Development and Adoption of Plug-in Electric Vehicles in China

Presented by:
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Institute for Sustainable Energy
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October 02, 2017
China: World’s largest vehicle market

Annual Vehicle Sales

% Global Sales

30.3%

22.2%

USA

China

Annual New Vehicle Sales (Million)

Year


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OICA: http://www.oica.net/category/sales-statistics/
China: World’s largest vehicle market...with room to grow

Annual Vehicle Sales

% Global Sales

Vehicles / 1,000 People

USA

China

China: OICA: http://www.oica.net/category/sales-statistics/
Potential of Electric Vehicles:
- Reduce Oil Dependence
- Reduce Pollution
- Technological Leadership

One week in Beijing, Oct. 2016

U.S. EIA: https://www.eia.gov/petroleum/data.php

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2016: 45% of world’s electric vehicles sold in China

Source: http://www.ev-volumes.com
Main Findings:

1. **Adoption:**
   Chinese car buyers may be more willing to adopt full electric vehicles than Americans.

2. **Development:**
   Domestic Chinese firms sold 95% of 2016 PEV sales in China, and they are experimenting with a wide variety of innovations.
   Second R&R at *Research Policy*
## “EV” Taxonomy

Plug-in Electric Vehicles (PEVs)

<table>
<thead>
<tr>
<th>CV (Conventional)</th>
<th>HEV (Hybrid)</th>
<th>PHEV (Plug-in Hybrid)</th>
<th>LSEV (Low-Speed EV)</th>
<th>BEV (Battery Electric)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="CV Icon" /></td>
<td><img src="image2" alt="HEV Icon" /></td>
<td><img src="image3" alt="PHEV Icon" /></td>
<td><img src="image4" alt="LSEV Icon" /></td>
<td><img src="image5" alt="BEV Icon" /></td>
</tr>
</tbody>
</table>

**Power Converter:**
- CV: Engine
- HEV: Engine + Motor
- PHEV: Engine + Motor
- LSEV: Motor
- BEV: Motor

**Battery Pack:**
- CV: --
- HEV: Small; Li-ion
- PHEV: Medium; Li-ion
- LSEV: Medium; Lead-acid
- BEV: Large; Li-ion

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Research Questions:

1. What are consumers’ preferences towards electric vehicles in the U.S. vs. China?
2. How do these consumer preferences shape adoption of electric vehicles?
### Past Automotive Demand Modeling Literature

<table>
<thead>
<tr>
<th>Paper</th>
<th>Year</th>
<th>Model Form*</th>
<th>EVs</th>
<th>Conjoint</th>
<th>Data years</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boyd &amp; Mellman</td>
<td>1980</td>
<td>MNL, MXL</td>
<td>x</td>
<td>x</td>
<td>1977-1978</td>
<td>USA</td>
</tr>
<tr>
<td>Goldberg</td>
<td>1995</td>
<td>NL, MNL</td>
<td></td>
<td></td>
<td>1989-1990</td>
<td>USA</td>
</tr>
<tr>
<td>Berry, Levinsohn, &amp; Pakes</td>
<td>1995</td>
<td>MNL, MXL</td>
<td></td>
<td></td>
<td>1971-1990</td>
<td>USA</td>
</tr>
<tr>
<td>McCarthy</td>
<td>1996</td>
<td>MNL</td>
<td></td>
<td></td>
<td>1983-1985</td>
<td>USA</td>
</tr>
<tr>
<td>Golob et al.</td>
<td>1997</td>
<td>P</td>
<td>x</td>
<td>x</td>
<td>1994</td>
<td>USA</td>
</tr>
<tr>
<td>Goldberg</td>
<td>1998</td>
<td>NL, MNL</td>
<td></td>
<td>x</td>
<td>1993</td>
<td>USA</td>
</tr>
<tr>
<td>Brownstone &amp; Train</td>
<td>1999</td>
<td>MNL, MXL, P</td>
<td>x</td>
<td>x</td>
<td>1993</td>
<td>USA</td>
</tr>
<tr>
<td>Brownstone, Bunch, &amp; Train</td>
<td>2000</td>
<td>MNL, MXL</td>
<td></td>
<td>x</td>
<td>1993</td>
<td>USA</td>
</tr>
<tr>
<td>McFadden &amp; Train</td>
<td>2000</td>
<td>MXL</td>
<td>x</td>
<td>x</td>
<td>1993</td>
<td>USA</td>
</tr>
<tr>
<td>Sudhir</td>
<td>2001</td>
<td>MXL</td>
<td></td>
<td></td>
<td>1981-1990</td>
<td>USA</td>
</tr>
<tr>
<td>Choo &amp; Mokhtarian</td>
<td>2004</td>
<td>MNL</td>
<td></td>
<td>x</td>
<td>1998</td>
<td>USA</td>
</tr>
<tr>
<td>Berry, Levinsohn &amp; Pakes</td>
<td>2004</td>
<td>MXL</td>
<td></td>
<td></td>
<td>1993</td>
<td>USA</td>
</tr>
<tr>
<td>Santini &amp; Vyas</td>
<td>2005</td>
<td>MNL</td>
<td>x</td>
<td>x</td>
<td>1998-2002</td>
<td>USA</td>
</tr>
<tr>
<td>Train and Wilson</td>
<td>2007</td>
<td>MXL</td>
<td></td>
<td>x</td>
<td>2000</td>
<td>USA</td>
</tr>
<tr>
<td>Dagsvik and Liu</td>
<td>2009</td>
<td>NL</td>
<td></td>
<td>x</td>
<td>2001</td>
<td>Shanghai</td>
</tr>
<tr>
<td>Axsen, Mountain, Jaccard</td>
<td>2009</td>
<td>MNL</td>
<td>x</td>
<td>x</td>
<td>2006</td>
<td>USA &amp; Canada</td>
</tr>
<tr>
<td>Axsen, Kurani</td>
<td>2009</td>
<td>--</td>
<td></td>
<td>x</td>
<td>2007</td>
<td>USA</td>
</tr>
<tr>
<td>Ziegler</td>
<td>2012</td>
<td>P</td>
<td>x</td>
<td>x</td>
<td>2007-2008</td>
<td>Germany</td>
</tr>
<tr>
<td><strong>This Study</strong></td>
<td>2015</td>
<td>MNL, MXL</td>
<td>x</td>
<td>x</td>
<td>2012</td>
<td>USA &amp; China</td>
</tr>
</tbody>
</table>

*MNL = Multinomial Logit, NL = Nested Logit, MXL = Mixed Logit, P = Probit*
Suppose these 3 vehicles below were the only vehicles available for purchase, which would you choose?

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Type</td>
<td>Conventional 300 mile range on 1 tank</td>
<td>Plug-In Hybrid 300 mile range on 1 tank (first 40 miles electric)</td>
<td>Electric 75 mile range on full charge</td>
</tr>
<tr>
<td>Brand</td>
<td>German</td>
<td>American</td>
<td>Japanese</td>
</tr>
<tr>
<td>Purchase Price</td>
<td>$18,000</td>
<td>$32,000</td>
<td>$24,000</td>
</tr>
<tr>
<td>Fast Charging Capability</td>
<td>--</td>
<td>Not Available</td>
<td>Available</td>
</tr>
<tr>
<td>Operating Cost (Equivalent Gasoline Fuel Efficiency)</td>
<td>19 cents per mile (20 MPG equivalent)</td>
<td>12 cents per mile (30 MPG equivalent)</td>
<td>6 cents per mile (60 MPG equivalent)</td>
</tr>
<tr>
<td>0 to 60 mph Acceleration Time**</td>
<td>8.5 seconds (Medium-Slow)</td>
<td>8.5 seconds (Medium-Slow)</td>
<td>7 seconds (Medium-Fast)</td>
</tr>
</tbody>
</table>

*To view an attribute description, click on: 🔗
**The average acceleration for cars in the U.S. is 0 to 60 mph in 7.4 seconds
Same survey, calibrated to U.S. & Chinese markets

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Respondents:</td>
<td>448</td>
<td>384</td>
</tr>
<tr>
<td>Choice Observations:</td>
<td>6,720</td>
<td>5,760</td>
</tr>
</tbody>
</table>

China Sample

U.S. Online Sample

U.S. Auto Show Sample

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Weights added to match car-buying demographic

Sample demographics compared to new car buyer survey by Ford

<table>
<thead>
<tr>
<th>Variable</th>
<th>U.S.</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Our Sample</td>
<td>Weighted Sample</td>
</tr>
<tr>
<td>Household Income</td>
<td>57.3 (29.3)</td>
<td>74.3 (28.7)</td>
</tr>
<tr>
<td>Age</td>
<td>33.9 (12.7)</td>
<td>51 (14.8)</td>
</tr>
<tr>
<td>Num Children</td>
<td>0.6 (1.1)</td>
<td>1.4 (1.4)</td>
</tr>
<tr>
<td>Num Vehicles</td>
<td>1.8 (0.8)</td>
<td>2 (0.7)</td>
</tr>
<tr>
<td>Daily VMT</td>
<td>22.9 (10.4)</td>
<td>23.3 (11.4)</td>
</tr>
<tr>
<td>Annual VMT</td>
<td>11,200 (4,800)</td>
<td>12,500 (4,600)</td>
</tr>
<tr>
<td>Household Size</td>
<td>2.7 (1.3)</td>
<td>2.7 (1.2)</td>
</tr>
<tr>
<td>Years Education</td>
<td>7.2 (1.9)</td>
<td>7.9 (2.3)</td>
</tr>
<tr>
<td>Percent Female</td>
<td>35.3%</td>
<td>32.6%</td>
</tr>
<tr>
<td>Percent Married</td>
<td>44.6%</td>
<td>68.9%</td>
</tr>
<tr>
<td>Percent with No Children</td>
<td>72.1%</td>
<td>40.3%</td>
</tr>
<tr>
<td>Percent College Graduates</td>
<td>52.3%</td>
<td>71.2%</td>
</tr>
<tr>
<td>Percent First Time Buyers</td>
<td>4.4%</td>
<td>1.3%</td>
</tr>
<tr>
<td>n</td>
<td>384</td>
<td>384</td>
</tr>
</tbody>
</table>

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Model choice behavior with random utility model

Utility to person \( n \) from choosing alternative \( j \):

\[ u_{nj} = \beta_n' x_j + \epsilon_{nj} \]

\( \epsilon_{nj} \sim \text{Gumbel} \left( 0, \frac{\pi^2}{6} \right) \)

**Goal of inference:**
Estimate \( \beta_n \) to understand how observable product attributes, \( x_j \), influence consumer choices
Maximize log-likelihood to estimate model coefficients

Maximize log-likelihood to estimate $\beta_n$:

$$\text{minimize}_{\beta} - L = - \sum_{n}^{N} \sum_{j}^{J} y_{nj} \ln P_{nj}(\beta_n | x_j)$$

Homogeneous model:

$$P_{nj} = \frac{\exp (\beta' x_j)}{\sum_{k \in J} \exp (\beta' x_k)}$$

Heterogeneous model:

$$P_{nj} = \int \left( \frac{\exp (\beta_n' x_j)}{\sum_{k \in J} \exp (\beta_n' x_k)} \right) f(\beta | \theta) d\beta, \quad \beta_n \sim f(\beta | \theta)$$
Estimate Models in “Willingness to Pay (WTP)” Space

WTP: $\omega_n = \beta_n/\alpha_n$

<table>
<thead>
<tr>
<th>Model Space</th>
<th>Model Specification</th>
<th>Parameter of interest</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preference:</td>
<td>$u_{nj} = \beta'<em>n x_j - \alpha_n p_j + \varepsilon</em>{nj}$</td>
<td>$\beta_n$</td>
<td>“Utility”</td>
</tr>
<tr>
<td>WTP:</td>
<td>$u_{nj} = \alpha_n (\omega'<em>n x_j - p_j) + \varepsilon</em>{nj}$</td>
<td>$\omega_n$</td>
<td>Currency ($)</td>
</tr>
</tbody>
</table>
Chinese Consumers More Receptive to Today’s Full Electric Vehicles Than American Consumers
USA
Consumers sensitive to limited electric range

China
Most Chinese are first time buyers
More alternatives for long-distance travel (e.g. high speed rail)
Given current subsidies...

Chinese drivers *less* receptive to PHEVs than Americans

Chinese drivers *more* receptive to BEVs than Americans

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Summary of Contributions

- First study to directly compare U.S. & China consumer preferences for PEVs.
- On average, Chinese respondents more receptive to BEVs than American respondents, regardless of subsidies.

Potential Implications:

- ✔ Reduce oil dependence
- ❓ Reduce pollution? (might increase local emissions)
- ❓ Technology leadership? (decrease global emissions)
  → global incentives for PEV R&D investment →
  → global PEV adoption →
  → reduced global emissions?

Second R&R at Research Policy
Global Conventional Vehicle Sales: Multinationals Dominate

Conventional Vehicles (69,500,000)

- **China** (23.8M)
- **Europe** (15.1M)
- **USA** (17.5M)
- **Other** (13M)

Brand:
- Chinese
- Multinational
- Tesla
- Unknown

2016 Sales

Global PEV Sales: Chinese Firms Dominate

Conventional Vehicles (69,500,000)

China (23.8M)  Europe (15.1M)  USA (17.5M)  Other (13M)

Plug-in Electric Vehicles (777,000)

China (350k)  Europe (210k)  USA (160k)  Other (60k)

Brand:  
Chinese  Multinational  Tesla  Unknown

45% Global PEV Sales

2016 Sales


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Research Question:
Why are (independent) Chinese firms leading China’s PEV market?

Conventional Vehicles (69,500,000)
- China (23.8M)
- Europe (15.1M)
- USA (17.5M)
- Other (13M)

Plug-in Electric Vehicles (777,000)
- China (350k)
- Europe (210k)
- USA (160k)
- Other (60k)

Brand: Chinese | Multinational | Tesla | Unknown

45% Global PEV Sales


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Inductive grounded theory-building

Vehicle Sales Data
  1: CAAM yearbooks
  2: Webscraped: Gasgoo.com
- U.S. & Europe: Annual by Make (2016)
  1: carsalesbase.com
  2: hybridcars.com

Archival Data
- 112 unique documents
- 3,215 pages of content

51 Interviews
- 27 - Four Case Study firms
- 10 - JV firms
- 4 - Universities
- 4 - Consultants
- 3 - Non-profis
- 2 - Gov’t Officials
- 1 - Reporter

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The Chinese Joint Venture System

1980s: 以市场换技术 = “Exchange market for technology”

Past research suggests system has largely failed to transfer technology
(Brandt & Thun, 2010; Feng, 2010; Howell, 2016; Huang, 2003; Lazonick & Li, 2012; Nam, 2011)
PEVs must be made / developed in China to get subsidies

To get subsidies, one of these must be made / developed in China:

- Battery
- Motor
- Control System

For Nissan, the following models are relevant:

- Nissan Leaf
- Dongfeng Motors
- Dongfeng-Nissan
- Venucia Morning Wind
<table>
<thead>
<tr>
<th>Foreign OEMs won’t bring most advanced PEV technologies to JVs</th>
<th>Chinese JV partners lack incentives to independently innovate</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Selling gas cars makes money! The business case (for EVs) is weak. Margins (for CVs) in China are around 10%!” - Former manager for JV firm</td>
<td>“It's like opium. Once you've had it you will be addicted forever.” - Guangyuan He, Former Minister of Machinery and Industry (Reuters, 2012)</td>
</tr>
<tr>
<td>“So when [MNE] and [JV partner] decided to do the [BEV], they thought, ‘Well, okay, we won’t make any money on it...but we will check the box and say we have built a ‘new energy vehicle’ in China and we're now selling it.’” - Former manager for JV firm</td>
<td>“[JV partners] like SAIC, Dongfeng, FAW...they don't have pressure to make EVs and improve their own brand image like BYD does. They're only focused on gas vehicles.” - Marketing manager for large JV</td>
</tr>
</tbody>
</table>
China Conventional Vehicle Sales: Multinationals Dominate

Conventional Vehicles (23,900,000)

- **Ind. (4.4M)**
- **JV Partners (19.5M)**

**Brand:**
- Chinese
- Multinational
- Tesla

**2016 Sales**

Data scraped from: https://www.gasgoo.com

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China PEV Sales: Independent Chinese Firms Dominate (Not Chinese JV partners)

Conventional Vehicles (23,900,000)

- Ind. (4.4M)
- JV Partners (19.5M)

Plug-in Electric Vehicles (352,000)

- Independent (259.2k)
- JV Partners (85.1k)

Brand:
- Chinese
- Multinational
- Tesla

2016 Sales

Data scraped from: https://www.gasgoo.com

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**Existing Theory**

*Limiting indigenous innovation in established industry*

(Brandt & Thun, 2010; Feng, 2010; Howell, 2016; Huang, 2003; Lazonick & Li, 2012; Nam, 2011)

**New Theory**

*Enabling indigenous innovation in emerging industry*
China’s Independent PEV Firms: Examples of Experimentation

Chery
脚踏实地
Stepping on solid ground

Jiayuan
存在就是合理的
“If it exists, it must be reasonable”¹

Haike
大巧若拙, 大道至简
“Dumbing down is the way up”²

Kandi
异曲同工
Different tune, equally melodic

Shared BEV / CV platform reduces overall BEV production costs; in-house battery design

Lower performance components and localized production enables entry into low cost LSEV market

Flywheel energy storage transmission reduces BEV battery and motor performance requirements and cost

Car sharing business model reduces driving range requirements and enables new refueling approaches

1: Interview #30
2: Interview #27
Cultivating Diverse Experimentation: Local Institutional Support

Chery
脚踏实地
Stepping on solid ground

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存在就是合理的
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异曲同工
Different tune, equally melodic

Subsidies restricted to locally-produced models
Subsidized production facilities; operation in regulatory “gray area”
Free office & pilot production facilities
Subsidized charging infrastructure; local subsidies for BEVs

1: Interview #30
2: Interview #27
Local Protection: Supporting experimentation across PEV industry...

...but might inhibit integration

Existing Theory

Experimentation in early phases of R&D important...
(Nelson, 1961; Scherer, 2011)

...but ultimately must transition from regional to national markets
(Boisot & Meyer, 2008; Meyer, 2008; Wei et al., 2017; Amsden & Chu, 2003; Nelson, 1993)

New Theory

Local Protection: Supporting experimentation across PEV industry...

...but might inhibit integration
Thanks!

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