Experience and market curves to analyze energy technology subsidies

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Subsidizing Energy Technologies

Governments around the world subsidize energy technologies:

• Research and Development
• Adoption – e.g. capital investment credit, Feed-in-Tariff

Why should governments subsidize?

• Technology currently brings externality benefits ≥ subsidy cost.
• Technology will improve and become cost-competitive, or at least to ≥ externality benefit.
• Encourage new competitive export industry.
Decision-making and Energy Subsidies

• How do governments decide:
  – Which technologies get subsidized?
  – How to subsidize?
  – When to stop?
• Apparently, heuristically and politically driven
• Need for analytical tools to support subsidy decision-making
Role of subsidy in diffusion

Successful diffusion =

Econ. Viability + Bribe + Persuasion + Education

“Core” subsidy

Supplemental subsidy, outreach, marketing programs
Cascading Diffusion Model for Market Activation

Experience curve for reduction in production costs

Willingness to pay in different sub-markets

Cumulative production of technology

Cost of Production

Public subsidy to stimulate diffusion

A – market activation
B – market saturation

Herron and Williams, Env. Sci Tech (2013)
Case Study of Cascading diffusion: Plug-in Hybrid Vehicles in the U.S.

• PHEVs are expensive to buy, e.g. Chevy Volt costs ~ $34,000, compare with Toyota Camry at $23,000
• PHEV saves running costs: $ electricity/mile cheaper than gas $/mile, high mpg in gas mode (since hybrid)
• Largest part of extra cost is lithium battery - $7,000. Batteries are getting cheaper.
Case Study of Cascading diffusion: Plug-in Hybrid Vehicles in the U.S.

Research questions:
• Can subsidies activate larger markets for PHEV?
• If yes, what is net cost of subsidy after “free” diffusion?

• Preliminary results
Experience Curve for Plug-in Hybrids

\[ \Delta \text{Cost}_{\text{PHEV}}(P) = 4000 + 7000(P/P_0)^{-\alpha} \]

- \( \Delta \text{Cost}_{\text{PHEV}} \) is cost premium of PHEV over similar conventional gasoline vehicle
- \( P \) is cumulative production, \( P_0 = 71,000 \) cars
- \$4,000 is “incompressible” cost, mainly electric motors (assume no tech. progress)
- \$7,000 is current Lithium battery price
- Two learning rates (LR):
  - High Learning, historical progress for Li batteries for consumer electronics LR = 22%, \( \alpha = 0.41 \)
  - Low Learning, IEA report, LR = 9.5%, \( \alpha = 0.15 \)
Experience Curve for Lithium Batteries in consumer electronics: 1993-2005

\[- \text{Cost}\ (P) = C_0 \times (P/P_0)^{-\alpha} = 600\ $/kW (P/2.3\ million\ kWh)^{-0.41}\]

Learning rate = 22%, \( \alpha = 0.41 \)
Market curves

• Analyzing “core” subsidy, so treat plug-in hybrid market as purely economic decision (PHEV vs. conventional vehicle)

• Market drivers are heterogeneous:
  – Geographical: state variability in gasoline and electricity prices
  – Individual: driving patterns vary, in particular annual miles driven.
Willingness-to-Pay (WTP)

- WTP = Net Present Value (Annual savings, 10% discount rate, 10 years)
- Annual savings = Gasoline cost for conventional vehicle (30 mpg) – (PHEV electricity (3 miles/kWh) + PHEV gasoline (40 mpg))
- Miles per day = annual miles/365
- If Miles per day < 40, all electricity
- If miles per day > 40, use some gasoline
WTP \( \rightarrow \) Market Curve

- Use micro-level individual data for annual miles driven from the National Household Transportation Survey (~300,000 responses)
- Based on state of residence, use state-specific electricity and gasoline prices
- Bin WTP into 50 different cohorts, then order from highest to lowest
- Assume potential adoption of 1 PHEV per vehicle purchaser
• Current price differential = $11,000, $7,500 subsidy enough to make NPV > 0 for ~ 80 million drivers.
• Why slow growth in adoption? $/mile is contributor, not determinant of consumer utility derived from vehicle (limited model choices big factor?)
• High learning: after 220,000 PHEVs on the road, NPV >0 for 68 million consumers until saturation
• Low learning: after 2.1 million PHEVs on the road, NPV >0 for 31 million consumer until saturation
Policy costs

- Constant subsidy: $7,500 until market activation
- Continuously tapered subsidy: follows experience curve until market activation

Subsidy cost per vehicle = \[
\frac{\text{Total cost}}{\text{Subsidized + “Free” adoption}}
\]

<table>
<thead>
<tr>
<th></th>
<th>Low learning</th>
<th>High learning</th>
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</thead>
<tbody>
<tr>
<td>Market activation</td>
<td>2.1 million</td>
<td>220,000</td>
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<tr>
<td>Market saturation</td>
<td>31 million</td>
<td>68 million</td>
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<tr>
<td>Total subsidy cost</td>
<td>$1.3-$16 billion</td>
<td>$210 million – $1.6 billion</td>
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<td>Subsidy per vehicle</td>
<td>$44-520</td>
<td>$3-21</td>
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Uncertainty

Results are sensitive to:

• Value of learning rate
• Gasoline and electricity prices
• Mpg of competing conventional vehicle

Governments need to measure learning rates as part of subsidy programs.
• Expensive gas makes economically attractive even with low learning
• Technology is a non-starter if gasoline becomes cheap (relative to electricity)
International Cascading Diffusion: Residential Solid Oxide Fuel Cells
So What?

- Cascading diffusion model informs necessary (if not sufficient) condition of economic viability
- Unfavorable learning rate and/or energy prices can lead to “no-go” decision for subsidy
- Should be part of larger modeling/data framework to plan energy technology subsidies.
- Dock with bribe, persuasion and/or education to achieve diffusion
- Potential for international cooperation (or at least information exchange) on energy technology subsidies.
Thank you for your attention!

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Letchworth State Park, near Rochester, New York
Variability of Saturation adoption with gas and electricity prices

![Graph showing the variability of saturation adoption with gas and electricity prices. The graph plots total adoption of PHEV on the y-axis against electricity price relative to current on the x-axis and gas price per gallon on the z-axis. The graph illustrates how changes in gas and electricity prices affect the total adoption of PHEVs.]