Peer Effects in Electric Car Adoption: Evidence from Sweden

Sebastian Tebbe (IIES)

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Transport Decarbonization

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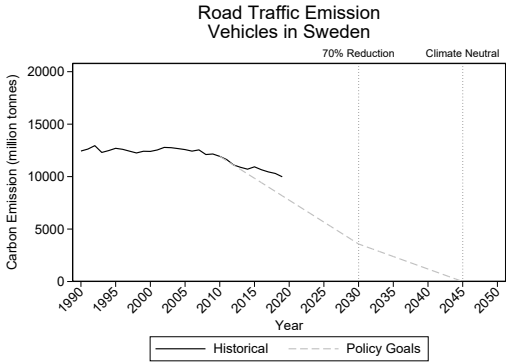
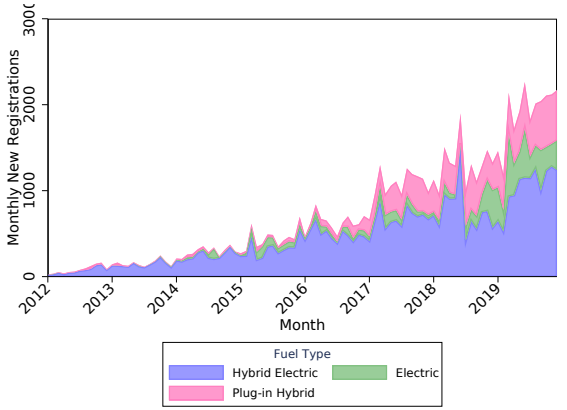


Transport Emission Road Traffic Emission

Evolution of Alternative Fuel Cars

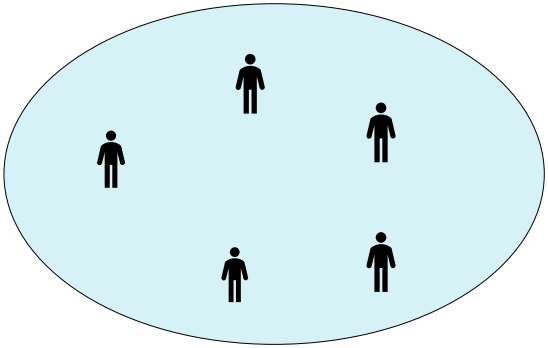


Vehicle Reforms Market Share Charging Station EV Types Top 5-Models Spatial Clustering

Peer Effects

Research question:

- How does one new electric car influence the subsequent electric car adoption in the peer group?



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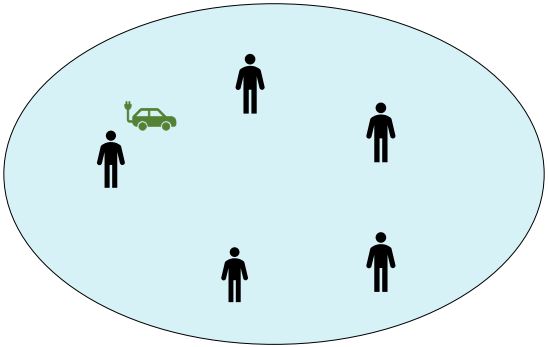

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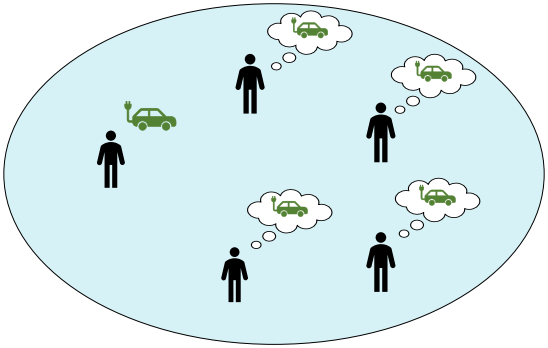

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3. **Policy implication:**
   - → I document how peer effects alter the level and dynamics of optimal subsidies

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Empirical findings:

1. One additional new peer EV triggers, in the next quarter:
   - → .077 EVs in the workplace
   - → .014 EVs in the family
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Policy implications:

- Optimal subsidy shifts upward in the presence of peer effects, but decreases along adoption curve

Literature Review

This work speaks to two strands of literature:

1. Social networks and consumption behavior
   → Consumption choices (De Giorgi *et al.*, 2020), education (Sacerdote, 2001; Graham, 2008), welfare participation (Dahl *et al.*, 2014, Hesselius *et al.*, 2009), charitable giving (DellaVigna *et al.*, 2012), product adoption (Bailey *et al.*, 2020), and criminal behavior (Bhuller *et al.*, 2018)

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2. Optimal policies with non-neoclassical agents
   - → Social reputation (Benabou & Tirole, 2011), salience (Chetty *et al.*, 2009), inattention (Farhi & Gabaix, 2020), social norms (Allcott, 2011), nudges (Allcott & Kessler, 2019; Allcott & Taubinsky, 2015), social-image concerns (Bursztyn & Jensen, 2014, 2017), non-standard decision making (Bernheim & Taubinsky, 2018)

Data

Primary data sources are Swedish administrative data (2012 to 2020):

1. Swedish vehicle register (*Fordonsregistret*)
2. Longitudinal integrated database for health insurance and labor market studies (*LISA*)
3. Population and housing census (*Folk- och bostadsräkningar)*
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Supplemented with charging station network and financial incentives for cars:

1. Publicly-available database of charging stations from ChargeX (*Uppladdning.nu*)
2. Government incentives from the Swedish Tax Authority (*Skatteverket*), Swedish Transport Agency (*Transportstyrelsen*), and Statistics Sweden (*Statistiska centralbyrån*)

Summary Statistics

Network Preparation

1. Workplace
   - → Co-worker is defined as someone who works in the same plant
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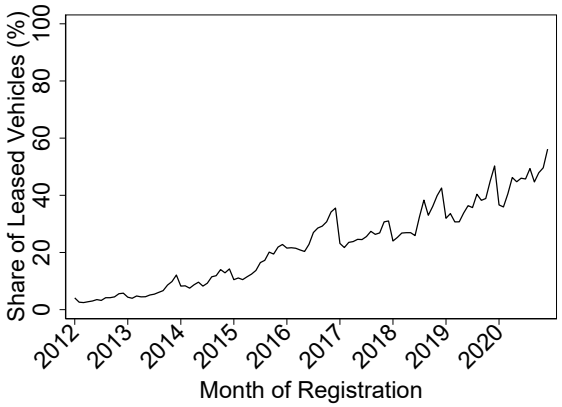
3. Neighborhood
   - → All neighbors living within a $125m$ radius in urban and a $500m$ radius in rural areas
   - → Average number of neighbors: 260.28

Network Statistics

Car Leasing Market

Two important facts:

1. Substantial proportion of new cars are leased (as opposed to purchased)



Leased EVs Fringe Benefit Predicted Propensities

Car Leasing Market

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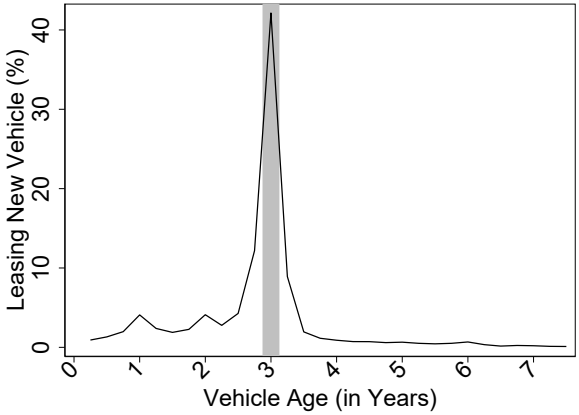
2. Leasing renewal is on a fixed three-year schedule



Event-Study

Empirical Strategy

Equation of interest:

$$V^e_{i,q} = \theta V^e_{p-i,q-1} + \delta X + \varepsilon_{i,q} \quad (1)$$

- $V^e_{i,q}$: Individual i adopts new *electric* car in quarter q, $\in \{0, 1\}$
- $V^e_{p-i,q-1} = \sum_{j \epsilon N, i \neq j} V^e_{j,q-1}$: New *electric* cars in peer group p
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Model assumption:

- Social transmission of one quarter
- Linear-in-sums

Control Variables Parameter Distinction

Identification Concerns

In a network composed of 2 persons, the empirical model becomes:

$$V_{1p}^{e} = \alpha_1 + \theta_{\mathbf{1}} \mathbf{V}_{\mathbf{2p}}^{\mathbf{e}} + \gamma_1 X_{1p} + \delta_1 X_{2p} + \rho_1 W_p + e_{1p}$$

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3. **Correlated unobservables**
   → Not all relevant characteristics (X_{1p}, X_{2p}, W_p) are observed

Exogenous Shocks

Assign exogenous instrument Z_{1p} only to individual 1:

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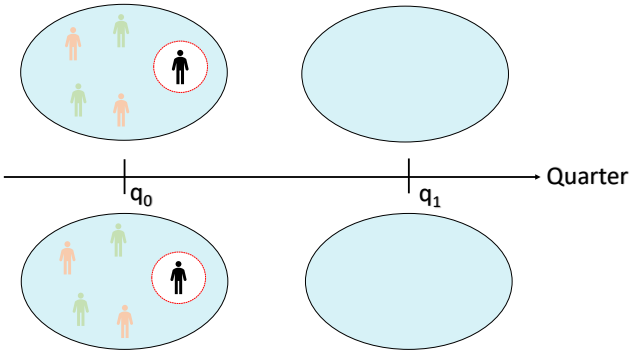
Identification Strategies

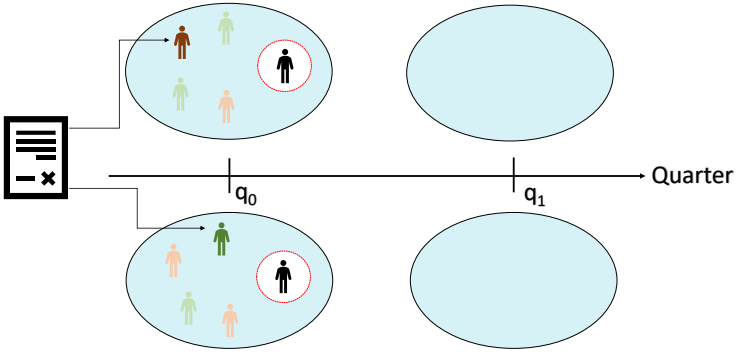
Network Example

Exogenous variation:



Network Example

Exogenous variation: *Timing of leasing renewal*



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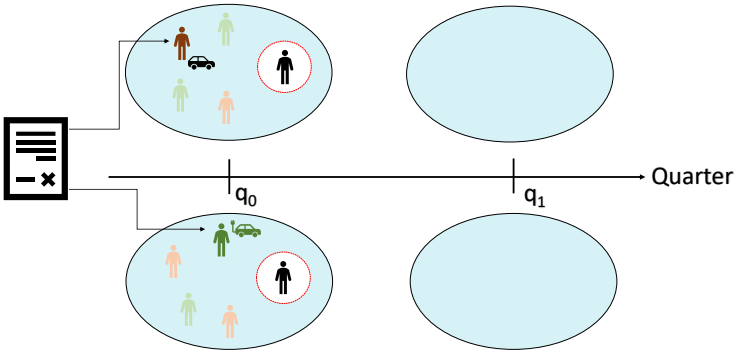

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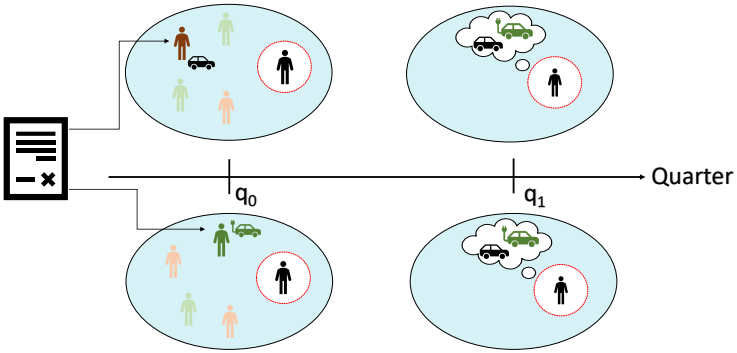
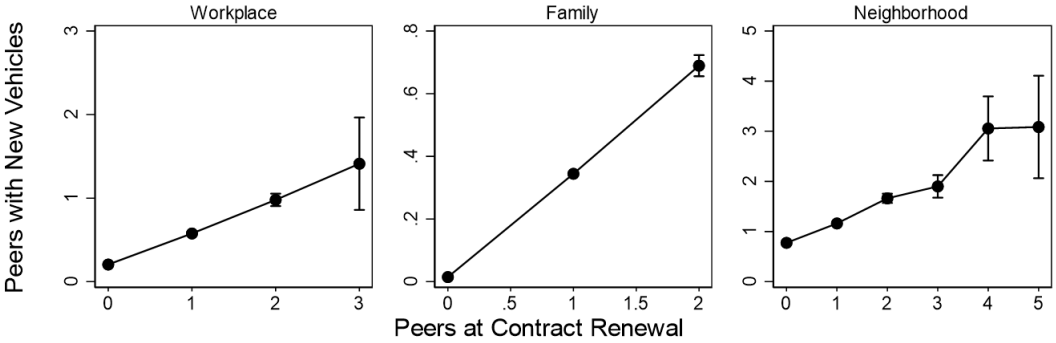


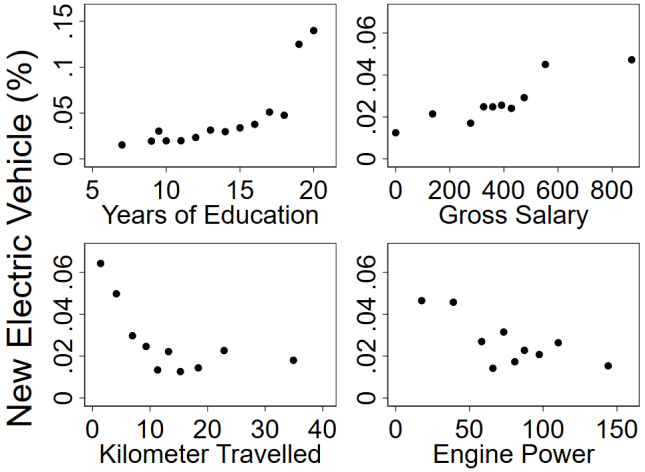
Leasing Contract Renewal

Exogenous-component: Exploit timing of peers' car leasing renewals



EV Adoption Prediction

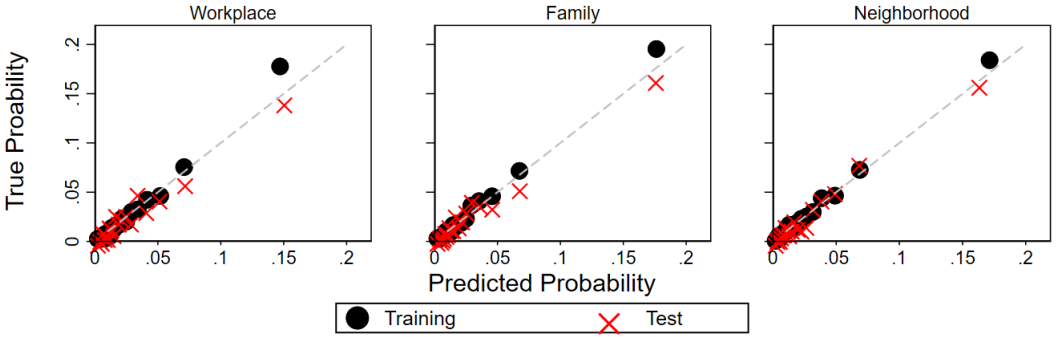
Non-random-component: Exploit heterogeneity of leasers to adopt new EV



Propensity Calculation

Prediction Performance

Neural network accurately predicts EV take-up at contract renewal



ROC Curves Predicted Propensities

Shift-Share Instrument

The shift-share design instruments peer EV adoption by the sum of peers at 3-year contract renewal and their propensity to adopt an EV at the contract renewal:

$$\underbrace{V^{e}_{p-i,q-1}}_{\text{Peers new EV}} = \beta_1 \sum_{j \epsilon N} \underbrace{V^{3y}_{j,q-1}}_{\text{Peers at contract renewal}} \cdot \underbrace{\widehat{Pr}(V^{e} \mid V^{3y}_{j,q-1} = 1)}_{\text{Propensity to buy EV}} \tag{2}$$

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Standard Errors:

- Clustered at peer-group level Standard errors comparison

Identifying Assumption & Validity Checks

The exclusion restriction can formally be stated as follows: (Borusyak *et al.*, 2022)

$$\mathbb{E}\left[\sum_{i}\Big(\sum_{j\epsilon N} V^{3y}_{j,q_{-1}} \cdot \widehat{Pr}(V^{e}|V^{3y}_{j,q_{-1}})_{j}\Big)_{i} \cdot e_{i} \mid \mathbb{X}_{i,p_{-i}}\right] = 0 \tag{3}$$

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Assumption 1 (*Many uncorrelated shocks*):

- High effective sample size, sufficient dispersion, and large number of shocks Shock summary statistics Shock distribution
- No clustering of shocks in peer groups Shock correlations

Identifying Assumption & Validity Checks

The exclusion restriction can formally be stated as follows: (Borusyak *et al.*, 2022)

$$\mathbb{E}\left[\sum_i \Big(\sum_{j \epsilon N} V^{3y}_{j,q_{-1}} \cdot \widehat{Pr}(V^e | V^{3y}_{j,q_{-1}})_j\Big)_i \cdot e_i \mid \mathbb{X}_{i,p_{-i}}\right] = 0 \tag{3}$$

Assumption 1 (*Many uncorrelated shocks*):

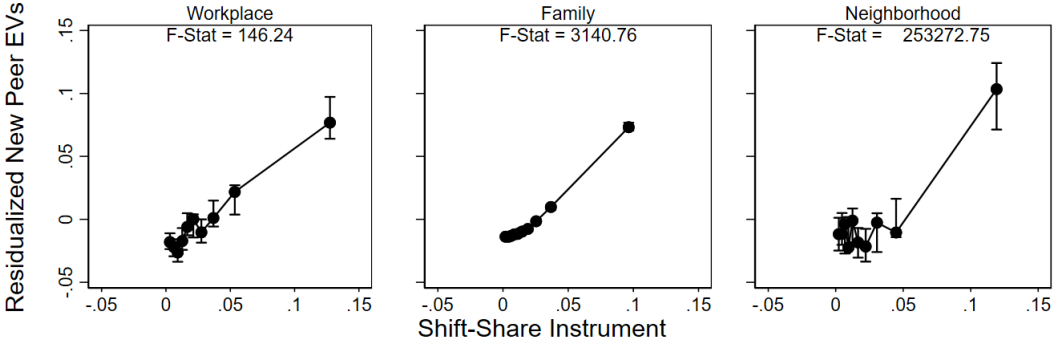
- High effective sample size, sufficient dispersion, and large number of shocks Shock summary statistics Shock distribution
- No clustering of shocks in peer groups Shock correlations

Assumption 2 (*Quasi-random assignment of shocks*):

- Shocks do not predict demographics Balance test
- No prior EV adoption prior to renewal

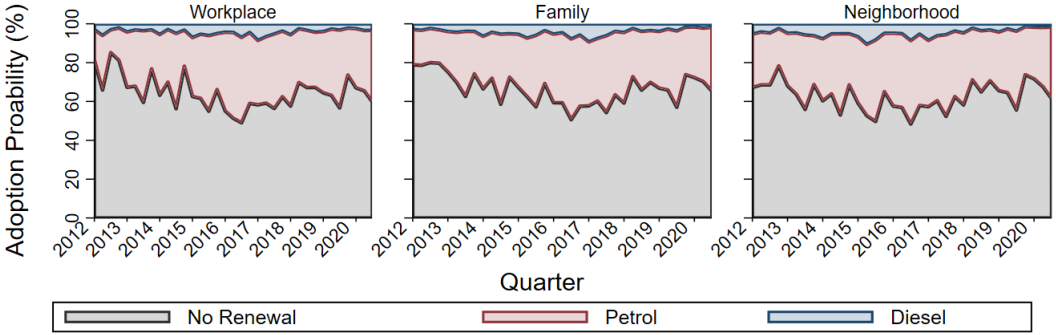
First Stage

Shift-Share instrument is a strong predictor of EV adoption



Interpretation of Treatment Effect

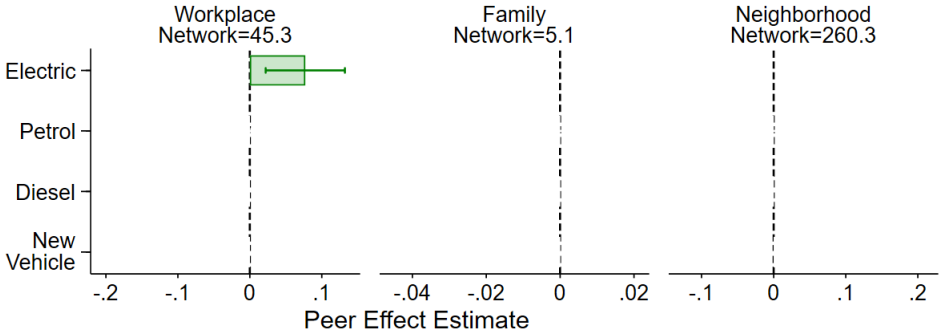
Control Group: 2/3 no new car, 1/3 new fossil fuel car



Control Group

Estimation Results

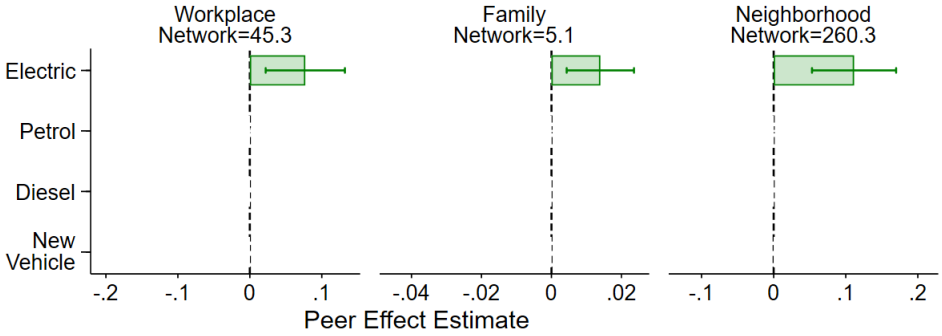
- One additional new peer EV triggers, in the next quarter:
  → .077 EVs in the workplace



Regression Results Peer Effects by Fuel Type

Estimation Results

- One additional new peer EV triggers, in the next quarter:
  - → .077 EVs in the workplace
  - → .014 EVs in the family
  - → .111 EVs in the neighborhood



Regression Results Peer Effects by Fuel Type

Estimation Results

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  - → .014 EVs in the family (.0027 EVs per relative)
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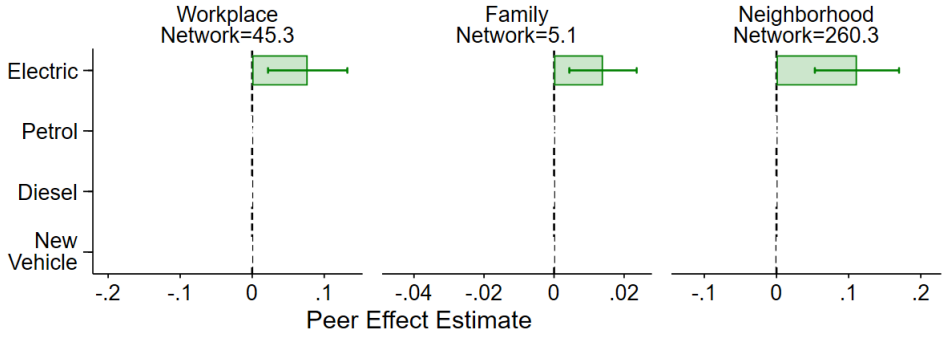

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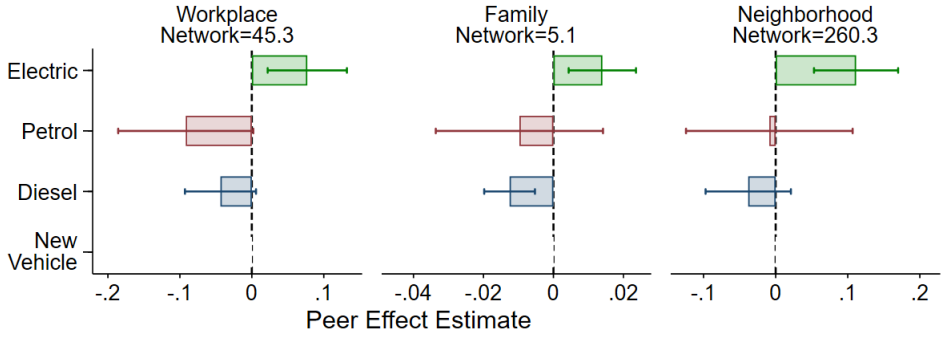

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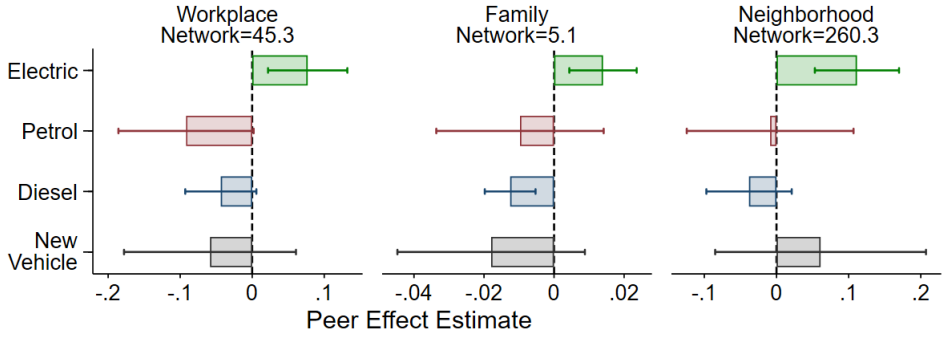
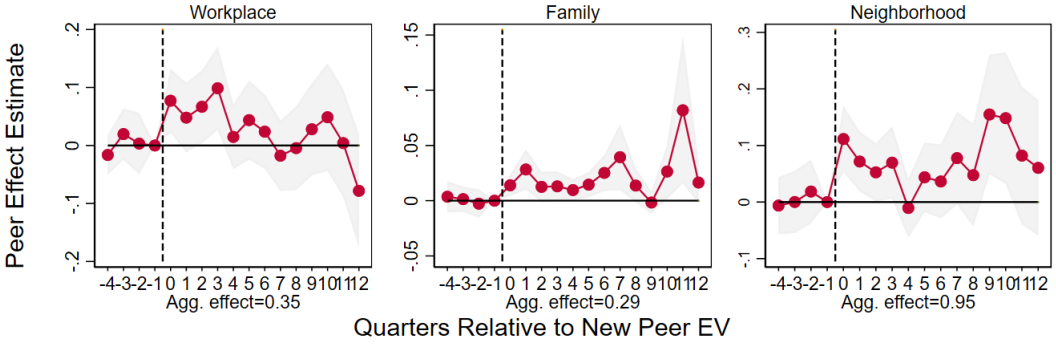
- Substitution in workplace and family, incremental demand in neighborhood



Regression Results Peer Effects by Fuel Type

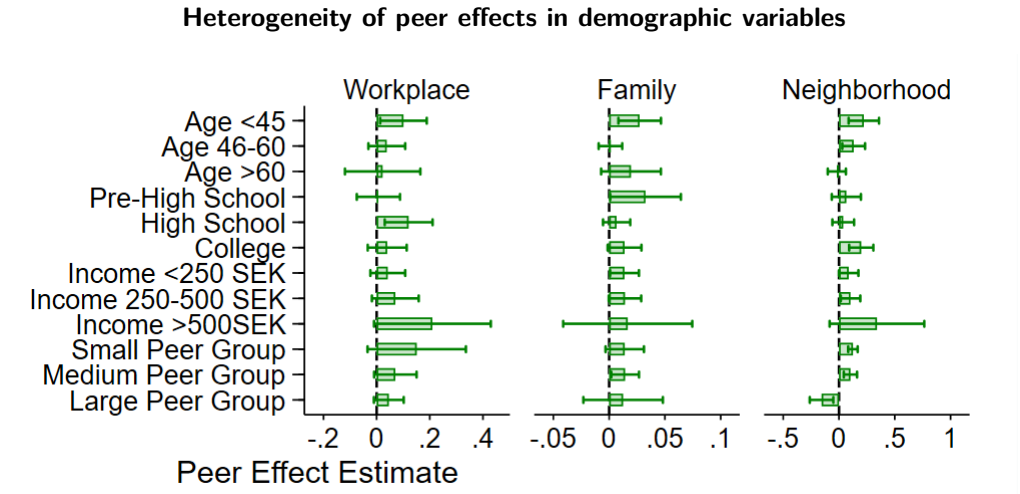
Peer Effect Dynamics

Social influence induces persistent, incremental demand for EVs



General Vehicle Dynamics Constant Peer Groups

Heterogeneity in Peer Effects

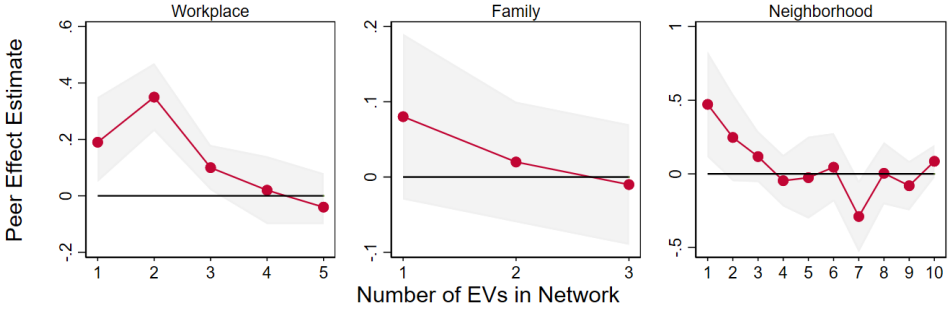


Geography

Peer Effect Mechanisms

The literature suggests that social interactions can influence EV take-up through two channels:

1. "Social learning" channel (Bikhchandani *et al.*, 1992; Banerjee, 1992)
   → Early peer EV adoption carries more information



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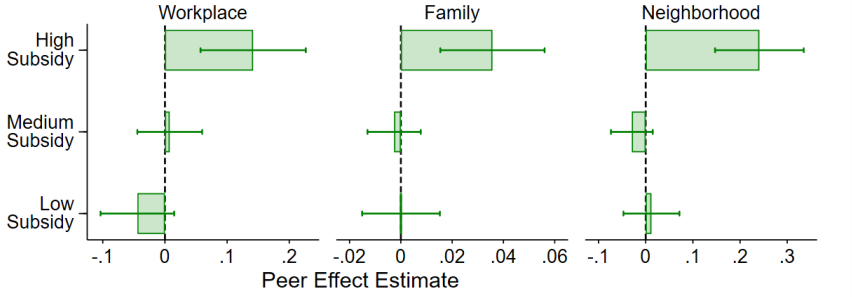

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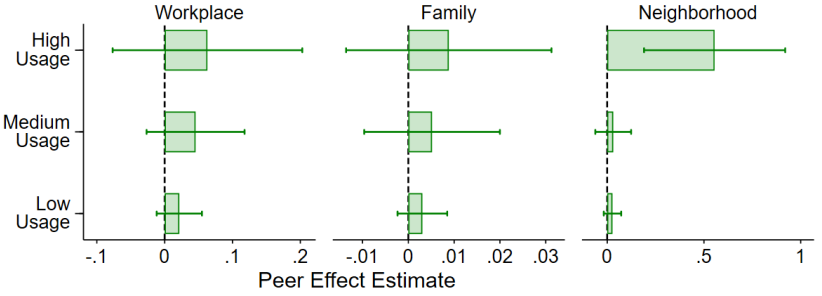

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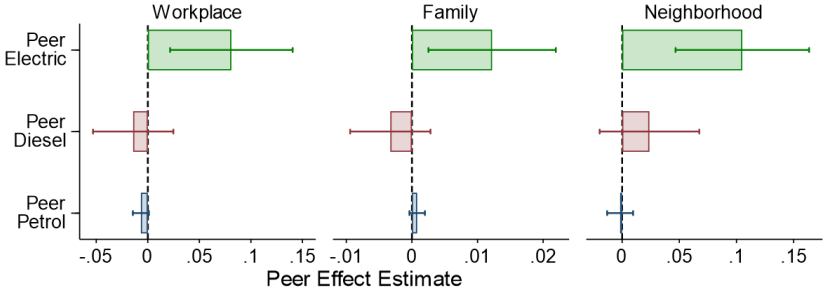

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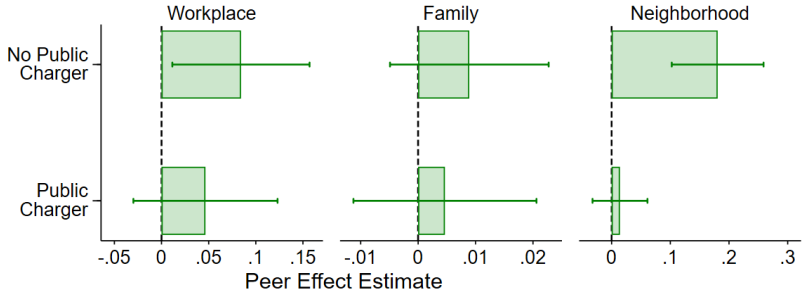
   - → EVs with greater usage transmit more information
   - → Newly fossil fuel cars provide no information
   - → No learning about public charging infrastructure



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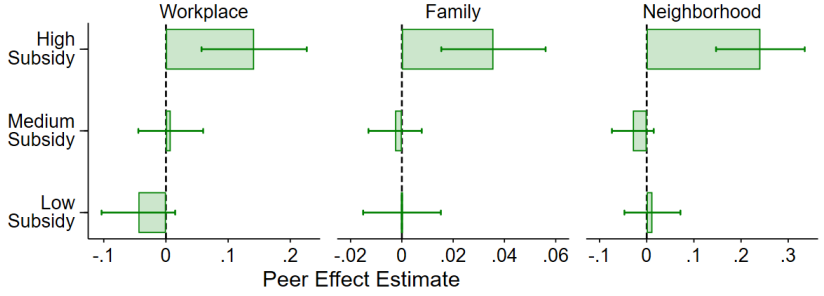
   → Social reputation: Peer effects are larger in high subsidy periods (Benabou & Tirole, 2006, 2011)



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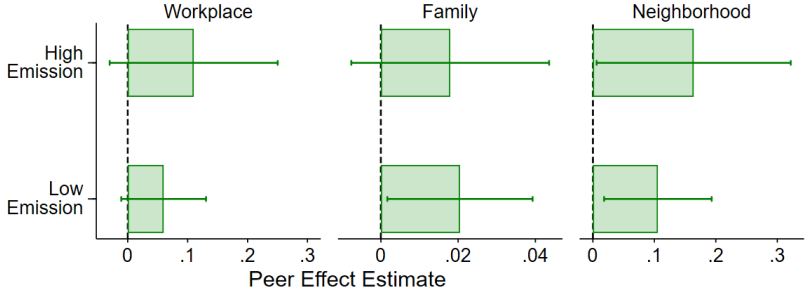
   - → Conformism: Low emission peer-groups exert larger peer effects (Bernheim 1994; Akerlof, 1997)



Vehicle Subsidies

Peer Effect Mechanisms

The literature suggests that social interactions can influence EV take-up through mediating factors:

1. "Observability" (Mas & Morretti, 2009; Bursztyn & Jensen, 2015; Karing, 2019)
   → Higher observability of EVs in neighborhoods that consist of houses (as opposed to apartments)

Overvability

Environmental Impact

What are the carbon-emission changes of a peer EV adoption?

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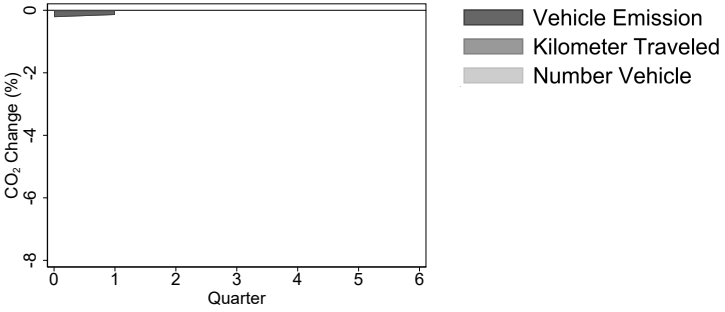

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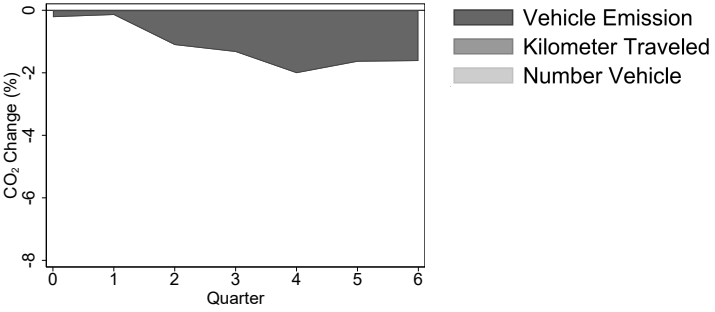

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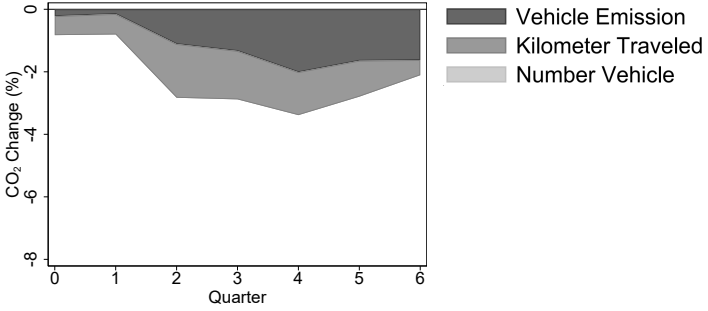

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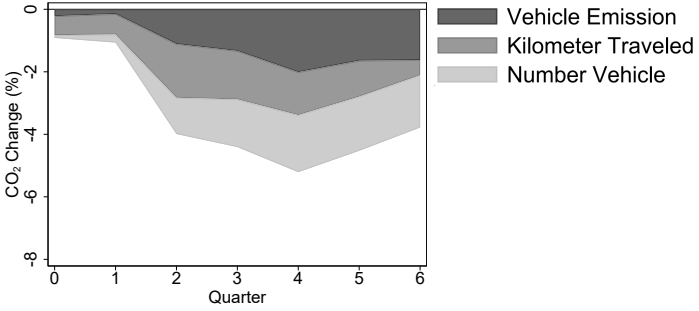

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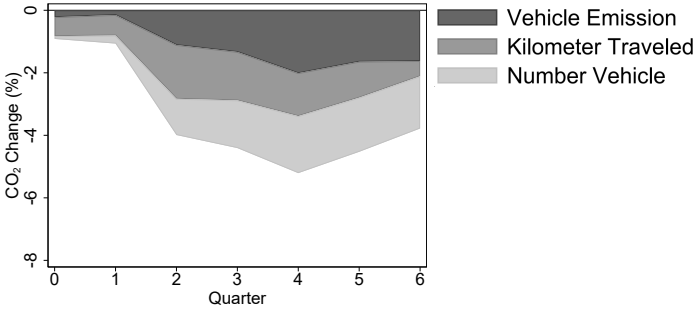

Additional outcomes: Weight ↓, engine power ↓, fuel efficiency ↑

Carbon Emission Model | Carbon Coefficients | Model Robustness | Emission in Other Groups | Second Hand Vehicles

Robustness Checks

Peer effect results remain robust along various dimensions:

1. Alternative specifications
   → Alternative estimation models, functional forms, outcomes, and sample restrictions Alternative Specifications

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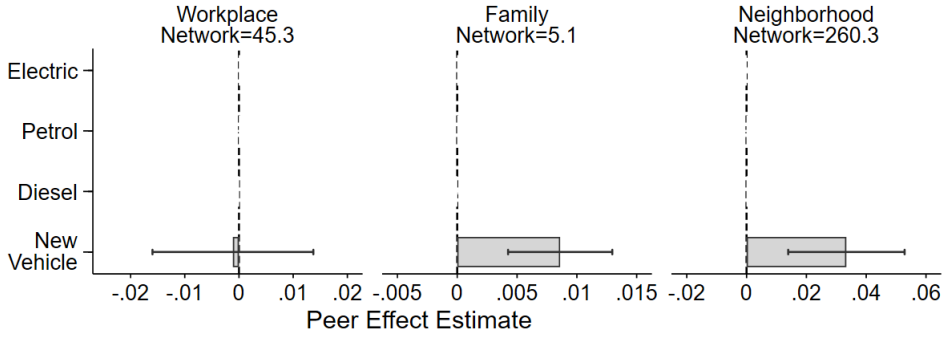
6. Varying peer dynamics
   → Peer effects persist for various aggregate time horizons Varying Horizon

Peer Effects - New Cars

- One additional new peer car triggers, in the next quarter:
  - → -.001 cars in the workplace
  - → .009 cars in the family
  - → .034 cars in the neighborhood



General Vehicle Results

Pigou Subsidy

Pigou prescription:

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Pigou subsidy for EVs:

- Subsidy τ for EVs equals sum of externalities e_j ($\tau^* = e$) (Rapson & Muehlegger, 2022)

$$e = \sum_{j=1}^{J} [\underbrace{e_j(V^e)}_{EV} - \underbrace{e_j(V^m)}_{Counterfactual\ Car}] \tag{4}$$

Pigou Model

Modified Pigou

How does peer EV adoption affect externalities?:

- Level: Externality reduction through follow-on adoption
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$$\tau^*(\theta) \;=\; e \cdot [1 \;+\; \underbrace{\theta(v^*)}_{\textit{Peer effect}} \;]$$

- $v^* = \sum_{j \in N, i \neq j} V_j^e$: Number of *electric* cars in peer group
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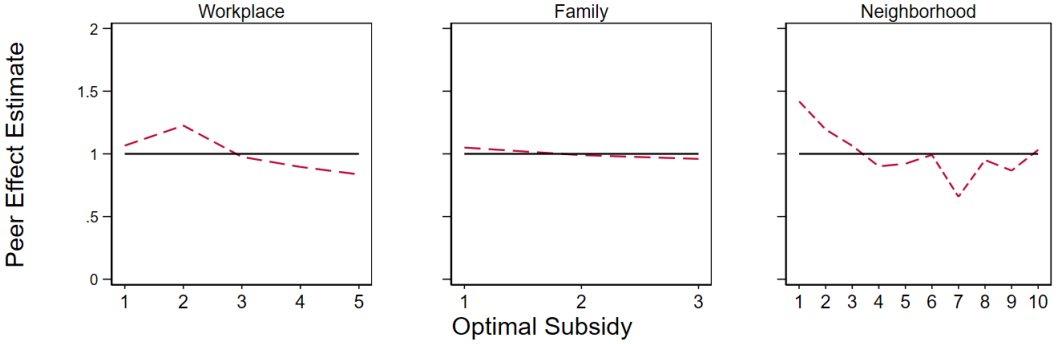
Assumptions:

1. No peer effect on fossil fuel adoption
2. Peer adoption has no impact on peer's welfare

Mechanism Fossil Fuel Adoption

Optimal Subsidies

Optimal subsidies shift up, but decrease along adoption curve



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- Substantial peer effects for co-worker, relatives, and neighbor
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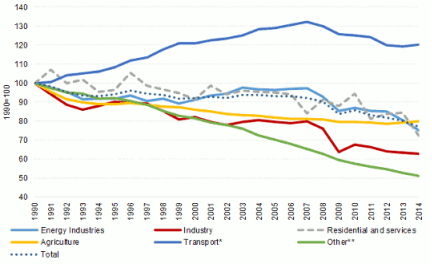
Policy implications:

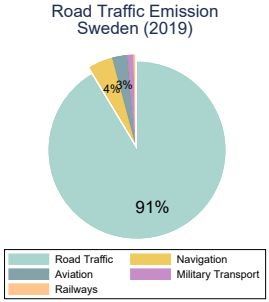
- Optimal subsidy shifts upward in the presence of peer effects, but decrease along adoption curve

EU Transport Emission



Transport Decarbonization

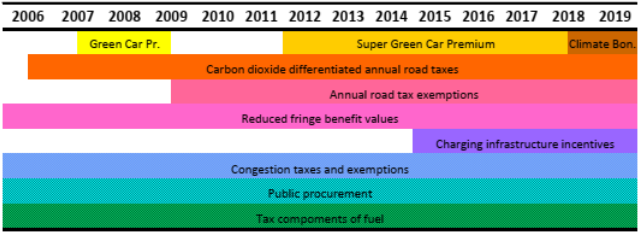
Road Traffic Emission



Transport Decarbonization

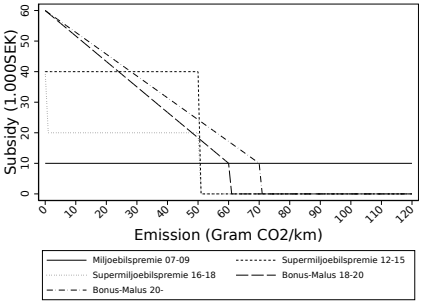
Vehicle Reforms

Main instruments of the Swedish vehicle reforms include various vehicle subsidies, annual road taxes and exemptions, reduced fringe benefit values and charging infrastructure incentives:



Alternative-Fueled Cars

Vehicle Subsidies



Mechanisms

Fringe Benefit

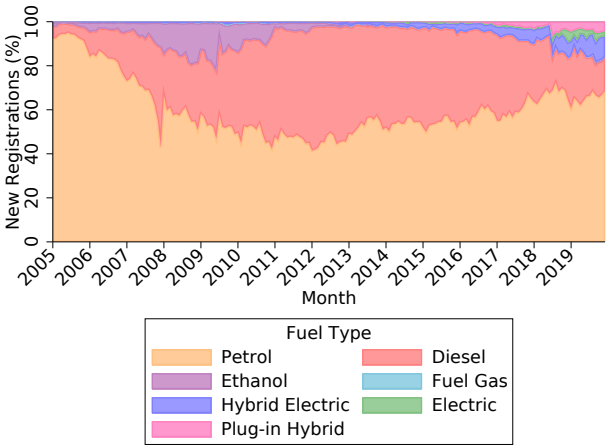
The fringe benefit value is calculated as

$$\textit{Fringe Benefit Value} = p \cdot 0.09 + \%PBV + 0.75 \cdot GB \cdot p \tag{5}$$

Year	Price Base Value (SEK)	% of Price Base Value	Government Bond Interest Rate (%)
2012	40,000	31.7	1.65
2013	44,500	31.7	1.49
2014	44,000	31.7	2.09
2015	44,500	31.7	0.90
2016	44,300	31.7	0.65
2017	44,800	31.7	0.50
2018	45,500	29	0.50
2019	46,500	29	0.51
2020	47,300	29	0.50

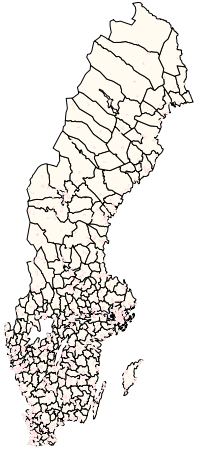
Leasing

Evolution of Alternative-Fueled Cars



Alternative-Fueled Cars

Charging Station Network



Alternative-Fueled Cars

Types of Electric Cars

Electric vehicles can be categorized into 3 types:

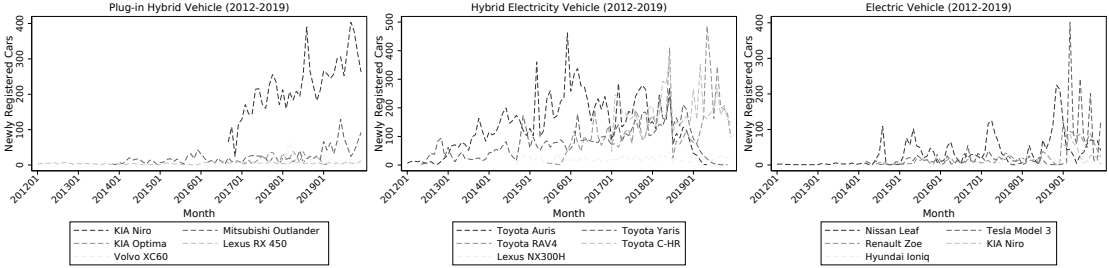
1. **All-Electric Vehicle (EV)**
   → Rechargeable battery (no secondary source of propulsion)

2. **Plug-in Hybrid Electric Vehicle (PHEV)**
   → Internal combustion engine + rechargeable battery

3. **Hybrid Electric Vehicle (HEV)**
   → Internal combustion engine + electric propulsion system (charged through regenerative braking)

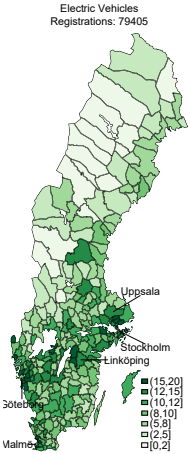
Alternative-Fueled Cars

Top 5-Models

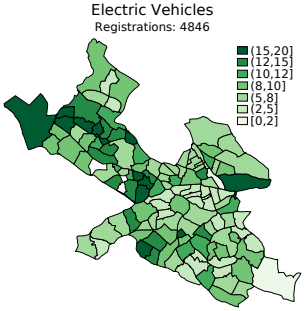


Alternative-Fueled Cars

Spatial Clustering



(a) Sweden



(b) Stockholm

Alternative-Fueled Cars

Descriptive Statistics

	Mean	Std. dev.	Min	Max	Obs.
A.Socio-Demographic Data					
Age	47.09	18.15	18	117	65,277,131
Female	0.50	0.50	0	1	65,277,131
Annual Gross Salary (in tho.)	323.61	265.32	0	81,443	65,277,131
Family Disposable Income (in tho.)	231.38	619.74	0	1,039,452	65,277,131
Annual Unemployment Days	5.06	31.69	0	366	65,277,131
Self-Employment (in %)	0.07	0.26	0	1	65,277,131
Number of Retire	0.20	0.40	0	1	65,277,131
Married or Cohabitant (in %)	0.57	0.50	0	1	65,277,131
At Least 1 Child (in %)	0.45	0.50	0	1	65,277,131
Years of Education	12.10	2.62	7	20	64,001,852
Commuting Distance	23.86	85.56	0	1,738	65,277,131
Share Commuting	0.67	0.47	0	1	65,277,131
At least 1 Vehicle (in %)	0.41	0.49	0	1	65,277,131
Average Number of Vehicles	0.49	0.67	0	3	65,277,131
B.Vehicle Data					
Vehicle Kilometer Travelled	11993.95	7674.94	0	497,937	32,288,962
Leased Vehicles (%)	0.02	0.15	0	1	32,288,962
Vehicle Age	10.73	8.67	0	116	32,288,939
Service Weight (kg)	1470.42	264.37	0	17,910	32,288,962
Engine Power (KW)	102.52	38.09	0	1,777	32,288,962
Vehicle Fuel Efficiency (l/100km)	5.97	3.08	0	66	32,288,962
Vehicle Carbon Emission (g/km)	147.69	73.97	0	500	32,288,962
C.Charging Infrastructure Data					
Charging Station	0.33	1.45	0	57	1,885,835
Charging Station Installation	0.04	0.19	0	1	1,885,835
Number of Plug-in	1.16	8.87	0	555	1,885,835
Power Wattage (kWh)	17.26	19.20	.43	350	1,885,835

Descriptive Statistics

Leasing Statistics

	Population		Vehicle Owner		
	Mean	Std. Dev.	Owner	New Vehicle	Leased Vehicle
A.Socio Demographic Variables					
Age	47.10	18.13	51.11	50.75	44.39
Female	0.50	0.50	0.38	0.36	0.42
Gross Salary (in tho.)	324.05	266.23	373.65	431.55	430.09
Disposable Income (in tho.)	231.62	622.78	249.17	311.98	266.09
Annual Unemployment Days	5.07	31.70	3.66	1.90	2.65
Self-Employment (in %)	0.07	0.26	0.05	0.06	0.04
Married or Cohabitant (in %)	0.57	0.50	0.66	0.71	0.67
At Least 1 Child (in %)	0.44	0.50	0.35	0.34	0.40
Years of Education	12.10	2.62	12.17	12.46	12.82
Share Commute (in %)	0.67	0.47	0.71	0.76	0.88
Distance Commute	23.88	85.54	24.10	26.47	30.25
B.Vehicle Attributes					
Vehicle Carbon Emission (g/km)	60.49	83.75	147.39	132.73	121.28
Engine Power (KW)	41.60	54.48	101.38	103.81	91.66
Vehicle Fuel Efficiency (l/100km)	2.45	3.42	5.98	5.42	5.10
Service Weight (kg)	601.34	737.62	1465.34	1495.75	1407.88
Electric Vehicle	0.01	0.08	0.02	0.07	0.06
Vehicle Kilometer Travelled	6053.96	9777.47	14752.31	10730.68	15599.27
Number of Observation	65,546,382		26,898,528	1,218,648	699,114

Descriptive Statistics

Leaser Comparison

	Population		Vehicle Owner		
	Mean	Std. Dev.	Owner	New Vehicle	Leased Vehicle
A.Socio Demographic Variables					
Age	47.10	18.13	51.11	50.75	44.39
Female	0.50	0.50	0.38	0.36	0.42
Gross Salary (in tho.)	324.05	266.23	373.65	431.55	430.09
Disposable Income (in tho.)	231.62	622.78	249.17	311.98	266.09
Annual Unemployment Days	5.07	31.70	3.66	1.90	2.65
Self-Employment (in %)	0.07	0.26	0.05	0.06	0.04
Married or Cohabitant (in %)	0.57	0.50	0.66	0.71	0.67
At Least 1 Child (in %)	0.44	0.50	0.35	0.34	0.40
Years of Education	12.10	2.62	12.17	12.46	12.82
Share Commute (in %)	0.67	0.47	0.71	0.76	0.88
Distance Commute	23.88	85.54	24.10	26.47	30.25
B.Vehicle Attributes					
Vehicle Carbon Emission (g/km)	60.49	83.75	147.39	132.73	121.28
Engine Power (KW)	41.60	54.48	101.38	103.81	91.66
Vehicle Fuel Efficiency (l/100km)	2.45	3.42	5.98	5.42	5.10
Service Weight (kg)	601.34	737.62	1465.34	1495.75	1407.88
Electric Vehicle	0.01	0.08	0.02	0.07	0.06
Vehicle Kilometer Travelled	6053.96	9777.47	14752.31	10730.68	15599.27
Number of Observation	65,546,382		26,898,528	1,218,648	699,114

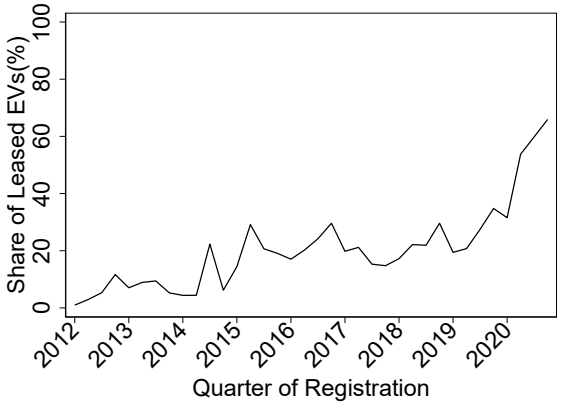
Peer Effects EV

Network Statistics

	Mean	Std. dev.	Min	Max	Obs.
A.Workplace Network					
Number of Co-worker	45.25	37.55	5	150	98,068,936
New Car Registrations	6.92	8.02	0	183	98,068,936
New EV Registrations	0.48	1.06	0	63	98,068,936
Contract Renewal	0.64	1.23	0	22	98,068,936
B.Family Network					
Number of Relatives	5.10	4.04	1	171	231,971,072
New Car Registrations	0.55	1.01	0	27	231,971,072
New EV Registrations	0.04	0.21	0	10	231,971,072
Contract Renewal	0.05	0.26	0	9	231,971,072
C.Neighborhood Network					
Number of Neighbors	260.28	327.01	5	2,853	243,356,013
New Car Registrations	27.79	30.48	0	303	243,356,013
New EV Registrations	1.85	2.67	0	26	243,356,013
Contract Renewal	2.52	3.58	0	41	243,356,013

Network Preparation

Leasing EVs



Leasing

Control Variables

Demographics	Network Statistics	Charging Network	Past cars
Age	*Age*	*New Installations*	*Partly Electric*
Gender	*Gender*	*Number of Plug-In*	*Alt. Fueled*
Salary	*Salary*	*Sum Chargers*	*Total Vehicles*
Income	*Income*	*Charger Capacity*	*Kilometer Traveled*
Unemployment Days	*Unemployment Days*	*Charging Time*	*Engine Power [hp]*
Self-Employed	*Self-Employed*		*Service Weight [kg]*
Retired	*Retired*		*Fuel Efficiency [Lit/100km]*
Married/Cohabitant	*Married/Cohabitant*		
Children	*Children*		
Years Education	*Years Education*		
Type of Education	*Type of Education*		
At Contract Renewal	*Avg. Peers at Contract Renewal*		
	(Avg. Propensity to Buy EV)		

Empirical Strategy

Parameter Distinction

Individuals belonging to the same group tend to behave similarly due to 3 effects: (Manski, 1993; Brock & Durlauf, 2001, Moffitt; 2001)

1. **Causal** (*endogenous*) peer interactions:
   → Peer electric car adoption (θ)

2. **Contextual** (*exogenous*) interactions:
   → Exogenous characteristics of the social network

3. **Correlated** effects:
   → Endogenous sorting into peer-group
   → Correlated unobserveables

Empirical Strategy

Identification of Peer Effects

Prior techniques to measure endogenous peer effects:

1. Random peers: Contexts in which individuals are exogenously assigned into different or new social networks and environments
   → Ex.: Shift assignment of cashiers (Mas & Moretti, 2009)

2. Structural endogeneity: Structural frameworks that combine a model of peer effects with a model of network formation
   → Ex.: Network formation model (Goldsmith-Pinkham & Imbens, 2013)

3. Random shocks: Exogenous variation within naturally occurring, self-chosen social network
   → Ex.: Parental leave take-up (Dahl *et al.*, 2014)

Exogenous Shocks

Propensity Calculation

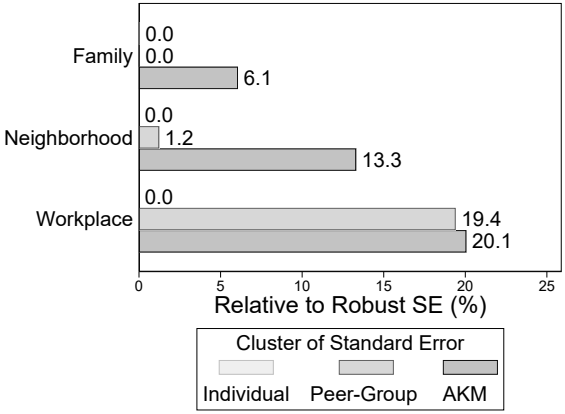
Non-random component: Using a neural network approach, equation (6) estimates the propensity to buy a new EV conditioning on being at the 3- year leasing renewal: (Belloni, Chernozhukov, & Hansen, 2014; Mullainathan & Spiess, 2017; Peysakhovich & Eckles, 2017; Athey, 2018; Chernozhukov *et al.*, 2018)

$$\hat{Pr}(V^e \mid V^{3y}_{i,q_{-1}} = 1)_{i,q_{-1}} = \sum_{m \epsilon M} g_m(\omega_m^T X_{q_{-1}}) \tag{6}$$

- X: Control variables (demographic variables, charging infrastructure and network characteristics, previous car attributes)

EV Adoption Prediction

Comparison of standard errors

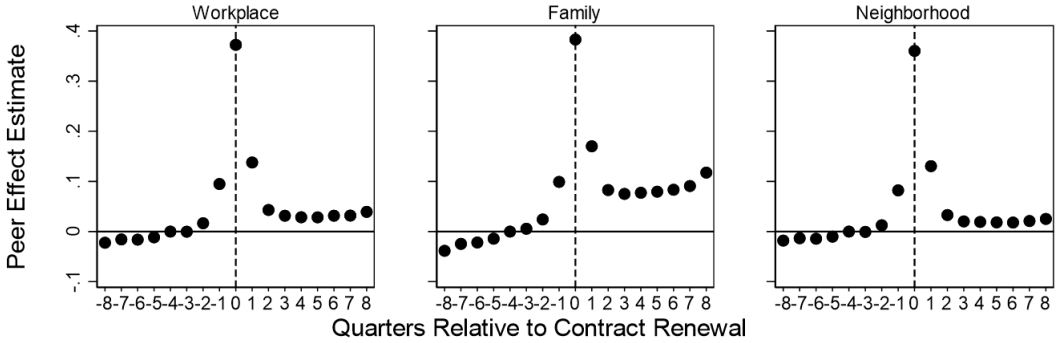


Shift-Share Instrument

Event-Study Analysis

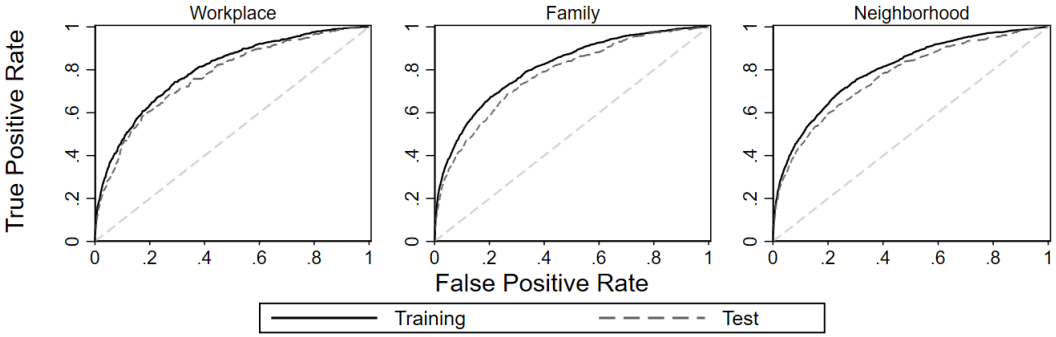
To estimate the effect of the contract renewal, I perform a quarterly event-study analysis relative to the 12-quarter contract renewal for quarters $\tau = -8, ..., 8$:

$$\overline{V}_{i,q} = \sum_{\tau=-8}^{8} \beta_\tau V_{i,12+\tau} + \phi_t + \phi_p + \varepsilon_{i,q}$$



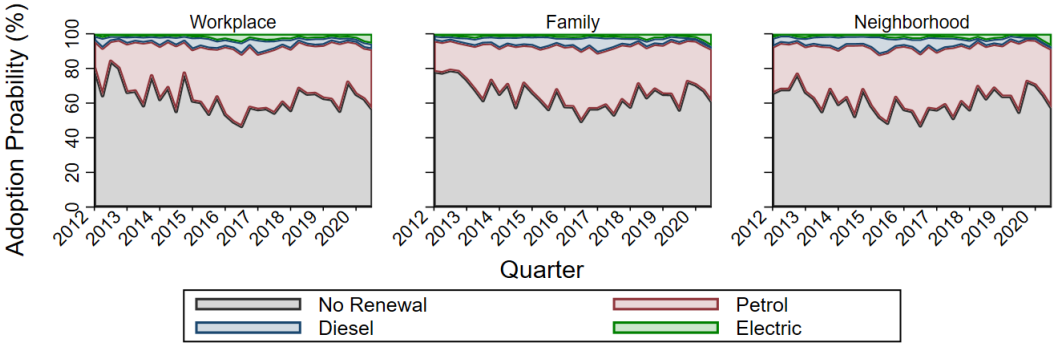
Leasing Contract Renewal

ROC Curves



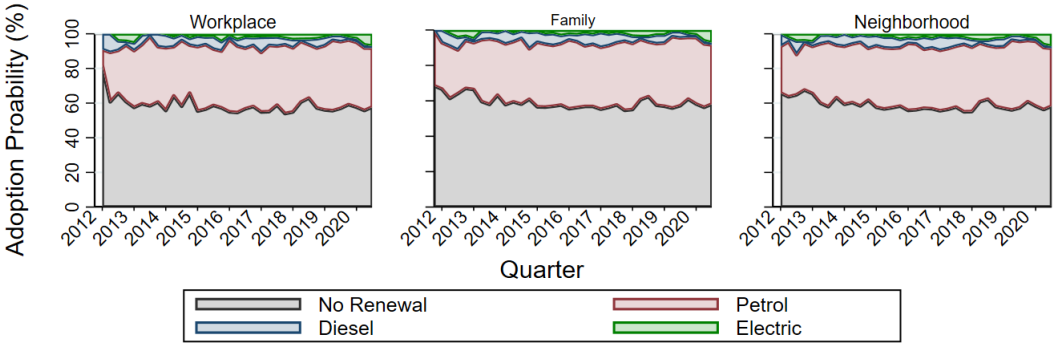
Prediction Performance

Predicted Propensities



Prediction Performance Leasing

Adoption Propensities



Prediction Performance

Shock summary statistics

	A.Workplace	B.Family	C.Neighborhood
Mean	0	0	0
Standard Deviation	.0196	.0142	.4438
Interquartile range	.0017	.0006	.3269
Effective sample size (1/HHI)			
Across peer-groups and quarters	358,077	85,416	31,777,512
Largest weights			
Across peer-groups and quarters	$<.0001$	$<.0001$	$<.0001$
Observation counts			
N(peer-group shocks)	27,619	53,320	50,409
N(peer-groups)	252,352	7,314,474	4,696

Identifying Assumption

Shock distribution

Identifying Assumption

Shock intra-class correlations

	A.Workplace	B.Family	C.Neighborhood
Shock ICCs			
Across peer-groups			

Identifying Assumption

Shock-balance test

	A. Workplace	B. Family	C. Neighborhood
	2SLS(1)	2SLS(2)	2SLS(3)
A.Socio-Demographics:			
Person Age	2.3817	84.3751	.1159
	(8.8859)	(71.6883)	(.1009)
Female	-.1139	-1.6481	.0001
	(.3044)	(2.4618)	(.0001)
Gross Salary	-.0000	-.0000	-.0000***
	(.0000)	(.0000)	(.0000)
Disposable Income	27.5184	108.7367	-3.4742
	(144.7592)	(555.6870)	(2.8974)
Unemployment Days	-5.9028	-.0000	-.5073**
	(25.6098)	(.0000)	(.2502)
Self-Employed	.0397	-1.0239	-.0003
	(.1022)	(1.4272)	(.0023)
Retired	-.1470	-1.1761	-.0010
	(.3050)	(1.3618)	(.0022)
Married	-.0000	1.6542	-.0018
	(.0000)	(2.1444)	(.0017)
Children	-.1042	-1.3137	.0015
	(.2953)	(1.8665)	(.0017)
Years Education	-.0592	.9610	-.0391*
	(.9206)	(10.0416)	(.0206)

Identifying Assumption

Regression Results

	OLS	First Stage	Second Stage	
	(1)	(2)	Total(3)	Per Capita(4)
A.Workplace Network				
Peer Coefficient	.0274***	1.1319***	.0771***	.0017***
	(.0061)	(.0816)	(.0281)	(.0006)
%-Effect	194.32	8033.43	546.92	546.92
Mean Dep. Variable	.014	.014	.014	0
B.Family Network				
Peer Coefficient	.0060***	1.1695***	.0140***	.0027***
	(.0005)	(.0169)	(.0049)	(.0010)
%-Effect	413.69	80945.65	966.66	966.66
Mean Dep. Variable	.001	.001	.001	0
C.Neighborhood Network				
Peer Coefficient	.0594***	1.4960***	.1114***	.0004***
	(.0023)	(.1029)	(.0298)	(.0001)
%-Effect	80.26	2022.11	150.64	150.64
Mean Dep. Variable	.074	.074	.074	0

Peer Effects

Peer Effects by Fuel Type

	Petrol	Diesel	Electric	All Vehicles
	(1)	(2)	(3)	(4)
A.Workplace Network				
Peer Coefficient	-.0918*	-.0436*	.0771***	-.0585
	(.0479)	(.0252)	(.0281)	(.0609)
%-Effect	-69.457	-67.84	546.924	-27.729
B.Family Network				
Peer Coefficient	-.0097	-.0013***	.0139***	.-.0089
	(.0085)	(.0004)	(.0049)	(.0131)
%-Effect	881.095	65.212	467.463	596.715
C.Neighborhood Network				
Peer Coefficient	-.0088	-.0381	.1114***	.0611
	(.0590)	(.0302)	(.0298)	(.0745)
%-Effect	-1.338	-11.418	150.636	5.708
Mean Dep. Variable	.659	.334	.074	1.07

Peer Effects

Peer Effects by Area

	OLS	First Stage	Second Stage	
	(1)	(2)	Total(3)	Per Capita(4)
A.Workplace Network				
Urban	.0236***	1.2905***	.0709**	.0016**
	(.0025)	(.0939)	(.0332)	(.0007)
Rural	.0285***	1.1808***	.0746**	.0017**
	(.0029)	(.0100)	(.0352)	(.0008)
B.Family Network				
Urban	.0055***	1.2413***	.0130**	.0025**
	(.0007)	(.0232)	(.0060)	(.0012)
Rural	.0063***	1.0877***	.0065	.0013
	(.0006)	(.0241)	(.0083)	(.0016)
C.Neighborhood Network				
Urban	.0116***	1.9577***	.0722***	.0012***
	(.0023)	(.1145)	(.0242)	(.0002)
Rural	.0254***	2.2604***	.1369***	.0038***
	(.0031)	(.1921)	(.0396)	(.0002)

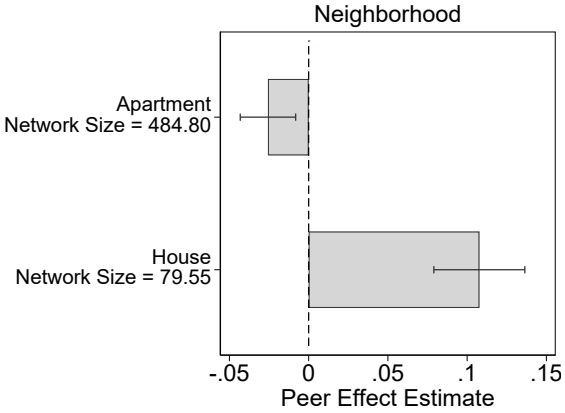
Heterogeneity

Peer Effect Channels

	Social Networks		
	A.Workplace	B.Family	C.Neighborhood
1A.Information about Benefits			
Subsidized EVs	.0905***	.0207***	.1465***
	(.0126)	(.0064)	(.0580)
Non-Subsidized EVs	.0270	.0186	.0602
	(.0783)	(.0159)	(.0826)
1B.Public Charging Infrastructure			
Residential Public Charger	.0466	.0047	.0142
	(.0390)	(.0081)	(.0239)
No Residential Public Charger	.0842**	.0089	.1807***
	(.0371)	(.0070)	(.0399)
2.Observability			
House	.0916***	.0049	.3328***
	(.0311)	(.0061)	(.0519)
Apartment	.0144	.0135	-.1111***
	(.0503)	(.0110)	(.0269)
3.Environmental Norms			
Low Carbon Emitting Fleet (<33%)	.1101***	.0143**	.1640**
	(.0361)	(.0096)	(.0077)
High Carbon Emitting Fleet (>67%)	.0604	.0091	.1057**
	(.0715)	(.0131)	(.0806)

Mechanism

Observability



Mechanism

Cross Peer Effects

	Petrol	Diesel	Electric	All Vehicles
	(1)	(2)	(3)	(4)
A.Workplace Network				
Peer Petrol	-.0497***	-.0142***	-.0067*	-.0708***
	(.0102)	(.0055)	(.0040)	(.0125)
Peer Diesel	-.0254	-.0785*	-.0142	-.1176
	(.0555)	(.0449)	(.0199)	(.0786)
Peer Electric	-.1443***	-.0776***	.0811***	-.1412**
	(.0499)	(.0277)	(.0303)	(.0642)
Mean Dep. Variable	.132	.064	.014	.211
B.Family Network				
Peer Petrol	.0197***	-.0020**	.0008	.0186***
	(.0020)	(.0008)	(.0006)	(.0022)
Peer Diesel	.0306***	.0142**	-.0033	.0414***
	(.0113)	(.0056)	(.0031)	(.0127)
Peer Electric	.0002	-.0157***	.0122**	-.0024
	(.0117)	(.0035)	(.0050)	(.0131)
Mean Dep. Variable	.013	.007	.001	.021
C.Neighborhood Network				
Peer Petrol	-.0486***	-.0461***	-.0018	-.0969***
	(.0165)	(.0083)	(.0058)	(.0204)
Peer Diesel	-.2372***	-.0596	.0239	-.2749***
	(.0675)	(.0372)	(.0222)	(.0830)
Peer Electric	-.0295	-.0146	.1051***	.0581
	(.0611)	(.0317)	(.0298)	(.0782)
Mean Dep. Variable	.659	.334	.074	1.07

Mechanism

Carbon Emission Model

A person's total car-related carbon emissions in a given quarter equals:

$$CO_{2,i,q} = \overline{KM_{i,q}} \cdot \overline{V_{i,q}^{CO_2}} \cdot N_{i.q} \tag{7}$$

The person's carbon emission change through the peer effect of adopting a new electric car :

$$\begin{aligned} \triangle CO_{2,i,q} = & \underbrace{\theta_{CO_2}^e \cdot \overline{KM_{i,q}} \cdot N_{i.q}}_{\triangle CO_2} + \underbrace{\theta_{KM}^e \cdot \overline{V_{i,q}^{CO_2}} \cdot N_{i.q}}_{\triangle Driving} \\ & + \underbrace{\theta_N^e \cdot \overline{V_{i,q}^{CO_2}} \cdot \overline{KM_{i,q}}}_{\triangle Vehicle} \qquad \forall q \in \{0, ..., 6\}, \end{aligned} \tag{8}$$

- $\overline{V_{i,q}^{CO_2}}$ Average carbon emission of the person's cars
- $\overline{KM_{i,q}}$: Average car kilometer traveled per person
- $N_{i,q}$: Number of car per person
- $\theta_{KM}^e, \theta_{CO_2}^e, \theta_N^e$: Peer effect on the total car kilometer traveled, average carbon emission, and number of cars

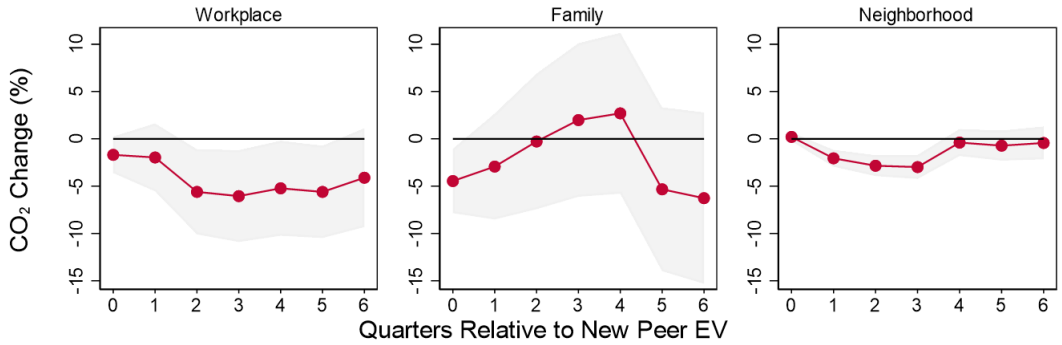
Environmental Impact

Environmental Impact

	Carbon Emission						
	q	q_1	q+2	q+3	q+4	q+5	q+6
Peer Coefficient	-.4751	-.3211	-2.3543***	-2.8012***	-4.1958***	-3.4077***	-3.3362***
	(.3682)	(.6104)	(.8139)	(.9006)	(1.0007)	(1.0943)	(1.2443)
%-Effect	-.72	-.48	-3.52	-4.14	-6.16	-4.97	-4.83
Mean Dep. Variable	65.67	66.3	66.95	67.59	68.06	68.55	69.06
	Vehicle Kilometer Traveled						
	q	q+1	q+2	q+3	q+4	q+5	q+6
Peer Coefficient	-28.0527**	-29.9844	-77.7567***	-69.3440**	-61.0044*	-50.5949	-21.2635
	(11.9542)	(20.3023)	(27.5086)	(29.7384)	(32.1308)	(33.2077)	(34.9169)
%-Effect	-1.96	-2.08	-5.35	-4.73	-4.13	-3.41	-1.42
Mean Dep. Variable	1431.71	1443	1454.49	1466.48	1475.41	1484.61	1494.38
	Number of Vehicle						
	q	q+1	q+2	q+3	q+4	q+5	q+6
Peer Coefficient	-.0015	-.0045	-.0198**	-.0259***	-.0308***	-.0291***	-.0279**
	(.0037)	(.0062)	(.0080)	(.0085)	(.0091)	(.0101)	(.0117)
%-Effect	-.28	-.81	-3.56	-4.61	-5.43	-5.09	-4.85
Mean Dep. Variable	.55	.55	.56	.56	.57	.57	.58

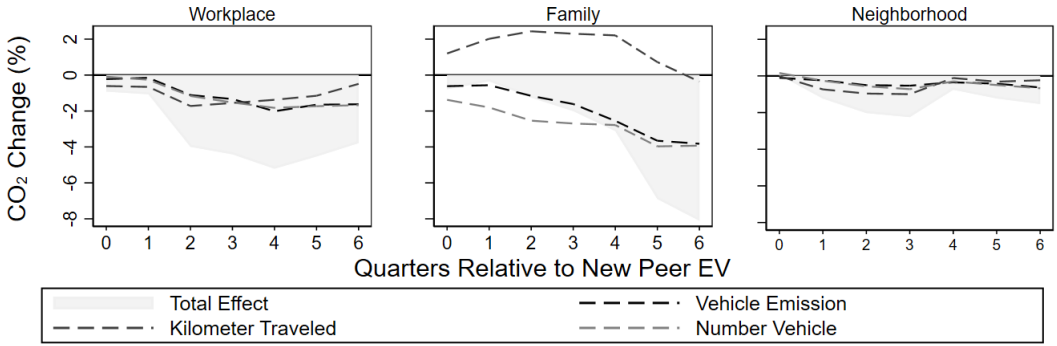
Environmental Impact

Carbon Emission Robustness



Environmental Impact

Environmental Impact



Environmental Impact

Second Hand Cars

	OLS	First Stage	Second Stage	
	(1)	(2)	Total(3)	Per Capita(4)
A.Workplace Network				
Peer Coefficient	.0115***	1.1319***	-.0010	-.0000
	(.0041)	(.0816)	(.0193)	(.0004)
%-Effect	78.97	7760.88	-6.9	-6.9
Mean Dep. Variable	.015	.015	.015	0
B.Family Network				
Peer Coefficient	.0021***	1.1695***	.0039	.0008
	(.0003)	(.0169)	(.0063)	(.0012)
%-Effect	152.37	86802.34	289.26	289.26
Mean Dep. Variable	.001	.001	.001	0
C.Neighborhood Network				
Peer Coefficient	.0219***	1.4960***	.0145	.0001
	(.0018)	(.1029)	(.0244)	(.0001)
%-Effect	30.03	2053.03	19.91	19.91
Mean Dep. Variable	.073	.073	.073	0

Environmental Impact

Alternative Specifications

	A. Workplace			B. Family			C. Neighborhood		
	OLS(1)	FS(2)	2SLS(3)	OLS(4)	FS(4)	2SLS(6)	OLS(7)	FS(8)	2SLS(9)
Peer Effect Estimate:									
Baseline	.0274***	1.1319***	.0771***	.0060***	1.1695***	.0140***	.0594***	1.4960***	.1114***
	(.0061)	(.0816)	(.0281)	(.0005)	(.0169)	(.0049)	(.0023)	(.1029)	(.0298)
Estimation Model:									
Probit	.1554***	1.1319***	.0896	.3602***	1.1695***	1.1134***	.1074***	1.4960***	.1059**
	(.0163)	(.0816)	(.1345)	(.0176)	(.0169)	(.1923)	(.0035)	(.1029)	(.0460)
Functional Form:									
Percentage Influence	.0060***	.9897***	.0394***	.0001***	1.122***	.0001***	.0887***	1.1767***	.0325***
	(.0014)	(.0743)	(.0105)	(.0000)	(.0327)	(.0000)	(.0023)	(.0758)	(.0150)
Binary Influence	.0098***	.9960***	.0021***	-.0037*	.9998***	-.0002	.0215***	.9829***	-.0118***
	(.0013)	(.0002)	(.0003)	(.0019)	(.0002)	(.0006)	(.0017)	(.0005)	(.0005)
Alternative Outcomes:									
Non-Leased	.0156***	1.1319***	.0133	.0036***	1.1695***	-.0016	.0355***	1.4960***	.0451**
	(.0031)	(.0816)	(.0160)	(.0004)	(.0169)	(.0028)	(.0017)	(.1029)	(.0214)
Non-Renewal	.0273***	1.1319***	.0742***	.0059***	1.1695***	.0150***	.0570***	1.4960***	.1032***
	(.0061)	(.0816)	(.0261)	(.0005)	(.0169)	(.0047)	(.0022)	(.1029)	(.0292)
Sample Restriction:									
Peer Leasing	.0404***	1.0937***	.0802*	.0087***	1.1469***	.0115	.0607***	1.4371***	.1419***
	(.0124)	(.0824)	(.0415)	(.0018)	(.0171)	(.0075)	(.0031)	(.1036)	(.0421)

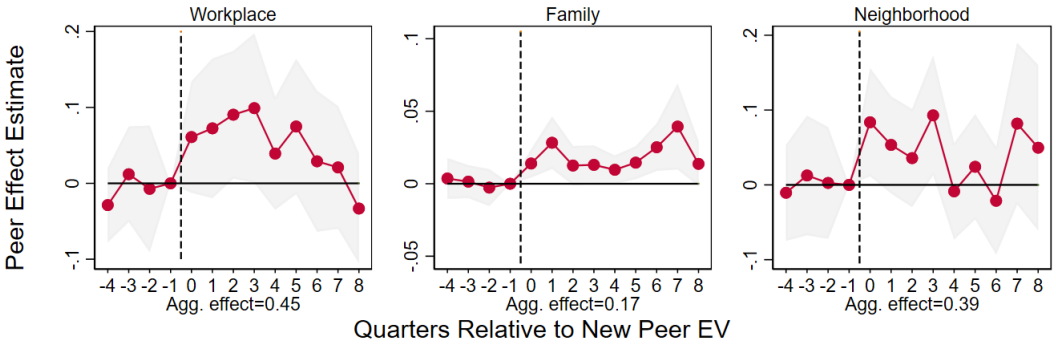
Robustness Checks

Non-overlapping Networks

	OLS	First Stage	Second Stage	
	(1)	(2)	Total(3)	Per Capita(4)
A.Workplace Network				
Peer Coefficient	.0264***	1.1271***	.0747***	.0017***
	(.0060)	(.0816)	(.0278)	(.0006)
%-Effect	190.74	8142.2	539.8	539.8
Mean Dep. Variable	.014	.014	.014	0
B.Family Network				
Peer Coefficient	.0039***	1.1680***	.0092***	.0026***
	(.0003)	(.0170)	(.0034)	(.0010)
%-Effect	390.73	115713.58	912.12	912.12
Mean Dep. Variable	.001	.001	.001	0
C.Neighborhood Network				
Peer Coefficient	.0594***	1.4960***	.1114***	.0004***
	(.0023)	(.1029)	(.0298)	(.0001)
%-Effect	80.26	2022.11	150.64	150.64
Mean Dep. Variable	.074	.074	.074	0

Robustness Checks

Constant Networks



Robustness Checks

Placebo Peers

	OLS	First Stage	Second Stage	
	(1)	(2)	Total(3)	Per Capita(4)
A.Workplace Network				
Firm Co-worker	-.0001	5.5945***	.0100	.0000
	(.0031)	(.8057)	(.0149)	(.0000)
%-Effect	-.09	4989.44	8.94	8.94
Mean Dep. Variable	.112	.112	.112	0
Future Co-worker	.0006	.8052**	-.0309	-.0051
	(.0005)	(.3979)	(.0216)	(.0035)
%-Effect	34.11	42337.59	-1626.53	-1626.53
Mean Dep. Variable	.002	.002	.002	0
C.Neighborhood Network				
Distant Neighbor	.0408***	1.4983***	.0595	.0001
	(.0039)	(.0869)	(.0540)	(.0001)
%-Effect	17.37	637.32	216.71	216.71
Mean Dep. Variable	.235	.235	.235	0

Robustness Checks

Placebo Contract Renewal

	OLS	First Stage	Second Stage	
	(1)	(2)	Total(3)	Per Capita(4)
A.Workplace Network				
Prior Renewal	.1482	-.8647	-.0107	-.0002
	(.0546)	(2.3967)	(.0281)	(.0004)
Past Renewal	.0559	-.0345	-.0082	-.001
	(.0421)	(.3644)	(.0115)	(.0002)
B.Family Network				
Prior Renewal	.0019	.0153	0.0058	.0000
	(.0055)	(.0008)	(.0359)	(.0311)
Past Renewal	.0200	.0609	-.0430	-.0057
	(.0126)	(.0036)	(.1305)	(.0172)
C.Neighborhood Network				
Prior Renewal	.0019	.0153	0.0195	.0000
	(.0055)	(.0008)	(.0239)	(.0311)
Past Renewal	.0200	.0609	-.0430	-.0057
	(.0126)	(.0369)	(.1305)	(.0172)

Robustness Checks

Control Group

	OLS	First Stage	Second Stage	
	(1)	(2)	Total(3)	Per Capita(4)
A.Workplace Network				
Control Group: Non-Renewal	.0272***	1.1885***	.0811***	.0018***
	(.0061)	(.0975)	(.0303)	(.0007)
Control Group: Fossil Fuel Veh.	.0271***	1.0246***	.0902***	.0020***
	(.0060)	(.0823)	(.0318)	(.0007)
B.Family Network				
Control Group: Non-Renewal	.0060***	1.2668***	.0122**	.0024**
	(.0005)	(.0220)	(.0050)	(.0010)
Control Group: Fossil Fuel Veh.	.0060***	1.2450***	.0098*	.0019*
	(.0005)	(.0176)	(.0050)	(.0010)
C.Neighborhood Network				
Control Group: Non-Renewal	.0588***	1.5731***	.1011**	.0004**
	(.0032)	(.1075)	(.0435)	(.0002)
Control Group: Fossil Fuel Veh.	.0592***	1.4847***	.1110**	.0004**
	(.0033)	(.1032)	(.0435)	(.0002)

Robustness Checks Interpretation of Treatment Effect

Varying Horizon

	OLS	First Stage	Second Stage
	(1)	(2)	(3)
A.Workplace Network			
1 Quarter (baseline)	.0274***	1.1319***	.0772***
	(.0061)	(.0816)	(.0282)
2 Quarter	.0250***	1.3421***	.0534***
	(.0063)	(.0904)	(.0175)
3 Quarter	.0239***	1.5025***	.0489***
	(.0057)	(.1047)	(.0128)
4 Quarter	.0236***	1.6095***	.0506***
	(.0054)	(.1139)	(.0113)
B.Family Network			
1 Quarter (baseline)	.0060***	1.1695***	.0140***
	(.0005)	(.0169)	(.0049)
2 Quarter	.0054***	1.2424***	.0367***
	(.0003)	(.0171)	(.0069)
3 Quarter	.0052***	1.2871***	.0397***
	(.0003)	(.0178)	(.0056)
4 Quarter	.0051***	1.3246***	.0427***
	(.0002)	(.0183)	(.0049)
C.Neighborhood Network			
1 Quarter (baseline)	.0594***	1.4960***	.1115***
	(.0023)	(.1029)	(.0298)
2 Quarter	.0457***	1.7038***	.0784***
	(.0017)	(.1089)	(.0174)
3 Quarter	.0320***	1.9240***	.0592***
	(.0014)	(.1361)	(.0121)
4 Quarter	.0192***	2.0704***	.0523***
	(.0012)	(.1533)	(.0103)

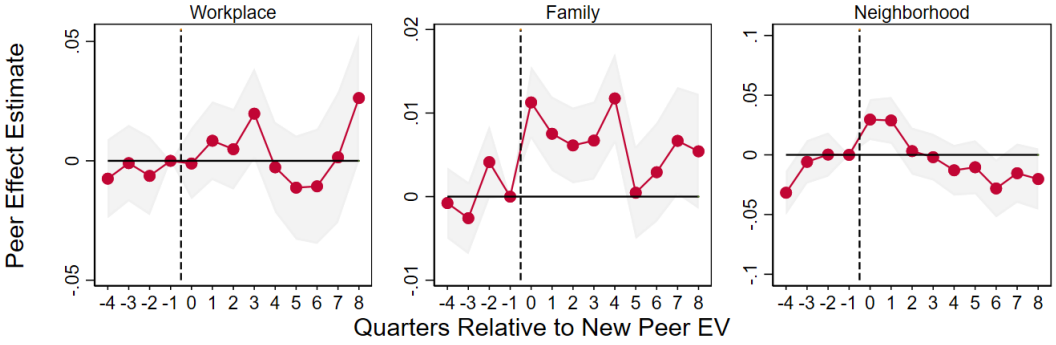
Robustness Checks

Estimation Results

	OLS	First Stage	Second Stage	
	(1)	(2)	Total(3)	Per Capita(4)
A.Workplace Network				
Peer Coefficient	.0336***	.3682***	-.0011	-.0000
	(.0021)	(.0080)	(.0076)	(.0002)
%-Effect	15.91	174.44	-.53	-.53
Mean Dep. Variable	.211	.211	.211	.005
B.Family Network				
Peer Coefficient	.0103***	.3297***	.0086***	.0017***
	(.0002)	(.0010)	(.0022)	(.0004)
%-Effect	47.97	1537.2	40.13	40.13
Mean Dep. Variable	.021	.021	.021	.004
C.Neighborhood Network				
Peer Coefficient	.0348***	.4104***	.0334***	.0001***
	(.0015)	(.0111)	(.0099)	(.0000)
%-Effect	3.25	38.35	3.12	3.12
Mean Dep. Variable	1.07	1.07	1.07	.004

Peer Effects - New Vehicles

Peer Dynamics



Peer Dynamics

Pigou Model

The optimal Pigouvian subsidy that accounts for peer effects $\tau^*(\theta^e)$ relative to a standard Pigouvian subsidy is given by the ratio of externalities with and without peer effects:

$$\begin{aligned}
\frac{\tau^*(\theta^e)}{\tau^*} &= \frac{e(\theta^e)}{e} \\
\frac{\tau^*(\theta^e)}{\tau^*} &= \frac{\sum_{j=1}^{J}[e_j(V^e) - e_j(V^c)] \cdot (1+\theta^e)}{\sum_{j=1}^{J}[e_j(V^e) - e_j(V^c)]} \\
\tau^*(\theta^e) &= \tau^* \cdot (1+\theta^e) \\
\tau^*(\theta^e) &= e \cdot (1+\theta^e) \qquad (9)
\end{aligned}$$

Pigou Subsdiy

Modified Pigou - Substitution

If we incorporate the peer effect of electric cars on the adoption of fossil fuel cars θ^c, the optimal Pigouvian subsidy becomes:

$$\begin{aligned}
\frac{\tau^*(\theta^e)}{\tau^*} &= \frac{\sum_{j=1}^{J}[e_j(V^e) - e_j(V^c)] \cdot (1 + \theta^e - \theta^c)}{\sum_{j=1}^{J}[e_j(V^e) - e_j(V^c)]} \\
\tau^*(\theta^e) &= \tau^* \cdot (1 + \theta^e - \theta^c) \\
\tau^*(\theta^e) &= e \cdot (1 + \theta^e - \theta^c) \qquad (10)
\end{aligned}$$

Modified Pigou