Policy Options to Promote Electric Vehicles: Evidence from China

Shanjun Li

Cornell University

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MIT Energy Initiative
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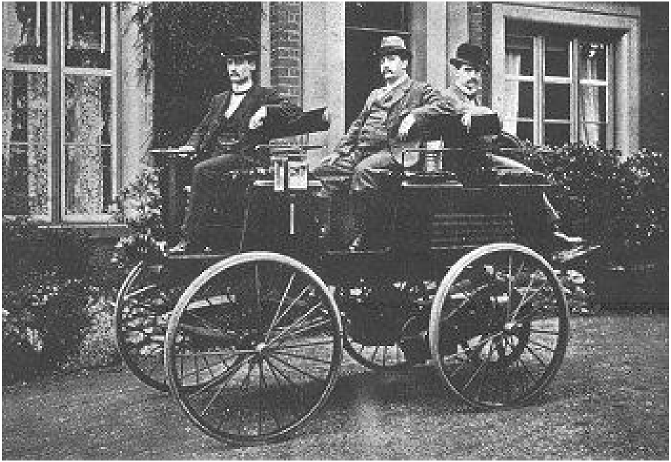
A Bit of History

Figure: First Production EV in 1884



Source: https://www.energy.gov/timeline/timeline-history-electric-car

A Bit of History

- EVs had advantages over their early-1900s competitors. They did not have the vibration, smell, and noise associated with gasoline cars. They also did not require gear changes and a manual effort to start.

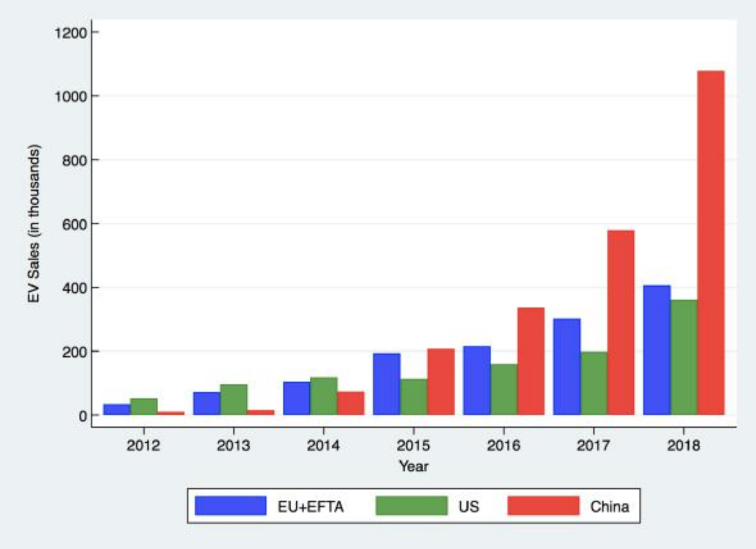
- By the turn of the 20th century, EVs accounted for 38% of the automobiles, stream 40%, and gasoline 22%. Over 30k EV registered

- EVs lost to gasoline cars in 1910's due to a confluence of factors:
  1. Improved road infrastructure and long-distance travel;
  2. Cheap gasoline from worldwide oil discoveries;
  3. Technology improvement such as muffler, and electric starter;
  4. Ford's Model T

Revenge of EVs

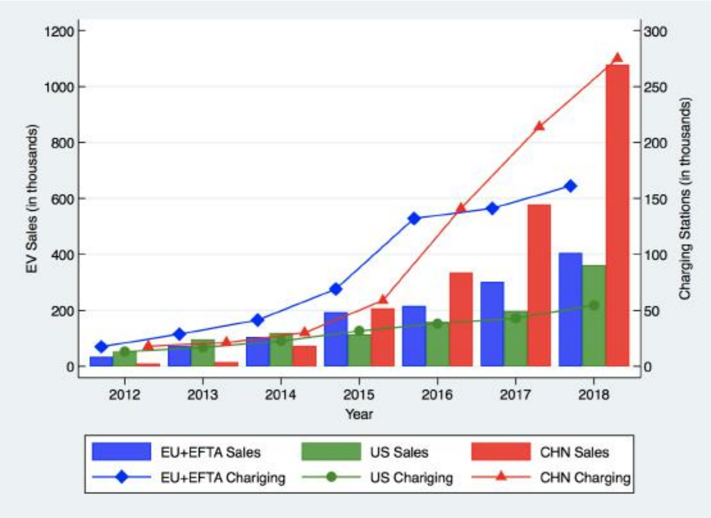
- From 1996-1998, GM introduced over 1,000 BEVs (EV1) in California, mostly made available through leases. In 2003, GM crushed their EVs upon the expiration of the leases
- Who killed the electric car? documentary by Chris Paine
  - Oil industry fears of losing monopoly on transportation fuel
  - Auto companies fears of development cost and long term profit
  - Federal government joined the auto-industry suit against California in 2002
  - CARB drastically scaled back the ZEV mandate in 2003
  - Lack of consumer interest (cheap oil, demand for SUV)
- Mass-produced Nissan Leaf (BEV) and Chevy Volt (PHEV) were introduced in Dec. 2010

Global Electric Vehicle Market: Sales



Note: New EV sales (BEV and PHEV) by country and region. Source: IEA, AECA.

Global Electric Vehicle Market: Infrastructure



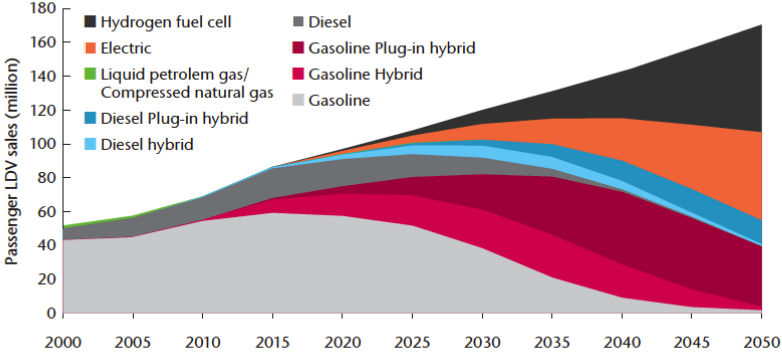
No. of EV Firms and Models

No. of EV firms and models (BEV, PHEV); imported sales included (in thousands)

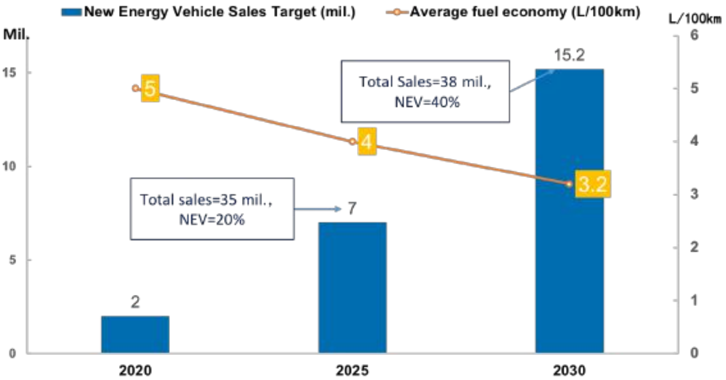
Top 5 EV Firms in China and US

Note: Top 5 EV firms in China and US

IEA's EV Roadmap to 2050



China's EV and Fuel Economy Targets



2020年—2025年节能与新能源目标来自《汽车产业中长期发展规划》
The energy conservation and new energy targets for 2020-2025 come from the medium and long-term development plan of the automobile industry.

2030年为非约束性目标，来自《节能与新能源汽车技术路线图》
2030 is a non-binding target, from "road map of energy conservation and new energy vehicle technology"

Barriers to EV Adoption

1. High price: 2019 Nissan Leaf starts at $30k and Toyota Prius Prime at $28k while gasoline counterparts (Nissan Sentra, Honda Civic, Toyota Corolla) at $18-20k
2. Range anxiety: most EV models are still less than 150 miles. Gasoline cars can travel more than 300 miles before refueling
3. Lack of charging infrastructure: 20k charging locations in 2019, compared to 120,000 gasoline stations in the US
4. Long charging time: Nissan Leaf 35h at 110V, 8 to 11h at 220V, 50 min at 440V

Rationales for Policy Intervention

- Are there market failures that warrant government intervention?

  1. Suboptimal tax on gasoline: air pollution, carbon, noise
  2. Consumer mis-perception of future fuel costs: energy paradox (consumer not taking up cost-effective investment)
  3. Technology and consumption spillovers: EV producers cannot appropriate all the benefit from investment

EV Policies in China and US

Policies with Financial Incentives

	Federal	Local
China	**Subsidy based on driving range** 2010: 10 pilot cities 2013: 88 pilot cities 2016: nationwide subsidy	Matched with central subsidy by 1:1 to 1:0.5 ratio Shared by provincial and city governments Total subsidy no more than 50% to 70% of MSRP
United States	**Subsidy based on battery capacity** From 2010: $2500 for 4kWh battery, with an additional $417 per kWh up to $7500 200k qualifying vehicles per automaker	Rebates: CA, IL, MA, NY, PA, TX Tax credit: CO, GA, LA, MD, SC, UT, WV Sales tax exemption or reduction: CO, NJ, WA Fee exemptions or reduced fee: AZ, IL

Common Non-Financial incentives:

- Free registration, exemption from license lottery
- Access to HOV lanes or restricted traffic zones subject to emission requirements
- Free municipal parking
- Increase public charging stations, modify building code

Central Subsidies in China from 2013 to 2018

Type	Range	2013	2014	2015	2016	2017	2018
BEV	≥ 80km	¥35,000	¥33,250	¥31,500	-	-	-
	≥ 100km				¥25,000	¥20,000	-
	≥ 150km	¥50,000	¥47,500	¥45,000	¥45,000	¥36,000	¥15,000
	≥ 200km						¥24,000
	≥ 250km	¥60,000	¥57,000	¥54,000	¥55,000	¥44,000	¥34,000
	≥ 300km						¥45,000
	≥ 400km						¥50,000
PHEV	≥ 50km	¥35,000	¥33,250	¥31,500	¥30,000	¥24,000	¥22,000

Local Policies in China

- Monetary Incentives: reduce ownership and operating cost
  - Vehicle purchase subsidy for BEV and PHEV, proportional to central subsidy. Total subsidy no more than 50% to 70% of MSRP
  - Vehicle tax exemption, parking fee reduction, license plate fee wavier
  - Charging fee subsidy
- Non-monetary Incentives
  - Preferential treatment on EVs under purchase quota systems: Shanghai, Beijing, Guangzhou, Tianjin, Hangzhou, and Shenzhen
  - Road access privilege many cities with driving restriction: Beijing, Changsha, Lanzhou, Wuhan, Nanchang, and Chengdu
  - Expand charging infrastructure and dedicated parking space for EV
  - Green plate: roll out in three waves from 2016

Policy Changes in 2018 and 2019

- Starting from 2018, the subsidy is adjusted base on two additional requirements
  - Minimum energy efficiency in kWh/100km (as a function of weight)
  - Battery energy density $\geq$ 105 Wh/kg
- Starting from 2019:
  - Local subsidies removed
  - Minimum range for subsidy is increased to 250 km
  - Maximum subsidy cut in half to 25k
  - NEV credit mandate: the credit per EV gets is a function of range and energy efficiency. The total credits from an automaker need to reach 10% of total sales in 2019 and 12% in 2020

Effectiveness of Policies on Sales

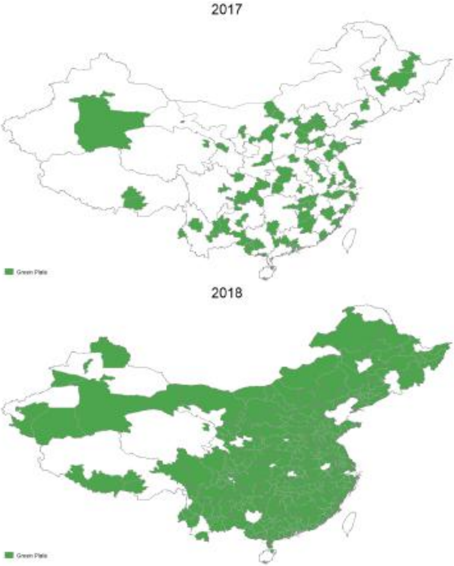
- Question: what is the impact of different policies on sales of electric vehicles?
- Data
  - EV sales by city by model by quarter during 2015-2018. 171 models (all the EV models)
  - Comprehensive local policies in 40 cities . Focus on top 40 cities with largest EV sales
- Method: Panel regression. Relies on spatial and temporal variation in policies and sales

Local Subsidies by City (in ¥10,000)

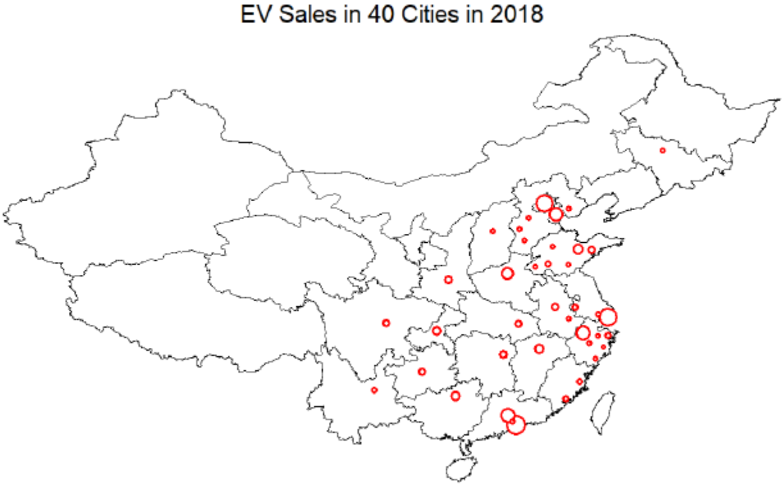
2016

2018

EV Green Plate Policy in China



EV Sales by City in 2008



Regression Results

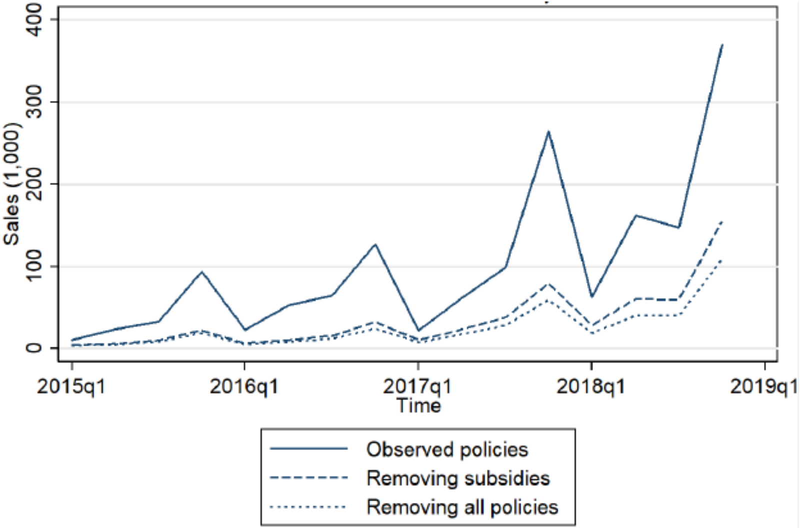
Variables	Dependent Var.: Log(Sales)	
Average Price (in ¥10k)	-0.054***	-0.053***
	(0.014)	(0.014)
Central Subsidy (in ¥10k)	0.135***	
	(0.038)	
Local Subsidy (in ¥10k)	0.156***	
	(0.036)	
Total Subsidy (in ¥10k)		0.146***
		(0.025)
Plate Restriction	0.648***	0.650***
	(0.087)	(0.089)
Driving Restriction	0.211*	0.215**
	(0.107)	(0.106)
Green Plate	0.112	0.113*
	(0.067)	(0.066)
Year-Quarter fixed effect	Yes	Yes
City-Model fixed effect	Yes	Yes
Observations	15,654	15,654
R-squared	0.719	0.719

Findings

- A ¥10,000 increase in price would lead to a 5% decrease in car sales
- Consumers respond to central subsidy and local subsidy similarly
- Consumers respond more strongly to subsidies than price (almost 3 times)

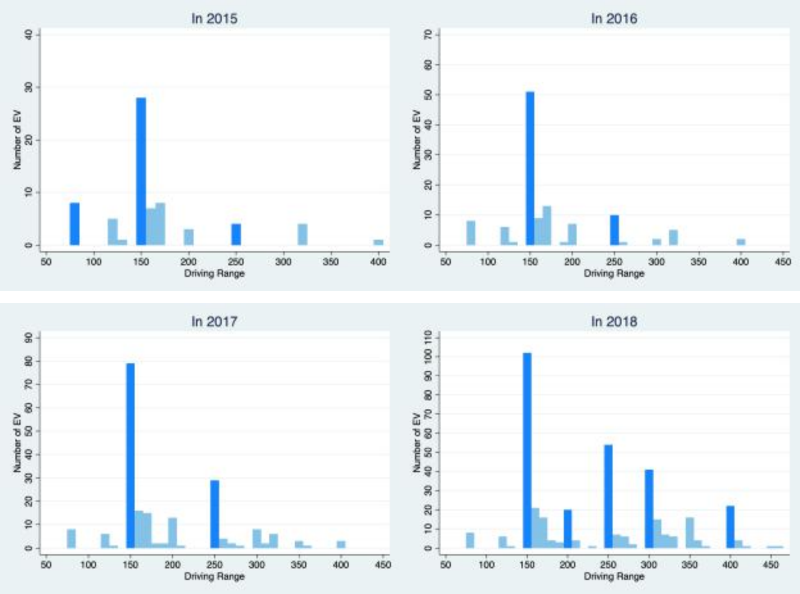
- Purchase restriction on gasoline vehicles $\approx$ ¥43,000 EV subsidy
- Driving restriction on gasoline vehicles $\approx$ ¥14,300 EV subsidy
- Green plate policy $\approx$ ¥7,500 subsidy

Policy Impacts on EV Sales

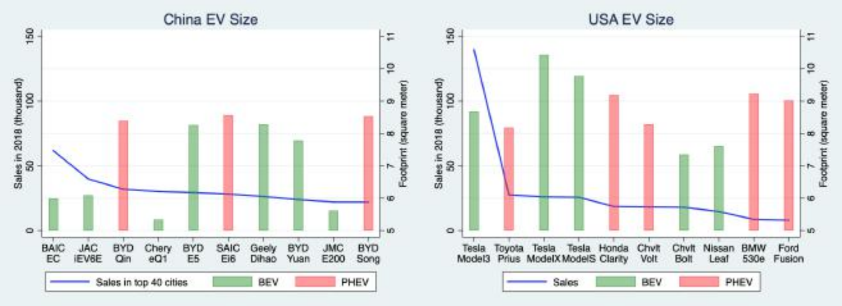


1. Global Trends in EV Market
2. EV Policies and Impacts on Sales
3. Firm Responses to Purchase Subsidies

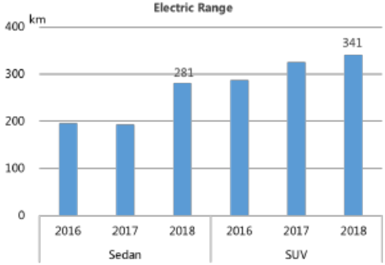
Bunching at the Cutoffs

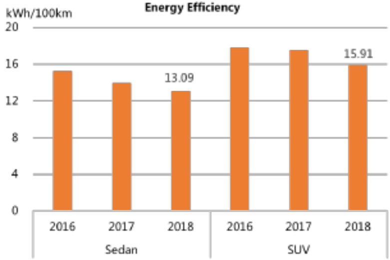


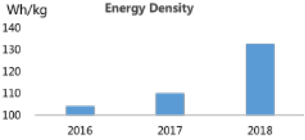
EV Size in China and US

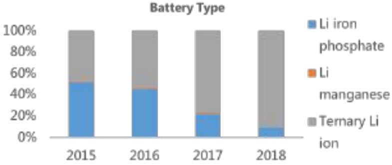


Battery Technology









Market Equilibrium Model of EVs

- A market equilibrium framework to analyze consumer and firm behavior in respond to shocks/policies
  - Demand side: consumers decide whether and which EV to buy based on choices available and preferences
    - Model premises: consumer preferences for attributes
  - Supply side: firms choose vehicle attributes to maximize profit subject to the subsidy policy
    - Model premises: Marginal cost of production, fixed cost of attribute changing, technology frontier
- Bring the model predictions to observed data (aggregate sales, household survey on who buys what) to estimate model premises
- Simulate market outcomes (EV model attributes, sales) under counterfactual scenarios

Demand Side: Utility Maximization

- The utility of consumer i from vehicle j in market m:

$$u_{ijm} = [\alpha_1 + \alpha_2 ln(Y_{im})]\tilde{P}_{jm} + X_{jm}\beta_i + \xi_{jm} + \varepsilon_{ijm}$$

- Y_{im}: Household income
- $\tilde{P}_{jm}$: consumer price ($\tilde{P}_{jm} = P_j - \text{subsidy}_{jm}$)
- X_{jm}: observed market and vehicle characteristics
- ξ_{jm}: unobserved vehicle characteristics
- ε_{ijm}: idiosyncratic preference shock (i.i.d. type I extreme value)

Estimates of Preference Parameters

Linear Parameters	Coef.	S.E.	Coef.	S.E.
Price Coefficients				
Price	-0.109	0.002		
α_1			-0.707	0.046
α_2			0.185	0.012
Horse power	0.030	0.001	0.035	0.000
Weight (100kg)	0.075	0.004	0.121	0.004
Fuel cost	-0.845	0.084	-0.465	0.089
EV	-4.051	1.309	-1.608	0.105
Driving range (km)	0.005	0.001	0.010	0.001
Auto Transmission	0.532	0.011	0.716	0.011
Purchase restriction*EV	3.209	0.428	1.840	0.090
Driving restriction*EV	1.823	0.320	0.858	0.137
Dispersion Parameters				
Constant, σ_1			-2.652	0.249
Weight (100kg), σ_2			0.051	0.006

Quarter, city-year, vehicle segment, firm fixed effects are included

Supply Side: Profit Maximization

- We allow firms to choose vehicle attributes (weight and battery capacity) as well as compete in price

$$\max_{(P_j,k_j,w_j)_{j\in J_f}} \Pi_f = \sum_{j\in J_f} (\tilde{P}_j + s \cdot 1_{\{D_j \geq \underline{D}\}} - mc_j)\, q_j - \sum_{j\in J_f} FC_j$$

- k_j and w_j affect driving range $D_j(k_j, w_j)$, marginal cost $mc_j(k_j, w_j)$, fixed cost $FC_j(k_j, w_j)$, and the demand $q_j(\boldsymbol{p}, \boldsymbol{k}, \boldsymbol{w})$
- For instance, an increase in k_j causes
  - (+) longer $D_j \Rightarrow$, which increases demand q_j
  - (-) higher mc_j and FC_j
  - (-) business stealing effect
- When benefits and costs from changing k_j or w_j are marginally balanced, $D_j(k_j^*, w_j^*) \neq \underline{D}$ [interior solution]

Specification of Supply Side Functions

Driving Range: $D_j = h(k_j, w_j) + \kappa_j = \eta_k k_j + \eta_w w_j + \kappa_j$

Marginal Cost: $\frac{\partial mc_j}{\partial k_j} = \gamma_k + \zeta_j^k$ and $\frac{\partial mc_j}{\partial w_j} = \gamma_w + \zeta_j^w$

- γ_k and γ_w are common components across different models
- ζ_j^k and ζ_j^k are model specific variations

Fixed Cost: $FC(k_j, w_j) = \frac{\phi_k}{2} k_j^2 + \frac{\phi_w}{2}(w_j - w_j^{natual})^2$

- $w_j^{natural}$ is the natural level of a vehicle weight
- Parameterize $w_j^{natural}$ with exogenous attributes $w_j^{natural} = Z_j \rho$

Supply Side: FOC

First Order Conditions

$$q + \Omega \otimes \Delta_P(P - mc) = 0$$

$$-\underbrace{(\gamma_k + \zeta_j^k)}_{\frac{\partial mc}{\partial k}}q + \Omega \otimes \Delta_k(P - mc) + \eta_w \Lambda = \underbrace{\phi_k k_j}_{\frac{\partial FC}{\partial k}}$$

$$-\underbrace{(\gamma_w + \zeta_j^w)}_{\frac{\partial mc}{\partial w}}q + \Omega \otimes \Delta_w(P - mc) + \eta_w \Lambda = \underbrace{\phi_w (w_j - W_j \rho)}_{\frac{\partial FC}{\partial w}}$$

- Ω: ownership matrix
- Δ_x: derivatives of market shares with respect to $x = P, k$, or w
- $\Lambda = (\lambda_1, ..., \lambda_J)$ where $\lambda_j \geq 0$

Supply Side: FOC

- At cutoffs $D_j(k_j^*, w_j^*) = \underline{D}$, marginal benefits and costs from changing k_j or w_j may not be equal [corner solution]

$$\frac{\partial \Pi_f}{\partial k_j} \leq 0 \text{ and } \frac{\partial \Pi_f}{\partial w_j} \geq 0$$

- A firm would have likely reduced k_j or increased w_j in the absence of the subsidy. But do not in order to get the subsidy

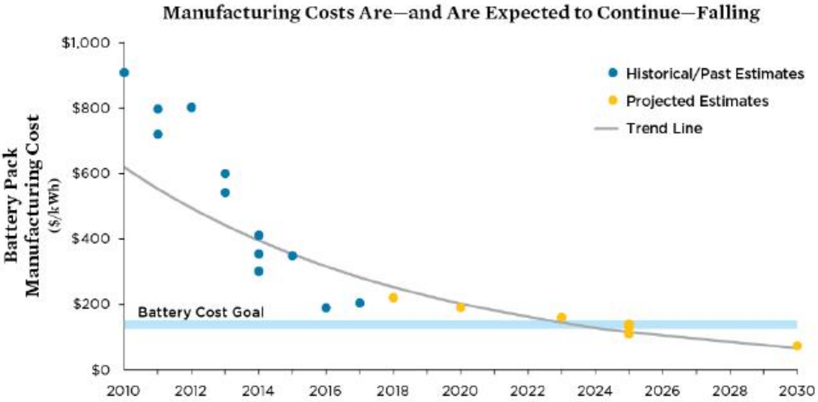
- The wedge in the F.O.C. captures the shadow price λ_j of relaxing the policy threshold $\underline{D}$

$$\frac{\partial \Pi_f}{\partial k_j} + \lambda_j \frac{\partial D_j}{\partial k_j} = 0 \text{ and } \frac{\partial \Pi_f}{\partial w_j} + \lambda_j \frac{\partial D_j}{\partial w_j} = 0$$

Estimates of Cost Parameters

- Marginal Cost of production in 2015:
  - MC $\Uparrow$ by \$350 for 1kWh $\Uparrow$ in battery capacity
  - MC $\Uparrow$ by \$50 for 10kg $\Uparrow$ in vehicle weight
- Fixed cost of attribute adjustment:
  - $FC_j(k_j, w_j) = C + 1100 \cdot k_j^2 + 2500 \cdot (w_j - w_j^{natural})^2$
  - 10kg deviation from natural weight incurs annual fixed cost $\Uparrow$ by \$2,500 while 20kg deviation incurs \$10,000 additionally
- Shadow price of subsidy constraint:
  - Firms are willing to pay on average \$18,560 and at most \$57,030 to relax $\underline{D}$ by 1km for a model at the threshold, $\underline{D}$
  - The shadow price λ_j is higher for the more profitable model

Battery Cost from the Literature



Simulations (Preliminary): Remove Range Requirement

- Keep constant the total subsidy to the EV buyers, but remove the link to vehicle range
- Simulate one firm at a time: holding fix the decisions of other firms

Range group	Range (km)		Weight (10kg)		Capacity (kWh)		Price (¥10k)	
	W/	W/O	W/	W/O	W/	W/O	W/	W/O
$150 \leq D < 160$	155.0	124.1	81.0	84.8	15.5	10.3	11.2	10.7
$250 \leq D < 260$	252.0	131.5	127.2	188.5	31.7	14.3	19.9	23.4

- Removing the range constraint leads to larger EVs, with smaller batteries

Comparing WTP and MC for EVs

- Does the subsidies lead to privately and socially undesirable products?

	Count	Sales	Subsidy (¥10k)	Price (¥10k)	MC (¥10k)	WTP (¥10k)	Footprint (m^2)	Weight (100kg)
WTP - MC $\leq$ 0	8	3125.75	8.43	7.46	11.29	8.66	5.47	7.39
0$<$ WTP - MC $\leq$ 10	14	2594.86	8.04	6.95	10.01	14.68	5.56	8.51
10 $<$ WTP - MC $\leq$ 20	8	1761.75	8.57	10.73	12.98	26.63	6.14	9.13
WTP - MC $>$ 20	13	1770.77	8.38	12.48	13.64	48.26	6.96	10.61

BEVs with WTP < MC

(a) Dongfeng DFM E30L

(b) Zotye Zhidou301

(c) Kandi Panda K11

(d) Qingnian Maidi i3

Concluding Thoughts

- China has become by far world's largest EV market. Government policies played a big role in promoting the technology.
  - The policies combined account for 70% sales in 2018 (58% from subsidies). Similar impacts were found for US and Norway as well.
- Subsidy based on driving range led to unintended consequences
  - Firms receive subsidies through downsizing vehicles rather than investing in battery
  - Subsidies led to (likely) socially undesirable vehicles being produced
- Questions to be answered:
  - Could China's market sustain its growth without large subsidies?
  - What are the environmental impacts of EVs?
  - With nearly 100 EV producers, is there misallocation of resources?