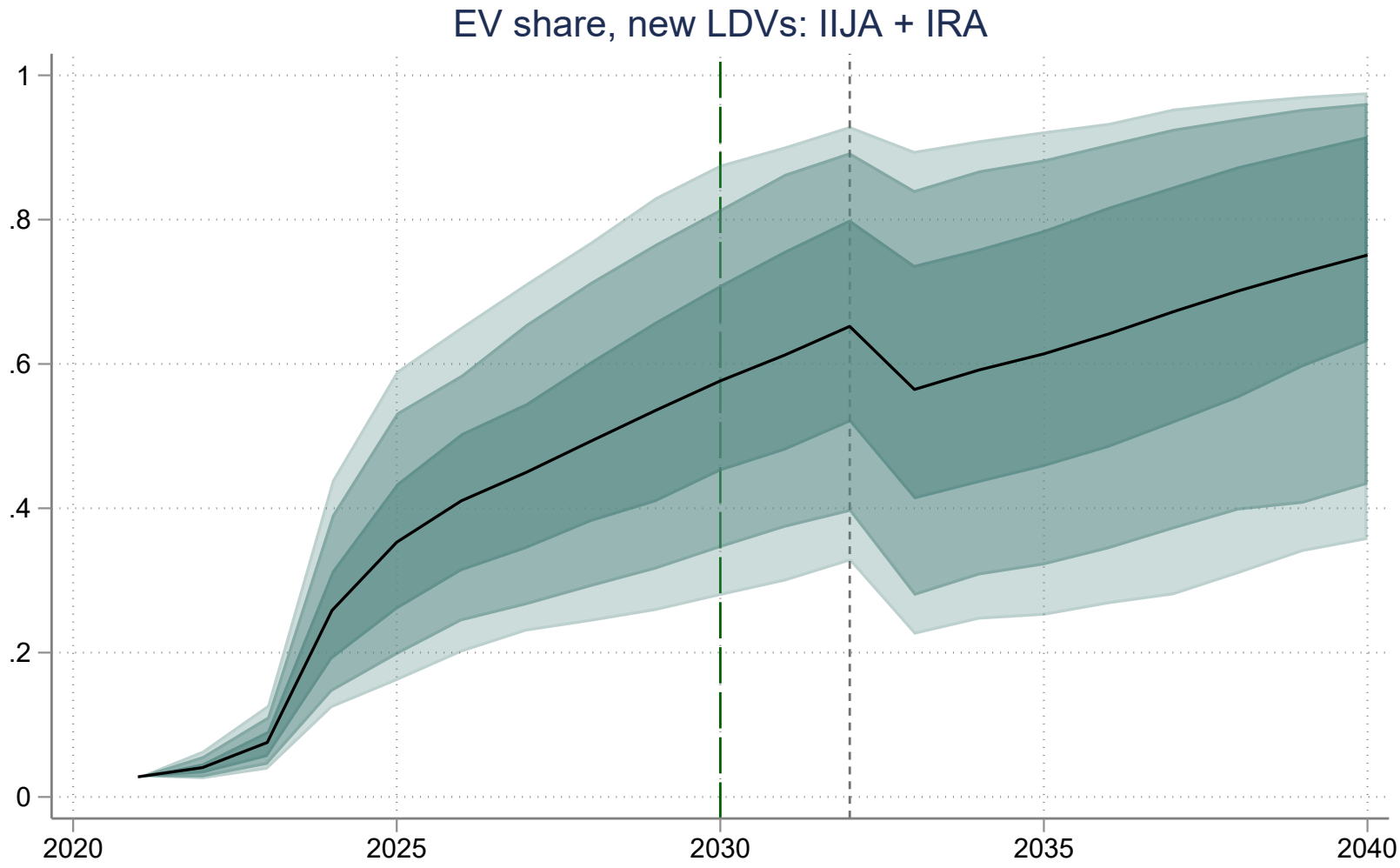
	EV Sales Share by 2030 (1)	Δ CO_2 in 2030 (mmt) (2)	Cost per ton CO_2 avoided (3)	Total (4)	Chargers (5)	Rebates (6)	**Inframarginal Rebates** (7)
0	0.366	-	-	-	-	-	-
IIJA	0.442	-31	97	6	6	-	-
IRA: charging stations	0.422	-15	90	4	4	-	-
IRA: rebates	0.490	-37	66	332	-	332	219
IRA	0.546	-54	80	382	6	376	219
IRA + IIJA	0.577	-80	95	451	11	440	219
E1	0.496	-63	94	276	9	267	160
E6	0.696	-112	118	253	43	210	94

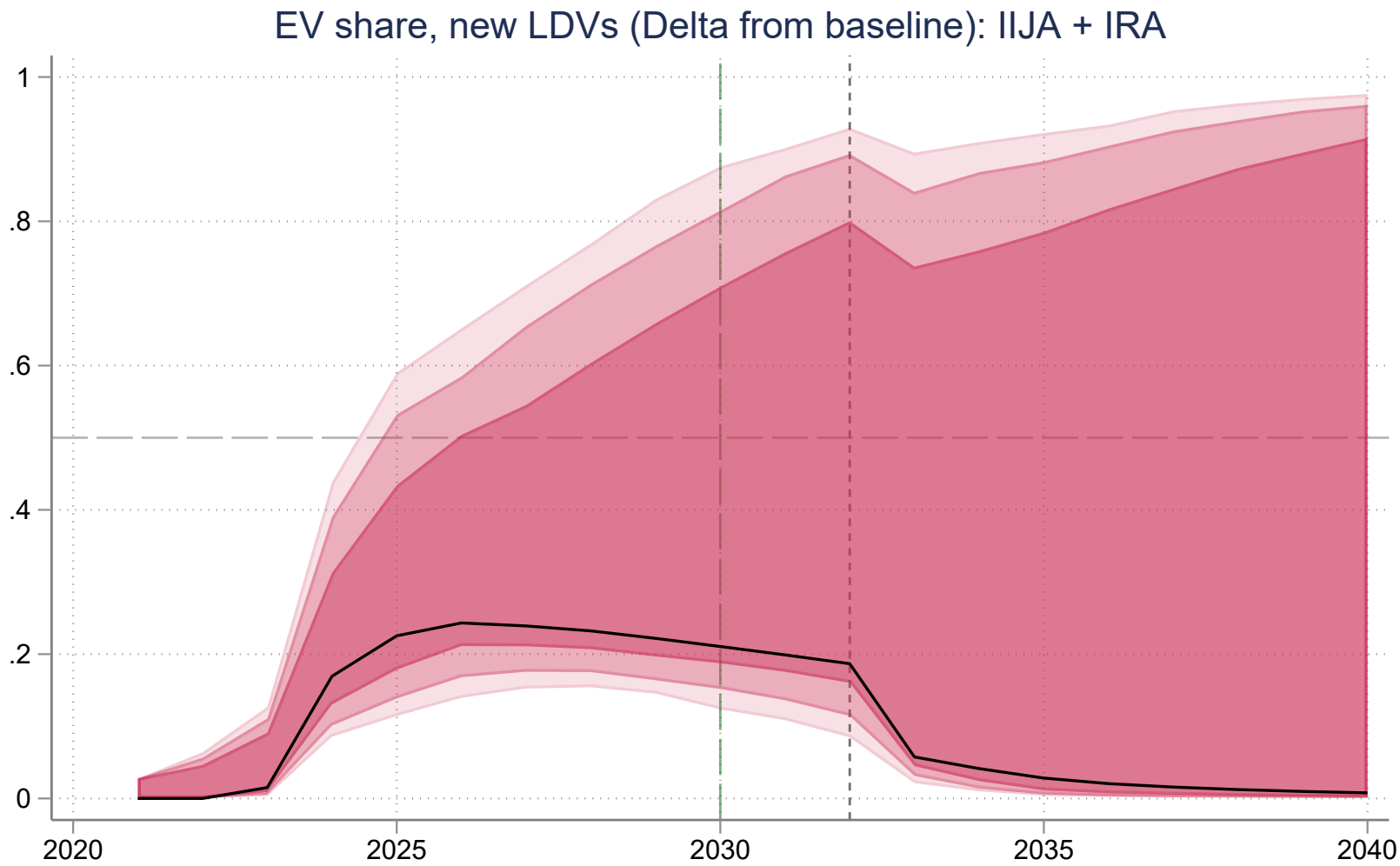
- EV rebate programs all involve substantial inframarginal transfers.

Main Results: IIJA & IRA



Notes: shading denotes 90%, 80%, 50% bands and mean.

Main Results: Uncertainty



Sensitivity Analysis: Low baseline

	EV share & Emissions			Fiscal costs through 2031 ($B, not discounted)			
	EV Sales Share by 2030 (1)	Δ CO_2 in 2030 (mmt) (2)	Cost per ton CO_2 avoided (3)	Total (4)	Chargers (5)	Rebates (6)	Inframarginal Rebates (7)
0	0.201	-		-	-	-	-
IIJA	0.286	-28	65	6	6	-	-
IRA: charging stations	0.248	-12	60	3	3	-	-
IRA: rebates	0.318	-32	38	222	-	222	128
IRA	0.376	-48	50	268	4	264	128
IRA + IIJA	0.423	-76	66	343	10	333	128
E1	0.347	-60	67	205	9	196	94
E6	0.565	-108	77	220	42	168	55

- EV shares in 2030 are lower than in benchmark, but combined policy impact of IRA & IIJA is slightly larger

Sensitivity Analysis: Reduced charger elasticity

	EV share & Emissions			Fiscal costs through 2031 ($B, not discounted)			
	EV Sales Share by 2030 (1)	Δ CO_2 in 2030 (mmt) (2)	Cost per ton CO_2 avoided (3)	Total (4)	Chargers (5)	Rebates (6)	Inframarginal Rebates (7)
0	0.366	-		-	-	-	-
IIJA	0.409	-16	101	6	6	-	-
IRA: charging stations	0.396	-8	96	4	4	-	-
IRA: rebates	0.537	-53	70	376	-	376	222
IRA	0.567	-62	78	406	6	400	222
IRA + IIJA	0.581	-76	88	433	11	413	222
E1	0.510	-57	85	261	9	249	163
E6	0.598	-72	113	171	42	165	95

$\eta_2 = \eta_3 = 0.2$, $\eta_P = -3.5$

- E6 still achieves substantially higher EV sales share in 2030 than E1

Conclusion

- IIJA & IRA substantially expedite the transition to EVs
  - Cost per ton well below social cost of carbon
  - Overall cost much higher than CBO estimates
- Charging station spending more effective than EV subsidies
  - Households who cannot install their own chargers require public charging, regardless of price
  - Substantial inframarginal spending
- Extensions for future research
  - Choice between cars and SUVs, or specific EV models
  - Zero emissions vehicle mandates
  - Charging station location

Appendix: Full Results

	Policies						EV share & Emissions			Fiscal costs through 2031 ($B, not discounted)			
	Station cost share				EV sales rebate		EV Sales Share	Δ CO_2 in 2030	Cost per ton				Inframarginal
	Level 2	Level 3	Budget ($B)	IRA	Rebate	Expenditures	by 2030	(mmt)	CO_2 avoided	Total	Chargers	Rebates	Rebates
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
0	-	-	-	-	-	-	0.366	-	-	-	-	-	-
I1	-	0.8	5	-	-	-	0.442	-31	97	6	6	-	-
I2	0.8	0.8	7.5	-	-	-	0.439	-40	107	9	9	-	-
I3	-	-	-	0.3	-	-	0.422	-15	90	4	4	-	-
I4	-	-	-	-	3604	6872	0.433	-20	63	286	-	286	123
I5	-	-	-	-	6410	6872	0.490	-37	66	332	-	332	219
I6	-	-	-	-	7208	10476	0.506	-43	67	528	-	528	246
I7	-	-	-	-	10014	10576	0.565	-63	71	608	-	608	342
I8	-	-	-	0.3	6410	6872	0.546	-54	80	382	6	376	219
I9	-	0.8	-	0.3	6410	6872	0.577	-80	95	451	11	440	219
E1	0.7	0.7	8	-	4700	4700	0.496	-63	94	276	9	267	160
E2	0.7	0.7	15	-	4000	4000	0.592	-76	100	266	16	250	137
E3	0.7	0.7	25	-	3500	3500	0.625	-80	103	251	25	226	120
E4	0.8	0.8	28	-	3300	3300	0.646	-89	107	252	29	223	113
E5	0.8	0.8	30	-	3150	3150	0.664	-99	111	257	32	225	108
E6	0.9	0.9	40	-	2750	2750	0.696	-112	118	253	43	210	94

Appendix: Low baseline

	Policies						EV share & Emissions			Fiscal costs through 2031 ($B, not discounted)			
	Station cost share				EV sales rebate		EV Sales Share	Δ CO_2 in 2030	Cost per ton				Inframarginal
	Level 2	Level 3	Budget ($B)	IRA	Rebate	Expenditures	by 2030	(mmt)	CO_2 avoided	Total	Chargers	Rebates	Rebates
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
0	-	-	-	-	-	-	0.201	-		-	-	-	-
I1	-	0.8	5	-	-	-	0.286	-28	65	6	6	-	-
I2	0.8	0.8	7.5	-	-	-	0.285	-38	77	9	9	-	-
I3	-	-	-	0.3	-	-	0.248	-12	60	3	3	-	-
I4	-	-	-	-	3604	6872	0.261	-16	36	180	-	180	72
I5	-	-	-	-	6410	6872	0.318	-32	38	222	-	222	128
I6	-	-	-	-	7208	10476	0.336	-37	38	359	-	359	144
I7	-	-	-	-	10014	10576	0.401	-57	42	439	-	439	199
I8	-	-	-	0.3	6410	6872	0.376	-48	50	268	4	264	128
I9	-	0.8	-	0.3	6410	6872	0.423	-76	66	343	10	333	128
E1	0.7	0.7	8	-	4700	4700	0.347	-60	67	205	9	196	94
E2	0.7	0.7	15	-	4000	4000	0.447	-70	66	203	16	187	80
E3	0.7	0.7	25	-	3500	3500	0.461	-73	65	190	22	168	70
E4	0.8	0.8	28	-	3300	3300	0.490	-82	68	197	27	170	66
E5	0.8	0.8	30	-	3150	3150	0.524	-94	72	207	32	175	63
E6	0.9	0.9	40	-	2750	2750	0.565	-108	77	220	42	168	55

Appendix: Reduced charging station elasticity

	Policies						EV share & Emissions			Fiscal costs through 2031 ($B, not discounted)			
	Station cost share				EV sales rebate		EV Sales Share	Δ CO_2 in 2030	Cost per ton				Inframarginal
	Level 2	Level 3	Budget ($B)	IRA	Rebate	Expenditures	by 2030	(mmt)	CO_2 avoided	Total	Chargers	Rebates	Rebates
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
0	-	-	-	-	-	-	0.366	-		-	-	-	-
I1	-	0.8	5	-	-	-	0.409	-16	101	6	6	-	-
I2	0.8	0.8	7.5	-	-	-	0.408	-21	108	9	9	-	-
I3	-	-	-	0.3	-	-	0.396	-8	96	4	4	-	-
I4	-	-	-	-	3604	6872	0.459	-27	65	311	-	311	125
I5	-	-	-	-	6410	6872	0.537	-53	70	376	-	376	222
I6	-	-	-	-	7208	10476	0.559	-60	71	604	-	604	250
I7	-	-	-	-	10014	10576	0.636	-89	78	715	-	715	347
I8	-	-	-	0.3	6410	6872	0.567	-62	78	406	6	400	222
I9	-	0.8	-	0.3	6410	6872	0.581	-76	88	433	11	413	222
E1	0.7	0.7	8	-	4700	4700	0.510	-57	85	261	9	249	163
E2	0.7	0.7	15	-	4000	4000	0.555	-60	92	229	16	220	139
E3	0.7	0.7	25	-	3500	3500	0.562	-59	98	200	24	198	121
E4	0.8	0.8	28	-	3300	3300	0.572	-63	101	193	28	189	114
E5	0.8	0.8	30	-	3150	3150	0.583	-67	105	190	32	184	109
E6	0.9	0.9	40	-	2750	2750	0.598	-72	113	171	42	165	95