Climate change and Technology Policy: 

identification of sources of cost reductions to inform policy design

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“Technology push” and “demand pull”

**Technology Push:** govt actions that reduce the **cost** of innovation to private actors

**Demand Pull:** govt actions that increase the **payoff** to successful innovation for private actors

<table>
<thead>
<tr>
<th>Technology push</th>
<th>Demand pull</th>
</tr>
</thead>
<tbody>
<tr>
<td>Govt Target:</td>
<td>↑ size of market</td>
</tr>
<tr>
<td>↑ availability of knowledge</td>
<td>↑ size of market</td>
</tr>
<tr>
<td>Examples:</td>
<td>IPR, tax credits, govt procurement, technology mandates, standards, taxes on substitutes</td>
</tr>
<tr>
<td>govt R&amp;D, tax credits, education, demonstration projects, knowledge networks</td>
<td></td>
</tr>
</tbody>
</table>

**Consensus:** *both necessary, neither sufficient*

But how to allocate?
Most technologies get cheaper...though not all.

Source: Nemet (2007)
Cost of electricity from photovoltaics 1957—2003

factor of 100 cost reduction

Source: Nemet (2006)
Price of PV modules

Source: Nemet (2006)
### PV: identification of cost reducing factors

<table>
<thead>
<tr>
<th>PV manufacturing process</th>
<th>Modeling cost dynamics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon feedstock</td>
<td>$\Delta Cost = f(\text{Plant size, Si cost, Wafer size, Module efficiency, Si Consumption, Yield, Poly-crystal %}, \epsilon)$</td>
</tr>
<tr>
<td>Crystallization</td>
<td></td>
</tr>
<tr>
<td>Wafering</td>
<td></td>
</tr>
<tr>
<td>Deposition</td>
<td></td>
</tr>
<tr>
<td>Encapsulation</td>
<td></td>
</tr>
</tbody>
</table>

Source: Nemet (2006)
Change in each factor

<table>
<thead>
<tr>
<th>Factor</th>
<th>Change</th>
<th>Multiple</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant size</td>
<td>76 kW/yr → 14 MW/yr</td>
<td>184</td>
</tr>
<tr>
<td>Si cost</td>
<td>300 $/kg → 25 $/kg</td>
<td>$12^{-1}$</td>
</tr>
<tr>
<td>Wafer size</td>
<td>45 cm² → 180 cm²</td>
<td>4</td>
</tr>
<tr>
<td>Module efficiency</td>
<td>6.4% → 13.5%</td>
<td>2.1</td>
</tr>
<tr>
<td>Si consumption</td>
<td>30 g/W → 18 g/W</td>
<td>$1.7^{-1}$</td>
</tr>
<tr>
<td>Yield</td>
<td>80% → 92%</td>
<td>1.2</td>
</tr>
<tr>
<td>Poly-crystal %</td>
<td>0% → 50%</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: Nemet (2006)
Sources of historical cost reductions for PV

85% of cost reduction due to R&D and expected demand

Source: Nemet (2006)
Results:
• Efficiency, plant size, silicon cost most important. . .
  . . . but weakly explained by experience and l-b-d.
• Result insensitive to uncertainty in data

Implications for models and policy:
1. Using exp-curves better than omitting them, but. . .
2. Exp-curves over-estimate tech change from deployment alone
3. Models need explanatory variables other than experience
4. Climate policy needs to create incentives for investments in cost-reducing activities—not just “ride down the learning curve”
Other work (preliminary) on identifying sources of cost reductions:

STE and wind
Cost reductions in wind power plants

Preliminary results:
- Unit scale, large
- Manf scale, less so
- More R&D + LbD interactions
- Learning-by-doing for siting and O&M
Cost reductions in solar thermal electric plants

Preliminary results:
- Unit Scale
- Manf. scale?
- O&M (through LbD)
- Applied R&D
PART 2: Motivation

1. Technology Policy:
   - Technology Push
     \[ \downarrow \text{costs of innovation} \]
   - Demand pull
     \[ \uparrow \text{payoffs to innovation} \]
   - Large public funds at stake
   - Allocation, Timing

2. Pre-commercial technologies
   difficult to model, often ignored
   possible large impacts

   Purely organic PV
   - low cost, organic material
   - scalable manf. process
   - building integration
Approach

How best to choose **level and timing** of **R&D and subsidies** to achieve cost target?

## Manufacturing costs

<table>
<thead>
<tr>
<th>Cost component</th>
<th>Costs ($/m^2)</th>
<th>Portion of total</th>
<th>Unit cost f(output)</th>
<th>b value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>28.15</td>
<td>37%</td>
<td>Declining</td>
<td>0.2</td>
</tr>
<tr>
<td>Processes (labor costs)</td>
<td>8.00</td>
<td>11%</td>
<td>Declining</td>
<td>0.2</td>
</tr>
<tr>
<td>Processes (capital costs)</td>
<td>23.50</td>
<td>31%</td>
<td>Declining</td>
<td>0.2</td>
</tr>
<tr>
<td>Overhead (fixed)</td>
<td>8.18</td>
<td>11%</td>
<td>Declining</td>
<td>0.2</td>
</tr>
<tr>
<td>Overhead (variable)</td>
<td>8.18</td>
<td>11%</td>
<td>Static</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>76.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Kalowekamo (2007)
R&D productivity: expert elicitation

<table>
<thead>
<tr>
<th>R&amp;D Investment</th>
<th>Lifetime: 5y</th>
<th>Lifetime: 30y</th>
<th>Lifetime: 15y</th>
</tr>
</thead>
<tbody>
<tr>
<td>No R&amp;D</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Low R&amp;D</td>
<td>63%</td>
<td>37%</td>
<td>0%</td>
</tr>
<tr>
<td>High R&amp;D</td>
<td>42%</td>
<td>39%</td>
<td>19%</td>
</tr>
<tr>
<td>Efficiency:</td>
<td>5%</td>
<td>15%</td>
<td>31%</td>
</tr>
</tbody>
</table>

Source: Baker (2007)
Calculating levelized costs

\[ M_t = \sum_{i=1}^{5} m_{i,t-5} \cdot \left( \frac{k_t}{k_{t-5}} \right)^{b_i} \]

\[ C_p = \frac{M}{Y} + BOS \]

\[ C = \frac{C_p}{F \cdot h} \cdot \frac{\delta}{1 - (1 + \delta)^{-L}} \]

- Manf costs $/m^2
- Cap. costs $/W
- Levelized costs $/kWh

**Source:** Nemet and Baker (2009)
DEMAND CURVES

Backup generation

Free storage

$0/tC

$1,000/tC

$/kWh

Demand (TW of capacity)

Thanks: Haewon

Gregory Nemet: Technology Policy and Climate Change
Approach

How best to choose level and timing of R&D and subsidies to achieve cost target?

Source: Nemet and Baker (2009)

Gregory Nemet: Technology Policy and Climate Change
RESULTS: PV Lev. costs ($/kWh)

<table>
<thead>
<tr>
<th></th>
<th>Subsidy</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>None</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>2040</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>0.536</td>
<td>0.201</td>
<td>0.162</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>0.111</td>
<td>0.042</td>
<td>0.035</td>
</tr>
<tr>
<td>High</td>
<td>0.087</td>
<td>0.033</td>
<td>0.028</td>
</tr>
<tr>
<td>2050</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>0.536</td>
<td>0.200</td>
<td>0.162</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>0.014</td>
<td>0.016</td>
<td>0.016</td>
</tr>
<tr>
<td>High</td>
<td>0.009</td>
<td>0.010</td>
<td>0.010</td>
</tr>
</tbody>
</table>

Source: Nemet and Baker (2009)
RESULTS: PV Lev. costs ($/kWh)
Impact of subsidies under 3 technical outcomes

5% efficiency
5 year lifetime

15% efficiency
30 year lifetime

31% efficiency
15 year lifetime

20% Capacity limit; no carbon tax; no CCS; advanced nuclear

Source: Nemet and Baker (2009)

Gregory Nemet: Technology Policy and Climate Change
PART 2 CONCLUSIONS

for this Pre-commercial Low-C tech:

- **Successful R&D** reduces costs to below the 4c/kWh target

- **Subsidies** alone do not reach this target

- Production effects (Lbd, Scale) less important than **investment + success of R&D**

- **Subsidies** provide a hedge against failure in R&D programs.

- These conclusions robust to uncertainty in parameters...and C-price, storage.
REMAINING QUESTIONS

Is there a **positive interaction** effect between Learning by Doing (LBD) and R&D?
- necessary to translate lab improvements to comm’l products?
- if so, value of interaction effect must be very large

Is large demand necessary to induce industry R&D?
- we are only considering government R&D
- commercial products impossible without big private tech dev?

Is there real social value to 10c/kWh PV?

Is hedge still valuable with multiple technologies?