Not all EVs are equal:
Heterogeneity in behavior and energy consumption in the plug-in vehicle fleet.

Stephen Zoepf
Not all EVs are equal:
Heterogeneity in behavior and energy consumption in
the plug-in vehicle fleet.

Stephen Zoepf
MIT Sloan Automotive Lab
February 6, 2015
Agenda

☐ Energy Consumption in PEVs
  ■ BMW ActiveE
  ■ Toyota Prius PHEV

☐ Charging Behavior

☐ Plug-ins in the rental context
How is this possible?
Accessories drive EV energy consumption at low speeds

![Energy Use vs. Constant Speed Graph]

- **Energy Use (Wh/km)**
- **Constant Speed (km/hr)**
- **Drive Energy**
- **Total (1 kW Aux)**
- **Total (2 kW Aux)**
- **Total (5 kW Aux)**

Figure: Rodgers, 2014
Climate control cuts range by more than 50% at low temps

Figure: Ford Motor Company
Rodgers, Zoepf & Prenninger

Key:
- Driver Options
- Energy Stored
- Energy Lost
BMW ActiveE Field Trial Insights

1. Lithium-Ion Battery.
2. Electric Engine.
3. Power Electronics.
Accessories averaged $\sim 25\%$ of total energy consumed.

<table>
<thead>
<tr>
<th>Probability Density</th>
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<tbody>
<tr>
<td>0</td>
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<tr>
<td>0.02</td>
</tr>
<tr>
<td>0.04</td>
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<tr>
<td>0.06</td>
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<table>
<thead>
<tr>
<th>Aux./Total Energy (%)</th>
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<tr>
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<td>25</td>
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<tr>
<td>50</td>
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<tr>
<td>75</td>
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<td>100</td>
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Subsequent trips show large heterogeneity in consumption.
Heterogeneity is higher in accessory loads.

Probability Density

<table>
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<th>Change in Energy Consumption (%)</th>
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<tr>
<td>Between Subsequent Drive-Charge Events</td>
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High trip-to-trip heterogeneity complicates range prediction

**Survey of EV users:** A more accurate Distance to Empty estimate may be more valuable than increasing the size of the battery pack

Franke, et al, August 2011
PHEVs only complicate matters!

- Driver aggressiveness
- Traffic / Ambient Conditions
- Accessory Usage

- PHEVs now add dual-fuel options:
  - Gasoline vs. electric consumption
  - When will driver recharge the vehicle?
The Prius Plug-In Hybrid

- 2010 Prius-based prototype
- 5.4 kWh (3kWh working capacity)
- 13mi/21km Charge-depleting range
- EV, “Blended” & CS operation modes
Electricity consumption varies widely

Mean: 218 Wh/km
Gasoline Consumption

- Charge-Sustaining
- Charge-Depleting
What % miles using electricity?

Mean: UF = 0.28   PDF = 0.14
What-If Analysis (OFAT)

- Simulated all 60k trips with new:
  - charging schedules (1x/day, opportunistic)
  - new battery sizes (up to 30kWh)
  - new charging rates (up to 8x)

- Recalculated Electricity, Gasoline, Utility Factor and Petroleum Displacement
What-If Takeaways

- Opportunistic 110V charging at all stops would double electric miles to 28%

- 15kWh battery (5x usable capacity) needed to achieve the same result

- For small battery capacity, fast charging does little
Agenda

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- Charging Behavior
- Plug-ins: Preferences in short rentals
- Conclusions & Questions
Charging Model

- Limited literature available on observed charging behavior
- Used a mixed logit model to assess probability of finding and using a charger
- Effects modeled:
  - Location
  - Battery State
  - Day, Time of Day
  - Time until next trip
Factors Increasing Charging Probability

- Longer time until next trip (up to 3 hrs)
- Last trip of the day
- Ending at home* location
- Lower state of charge
- Earlier in the day

- Significant Heterogeneity!
Simulating the charging probability

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<tr>
<td>Ends @ &quot;home&quot; (1=yes, 0=no)</td>
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<tr>
<td>Ends on weekend (1=yes, 0=no)</td>
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</tr>
<tr>
<td>End time</td>
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**Simulated Probability** 0.53

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<td>Ends @ &quot;home&quot; (1=yes, 0=no)</td>
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<td>End time</td>
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**Simulated Probability** 0.33

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<tr>
<td>End time</td>
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**Simulated Probability** 0.04
Conclusions & Recommendations

- High variability PEV energy consumption, even trip-to-trip

- Accessories are source of large power draw and variability

- Charging 100% every night not a good assumption – more study needed.
Break for Questions

☐ Thank you for your attention!

☐ Stephen Zoepf
  ■ szoepf@mit.edu
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- Conclusions & Questions
Why Study Carsharing?

- Opportunity to study over a million consumers who select and use new vehicle technology for short duration

- Carsharing fleets count towards Zero Emission Vehicle law requirements (CA)

- A large portion of carsharing users may purchase a vehicle within a few years
What Matters when Renting?

- Price, Distance & Availability top-cited criteria
- Environmental Impact ranked 8th
- 63% were interested or extremely interested in EVs
- Hybrids and electric vehicles were top requested cars in 2012
Survey Summary

- 68,982 survey email invitations

- “Random” selection of member base

- ~4,000 respondents (>5% response rate (!!) )
Users familiar with hybrids only

Experience with HEVs by Respondent

- Own or Previously Owned: 50.5%
- Driven a Hybrid: 28.3%
- Never Driven a Hybrid: 13.8%
- Don't Know: 4.1%

Experience with PHEVs by Respondent

- Own or Previously Owned: 86.3%
- Driven a PHEV Elsewhere: 7.5%
- Never Driven a PHEV: 2.9%
- Don't Know: 3.3%

Experience with EVs by Respondent

- Own or Previously Owned: 88.4%
- Never Driven an EV: 5.3%
- Don't Know: 2.3%

Suggests ~400:1 ratio of exposure per hybrid in service
Users overstate travel distance

This is bad news for range-limited vehicles!
PEV Utility is Distance-Dependent

**Piecewise Utility of Distance Interacted with Fuel Type**

- **Gasoline**
- **Hybrid**
- **PHEV30**
- **EV100**

**Reported Reservation Distance (miles)**
Summary

1. Zipcar is exposing large numbers of users to alt-fuel vehicles
2. Users are good at estimating time, frequency but overestimate distance (bad for plug-in vehicles)
3. Plug-in vehicle desirability falls off with travel distance (never positive!)
Questions or Comments?

☐ Thank you for your attention!

☐ Stephen Zoepf

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