The Distributional Effects of Electric Vehicle Subsidies in China

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Background

1. Many countries have introduced incentive programs to encourage the adoption of electric vehicles (EVs).
2. To promote innovation, incentives such as subsidies are usually based on the vehicles' attributes. Example
3. However, EVs that feature more advanced technologies are more expensive and thus are usually purchased by high-income individuals, who are actually less sensitive to subsidies. The progressive feature of the subsidy may reduce its effectiveness.
4. Manufacturers' strategic decisions on subsidy pass-through will further complicate the analysis of subsidy effectiveness:
   - They can take advantage of high-income consumers' lower price sensitivity and pass through less subsidy to them, which further undermines the effectiveness of the subsidy.
   - Or, they have to offer higher pass-through to consumers in order to get higher market shares, which improves the overall effectiveness of the subsidies.

Literature

- Previous research has examined the effectiveness of the subsidies.
  - Li et al. (2022) document that more than half of EV sales can be attributed to consumer subsidies in China.
  - Li et al. (2018); Guo and Xiao (2022) suggest that the effectiveness of subsidies depends on the substitutability between EVs and ICEVs.
- These studies, however, have not looked into the mechanisms of subsidy effectiveness. In particular, the distributional effects of the subsidies, which play an important role in determining the effectiveness of the subsidies, have not been fully examined.

Distributional features of EV subsidies

- The distributional consequences of the subsidies have two aspects:
  1. the incidence, which captures the subsidy distribution between EV manufacturers and consumers, and
  2. the progressivity, which captures the subsidy distribution over consumers of different incomes. Diagram
- Importance: the distributional effects are essential in determining the effectiveness of the subsidies for two reasons.
  1. The incidence, or the pass-through of the subsidies to the consumers from their aspects, determines *how much* consumers can get from the total subsidies.
  2. The progressivity determines *how* the portion of the subsidies passed-through to the consumers should be distributed over different income groups.

Objectives

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- Employing the micro-moments BLP identification methods (Berry et al., 1995; Petrin, 2002) and the city-level sales and buyer survey data of the passenger vehicles during the years 2016–2019, we estimate the structural model.
- Further, using the estimated model, we conduct counterfactual analysis to study the pass-through of EV subsidies to consumers and the progressivity of subsidies in incomes.

Findings

- The EV subsidy scheme is progressive on income.
- In response to different price sensitivities of consumers, the subsidy pass-through also varies across income groups: Consumers in high-income groups can receive higher pass-through, while those in low-income groups get lower pass-through.
- With the same subsidy size, a progressive (current) scheme is more effective than a regressive (simulated) scheme in terms of promoting EV adoption.
- The regressive subsidy design reallocates the EV subsidies from high-income consumers with lower price sensitivities to low-income consumers with higher price sensitivities. It is not necessary to pass through many subsidies to low-income consumers. The prices of all vehicles increase in such scenarios.
- The consumer surplus will be even lower with regressive subsidies than with progressive subsidies.

Contribution

- It is the first study of the subsidy pass-through and its impact on EV adoption in China.
- Our empirical findings extend previous works on the progressivity of subsidies and the implications of the distributional effects on policy efficiency.
- This paper contributes to the scant empirical studies on the relationship between progressivity and the incidence of subsidies, the two primary aspects of the distributional consequence.
- This paper contributes to the emerging literature on the Chinese EV markets in two ways.
  1. It applies the micro-moment method proposed by Petrin (2002) to the EV buyer survey data.
  2. This paper has important policy implications for policymakers in China as well as other countries.

Outline

Roadmap

1. Data
2. Methodology
3. Empirical Results
4. Conclusions

Data: sales

- The sales data cover the product-city-level monthly sales of 13 cities in China from 2016 to 2019. Sales are approximated by the number of subscribed compulsory vehicle insurance policies.
- Product features are at the trim level, including MSRP, vehicle body type (SUV or sedan), fuel type (gasoline, diesel, electricity, or hybrid), transmission type (auto or manual), weight, power, fuel consumption, length, width, and height. Each trim level has different features. We define a product model as all trim-level model variants with the same model name and specifications of the key features that are no more than 1% higher than those of the base models with the same name.
- We aggregate the sales over all product variants into the model level, taking the sales-weighted mean of the key features as the measure of the feature variables of the products.

Data: income

1. Incomes used for random draws
   - Average Incomes of Residents by District
2. Incomes used for micro-moments
   - The buyers' incomes are collected by CVSC-TNS Research (CTR).
   - CTR conducts the survey on passenger vehicle buyers both online and offline in 61 cities of 30 provinces or municipalities from 2016 to 2019. The survey data cover 760 vehicle models from 60 manufacturers, including most Chinese manufacturers and the international manufacturers of the primary imported brands. The survey data provide the average monthly individual incomes of each sample vehicle model in each year.

Stylized facts from reduced-form analysis

Subsidy Pass-through from Hedonic Pricing Analysis

	log(MSRP)
Subsidy-MSRP ratio[a]	-2.262***[b]
	(0.191)
log(Power)	0.0666
	(0.060)
log(Energy consumption) [c]	-0.571***
	(0.137)
log(Weight)	1.196***
	(0.187)
log(Size)	-0.0270
	(0.208)
SUV	0.0149
	(0.028)
Constant	4.006***
	(0.596)
Observations[d]	271

[a] Only central subsidies are used for the ration calculation. As central subsidies do not vary across cities but vary over time, we take the average of the model-level subsidies over the sample period and then calculate the ratio of the expected subsidies to MSRP for each model.
[b] Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
[c] Energy consumption measures the electricity consumed for a given travel distance. The unit is Kilowatt-hours per 100 kilometers.
[d] The sample only includes EVs. The observations are at the model level. Brand and time fixed effects are controlled.

Stylized facts from reduced-form analysis

Correlation between Subsidies and Individual Incomes

	Central Subsidy[a]
Buyer income (Thousand)	0.198***[b]
	(0.006)
Constant	31.142***
	(0.030)
Observations[c]	2416

[a] The central subsidy received by an EV model is measured in RMB 1,000.
[b] Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
[c] Only EV models are included. The observations are at EV model level. City$\times$Time fixed effects are controlled to capture the regional and time variation in consumers' preference over vehicles.

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Methodology

- We apply the structural model proposed by Berry et al. (1995), which features a random coefficient discrete choice model on the demand side and a Bertrand competition model on the supply side, which can capture the strategic interaction among automakers in this market.

Specifying consumer preferences over product characteristics

↓

Deriving the individual demand

↓

Aggregating into a market level demand

↓

Estimating the parameters of demand

↓

Estimating the parameters of supply

Individual preference

- Assume that heterogeneous consumers will make a choice over all J products in market m at time t to maximize their utilities.
- The indirect utility of consumer i is given by

$$u_{ijt} = \delta_{jt}(x_{jt}, p_{jt}, \xi_{jt}; \theta_1) + \mu_{ijt}(x_{jt}, p_{jt}, v_i, D_i; \theta_2) + \epsilon_{ijt} \tag{1}$$

where

- $\delta_{jt} = x_{jt}\beta - p_{jt}\alpha + \xi_{jt}$
    - the mean utility is the same for all consumers
    - p_j is the price, x_j is the observed characteristics of product i, and xi_j is the unobserved characteristics.
- $\mu_{ijt} = [-p_{jt}, x_{jt}](\prod D_i + \sum v_i)$
    - D_j is demographic variables and v_i is consumer i's idiosyncratic taste over product features
- ϵ_{ijt} follows the extreme value distribution.

Individual demand and Market share

- We can derive the conditional probability of choosing product J in market m at time t conditional on consumer taste v_i and demographic D_i as follows:

$$s_{ijt} = \frac{exp(\delta_{jt}(x_{jt}, p_{jt}, \xi_{jt}; \theta_1) + \mu_{ijt}(x_{jt}, p_{jt}, v_i, D_i; \theta_2))}{1 + \sum_{k=1}^{J} exp(\delta_{jt}(x_{jt}, p_{jt}, \xi_{jt}; \theta_1) + \mu_{ijt}(x_{jt}, p_{jt}, v_i, D_i; \theta_2))} \quad (2)$$

- Integrate into the market share

$$s_{jt} = \int \frac{exp(\delta_{jt}(x_{jt}, p_{jt}, \xi_{jt}; \theta_1) + \mu_{ijt}(x_{jt}, p_{jt}, v_i, D_i; \theta_2))}{1 + \sum_{k=1}^{J} exp(\delta_{jt}(x_{jt}, p_{jt}, \xi_{jt}; \theta_1) + \mu_{ijt}(x_{jt}, p_{jt}, v_i, D_i; \theta_2))} dP_v dP_D \quad (3)$$

Estimation Algorithm

1. Simulated the market share
   - Take N simulation draws of v and D from their distribution P_v and P_D, respectively.

$$\hat{s_{jt}} = \frac{1}{N}\sum_{n=1}^{N} \frac{exp(\delta_{jt}(x_{jt}, p_{jt}, \xi_{jt}; \theta_1) + \mu_{ijt}(x_{jt}, p_{jt}, v_i, D_i; \theta_2))}{1 + \sum_{k=1}^{J} exp(\delta_{jt}(x_{jt}, p_{jt}, \xi_{jt}; \theta_1) + \mu_{ijt}(x_{jt}, p_{jt}, v_i, D_i; \theta_2))}$$

2. Contraction mapping
   - Stopping at tolerance level

$$\delta_{jt}^{k} = \delta_{jt}^{k-1} + lns_{jt} - ln\hat{s}_{jt}$$

3. Iterate over θ
   - $\delta_{jt} = x_{jt}\beta - \alpha p_{jt} + \xi_{jt} \Rightarrow \xi_{jt} = \delta_{jt} - x_{jt}\beta + p_{jt}$
   - ξ constructs the moment condition.

Identification

The estimation was done using the generalized method of moments (GMM) approach and two sets of moments were constructed.

1. The first set of moments follows BLP.
   - $E(\boldsymbol{Z}'_{jt}\xi_{jt}) = 0$
   - $z_{jk}, \sum_{r \neq j, r \in F_f} z_{jk}, \sum_{r \neq j, r \notin F_f} z_{jk}$
2. An additional moment condition based on the predicted income value of vehicle buyers is built using Petrin's (2002) approach.
   - $E(|\hat{y_{jt}} - y_{jt}|) = 0$
   - y_{jt} is the observed average income of purchasers of vehicle model j, $\hat{y_{jt}}$ is the income from simulations:

$$\hat{y_{jt}} = \sum_{i}^{ns} \frac{Pr(l_{ijt} = 1)}{Pr(\sum_{i \in N}(l_{ijt} = 1))} h_{it}$$

- consumer i has choice $l_{ijt} \in \{0, 1\}$ and $\sum_{j \in J} l_{ijt} = 1$ if consumer i purchase a vehicle at time t
- h_{it} is consumer i simulated income.

Objective function

We can construct a GMM estimator stacking these two set of moments.

$$\arg\min_{\theta} g'(\theta)\boldsymbol{W}^{-1}g(\theta)$$

$$g(\theta) = \begin{bmatrix} \frac{1}{N}\sum z'_{jt}\xi_{jt} \\ \frac{1}{N_1}\sum \hat{y_{jt}} - y_{jt} \end{bmatrix}$$

$$\boldsymbol{W} = \begin{bmatrix} \frac{1}{N}\sum(z'_{jt}\xi_{jt})'(z'_{jt}\xi_{jt}) & 0 \\ 0 & \frac{1}{N_1}\sum(\hat{y_{jt}} - y_{jt})'(\hat{y_{jt}} - y_{jt}) \end{bmatrix}$$

where N is the number of observations of sales and $N_1 \subset N$ is the number of observations of income data.

Firm decision and Supply

F firms in the market, firm f produce F_f of J products.

1. Observed cost characteristics w_j, unobserved part ω_j (Berry et al., 1995).
$$ln(mc_j) = w_j\gamma + \omega_j \tag{4}$$
2. For each product, profit equals to unit profit times quantity. For each firm, profit equals to the sum of all products.
$$\max \pi_f = \sum_{j \in F_j} (p_j - mc_j)(Ms_j(p, x, \xi; \theta) \tag{5}$$

FOC:

$$p = mc_j + \triangle^{-1} s, \text{ where } \triangle = \begin{bmatrix} \frac{\partial s_1}{\partial p_1} & \cdots & \frac{\partial s_J}{\partial p_1} \\ \vdots & \ddots & \vdots \\ \frac{\partial s_1}{\partial p_J} & \cdots & \frac{\partial s_J}{\partial p_J} \end{bmatrix}$$

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3. **Empirical Results**

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Results from demand estimation

Table 1: Estimation Result for the Demand Side [a]

Variable	OLS	TSLS	GMM Mean	GMM Random	Income [b]
log(Price)	-0.161*** [c]	-6.151***	-22.383***	-0.016	3.000***
	(0.028)	(0.474)	(0.385)	(0.199)	(0.007)
Constant	-10.276***	-6.850***	-0.018	-0.076	
	(0.327)	(0.486)	(0.152)	(0.364)	
log(Horsepower)	-0.507***	2.922***	3.560***	0.027	
	(0.037)	(0.275)	(0.227)	(0.155)	
log(Operation costs)	-1.228***	-1.649***	-2.198***	0.018	
	(0.050)	(0.070)	(0.079)	(0.167)	
log(Weight)	0.607***	8.138***	10.132***	-1.132*	
	(0.094)	(0.606)	(0.476)	(0.513)	
log(Size)	2.819***	2.697***	2.726***	0.027	
	(0.117)	(0.145)	(0.179)	(0.199)	
EV	-2.601***	-1.014***	-1.841***		
	(0.106)	(0.181)	(0.234)		
Import	-0.979***	-0.305	-0.053		
	(0.221)	(0.278)	(0.279)		
AT	0.282***	0.638***	0.755***		
	(0.011)	(0.031)	(0.026)		
EV×VQS	0.205	-2.578***	-1.855***		
	(0.142)	(0.281)	(0.413)		
EV×VQS×WP	-0.098***	-0.454***	-0.387***		
	(0.024)	(0.041)	(0.067)		
Local	0.460***	0.452***	0.416***		
	(0.016)	(0.02)	(0.025)		
SUV	0.360***	0.367***	0.402***		
	(0.012)	(0.015)	(0.02)		

[a] There are 87,687 observations at the brand-city-half-year level in all regressions. Time, brand, and city fixed effects are included for all regressions.
[b] The demographic characteristic is household disposal income, which is assumed to follow a log-normal distribution.
[c] Standard errors are reported in parentheses; *, **, and *** indicate that the estimators are statistically significant at the levels of 5%, 1%, and 0.1%, respectively.

Counterfactual analysis

- We simulate four scenarios.
  1. assuming that the subsidies have been retained at their 2015 levels, we simulate a scenario in which the low subsidies are replaced by high subsidies.
  2. we simulate the case in which subsidies are completely removed. This is the benchmark for incidence or pass-through analysis.
  3. we design a regressive subsidy scheme that discounts the observed subsidies in the null scenario based on buyers' income categories.
  4. we fix the government budget on subsidy at the same level as the one in the null scenario and solve for an optimal regressive subsidy scheme that depends on both EV range and income. We set the policy objective to be maximum sales in order to maximize consumer surplus from vehicle consumption.

Results from counterfactual analysis

Scenarios [a]	Null	(1)	(3)	(4)
EV manufacturers[b]	114.07%	114.02%	113.72%	113.58%
Hybrid manufacturers [c]	113.97%	113.90%	113.65%	113.79%
All manufacturers[d]	113.98%	113.92%	113.66%	113.75%

[a] The equilibrium prices in scenario (2) are used as the benchmark for the pass-through calculation since scenario (2) simulates the zero-subsidy policy. In the other scenarios, the pass-through is defined as the ratio of the price decrease, relative to the no-subsidy price, to the subsidies.

[b] This row presents the average pass-through of EVs made by firms only producing EVs, including Beijing Electric Vehicle, Nio, WM Motor, and Xpeng.

[c] This row presents the average pass-through of EVs made by firms producing both EVs and ICEVs, including Beijing Benz, Beijing Borgward, Beijing Hyundai, BAIC Motor, BYD, Chery, Chongqing Changan, Dongfeng Honda, Dongfeng Motor, FAW-Volkswagen, GAC Honda, GAC Mitsubishi, GAC Motor, Geely, JAC Motor, SAIC-GM, SAIC Motor, and SAIC-Volkswagen.

[d] This row presents the average pass-through of EVs produced by all firms.

Pass-through

- In all scenarios, the overshifting of subsidies is observed.
- This overshifting of subsidies to consumers is attributed to the imperfect competition between EVs and ICEVs.

Progressivity

- Using the Bayesian rule applied to the prediction of buyers' income, we calculate the sales-weighted average subsidies for each income level as follows: Diagram

$$\hat{sb}_i = \sum_j \frac{s_{ij} sb_j}{\sum_j s_i j}$$

- The estimated buyers' subsidies by incomes suggest the following:
  1. The subsidy schemes independent of buyers' income (scenarios null and 1) generate actual subsidies progressive on incomes.
  2. The schemes that are conditional on buyers' income generate regressive subsidies.
  3. In particular, the scheme in scenario (4) is a continuous function of income whereby the subsidies diminish as buyers' income increases.

Pass-through and Progressivity

- The pass-through in the scenarios with regressive-subsidy designs is lower than that in the scenarios with progressive-subsidy schemes.
- By design, the regressive subsidy scheme should be more effective in promoting EV sales than the progressive subsidy scheme since it disproportionately targets the high price-sensitive consumers.
- In imperfect competition, however, the manufacturers can take advantage of the scheme design, and pass fewer subsidies through to the EV buyers to achieve the same sale target.

Cost-benefit analysis

Scenarios [a]		Null	(1)	(2)	(3)	(4)
Compensating variation[b]			2.0532	-0.2873	-0.0233	-0.0040
Profits						
Domestic	EV manufacturers	6.3308	6.8948	6.2084	6.3223	6.3453
	ICEV manufacturers	2.8460	2.5154	2.9076	2.8510	2.8595
Imported	EV manufacturers	0.1548	0.1361	0.1585	0.1551	0.1557
	ICEV manufacturers	1.2584	1.1080	1.2881	1.2608	1.2661
Subsidy		0.4085	5.2583	0.0000	0.3804	0.4085
Subtotal for sales		10.1815	7.4492	10.2753	10.1855	10.2141
Externalities[c]						
EVs	(Coal-fired electricity)	89.1917	484.5169	37.4508	84.978	92.8927
EVs	(Natural-gas-powered electricity)	19.0276	103.3636	7.9895	18.1286	19.8171
ICEVs		364.7407	327.1915	371.2565	365.2693	365.8749
Subtotal	(Coal-fired electricity)	453.9324	811.7084	408.7073	450.2473	458.7676
Subtotal	(Natural-gas-powered electricity)	383.7683	430.5551	379.2460	383.3979	385.6920
Total	(Coal-fired electricity)	-443.7509	-804.2592	-398.4320	-440.0618	-448.5535
Total	(Natural-gas-powered electricity)	-373.5868	-423.1059	-368.9707	-373.2124	-375.4779

[a] Scenario null: the subsidy scheme is the same as that for 2019. Scenario (1): the subsidy scheme is the same as that for 2015. Scenario (2): subsidy is zero for all EVs. Scenario (3): the base of this subsidy scheme is designed for the lowest income group (with annual income less than RMB 60,000) and it is the same as the scheme for 2019. The high-income groups get percentage discounts on the base level as shown in Table ??. Scenario (4): the subsidies depend on both income and vehicle ranges. The subsidy is given by $sb_{ij} = 8.1227 - 1.445 \times y_i + R_j \times 0.004$, where R_j is the range of vehicle j. The subsidy is in RMB 10,000.

[b] All values are in RMB billions. The estimates are for Shanghai in the second half of 2019.

[c] The estimates depend on the energy source of electricity generation. Electricity can be generated by coal-fired power plants or by natural gas-fired power plants, which are cleaner. See Appendix ?? for details of the marginal externalities of power generation by energy sources.

Cost-benefits analysis

1. Government expense on subsidy increases dramatically when the subsidy per vehicle increases (scenario 1 versus null). This outcome is due to the changes in both the intensive margin and extensive margin of subsidy expense. The intensive margin refers to the subsidy per vehicle.
2. Another interesting finding is that the subsidy can generate distortion. The subtotal surplus, including consumer surplus and producer surplus, net of subsidy, is negatively correlated with subsidies.
3. The regressive subsidies may generate welfare gain, without the need to increase the subsidy size.

Roadmap

Conclusions

1. The distributional effects of the subsidies also play an important role in determining the policy effectiveness and welfare effects.
2. This paper analyzes the distributional effects of EV subsidies in two dimensions: the subsidy pass-through, or distribution between manufacturers and consumers, and progressivity, or distribution over consumers of different incomes.
3. Our findings suggest that the subsidy pass-through to the consumers is more than complete:
4. The current subsidy program is progressive, with the majority of subsidies going to high-income consumers who are less price-sensitive, implying that the policy design may be not optimal in the sense that it has not maximized its effectiveness in promoting EV sales.
5. We proposed alternative subsidy schemes, by which the subsidies are regressive on incomes. Counterintuitively, we find that the regressive subsidy scheme reduces consumer surplus, compared with the progressive subsidy schemes.

Thank you!

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EV subsidy of China

In 2013, China launched an attribute-based subsidy on electric vehicles (EVs).

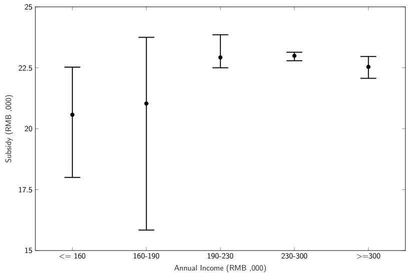
- Subsidy on EV purchase based on the range.

	$80 \leq$ Range < 150	$150 \leq$ Range < 250	$250 \leq$ Range
2013	35,000 CNY	50,000 CNY	60,000 CNY
2014	33,250 CNY	47,500 CNY	57,000 CNY
2015	31,500 CNY	45,000 CNY	54,000 CNY

(source: Development and Reform Commission) Back

Distribution of subsidies over income groups

Figure 1: Subsidy Distribution Based on Income Group



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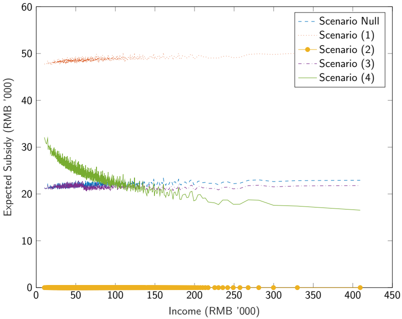
Note: The figure shows subsidies from the central government and the annual income of car consumers in 2019. Income groups are defined based on the quintile in which the annual household income falls. The subsidies are aggregated to consumers with similar incomes. The top and bottom borders of the blue boxes are the 25th and 75th percentiles. The red line in each box is the median.

Estimated subsidies by income groups

Figure 2: Subsidy Distribution over Income



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Note: The figure shows the subsidy received by EV buyers with different incomes. The horizontal axis measures the annual income of consumers. The vertical axis measures the subsidies received by EV buyers. Both subsidy and income are in RMB thousands.