Policy Designs for Clean Vehicle Adoption: A Study of Electric Vehicle Subsidy Program in China

Jing Qian

Dyson School of Applied Economics and Management
Cornell University

Aug 14, 2018

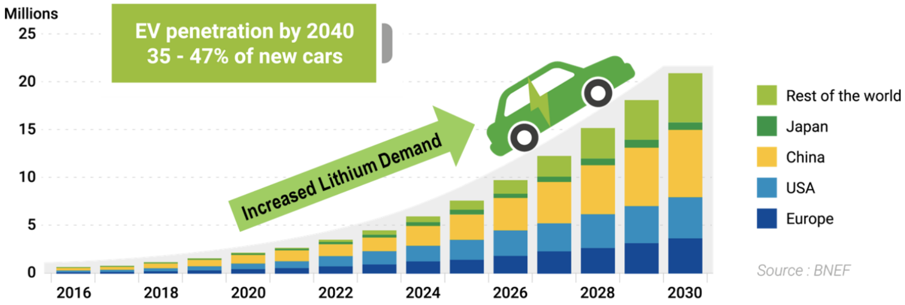
Background

- In 2014, the transportation sector was responsible for 23% of global CO_2 emissions (IEA, 2016). In China, this sector was estimated to account for 7-8% of CO_2 emissions.
- 30% of PM2.5 is from tailpipe emissions from road transport by the World Health Organization (WHO).
- Transportation sector accounts for 19% of global energy use. China has become the world's largest automobile market and crude oil importer.

Financial incentives have been proposed to promote electric vehicles (EVs) around the world.

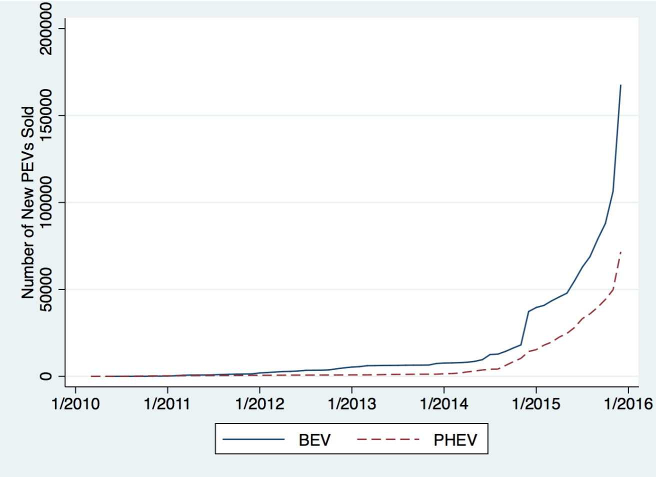
- United States: federal tax credits (based on battery capacity; up to \$7,500) + state incentives (rebate or tax credit)
- Netherlands: registration tax exempted for cars emitting zero CO_2; plug-in hybrid electric vehicles (PHEVs), emitting below 80 g CO_2/km, pay EUR 6 per g CO_2/km
- Norway: EVs exempted from purchase tax; battery electric vehicles (BEVs) additionally exempted from VAT
- China: A one-time subsidy solely based on the driving range.

Predicted EV Sales



EV Sales in China

Figure: EV Sales in China, 2010-2015

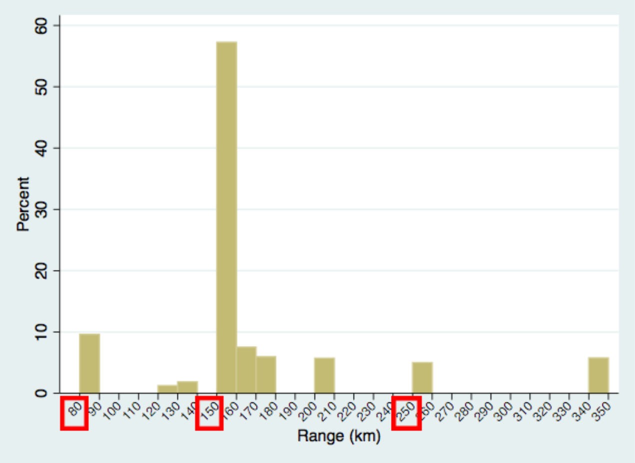


Notes: The figure shows the monthly cumulative sales of EVs in China.

- In 2015, China for the first time became the largest EV market, overtaking the United States (Global EV Outlook, 2016).

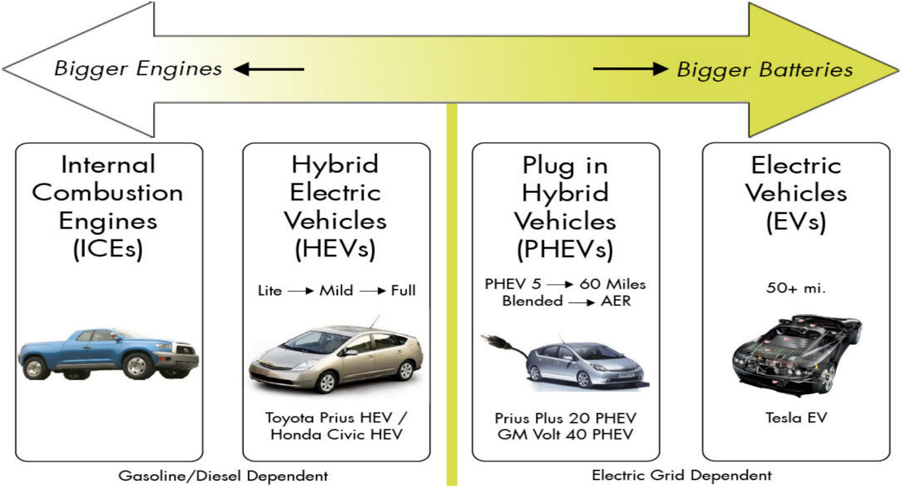
EV Attributes

Figure: Distribution of EV Range in China



Notes: The figure shows the distribution of EV ranges in the 19 cities between 2010 and 2015.

- The ranges bunching just above the thresholds, especially at 150 km



Source: https://phev.ucdavis.edu/about/faq-phev/

- Battery Electric Vehicles (BEVs)
- Plug-in Hybrid Electric Vehicles (PHEVs)

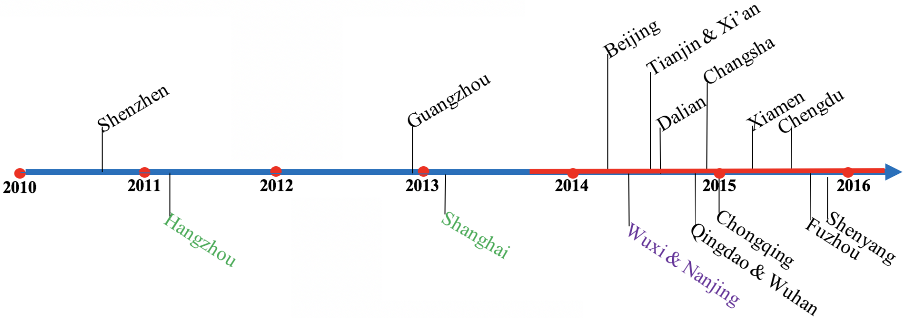
Subsidy Program in China

Table: Central Government Subsidies for Qualified EVs, Sep 2013-2015

Vehicle Type	Range (km)	2013	2014	2015
BEV	80≤R<150	¥35,000 ($ 5,394)	¥33,250 ($ 5,124)	¥31,500 ($ 4,854)
	150≤R<250	¥50,000 ($ 7,705)	¥47,500 ($ 7,320)	¥45,000 ($ 6,935)
	R≥250	¥60,000 ($ 9,246)	¥57,000 ($ 8,784)	¥54,000 ($ 8,322)
PHEV	R≥50	¥35,000 ($ 5,394)	¥33,250 ($ 5,124)	¥31,500 ($ 4,854)

- Central government subsidies decreased by year.
- Central government subsidies increased as range increased.

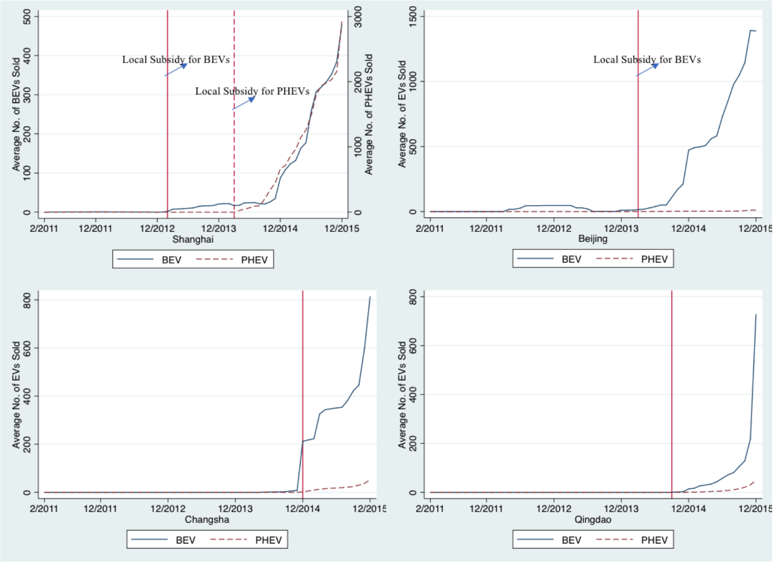
Figure: Starting Date of Local Subsidy



- Shanghai and Hangzhou offered a fixed amount of subsidy.
- Jiangsu province started to subsidize EVs based on their wheelbase in March 2015.
- 14 out of 19 cities provided a subsidy proportional to the central subsidy in a fixed ratio for each city.

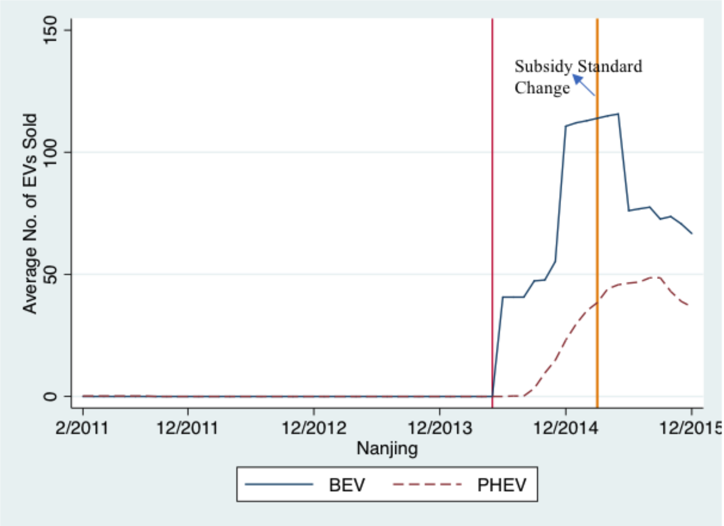
EV Sales across Cities

Figure: EV Sales in Representative Cities, 2010-2015



Notes: The figure shows the 12-month rolling average of EV sales.

Figure: EV Sales in Nanjing, 2010-2015



Notes: The figure shows the 12-month rolling average of EV sales.

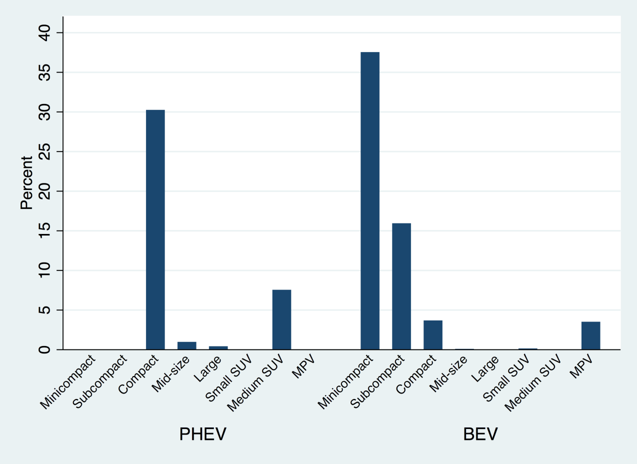
Distortion in Consumer Choices

Table: Five Best-selling EVs in China and the U.S., 2015

Firm	Model	Type	Range (km)	Size (m2)	CurbWeight (lb)	Horsepower (hp)	MSRP ($1,000)	MktSh (%)
Panel A: Five best-selling PEVs in China, 2015								
BYD	Qin	PHEV	70	8.39	3792	154	32.19	15.17
Geely	Zhidou	BEV	152	4.29	1521	24	24.47	12.86
Zotye	Yun-100	BEV	155	5.77	2134	24	24.49	8.21
BYD	Tang	PHEV	84	8.93	4894	205	38.73	7.56
BAIC	EV 200	BEV	176	6.92	2855	72	32.19	7.07
Panel B: Five best-selling PEVs in the U.S., 2015								
Tesla	Model S	BEV	405	9.76	4936	691	105.00	22.06
Nissan	Leaf	BEV	134	7.79	3243	107	29.01	15.12
Chevrolet	Volt	PHEV	61	8.01	3786	149	34.17	13.47
BMW	i3	BEV	130	7.10	2799	170	42.40	9.65
Ford	Fusion Energi	PHEV	32	9.03	3913	188	34.80	8.53

- Geely, BAIC, and Zotye are young domestic private firms.
- Compared with the best-selling models in the U.S., the popular models in China have lower prices but worse performance.

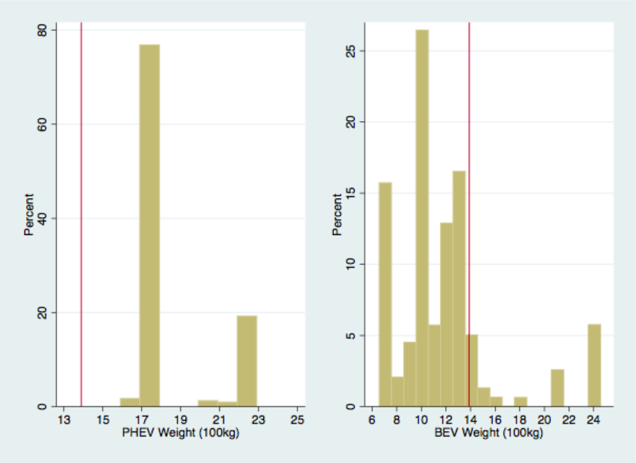
Figure: Distribution of EV Size in China



Notes: The figure shows the distribution of EV segments in the 19 cities between 2010 and 2015.

- Subsidizing EVs solely based on driving ranges results in distortion in consumer choices.

Figure: Distribution of EV Weight in China



Notes: The figure shows the distribution of EV weights in the 19 cities between 2010 and 2015. Average weight of all the vehicles: 1,400 kg.

- Subsidizing EVs solely based on driving ranges results in distortion in consumer choices.

Literature Review

- Literature on second-best subsidy: the subsidy for an electric vehicle should be the difference in lifetime damages between an electric vehicle and a gasoline vehicle (Holland et al. 2016).
- Empirical research on the vehicle incentive policies:
  - studies on cost effectiveness and welfare impacts of cleaner technology adoption policies: DeShazo, Sheldon, and Carson (2017), Clinton and Steinberg (2016); Beresteanu and Li (2011)
  - the impacts of different subsidies in the presence of network externalities: Li et al. (2016) and Springel (2017)
  - studies on China's EV market: Helveston et al. (2015); Hao et al. (2014); Ma, Fan, and Feng (2017)

Research Objectives

- Utilize historical registration data at the city-model level to assess the welfare impact of the current subsidy program in China.
  - Is China subsidizing too much on some low-cost products?
  - To what extent does the subsidy program affect firm profits, consumer surplus, and externalities?
- Propose alternative policies to adopt green technologies.
  - Subsidize a vehicle according to its battery capacity.
  - Internalize externalities using gasoline tax

Data

- Focusing on the top two tier (19) cities from 2010 to 2015
  - The 19 cities account for 74.26% of the national EV sales
- Registration data complied by the State Administration of Industry and Commerce
  - Aggregated to model year month city to construct the market share for each model
  - Model is defined at model-transmission type-fuel type-segment level: Toyota Camry-automatic-gasoline-sedan
  - The number of choices for each model year: 182, 197, 216, 248, 263, and 305
- Model-level vehicle attributes from major automotive websites
  - miles per gallon, horsepower, size...

- Household-level car ownership survey data complied by Ministry of Industry and Information Technology (MIIT)
  - Vehicle models purchased
  - Household demographics (residential city, income, family size,...)
  - Average number of households in each year: 1244
- City-level household income data from China Statistical Yearbook
  - City-level household income percentiles
- Subsidy for EVs collected from government and major automotive websites
  - total amount of subsidies by period, city, and model

Consumer Demand

- Household i's utility from choosing product j in market m and month t is defined as:

$$u_{mtij} = \underbrace{\sum_k x_{tjk}\bar{\beta}_k + F_j + \zeta_m + \eta_{yr} + \eta_{mon} + \xi_{mtj}}_{\delta_{mtj}(\theta_1)} \underbrace{-\alpha_{mti} ln(p_{mtj}) + \sum_k x_{tjk}\sigma_k \nu_{mtik}}_{\mu_{mtij}(\theta_2)} + \epsilon_{mtij},$$

and α_{mti} is defined as $e^{\bar{\alpha}_i} * e^{\sigma_p \nu_{mti}} * \frac{1}{y_{mti}}$.

- The probability that household i chooses product j is:

$$Pr_{mtij} = \frac{e^{\delta_{mtj}(\theta_1)+\mu_{mtij}(\theta_2)}}{1+\sum_{l=1}^{J_{mt}}(e^{\delta_{mtl}(\theta_1)+\mu_{mtil}(\theta_2)})}.$$

- The predicted market share of product j is given by

$$s_{mtj}(p, x, \xi; \theta_2) = \int \frac{exp(\delta_{mtj} + \mu_{mtij}(p_{mtj}, x_{mtj}, y_{mti}, \nu_{mti}; \theta_2))}{1 + \sum_{l=1}^{J_{mt}} exp(\delta_{mtl} + \mu_{mtil}(p_{mtl}, x_{mtl}, y_{mti}, \nu_{mti}; \theta_2))} dP^*(\kappa)$$

  - κ_i is the vector of unobserved individual attributes and $P^*(\kappa)$ is the population distribution function of κ

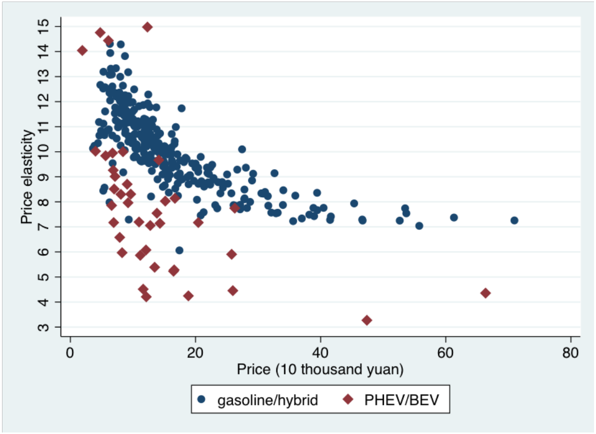
- Non-linear parameters $\theta_2 = \{\bar{\alpha}_i, \sigma_k\}$ are estimated by simulated GMM with two sets of moment conditions.
    - Excluded instruments that capture product differentiation: logarithm of the number of products in the same vehicle segment and fuel type by the same firm, logarithm of the number of products in the other same vehicle segment and fuel type by rival firms, and logarithm of the central subsidy for EVs.
    - 90 micro-moments that match the model predictions to the observed conditional means from the car ownership survey (Petrin, 2002).
- For each θ_2 search, δ_{mtj} is estimated by contraction mapping following BLP (1995).

Demand Estimation Results

	Est.	S.E.
Linear parameters		
EV dummy	1.96*	1.04
Power	8.58***	0.67
Fuel cost	-2.63**	1.29
Size	6.67***	1.59
Auto Transmission	1.96***	0.20
Plate	0.52	0.91
Driving Restriction Exemption	9.64***	0.93
Purchasing Restriction	-2.63***	0.21
Price coefficient		
$e^{\bar{\alpha}}$	217.02***	24.23
Random coefficients		
Cons	-2.14***	0.41
Power	-1.73*	1.01
Size	8.00***	1.07
log(Price)	0.33***	0.01

Notes: N: 281669. Controlling for firm, year, month fixed effects, and city and segment interactions.

Elasticity



- More expensive models tend to have lower price elasticity.
- The sales-weighted elasticity of 2014 and 2015 is -9.6%, larger than -8.4% in the U.S. market estimated by Beresteanu and Li (2011).
- Consumers are less price sensitive to electric vehicles.

Supply

- The unit price (p^f_{mj}) firm gets is defined as (t is suppressed for simplicity):

$$p^f_{mj} = \frac{p^0_j - b_{mj}}{1 + t^{va}_j} * (1 - t^c_j) + b_{mj},$$

  - p^0_j is product j's MSRP. b_{mj} is product j's subsidy in market m. t^{va}_j and t^c_j are product j's value-added and consumption tax, respectively.

- The annual profit for firm f is:
$\pi_f = \sum_{m=1}^M \sum_{j \in \mathscr{F}} (p^f_{mj} - mc_j) M_m s_{mj} = \sum_{m=1}^M \sum_{j \in \mathscr{F}} [\tau_j (p^0_j - b_{mj}) + b_{mj} - mc_j] M_m s_{mj},$

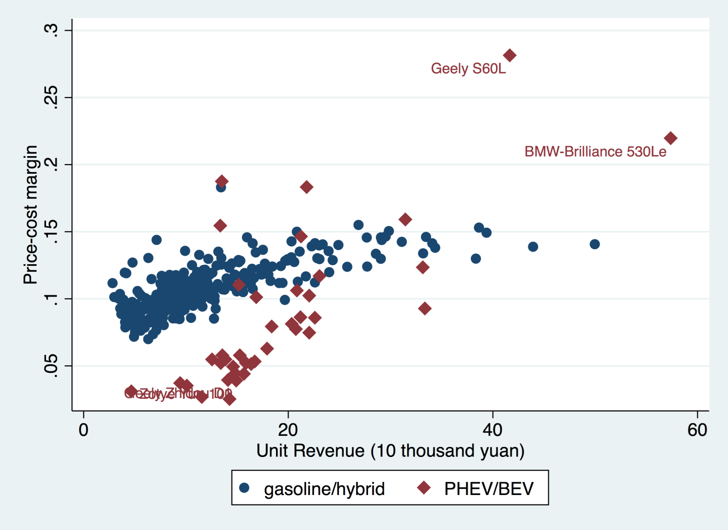
  - $\tau_j = \frac{1 - t^c_j}{1 + t^{va}_j}$ is the fraction firm f can get after tax.

- Each firm choose $\{p_j^0, j \in \mathcal{F}\}$ to maximize its total profits. Given this assumption, p_j^0 satisfies the following first-order condition:

$$\tau_j \sum_{m=1}^{M} M_m s_{mj} + \sum_{r \in \mathscr{F}} (1-\tau_r) \sum_{m=1}^{M} M_m b_{mr} \frac{\partial s_{mr}}{\partial p_j^0} + \sum_{r \in \mathscr{F}} (\tau_r p_r^0 - mc_r) \sum_{m=1}^{M} M_m \frac{\partial s_{mr}}{\partial p_j^0} = 0, \forall j,$$

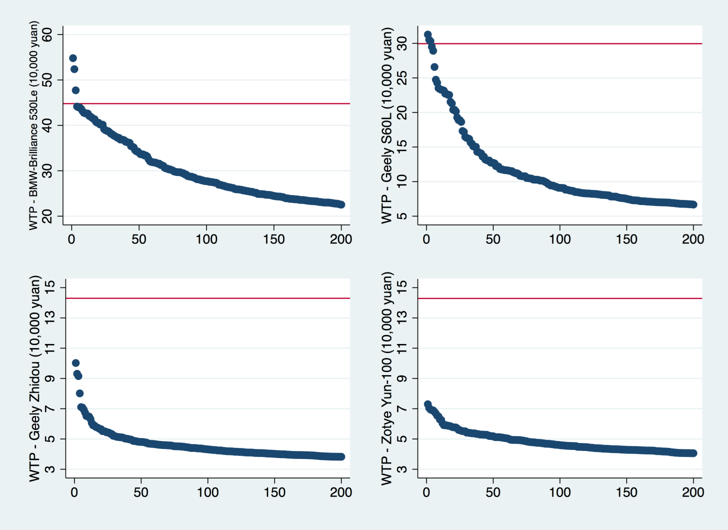
  - Second item: subsidy exempted from tax.

Price-cost margins



- More expensive models tend to have higher price-cost margins
- Price-cost margins of some EVs are small

Simulation - Willingness to Pay



Counterfactual Analysis

- What would happen if subsidies were removed in 2014 and 2015

Aggregate Sales	Before	After	Change
Gasoline	6,864,428	6,954,856	90,428
Hybrid	7,268	7,416	148
PHEV	67,187	6,983	-60,204
BEV	103,549	2,934	-100,615

- Products with low price-margins exit the market
- High-end EVs have the lease decrease in sales: Geely S60L and BMW-Brilliance 530Le.

Attributes without Subsidy

Figure: Distribution of EV Range without Subsidy

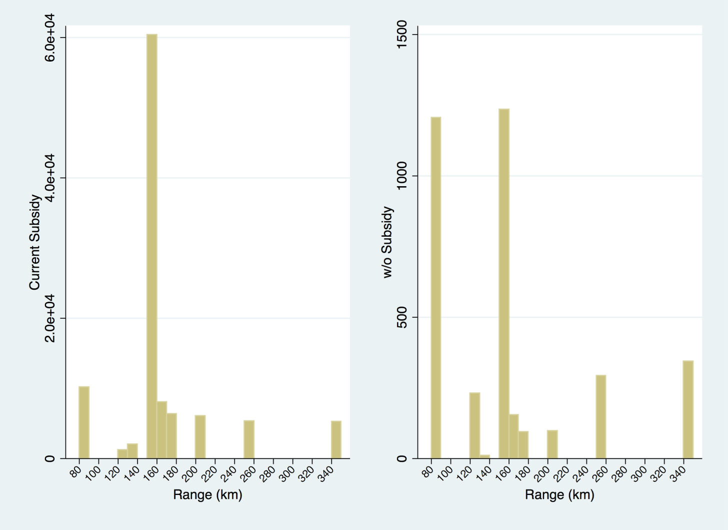


Figure: Distribution of EV Size without Subsidy

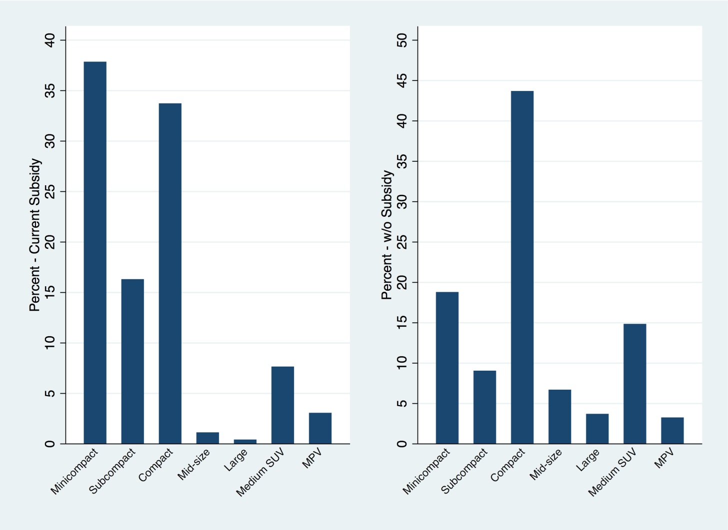
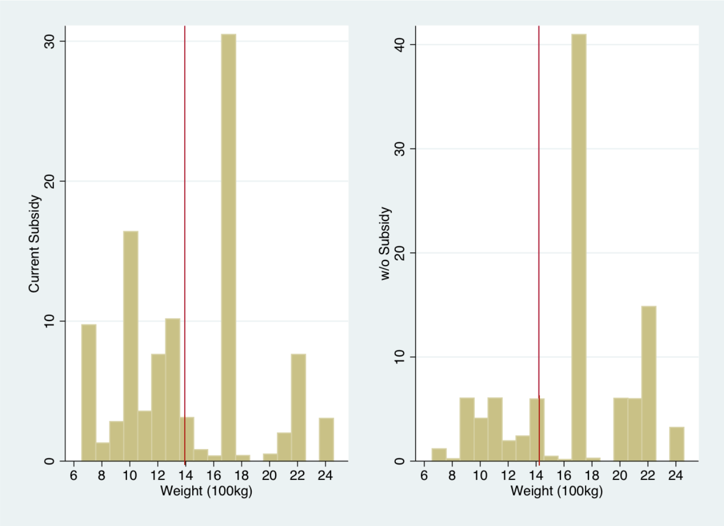


Figure: Distribution of EV Weight without Subsidy



Welfare Change

- Welfare change if removing subsidies in 2014 and 2015

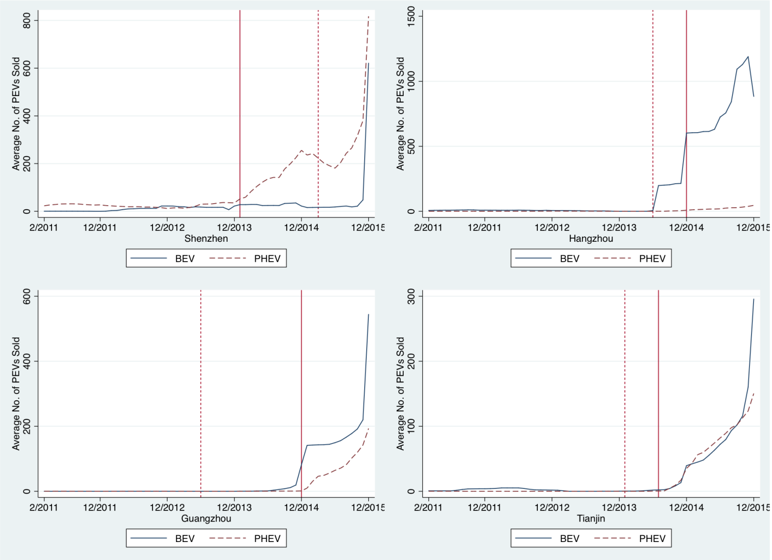
Change in Welfare	billion yuan
Consumer surplus	5.36
Firm profit	0.05
CO2 emission externality savings	-0.07
Government spending	12.37
Total social welfare	17.71 (2.72 bn US dollars)

Conclusion

- Most of the EV sales were driven by China's unique subsidy policy which subsidizes EVs only in terms of their driving range.
  - Low-end models would exit the market without subsidy.
- The current subsidy program induced 17.71 billion yuan ($\approx$ \$ 2.72 billion) welfare loss
  - A great distortion in consumer choices
  - Profits transfered from traditional automakers to EV automakers
- Further studies
  - Alternative policies such as subsidizing EVs based on battery capacity and increasing the gasoline tax are in progress.
  - supply side modeling needs to be explored to reduce the limitation that the vehicle models are given in the market.

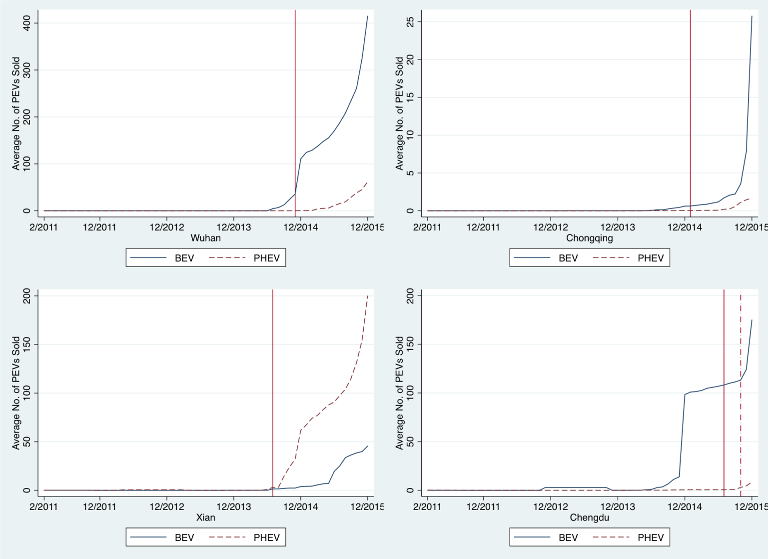
Thank you and comments welcome!

Figure: EV Sales across Cities, 2010-2015



Notes: The figure shows the 12-month rolling average of EV sales.

Figure: EV Sales across Cities, 2010-2015



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