Technology Learning in the ETP Model

Dolf Gielen
Niclas Mattsson
Fridtjof Unander

International Energy Agency
IEW
Paris, 22-24 June 2004

Topics

1. The Technology Learning Modelling Challenge
2. The ETP Experience
3. Case Study Renewables
4. Conclusions
1 The Technology Learning Modelling Challenge

Issues

- Applicability of theory;
- Data uncertainty;
- Calculation efforts vs. policy relevance;
- Algorithm choice.
Basic Theory

Investment cost decline continuously with X % for each doubling of the cumulative capacity

Is This Theory Really Widely Accepted?

Some statements:
- "All technologies have a PR of 0.82";
- "Established technologies learn at a lower rate than emerging technologies";
- "Learning rates will decline as the technology matures";
- "Technology learning will require more R&D funds";
Modelling creates new learning issues

• What about salvaging of learning
• What about regional spill-over effects
• What about learning-by-doing vs. learning by R&D
• What is a “correct” discount rate for learning investments
• What is a credible maximum industry growth rate

Data Uncertainty
Example Fuel Cells: 0.7 or 4.5 trillion US$ Needed?

<table>
<thead>
<tr>
<th>VEHICLE PRODUCTION</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative FCV Production, OECD (millions)</td>
<td>0.1</td>
<td>14.1</td>
<td>95</td>
<td>261.2</td>
</tr>
<tr>
<td>Cumulative FCV Production, World (millions)</td>
<td>0.1</td>
<td>14.7</td>
<td>113.7</td>
<td>404.3</td>
</tr>
<tr>
<td>FCV Share of Sales, OECD (%)</td>
<td>0.1</td>
<td>10</td>
<td>30</td>
<td>90</td>
</tr>
</tbody>
</table>

VEHICLE COSTS, OPTIMISTIC CASE

| Incremental cost per vehicle - 0.82 progress ratio ($) | 13,000 | 3,300 | 1,850 | 1,300 |
| Total FCV incremental cost ($ bln) | 2 | 55 | 255 | 654 |

VEHICLE COSTS, PESSIMISTIC CASE

| Incremental cost per vehicle - 0.9 progress ratio ($) | 34,000 | 16,400 | 12,000 | 9,000 |
| Total FCV incremental cost ($ bln) | 6 | 257 | 1,501 | 4,481 |

Source: IEA 2003
### Strict Application of the Theory in an Energy Model

*Can PV cost really decline by a factor 10? Reality check needed*

<table>
<thead>
<tr>
<th>Year</th>
<th>Cumulative Capacity (GW)</th>
<th>Investment Costs ($/kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>0.3</td>
<td>5500</td>
</tr>
<tr>
<td>2010</td>
<td>2.1</td>
<td>3058</td>
</tr>
<tr>
<td>2020</td>
<td>13.0</td>
<td>1700</td>
</tr>
<tr>
<td>2030</td>
<td>65.3</td>
<td>1012</td>
</tr>
<tr>
<td>2040</td>
<td>264.2</td>
<td>646</td>
</tr>
<tr>
<td>2050</td>
<td>685.3</td>
<td>475</td>
</tr>
</tbody>
</table>

### Calculation Efforts vs. Policy Relevance

- ETL can be of key importance;
- But calculation time multiplies with ETL;
- End point (2050) can look similar with ETL and endogenous investment cost reductions;
- Using ETL will result in higher initial investments 2000-2030;
- ETL is important if competition between learning technologies is analysed;
- ETL is less important if competing policy packages (picking winners) are analysed.
MARKAL Algorithm Choice

- **ETL:**
  \[ IC(t) = f(IC(t_0), \text{GROWTH}, \text{CCAP}(t_0), \text{PR}, \text{Investmnt}(t_0\ldots t)) \]

- **HETL:**
  \[ IC(t) = f(IC(t_0), \text{GROWTH}, \text{CCAP}(t_0), \text{PR}) \]

- **IETL:**
  \[ IC(t) = f(IC(t_0), \text{GROWTH}, \text{CCAP}(t_0), \text{PR}, \text{growth path}) \]

- **SETL:**
  \[ IC(t) = \text{user defined, in combination with lower bound on investments} \]

- **HETL/IETL:** code is available, not yet tested

---

2 The ETP Experience
What is ETP?

- Energy Technology Perspectives model;
- ANSWER-MARKAL based;
- Global, 15 regions;
- “From Well to Wheel”;
- So far applied for CCS, hydrogen, transport and renewables;

- IEA - ETP model takes 45 minutes to solve (2000-2050, 15 regions).

ETP model structure

Model definition

- Technology library
- Resource availability
- Operators
- Development Constraints
- Policy scenarios

Calibration

- IEA energy statistics
- Energy indicators
- End-use information
- WEO RS demand vectors

- ETP-ANSWER

ETP-MARKAL matrix generation/optimisation

- Importing results into ANSWER or VEDA

Analysis

Reporting
ETP Technology Learning
“Uphill progress“

- ETL: works, but too slow for complex problems
- SETL: works, but interpretation is tricky
- IETL: code implemented, to be tested

3 Renewables Case Study
(SETL)
Policy Questions

- Do we need investment subsidies forever?
- Will long-term benefits outweigh short-term cost?
- What about renewables – CO₂ capture competition?
- Can transfer of cheap renewables technologies (post learning phase) solve the CO₂ problem?

Deployment Policies

(Lower bounds in model terms)

<table>
<thead>
<tr>
<th>Deployment targets [PJ/yr]</th>
<th>WEU</th>
<th>USA</th>
<th>Other IEA</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small hydro</td>
<td>257.7</td>
<td>51.5</td>
<td>216.4</td>
<td>505.2</td>
</tr>
<tr>
<td>Biomass</td>
<td>468.3</td>
<td>622.5</td>
<td>287.9</td>
<td>546.3</td>
</tr>
<tr>
<td>Geothermal</td>
<td>46.4</td>
<td>140</td>
<td>56.3</td>
<td>281.7</td>
</tr>
<tr>
<td>Wind</td>
<td>3026.2</td>
<td>509.5</td>
<td>100.3</td>
<td>493.8</td>
</tr>
<tr>
<td>Solar</td>
<td>16.7</td>
<td>109.8</td>
<td>13.9</td>
<td>26.2</td>
</tr>
<tr>
<td>Tidal</td>
<td>47.3</td>
<td>9.5</td>
<td>0.3</td>
<td>3</td>
</tr>
</tbody>
</table>
### Investment Cost Reductions

<table>
<thead>
<tr>
<th>Learning rate</th>
<th>DEPLOYMENT</th>
<th>BASE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000</td>
<td>2010</td>
</tr>
<tr>
<td>Wind onshore</td>
<td>10%</td>
<td>1000</td>
</tr>
<tr>
<td>Solar PV</td>
<td>20%</td>
<td>5500</td>
</tr>
<tr>
<td>Solar thermal</td>
<td>5%</td>
<td>2400</td>
</tr>
<tr>
<td>Geothermal</td>
<td>5%</td>
<td>1250</td>
</tr>
<tr>
<td>Small hydro</td>
<td>5%</td>
<td>2500</td>
</tr>
<tr>
<td>Bio IGCC</td>
<td>10%</td>
<td>-</td>
</tr>
<tr>
<td>Tidal</td>
<td>5%</td>
<td>3200</td>
</tr>
</tbody>
</table>

### Impact on Power Sector Fuel Mix

- **Solar**
- **Tidal**
- **Wind**
- **Geothermal**
- **Bio/waste**
- **Hydro**
- **Gas - CO2**
- **Gas**
- **Coal - CO2**
- **Coal**
- **Oil**
- **Nuclear**
Consistency Check:

Wind seems ok, given data uncertainty

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assumed capacity doublings</td>
<td>2.3</td>
<td>5.2</td>
<td>6.9</td>
<td>7.5</td>
<td>7.9</td>
<td></td>
</tr>
<tr>
<td>Model capacity doublings</td>
<td>2.1</td>
<td>5.0</td>
<td>5.7</td>
<td>6.2</td>
<td>7.2</td>
<td></td>
</tr>
<tr>
<td>Assumed investment cost index [-]</td>
<td>100</td>
<td>78</td>
<td>58</td>
<td>48</td>
<td>45</td>
<td>43</td>
</tr>
<tr>
<td>Model implicit investment cost index [-]</td>
<td>100</td>
<td>80</td>
<td>59</td>
<td>55</td>
<td>52</td>
<td>47</td>
</tr>
<tr>
<td>PV</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assumed capacity doublings</td>
<td>2.7</td>
<td>5.7</td>
<td>7.4</td>
<td>8.0</td>
<td>8.4</td>
<td></td>
</tr>
<tr>
<td>Model capacity doublings</td>
<td>2.1</td>
<td>4.9</td>
<td>4.9</td>
<td>9.4</td>
<td>11.4</td>
<td></td>
</tr>
<tr>
<td>Assumed investment cost index [-]</td>
<td>100</td>
<td>55</td>
<td>28</td>
<td>19</td>
<td>17</td>
<td>15</td>
</tr>
<tr>
<td>Model implicit investment cost index [-]</td>
<td>100</td>
<td>63</td>
<td>33</td>
<td>33</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Model implicit investment cost index PR = .83 [-]</td>
<td>100</td>
<td>68</td>
<td>40</td>
<td>40</td>
<td>17</td>
<td>12</td>
</tr>
</tbody>
</table>

Consistency Check:

Investments continue post-2020: The Market Forces take over from Policy Initiatives
Policy Cost-Effectiveness
Not cost-effective pre-2050 (excluding CO₂ externalities): technology transfer alone is insufficient

DEPLOYMENT + CO2 Tax
Renewables and CCS are both needed
Conclusions so far

- New technology and technology learning is a key policy issue;
- Especially relevant for certain emerging technologies;
- Modelling of learning still under development;
- The relevance of endogenous learning depends on the type of policy analysis.
Outlook

- Test IETL
- Reality check of cost reductions via learning
- Learning by R&D vs learning-by-doing
- Spill over effects/technology transfer
- Focus on fuel cells/solar