Toward Cost Buydown Via Learning-By-Doing For Environmental Energy Technologies

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LEARNING CURVES

• Learning curves relate labor costs for given product by specific firm to cumulative production as quantification of observations that:
  – Manufacturing experience facilitates worker skill improvements.
  – Benefits tend to increase in regular manner with cumulative production—which serves as proxy for stock of worker skill improvements thereby achieved.

• Quantification: For many products over long time periods, cost of producing a unit of product found to be related to its cumulative production by learning-by-doing (LBD) equation: \( y = ax^{-b} \), where:
  
  \- \( y \) = cost of producing next unit of product
  \- \( x \) = cumulative production
  \- \( a \) = constant coefficient
  \- \( b \) = learning rate exponent.

• Learning rate exponent usually presented as progress ratio \( PR = (100*2^{-b}) \) or learning rate \( LR = 100*(1 – 2^{-b}) \).
EXPERIENCE CURVES

- During 1970s, Boston Consulting Group (BCG) introduced experience curves that generalize learning curve concept:
  - Empirical evidence that overall costs tend to increase with each doubling of cumulative production… as result of improvements from all conceivable opportunities for cost reduction, including technological improvement via fruits of R&D, input substitution, economies of scale, new product design, and changing input prices.
  - Typically, experience curves presented in terms of product prices, which are readily observable, instead of costs, which are not.
- Dutton and Thomas (1984) compiled > 100 firm-level experience curve studies from variety of manufacturing sectors, finding mean LR ~ 20% (~ PR = 80%).
- When innovations spill over among competing firms, industry-wide experience curve can be estimated (weighted average of experience curves for individual firms).
- Competitive industries that make major R&D investments tend to have high LRs, while more mature industries that invest little in R&D tend to have low LRs (Cody and Tiedje, 1992).
MacDonald and Schrattenholzer (2001) catalogue experience curves for wide range of energy technologies and find LRs in range 5-25%:

- Higher LRs for more modular systems amenable to mass production in factories;
- Lower LRs for large field-erected plants for which standardized designs are more difficult to realize.
Specific investment costs for nuclear power rose with experience in France [to $1920/kW_e (2002 US$) in 2000], despite the favorable investment climate for nuclear technology and French success in standardizing nuclear power plant designs.

**Source:** Calculations (preliminary) carried out by Arnulf Grübler (IIASA), based on data presented in P. Girard (Commissariat à l’Énergie Atomique), Y. Marignac (WISE-Paris), and J. Tassart (La Commission Française du Développment Durable), *Le Parc Nucléaire Actuel*, Mission d’évaluation économique de la filière nucléaire, March 2000.
THEORY OF EXPERIENCE CURVE NEEDED

• Simplicity of experience curve model with cumulative production as *the* main explanatory variable for estimating cost reductions is appealing…but model lacks sound theoretical basis.

• Duke (2002) suggests why R&D & scale economy impacts might roughly be captured by cumulative production index:
  – Key part of new technology deployment process is firm’s R&D, for which cost $\propto$ sales revenues…and government support for industrial R&D tends to be cost-shared $\Rightarrow$ plausibly, cumulative total R&D investments $\propto$ cumulative production.
  – There are limits on firm’s ability to reduce costs through dramatic scale-up without first working out the kinks in intermediate-scale manufacturing facilities $\Rightarrow$ LBD is integral part of process of ramping up production.
UNCERTAINTIES IN USING EXPERIENCE CURVES TO PREDICT PRICES—PV EXAMPLE

Cost of “buying down” PV cost to $1/Wp:

- $70 billion if historical LR (19.7%) persists
- $225 ($30) billion if LR changes to 15% (25%)
- $7 billion if thin-film PV experience curve with same LR (19.7%) takes over
SOME IMPORTANT USES OF EXPERIENCE CURVES IN ENERGY TECHNOLOGY POLICY ANALYSIS

• Explore (e.g., via IAMs) implications for costs of mitigating climate change and other insults of LBD for advanced energy technologies.

• Explore effort required to reach cost goals for advanced technologies by combining experience curve analysis with detailed technology assessment (TA) of manufacturing costs under mass-production conditions.

• Assist policymakers in selecting technologies for public sector buydown support and subsequently in deciding whether to sustain or curtail such support.
APPLICATION OF LBD TO CCS FOR MAKING ELECTRICITY, H₂ & C-BASED SYNFUELS

• Rubin et al. (2003) measured LRs = 11% and 12% for capital costs for FGD (SO₂) and SCR (NOₓ) stack-gas clean-up technologies…and found that most of the cost reduction was accounted for by technological innovation

• As follow-up, Riahi et al. (2003) used IIASA MESSAGE-MACRO IAM to explore impacts of LBD for CO₂ capture & storage (CCS) in reducing global CO₂ emissions for variant of IPCC’s A2 global energy scenario (from SRES) that incorporates CCS technologies to help reduce atmospheric CO₂ in 2100 from 783 ppmv to 550 ppmv, assuming, alternatively, LR = 12% and 0% for CCS technologies

• This IAM exercise found that:
  – With LBD, the required carbon tax would be reduced:
    • In 2020 to $19/tC—from $25/tC without LBD
    • In 2050 to $27/tC—from $82/tC without LBD
  – By 2100, twice as much CO₂ would be sequestered with LBD than without LBD
WHY PUBLIC-SECTOR COST BUYDOWN SUPPORT FOR ENVIRONMENTAL ENERGY TECHNOLOGIES

- Radical technological change needed to cope with 21st century energy challenges [climate change, air pollution (esp. small particle health impacts), energy supply insecurity] while keeping energy affordable.

- Need for government support for energy R&D widely appreciated.

- Conventional wisdom: private sector should have sole responsibility for commercialization (technology cost buydown).

- In part, government support for environmental energy technology commercialization justified because costs of environmental/energy supply insecurity damages not fully internalized in energy prices.

- More fundamentally, government support warranted because of positive externality: private firm underinvests in technology cost buydown via LBD because of risk that fruits of buydown investment will spill over to competitors (Duke and Kammen, 1999; Duke, 2002).
CRITERIA FOR MAXIMIZING NPV OF PUBLIC-SECTOR BUYDOWN SUPPORT FOR NEW ENERGY TECHNOLOGIES (Duke, 2002)

- High LBD spillover;
- Emerging data suggest steep experience curve;
- Technology assessments project low price floor;
- Niche markets insufficient to pull prices down rapidly, but at lower prices demand is price elastic s.t. buydown subsidies can open up large markets;
- No other technology (incumbent or emerging) has better long-term prospects in the relevant market segments;
- Targeted technology produces strong public benefits not related to private under-investment in LBD—e.g., major environmental benefits.
TOWARD A POLICY FOR PUBLIC-SECTOR SUPPORT OF TECHNOLOGY COST BUYDOWN

• Support portfolio of technologies that satisfy selection criteria—thus reducing overall program performance risk through diversification.

• Minimize potential for evolving pork barrel projects (e.g., grain ethanol subsidies)—is an independent *Energy Commercialization Policy Agency* needed [as proposed by Duke (2002)]?

• Develop efficient policy instruments for buydown support:
  – Those that maximize use of market forces for resource allocation among qualifying technologies desirable.
  – Explore prospects for adapting successful existing policy instruments to buydown task—e.g., might the Renewable Portfolio Standard be adapted to this task?
ILLUSTRATIVE POLICY OPTIONS

• Establish *Energy Commercialization Policy Agency* (Duke, 2002) independent of any agency promoting technologies that might become candidates for buydown support. ECPA would assist policymakers by:
  – Providing TA advice regarding candidate technologies for buydown support;
  – Monitoring/evaluating field performance of subsidized technologies;
  – providing advice on periodic reallocation of subsidy resources in light of monitoring/evaluations;
  – Subjecting its activities to external review by academics and disinterested managers with generic expertise in technology commercialization.

• Convert Renewable Portfolio Standard into buydown instrument:
  – RPS uses market forces to allocate subsidy resources among qualifying technologies;
  – Texas RPS deals with concern about uncertain future costs for renewables by putting price cap on Renewable Energy Credit;
  – By specifying quantity of supply to be subsidized over time, renewable-energy developers are given confidence to launch projects;
  – RPS could be adapted to buydown by redesign to support portfolio of qualifying technologies…including qualifying non-renewable energy technologies;
  – ECPA activities would help control costs.
CURRENT/PROJECTED COAL IGCC PERFORMANCE/COST [FOSTER-WHEELER (2003) FOR IEA GHG R&D PROGRAMME]

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<th>Current, CO₂:</th>
<th>2020 (projected), CO₂:</th>
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<tr>
<td></td>
<td>vented</td>
<td>cap/stor</td>
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<tr>
<td>Capacity (MWe)</td>
<td>827</td>
<td>730</td>
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<tr>
<td>Efficiency (%, LHV)</td>
<td>38.0</td>
<td>31.5</td>
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<tr>
<td>Specific investment cost ($/kWe)</td>
<td>1187</td>
<td>1495</td>
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<tr>
<td>Generation cost (¢/kWh)</td>
<td></td>
<td></td>
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<tr>
<td>With venting</td>
<td>4.14</td>
<td>4.14</td>
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<tr>
<td>CO₂ capture (85% capture)</td>
<td>-</td>
<td>1.00</td>
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<tr>
<td>CO₂ transport/storage (@ $5/t CO₂)</td>
<td>-</td>
<td>0.43</td>
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<tr>
<td>Total generation cost</td>
<td>4.14</td>
<td>5.57</td>
</tr>
<tr>
<td>Incremental cap/stor cost (¢/kWh)</td>
<td>1.43</td>
<td>-</td>
</tr>
<tr>
<td>Cost of emissions avoided ($/t C)</td>
<td>-</td>
<td>79</td>
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THOUGHT EXPERIMENT: PORTFOLIO STANDARD TO ADVANCE CO$_2$ CAPTURE/STORAGE FOR US COAL POWER w/LBD & w/o LBD

• Require 20% of US coal power decarbonized (85% level) by 2020
• Assume:
  • Coal power generation constant at 2005 level (1990 TWh/y)
  • Linear ramp up of decarbonized IGCC power, 2005-2020
  • Cost for capture/storage paid by CO$_2$ emissions fee on coal power plants
  • For LBD case assume FW IGCC cost projections are realized by 2020
    ⇒ LR for CO$_2$ capture/storage = 14.9%

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<th>w/LBD</th>
<th>w/o LBD</th>
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<tr>
<td>Cumulative Subsidy ($10^9$)</td>
<td>35.1</td>
<td>42.3</td>
</tr>
<tr>
<td>“Effective” ave CT ($/tC)</td>
<td>4.8</td>
<td>5.8</td>
</tr>
<tr>
<td>Incremental coal steam power cost in 2020 (¢/kWh)</td>
<td>0.24</td>
<td>0.34</td>
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Impacts:
• CO$_2$ emissions for coal power (2020) = 0.83X 2005 rate
• CO$_2$ storage rate for coal power (2020) = 300 million t CO$_2$ per year
TOWARD AN INTEGRATED AND EFFECTIVE ENERGY TECHNOLOGICAL INNOVATION POLICY

• Radical technological change for energy technology is required to address effectively the major environmental and energy supply insecurity posed by conventional energy.

• Both reinvigoration of energy R&D enterprise and technology cost buydown support are needed.

• These activities would be mutually reinforcing:
  – Increased R&D would help sustain high LRs;
  – Market growth from buydown success would catalyze increased R&D investments by firms involved.

• Experience has highlighted promising policy instruments that might be adapted to buydown, although experimentation with alternative approaches is desirable to find out what works best with different classes of technologies and perhaps in different regions as well.
References


