Optimal Policy for Plug-In Hybrid Electric Vehicles Adoption

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• Problem Statement
• Methodology
• Results
• Conclusion & Future Work
Motivation

• Consumers’ adoption of energy-efficient technologies

• Government’s role
  • Rebates, tax credits, subsidies, loan guarantees,…

• Government’s goals
  • Energy security and independence
  • Pollution prevention
  • Sustainability

• The challenge?
  • Solyndra, Beacon Power, Konarka,…
Motivation

• The proposal
  • Build a decision aid tool for policy makers
    • To further our understanding of the dynamics between consumers' adoption of energy-efficient technologies and government intervention efforts
    • To capture system-wide and local impacts of policies
  • An integrated energy-system model

• Why PHEVs?
Policies of Interest

Problem Statement

- **Market penetration target**
  - Subsidy/Tax Break
  - Tax on conventional vehicle users
  - Penalties on manufacturers
  - CAFE Standards
  - California’s ZEV Program

- **GHG emissions reductions target**
  - Carbon Tax
  - Cap and Trade
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Integrated Energy System Model

• Integrate a PHEV adoption model with an energy system model to devise efficient energy-efficiency policies
  • Track impact of one sector on the others

• Iterative approach
PHEV Adoption Model

- Based on discrete choice analysis
  - Traced back to the 70s [McFadden]
  - Models choices made by people among a finite set of alternatives
    - Choice behavior based on the attributes of the individual and alternatives
  - Calculates the probability that a person chooses a particular alternative
    - Based on utility theory
  - Has several variations based on:
    - Number of available alternatives
      - Binomial choice
      - Multinomial choice
    - Model specification
      - Logit
      - Probit
PHEV Adoption Model: Formulation

- Based on discrete choice analysis (Binary Logit model)

\[
x_{it+1} = \delta_{it} x_{it} + d_{it} (x_{it}, s_{it}) \quad \forall \ i, t = 1, \ldots, T - 1
\]  

\[
PHEV\text{ Demand} = \text{Market Size} \times \text{PHEV Purchase Probability}
\]

\[
d_{PHEV_t}(x_{CV_t}, x_{PHEV_t}, s_{PHEV_t}) = M_t \left\{ \frac{1}{1 + e^{aD\Delta TOC - bD \log \left( \frac{x_{PHEV_t}}{x_{CV_t}} \right) + cD}} \right\} \quad \forall \ t
\]

Total Vehicle Ownership Cost = Purchase Price + O&M Cost – Government Subsidy

\[
TOC_{it}(s_{it}) = P_{it} + OM_{it} - s_{it} \quad \forall \ i, t
\]

\[
P_{PHEV_t} = P_{PHEV_1} \left( \sum_{k=1}^{t-1} d_{PHEV_k} \right)^{-b_L} \quad \forall \ t = 2, \ldots, T
\]

\[x_{it}, s_{it} \geq 0 \quad \forall \ i, t\]
**PHEV Adoption Model: Parameter Estimation**

- **Challenges and assumptions**
  - Limited history of annual sales data for PHEVs
    - Use hybrid vehicle history for parameter estimation
  - Classify available vehicles into two categories
    - Conventional vehicles and PHEVs

- **Data sources**
  - Market size, vehicle purchase price, efficiency and stock
    - EIA’s Annual Energy Outlook reports
  - Annual miles driven, vehicle retirement rates and maintenance costs
    - DOE’s Transportation Energy Databook and Quality Metrics report
Government's Optimal Subsidy Problem

- Cost minimization approach

**Model**

Minimize Total Subsidy Cost
(Subsidy per Vehicle x Number of Vehicles Demanded)

\[
\min TSC(x_{lt}, s_{lt}) = \sum_{i=1}^{2} \sum_{t=1}^{T} r^{t-1}s_{lt}d_{lt}(x_{lt}, s_{lt})
\]

s. t.

*Target Percentage of PHEVs Constraint*

*Logit Model Constraints*
Energy System Model

- Based on EPA’s National MARKAL Model
  - Bottom-up energy system model
  - Detailed technology representation and multiple sectors
  - Demand driven, multiperiod, linear programming optimization model
  - Least-cost path to user-provided demands and imposed policies
  - Can reflect pollutant emissions
  - Reference Energy System (RES)
OUTLINE

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PHEV Adoption Model Results

- Three scenarios based on PHEV market share by 2045:
  - High Penetration: 50% PHEV share
  - Medium Penetration: 25% PHEV share
  - Low Penetration: 10% PHEV share

\[ \text{Subsidy Amount} \]

- Word-of-mouth
- Learning-by-doing
Integrated Energy System Model Results

- Gasoline and electricity demand
  - Convergence achieved after 4 iterations
Integrated Energy System Model Results

- Electricity and gasoline prices
Integrated Energy System Model Results

- GHG Emissions

Transportation Sector GHG Emissions

System GHG Emissions

[Graphs showing GHG emissions from 2010 to 2045 for different penetration levels: High, Medium, Low, and Baseline.]
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Conclusion

• PHEVs are not economical \textit{without subsidies}

• Government should not give out the subsidies \textit{all up-front}

• \textbf{Minimal} impact on \textit{electricity prices}

• \textbf{Bigger} impact on \textit{gasoline prices}

• System GHG emissions heavily dependent on \textit{generation mix}
Future Work

- Impact of PHEV charging behavior
- State-level policy impact
- Improve the consumer choice model
  - Number of vehicle categories considered

Thank you!
Integrated Energy System Model

• Convergence metric
  • Similar to the metric used in EIA’s NEMS model
    • Qualitative metric, based on a 4-point grading scale
    • Compares deviations of convergence variables at each iteration with deviations from the previous iteration (as a percentage)
    • A grade point average (GPA) is given to each convergence variable based on the following grading metric

<table>
<thead>
<tr>
<th>Score (% basis)</th>
<th>Grade on 4-pt scale</th>
<th>Letter grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05 or less</td>
<td>4.0</td>
<td>A</td>
</tr>
<tr>
<td>0.20</td>
<td>3.0</td>
<td>B</td>
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<tr>
<td>0.50</td>
<td>2.0</td>
<td>C</td>
</tr>
<tr>
<td>1.00</td>
<td>1.0</td>
<td>D</td>
</tr>
<tr>
<td>1.50 or more</td>
<td>0.01</td>
<td>F</td>
</tr>
</tbody>
</table>

• Continue iterations until either a pre-specified number of iterations or inter-cycle convergence objective is met