Externalities and Incentives

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Linking Regulatory Means and Environmental Ends:
Intended and Unintended Consequences

Harvard Electricity Policy Group

Cambridge, MA
May 28, 2009
Energy Externalities

“‘Externalities’ refers to situations when the effect of production or consumption of goods and services imposes costs or benefits on others which are not reflected in the prices charged for the goods and services being provided.” (OECD Glossary of Statistical Terms)

• Air, Water, Land Pollution.
• Occupational Risks in Energy Production.
• Oil Imports and Energy Security.
• Greenhouse Gases and Global Warming.
• Network Congestion.
• Learning by Doing.
Externalities and Market Failures

• R & D and Information Spillovers
  – Government Funding
  – ARPA-E Innovation

• Infant Industries and Learning by Doing
  – Getting Started
  – Targeted Subsidies

• Environmental Pollution
  – Large and Sustained
  – Efficiency Standards
  – Cap and Trade or Taxes
Example Policy Instruments

- Quantity Targets
- Renewable Portfolio Standards
- Feed-in Tariffs
- Production Tax Credits
- Investment Tax Credits

Linking Regulatory Means and Environmental Ends:
Intended and Unintended Consequences
DICE Tax Under Stern Discount Rates
Comparing Consumption Profiles

Per Capita Consumption Versus Baseline

![Graph showing consumption profiles over years, with deviations from baseline marked.](image-url)
Learning-By-Doing

Linking Regulatory Means and Environmental Ends

Example of the California Solar Initiative
Schwarzenegger Plan

• Target Date of 2015.
• “California Solar Initiative” (CSI).
• Solar Installation Incentives Over 11 Years.
Externalities and Solar Policy

• Consumer Choice
  – Net Present Value
  – Diffusion Process

• Environmental Externalities, CO$_2$

• Learning By Doing
  – Cumulative Production (global)
  – Cumulative Installations (local)
Modeling Consumer Choice

Demand Curve

\[ q_t = \frac{a_t q_{\text{max}}}{a_t + (q_{\text{max}} - a_t) e^{-bNPV_t}} + \text{diff}_t \]

Diffusion (indirect LBD)

\[ \text{diff}_t = \gamma q_{t-1} \left(1 - \frac{q_{t-1}}{q_{\text{max}}} \right) \]

Base Demand Updating

\[ a_t = a_{t-1} \left(\frac{q_{t-1} + \text{diff}_{t-1}}{q_{t-1}} \right) \]

Consumer Net Present Value

\[ NPV_t \left(\text{Cost}, \text{Subsidy} \right) \]
Learning-By-Doing

Production Cost

\[ P_t = \alpha_M Q_{G,t-1}^{-\beta_M} + \alpha_{BOS} Q_{t-1}^{-\beta_{BOS}} \]

Learning Rate (LR) is the percentage decrease in cost from a doubling of experience.

Learning Rates

Global Production, \( LR = 1 - 2^{-\beta_M} = 10\% \)

Local Installation, \( LR = 1 - 2^{-\beta_{BOS}} = 10\% \)
Economic Efficiency

Choose the trajectory of incentives to maximize the present value of the CSI.

\[ \text{Max PVSB}(I_t) = \sum_{t=1}^{T} \left\{ Xq_t(I_t) + q_t(I_t) \frac{NPV_t(I_t, Q_t, e) - q_t(I_t)I_t}{(1+r)^t} \right\} \]

Carbon Externality: \( X \)

Electricity Price Growth Rate: \( e \)

Consumer Incentives: \( I_t \)
Model Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X$</td>
<td>Environmental externality benefit per installed Watt</td>
<td>$0.015 \text{ per year}$</td>
</tr>
<tr>
<td>$\gamma_{BM}$</td>
<td>Progress ratio for modules</td>
<td>0.9</td>
</tr>
<tr>
<td>$\gamma_{BROS}$</td>
<td>Progress ratio for balance of system</td>
<td>0.9</td>
</tr>
<tr>
<td>$g_G$</td>
<td>Long-term global solar growth rate</td>
<td>10%</td>
</tr>
<tr>
<td>$a_{RR}$</td>
<td>Demand curve parameter, residential retrofit</td>
<td>1,000</td>
</tr>
<tr>
<td>$b_{RR}$</td>
<td>Demand curve parameter, residential retrofit</td>
<td>1.04</td>
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<tr>
<td>$q_{max, RR}$</td>
<td>Maximum yearly number of installations (res. ret.)</td>
<td>200,000</td>
</tr>
<tr>
<td>$a_{NC}$</td>
<td>Demand curve parameter, new construction</td>
<td>212</td>
</tr>
<tr>
<td>$b_{NC}$</td>
<td>Demand curve parameter, new construction</td>
<td>1.04</td>
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<tr>
<td>$q_{max, NC}$</td>
<td>Maximum yearly number of installations (new cons.)</td>
<td>75,000</td>
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<td>$\gamma_{RR}$</td>
<td>Diffusion parameter, residential retrofit</td>
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<tr>
<td>$\gamma_{NC}$</td>
<td>Diffusion parameter, new construction</td>
<td>0.15</td>
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</table>

Demand Model

Yearly Installations of Residential PV Systems Versus NPV per Watt, and the Fitted Demand Curve

## NPV Parameters

### Parameter Values for the NPV Spreadsheet Model (Residential Retrofit)

<table>
<thead>
<tr>
<th>Parameter (technical)</th>
<th>Value</th>
<th>Parameter (economic)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average system size</td>
<td>5,520 DC rated Watts</td>
<td>Discount rate</td>
<td>7%</td>
</tr>
<tr>
<td>2003 net installation price per DC rated Watt</td>
<td>$7.28</td>
<td>Residential borrowing rate</td>
<td>5%</td>
</tr>
<tr>
<td>kWh savings per year</td>
<td>7,176</td>
<td>Marginal tax rate</td>
<td>32%</td>
</tr>
<tr>
<td>Inverter replacement cost</td>
<td>$3,600</td>
<td>Loan term</td>
<td>30 years</td>
</tr>
<tr>
<td>Maintenance cost per year</td>
<td>$10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time-of-use (TOU) factor</td>
<td>1.25</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Panel expected life</td>
<td>30 years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inverter expected life</td>
<td>10 years</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Solar Requires Subsidies

<table>
<thead>
<tr>
<th>Market Segment</th>
<th>Price ($000)</th>
<th>Incentive ($000)</th>
<th>NPV no inc. ($000)</th>
<th>NPV with inc. ($000)</th>
<th>NPV/Watt with inc. ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Res Retrofit</td>
<td>36.9</td>
<td>14.3</td>
<td>-7.7</td>
<td>1.6</td>
<td>0.35</td>
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<tr>
<td>PV Res New</td>
<td>12.5</td>
<td>5.3</td>
<td>-2.1</td>
<td>1.4</td>
<td>0.78</td>
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</tbody>
</table>

Retrofit Costs and Benefits

Costs and Benefits of CSI for PV Residential Retrofit

Installation Profile


Comparing Policy Profiles

<table>
<thead>
<tr>
<th>Year</th>
<th>Optimal</th>
<th>CSI</th>
<th>Year</th>
<th>Optimal</th>
<th>CSI</th>
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<tbody>
<tr>
<td>2006</td>
<td>$3.23</td>
<td>$3.10</td>
<td>2012</td>
<td>$1.82</td>
<td>$1.85</td>
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<tr>
<td>2007</td>
<td>$2.96</td>
<td>$2.83</td>
<td>2013</td>
<td>$1.58</td>
<td>$1.70</td>
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<tr>
<td>2008</td>
<td>$2.74</td>
<td>$2.59</td>
<td>2014</td>
<td>$1.34</td>
<td>$1.57</td>
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<tr>
<td>2009</td>
<td>$2.52</td>
<td>$2.37</td>
<td>2015</td>
<td>$1.09</td>
<td>$1.46</td>
</tr>
<tr>
<td>2010</td>
<td>$2.30</td>
<td>$2.18</td>
<td>2016</td>
<td>$0.78</td>
<td>$1.35</td>
</tr>
<tr>
<td>2011</td>
<td>$2.06</td>
<td>$2.00</td>
<td>Average</td>
<td>$2.04</td>
<td>$2.09</td>
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</tbody>
</table>

Optimal Policy Depends on LBD Rate

Average Incentives as a Function of the Progress Ratio,
Holding All Other Parameters Constant

California Solar Initiative

• Dominant Market Failure
  – LBD Incentive Provides Most of the Benefits.
  – Carbon Impact is a Byproduct.

• At Nominal 90% Progress Rate
  – Substantial Expected Net Benefits.
  – 250,000 Home by 2017 vs. 1,000,000 Target.
  – Actual Installations Higher or Lower Depending on LBD Rate.
Externalities and Incentives

- Structure of Externality Problem Materially Affects Structure of Optimal Policy.
- With Many Competing Policies, There is a High Risk of Unintended Consequences.
- Bad Outcomes Include High Costs and Little Sustainable Environmental Benefit.
- Strong Interactions with Market Design, Smart Grids, and Smart Pricing Incentives.