From single-factor to multi-factor learning curves for modelling innovation - a review

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What is happening energy technology costs (e.g. PV)?

Source: Bloomberg NEF
How to model cost reductions due to energy technology learning?

Basic method: SINGLE FACTOR LEARNING CURVE

\[ C_t = f(Q) = a Q^\beta \]

- \( C_t \) is unit costs
- \( Q \) is learning by-doing factor (e.g. capacity installation)
- \( \beta \) is elasticity of learning \( \rightarrow \) learning rate \( LR = F(\beta) = 1 - 2^\beta \)

Relates cost reductions of a technology to deployment
What drove cost reductions of PV from 1979 to 2001?

Source: (Nemet, 2006)
How many academic papers use multi-factor learning curves?

<table>
<thead>
<tr>
<th>Energy Technology Cost Reduction Drivers</th>
<th>Number of Papers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learning By Doing</td>
<td>33</td>
</tr>
<tr>
<td>Learning By Researching</td>
<td>19</td>
</tr>
<tr>
<td>Learning by Interacting (geographical)</td>
<td>6</td>
</tr>
<tr>
<td>Learning by Interacting - Industry</td>
<td>6</td>
</tr>
<tr>
<td>Input material</td>
<td>13</td>
</tr>
<tr>
<td>Economies of scale</td>
<td>16</td>
</tr>
<tr>
<td>External learning - Policy</td>
<td>7</td>
</tr>
<tr>
<td>External learning - Market</td>
<td>5</td>
</tr>
<tr>
<td>External learning - Resource/technology</td>
<td>9</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>114</strong></td>
</tr>
</tbody>
</table>
What learning dynamics are not explained in 1FLCs?

1. Differences between Emerging Technologies vs Current Technologies

2. Drivers impacting Global Learning and Local Learning

3. Drivers impacting Market-Wide vs Industry-Wide learning

4. Different costs components learning
   • Technology Vs one-component learning vs system learning
How does learning differ for emerging vs current technologies?
What is the difference between global vs local learning?

WIND ONSHORE

1) Research in different countries during 1970s (DENMARK, US, GERMANY)

2) Collaboration and deployment in niche market during 1980s (e.g. Danish turbines deployed in US)

   Local deployment achievements → Capacity deployment in-country

3) Delocalization manufactures, market expansion in new interesting markets

   KNOWLEDGE SPILLOVER IN NEW COUNTRIES
   Research knowledge, technical achievement
   Manufacturing learning

   INTERACTION BETWEEN COUNTRIES and ACTORS
   Technical achievement
   Manufactures learning
What is difference between Industry-wide Vs Market-wide learning and interaction?

Industry-wide learning

Public R&D

Company 1

Company 2

Company n

Manufacturing learning

R&D LEARNING and SUPPORT

MANUFACTURING DEPLOYMENT EXPERIENCE

CLUSTER & SPILLOVERS

INNOVATION: MATERIAL USE AND TECHNOLOGY SCALE

Feedback from the market

Market-wide learning

Policy

Regulation

Energy quality

Market changes

Market n

POLITICAL and NATIONAL STABILITY

DEVELOPMENT OF MARKET STRUCTURE e.g. infrastructures

Fees, exchange rate, inflation, input material price changes

MARKET SPILLOVERS and NETWORKING

Source: Adapted from Martinsen 2009, based on figure 2.2 and 2.9 in IEA (2000), figure 2.3 and 3.1 in Neij et al. (2003).
How does learning vary by costs components? technology vs multi-component learning vs system learning

Input costs → Technology costs → Project plant costs + Operating costs → Energy prices

Silicon, Silver price  
Energy consumptions  
Capital costs PV manufactures  
Labour costs  

PV module panel  
Balance of the system:  
Inverter  
Mounting system  
Electrical cabling  

Technology costs  
Hard/Soft deployment costs:  
Installation, transportation, project design, customer acquisition  
Financing, support scheme  

Maintenance work (cleaning, inspection, repair)  
Insurance  
Metering  
Legal-administrative work (e.g. processes related to taxation)  
Decommissioning  

Previous costs  
Energy performance (Capacity factor, technology life)  
Financial return  

Single Factor Learning Curves cannot explain all cost reductions

Risk of overestimation of deployment effect and underestimation of other drivers
Multi-factor learning curves **advantages**

Includes broader set of factors impacting costs reduction:

- Value of innovation activities and R&D investments
- Value of spillover of knowledge between countries
- Value of interaction between different actors, knowledge exchange between partners in same industry
- Effect of economies of scale of a device, plant, or an industry
- Material use change, market price changes
Multi-factor learning curves summary

- Multi factor learning curve models can incorporate more information to understand the innovation challenges

- 2-factor experience curves shed new light on value of R&D investment and innovation activity on renewable energy

- Learning by-interacting driver explore the effect of industry formation on costs reduction

- Drawback: limits on data access, model limitation as dangers of overfitting, correlation between learning factors, causation between dependent and independent variables
Thank you

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