Indirect network effects and policy implications: empirical analysis of the Chinese electric vehicle market

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Roadmap

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Background

Electric vehicle adoption and government policies

- The adoption rates of EVs are still low in most countries.
  - Two issues have impeded the mass market adoption of EVs: high ownership costs and limited charging infrastructure availability [Meunier and Ponssard, 2020].
- To combat the first issue, governments worldwide have introduced various incentive programs to subsidize EV consumption [Axsen and Wolinetz, 2018, Beresteanu and Li, 2011, DeShazo et al., 2017, Li et al., 2017, Springel, 2020].
- To combat the second issue, countries have issued subsidies on charging infrastructure [Greene et al., 2020]

Background

Working mechanisms of alternative policies

- EV purchase subsidy
  - Direct effects on EV adoption
  - More effective when consumers are price sensitive
- Infrastructure subsidy
  - Indirect effects on EV adoption through indirect network effects.
  - More effective when consumers are concerned with EV travel distance (range anxiety).

Background

Who should be subsidized? Consumers or the charging service providers?

- Separate studies on the efficiency of alternative policies.
  - Axsen and Wolinetz [2018], Azarafshar and Vermeulen [2020], Münzel et al. [2019] suggest that a significant part of EV sales is attributed to purchase incentives.
  - Greene et al. [2020] suggest that public charging infrastructure has tangible and intangible value, such as reducing range anxiety [Meunier and Ponssard, 2020] or building confidence in the future of the PEV market.
- Optimality of alternative policies.
  - Subsidizing the charging infrastructure is more efficient.
  - Li et al. [2017] and Springel [2020] suggest that compared to high ownership costs of EV, consumers are more concerned with charging infrastructure availability.
  - The Indirect network effect of charging stations plays a significant role in EV adoption.

Motivation

Which policy is more cost-effective?

- The relative efficiency of the two subsidy policies may change as technology evolves and the distribution of product quality changes significantly in this dynamic industry.
    - China has the largest network of charging stations worldwide, and most EVs currently have much longer ranges than they had previously;
    - Chinese consumers are more price sensitive, as their income is much lower than that documented in previous studies by Li et al. [2017], Springel [2020]
- The effectiveness of the polices varies in products or markets since the indirect network effects could be heterogeneous over products of different quality and varying over markets of different infrastructure conditions.

Objective

This paper

- studies the key determinants of EV adoption and the equilibrium number of charging infrastructure;
  - investigates the indirect network effects between EV demand and charging infrastructure supply when EV quality has been improved significantly and the charger network has been developed to some extent;
  - analyzes the heterogeneity of the indirect network effects of charging infrastructure on the adoption of EVs with different technological features; and
- assesses the cost-effectiveness of alternative subsidy policies and their effects on the distribution of products quality.

Main findings

- EV purchase subsidies are more effective in stimulating EV adoption than equally budgeted subsidies on chargers in China, which is opposite to the findings in the previous literature [Li et al., 2017, Springel, 2020].
- The indirect network effect of charging infrastructure is lower than the estimates in the previous literature.
- Significant heterogeneity of indirect network effects exists, with lower-range EVs being more sensitive to charging infrastructure than higher-range models.
    - EV subsidies can serve as a better policy instrument to promote technology adoption.
- EV subsidies are more cost effective than charger subsidies in the sense that the gain in consumer surplus net of externalities is higher under EV subsidies than under charger subsidies with an equal budget size.

Contribution

- This paper investigates the heterogeneous indirect network effects of charging infrastructure on EVs with different characteristics (particularly, driving range) and the heterogeneous welfare effects of government policies on the consumers of these differentiated EVs..
- Our empirical findings suggest that the indirect network effects of chargers on EV adoption depends on the development stage of the industry.
- Our paper presents the first study on the mutual indirect network effects between EVs and charging stations in a developing economy.
- This paper also estimates the subsidy effects on the externalities of EV consumption, considering China's current electricity generation methods and notable transition towards clean energy.

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Industrial structure

Table 1: Concentration index of the Chiese EV and ICEV industries over years 2016-2019

Year	EV			ICEV		
	CR4[a]	CR10[b]	HHI[c]	CR4	CR10	HHI
2016	67.76%	95.75%	0.1608	33.22%	57.57%	0.0464
2017	62.10%	91.50%	0.1226	31.16%	56.65%	0.0439
2018	58.12%	83.40%	0.1101	34.44%	58.54%	0.0482
2019	44.14%	70.21%	0.0823	36.62%	61.78%	0.0533

[a] Concentration ratio of the top 4 firms, $\sum_{i=1}^{4} s_i$, where s_i is the market share of firm i.

[b] Concentration ratio of the top 10 firms, $\sum_{i=1}^{10} s_i$, where s_i is the market share of firm i.

[c] Herfindahl-Hirschman index, $\sum_{i=1} s_i^2$.

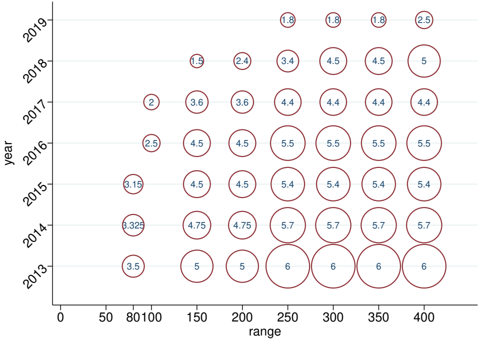
Table 2: Major charging station firms in China

Order #	Corporate Name	Establishment Time	City of Headquarter	Number of Charging Stations[a]
1	Qingdao Teld New Energy	9/4/14	Qingdao, Shandong	144,000[b]
2	Star Charge	9/16/14	Changzhou, Jiangsu	112,000
3	State Grid Corporation of China	5/13/03	Beijing	88,000
4	Jiangsu YKC New Energy Technology	11/1/16	Nanjing, Jiangsu	33,000
5	EV Power	11/6/14	Shanghai	25,000
6	AnYo Charging	10/13/15	Shanghai	18,000
7	Potevio New Energy	10/29/10	Beijing	14,000
8	Shenzhen Car Energy Network	4/5/16	Shenzhen, Guangdong	12,000

[a] Data source: The China Electric Vehicle Charging Infrastructure Promotion Association. The eight operators together represented 90.0 % of all stations in operation across the country.
[b] The statistics are up to November 2019.

Subsidies

Figure 1: Central subsidy on EVs over travel ranges and years*



*

Notes: The size of the circles is proportional to the EV subsidies, which are labelled in the circles in RMB 10,000.

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Data

1. Monthly data on EV sales and the number of EV chargers of the top 50 prefecture-level cities in EV sales rankings for China for 2016-2019 ;
2. The installed base of EV charger network is obatained from the EV Charging Infrastructure Promotion Alliance (EVCIPA).
    - Numbers of both AC and DC chargers are reported for both public stations serving all EV drivers and specialized stations serving public transport vehicles only.
3. The market is defined at the city-month level.
4. Subsidy information is collected from government websites.
    - On average, the EV subsidies from the central government amount to approximately 10% of the average EV price, while the EV subsidies from the local government are only approximately 6.34% of the central government's subsidies.

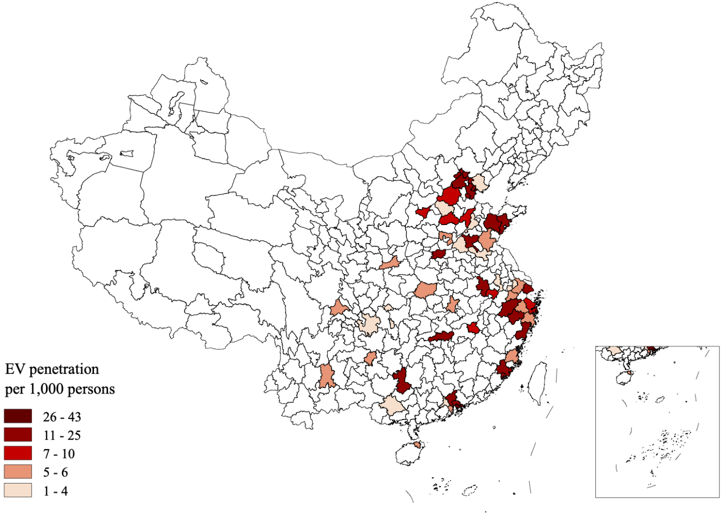


Figure 2: EV penetration (2019)

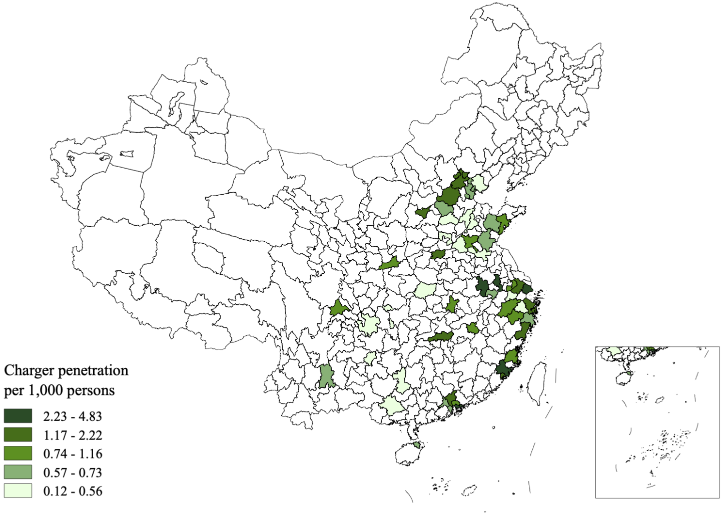


Figure 3: Charger penetration (2019)

Roadmap

Empirical methodology

- We use a discrete choice model to analyze EV demand.

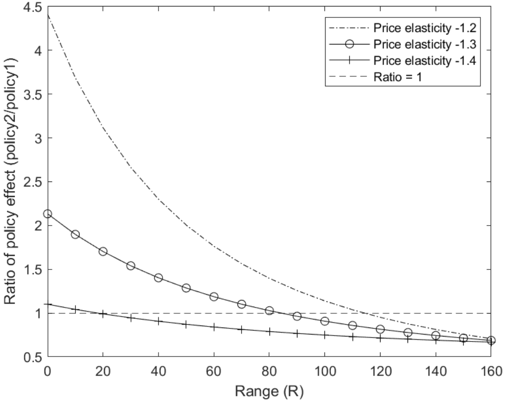
$$\begin{aligned} log(s_{jmt}) - log(s_{omt}) = \tau_j - \theta_e e_{jmt} - \theta_N log(N^c_{mt}) + \theta_C C\{R_j\} \\ \times log(N^c_{mt}) + \theta_g gp_{mt} \times FE_j + \tau_m + \tau_t + \xi_{jt} \end{aligned}$$

- Supply of charger stations:

$$N^c_{mt} = A(SC^c_{mt})(N^{EV}_{mt})^{\alpha_N} exp(\mu_{mt}) \quad (1)$$

Numerical illustration: effectiveness of the two subsidy policies

Figure 4: Policy Effectiveness and Electric Range



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Estimation results

Results of EV demand estimation

	OLS			TSLS		
	(1)	(2)	(3)	(4)	(5)	(6)
log(price - subsidy)	-1.881***	-1.878***	-1.947***	-1.914***	-1.972***	-1.985***
	(0.361)	(0.362)	(0.366)	(0.394)	(0.396)	(0.396)
$log(N^c_{mt})$	0.049*	0.053*	0.130***	0.132*	0.095	0.170**
	(0.027)	(0.027)	(0.028)	(0.073)	(0.072)	(0.075)
gasoline price	0.002	0.003	0.005**	0.002	0.003	0.004**
× fuel economy	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
$R \times log(N^c_{mt})$		-0.017***			-0.015***	
		(0.005)			(0.006)	
$C\{150km \leq R < 300km\} \times log(N^c_{mt})$			-0.167***			-0.111***
			(0.019)			(0.023)
$C\{300km \leq R\} \times log(N^c_{mt})$			-0.062***			-0.055***
			(0.016)			(0.020)
Number of Observations	86656	86656	86656	86656	86656	86656
Period FE	Y	Y	Y	Y	Y	Y
City FE	Y	Y	Y	Y	Y	Y
EV model FE	Y	Y	Y	Y	Y	Y
R^2	0.41	0.41	0.41			
Adjust R^2	0.40	0.40	0.41			
First-Stage F-statistics						
Price				857.77	731.38	624.95
Station				103.82	118.94	140.20
First-Stage R^2						
Price				0.92	0.92	0.92
Station				0.15	0.16	0.17

* p<0.05, ** p<0.01, and *** p<0.001.

Results of the demand estimation with different measures of indirect network effects

	DC network effects			AC network effects		
	(1)	(2)	(3)	(4)	(5)	(6)
log(price - subsidy)	-1.989***	-1.930***	-1.976***	-2.009***	-2.054***	-2.074***
	(0.395)	(0.393)	(0.398)	(0.395)	(0.398)	(0.396)
$log(N^c_{mt})$	0.155***	0.151***	0.157***	0.074	0.047	0.149*
	(0.054)	(0.053)	(0.054)	(0.083)	(0.082)	(0.085)
gasoline price	0.003	0.004*	0.006***	0.003	0.003	0.005**
$\times$ fuel economy	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
$R \times log(N^c_{mt})$		-0.016***			-0.016***	
		(0.005)			(0.006)	
$C\{150km \leq R < 300km\} \times log(N^c_{mt})$			-0.122***			-0.126***
			(0.021)			(0.023)
$C\{300km \leq R\} \times log(N^c_{mt})$			-0.057***			-0.058***
			(0.019)			(0.020)
Period FE	Y	Y	Y	Y	Y	Y
City FE	Y	Y	Y	Y	Y	Y
EV model FE	Y	Y	Y	Y	Y	Y
First-stage F-statistics						
Price	854.04	731.21	624.63	860.54	738.40	645.59
Station	85.88	72.72	70.97	71.80	90.40	116.98
First-Stage R^2						
Price	0.92	0.92	0.92	0.92	0.92	0.92
Station	0.92	0.92	0.92	0.91	0.91	0.91
J-test	201.66	202.71	287.47	203.41	208.55	291.51

Results of the estimation of the charger supply function

	OLS		TSLS	
	(1)	(2)	(3)	(4)
$log(N_{mt}^{EV})$	0.933***	0.330***	1.108***	0.916***
	(0.076)	(0.100)	(0.113)	(0.268)
log(subsidy) ($log(SC_{mt}^{c})$)	0.304***	0.073**	0.275***	0.082**
	(0.087)	(0.031)	(0.091)	(0.033)
Number of observations	2352	2352	2352	2352
Period FE	Yes	Yes	Yes	Yes
City FE	No	Yes	No	Yes
First-Stage F-statistics			335.19	93.36

Notes: Standard errors in parentheses. * p<0.10, ** p<0.05, and *** p<0.01

The effects of EV subsidies

- We use the data for the period from June to December 2018 for this analysis.

Table 3: Summary of the subsidies in the counterfactual scenarios

Range categories		Subsidies (RMB 10,000)		
			Scenarios	
LB[a](km)	UB[b](km)	Null	(i)	(ii)
150	200	1.5	2	1.5
200	250	2.4	3.6	2.4
250	300	3.4	4.4	3.4
300	400	4.5	4.4	3.4
400	max	5	4.4	3.4

[a] Lower bound of the range category.
[b] Upper bound of the range category.

Infrastructure subsidy changes

- We simulate the scenario in which EV subsidies are replaced by infrastructure subsidies.
- The total amount of infrastructure subsidies is constrained to the level of EV subsidies in the null scenario.

Equilibrium and welfare effects of subsidy changes

Counterfactual Scenarios of			EV subsidies			Charger subsidies
Indirect network effects		No	No	Yes	Yes	Yes
Scenario Index	Null	(i)	(ii)	(iii)	(iv)	(v)
Sales[a]	599471	638349	567584	639616	566787	445889
Subsidies (million RMB)	23123	26882	18757	26937	18732	23123
Changes in consumer surplus (ΔCS, million RMB)[b]	21576	25483	18379	26063	18745	5267
Changes in consumer surplus per capita (ΔCS, RMB)	14	17	12	17	13	4
Changes in externalities (ΔEC, million RMB)[c]	3612	4262	2977	4340	3024	621
Changes in externalities (ΔEC, million RMB)[d]	886	1025	751	1049	766	189

[a] Half-year sales for selected cities.
[b] The benchmark is consumer surplus in the scenario without EV subsidies.
[c] The benchmark is the externalities in the scenario without EV subsidies. The marginal externality of EV is assumed to be RMB 1.155/kWh.
[d] The marginal externality of EV is assumed to be RMB 0.246/kWh.

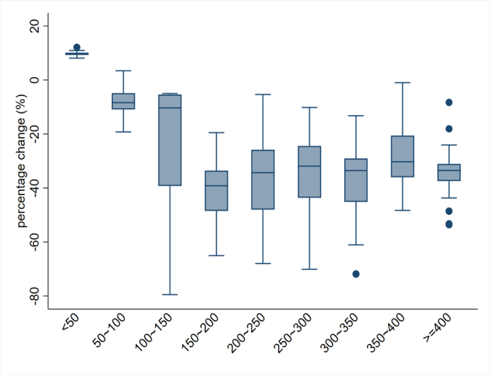

Figure 5: Effects of charger subsidies on EV sales by range*

*Notes: The boxplot indicates the distribution of the percentage changes in sales of EVs with ranges falling in the categories on the horizontal axis. The lower and upper boundaries of the box indicate the 25% and 75% quartiles of the distribution. The median is represented by a line subdividing the box. The length of the box represents the interquartile range (IQR) of the distribution. The upper and lower lines span the values within 1.5 IQR of the nearer quartile.

Roadmap

Conclusion

- With equal-size subsidy expenditures, EV subsidies are 34.4% more effective than charger subsidies in promoting EV sales.
    - Chinese consumers are more sensitive to prices but less sensitive to the size of charger networks than consumers in the US.
    - The technological advance in EV driving distance significantly reduces consumers' range anxiety and makes EV drivers less dependent on the charger network.
- This subsidy replacement also changes the composition of sales to the low-range end.
- Replacing EV subsidies with charger subsidies leads to welfare loss since the loss in consumer surplus dominates the reduction in externalities.

Thank you!

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