Experience Curves, Renewable Energy, and Growth

Peter Hartley   Kenneth Medlock III   Ted Temzelides   Xinya Zhang

Rice University

January 29, 2010

Introduction

- President Obama proposed spending \$150B/year over next 10 years in renewable energy R&D compared to current \$5B/year
- Technological progress in renewable energy as an engine of macroeconomic growth
- R&D expenditure low and not obviously increasing
- Two competing hypotheses:
  - Under-investment in R&D (creative destruction)
  - Decreasing returns to R&D
- More research needed to discriminate between the two

Measures of R&D Output

- Patents (cited)
- Experience (learning) cost curves: cost declines as a function of cumulative production
- Independent variable? Two possibilities:
    - time (wait and see)
    - volume (the sooner install the better)

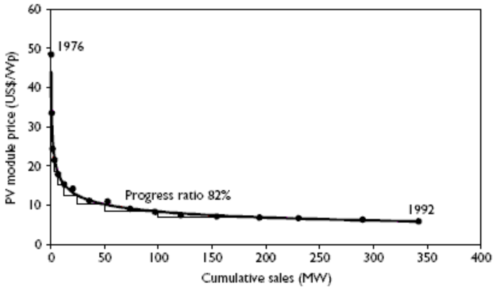
Plan for the Presentation

- Experience curves
- Imbed experience curves into macroeconomic model
- Compute equilibrium
- To be done:
  - Calibrate the model and study effect of different scenarios
  - optimal R&D investment strategies (fossil versus renewable)
  - optimal rates of renewable technology adoption
  - GDP Growth

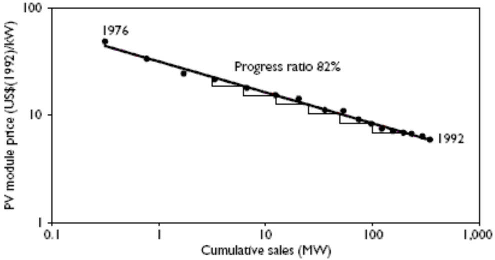
Experience Curves

- Describes how MC declines with cumulative production
- $P_t = P_0 X^{-\alpha}$ *"power law"*
  - P_0, the initial price (*\$ cost of* first *MW of sales)*
  - X, cumulative production in year t
  - $2^{-\alpha}$, Progress ratio (PR)
  - For each doubling of cumulative production (sales), price $\downarrow$ to $PR\%$ of its previous value
- Rewrite as: $\ln P_t = \ln P_0 - \alpha \ln X$; straight line in a $\log - \log$ plot:

Experience Curve for Photovoltaic Modules, 1976-1992

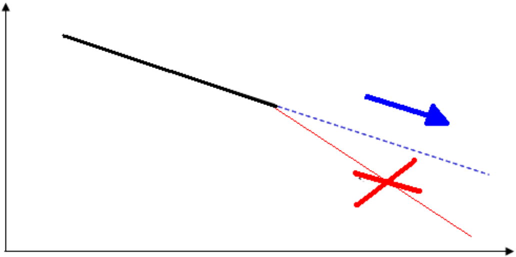


Experience Curve for Photovoltaic Modules, 1976-1992

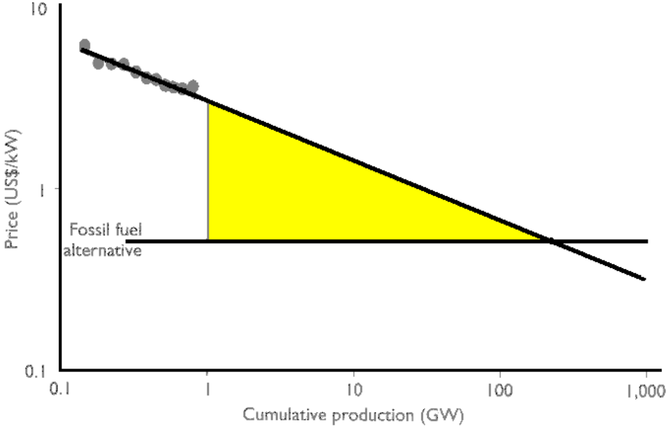


- Why do *MC* Decline?
- Process innovation, learning-by-doing, economies of scale, product innovation/redesign, input price declines...
- Experience curves aggregate these factors
- Consistent with "decreasing returns to R&D"

- Experience curves and policy
- No evidence that subsidies "bend down" experience curve. At best, accelerate "riding down"



Experience Curves as Policy Tools

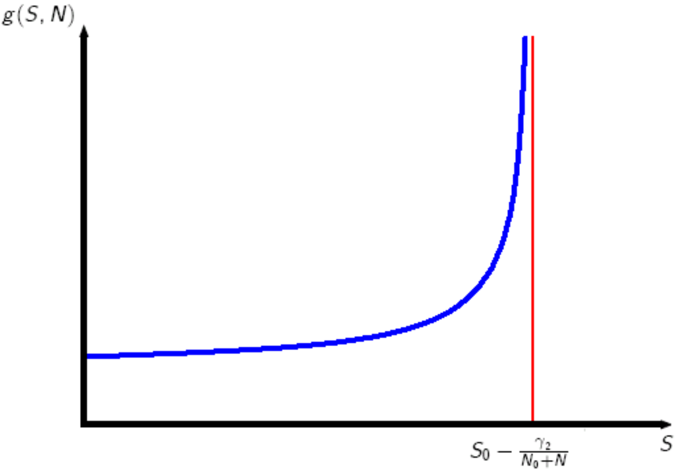


- Area in triangle: "cost needed to reach break-even point"...
- ... but not the only cost!
  - "Sunk cost" of existing technology
  - Opportunity costs of subsidies
  - Learning-by-doing takes time, not just volume
- Need macro model to quantify opportunity costs/effects on other sectors

The Macro Model

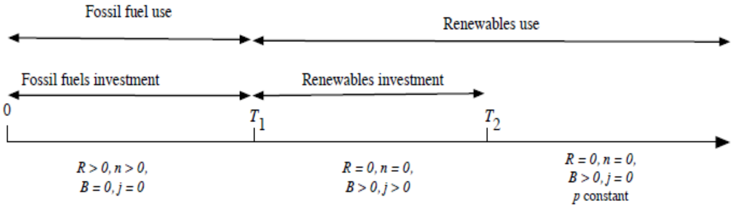
- c, consumption; output: $y = Ak$
- R, fossil fuel energy, B renewable energy used to produce output
- R and B perfect substitutes: $R + B = y$
  - important limitation $\longrightarrow$ "Bang-Bang" solutions
- S, cumulative fossil fuel use
- Most easily-mined/richest fields exhausted first $\longrightarrow$ MC increase in S

- Technical change in mining exploration
- N, current technical knowledge; n, investment in mining technology
- Marginal cost of extraction: $g(S, N)$
- g matches GDP share of value added in energy sector: 0.05 average across countries
    - lower in US, Japan; as high as .35 in some African oil producing countries
- Estimated "ultimately recoverable" oil reserves: 10^{16} BTUs
- Recoverable reserves (current technology): 1/20th of ultimately recoverable


g(S, N)
S
$S_0 - \frac{\gamma_2}{N_0 + N}$

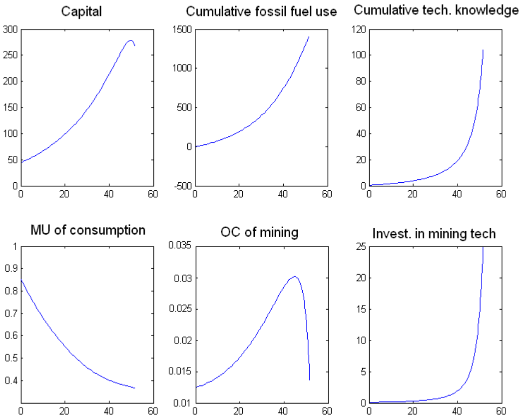
- p, MC of the energy produced using renewable technology
  - declines as new knowledge gained either through experience or via direct investment in research
- H, stock of knowledge about renewable energy production:
- $p = (\Gamma_1 + H)^{-\alpha}$ until lower limit is reached
- $\alpha = 0.5 \rightarrow PR = 71\%$
- j, direct investment necessary for accumulating knowledge about renewable technology
  - $\dot{H} = j(1 + \psi B)$

Equilibrium Regimes

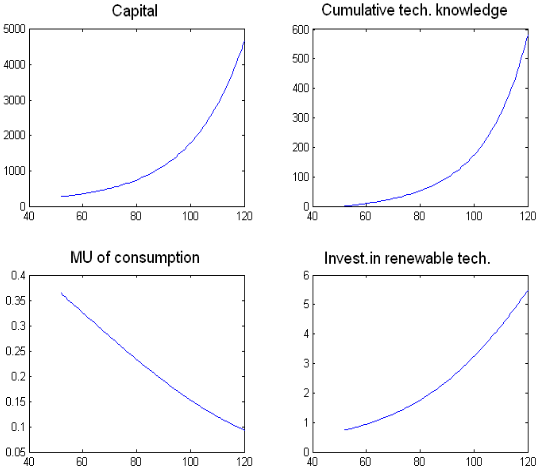


Numerical Examples

- $T_1 = 52; \; T_2 = 120$
- Regime 1:



- Regime 2:


Capital
5000
4000
3000
2000
1000
0
40
60
80
100
120
Cumulative tech. knowledge
600
500
400
300
200
100
0
40
60
80
100
120
MU of consumption
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
40
60
80
100
120
Invest.in renewable tech.
6
5
4
3
2
1
0
40
60
80
100
120

Scenarios to study

- Different learning parameters for renewable energy
- Effects of various subsidies for use/R&D in renewable energy (financed through taxation)
- Effects of taxing fossil fuel use

Summary

- Experience curves: useful measure of technological progress, informative for policy analysis
- Limitations:
  - Deterministic technological progress
  - Macro models needed to capture trade-offs between sectors
- Analysis does not consider *climate change* or *energy independence* issues

Sources

- Bental B. and D. Peled (2002): Quantitative Growth Effects of subsidies in a Search Theoretic R&D Model. *Journal of Evolutionary Economics* 12,397-423
- Experience Curves for energy technology Policy. *International Energy Agency* (2000)
- Gaffigan M.E. (2008): Advanced Energy technologies. Testimony Before the Subcommittee on Energy and Environment, Committee on Science and Technology, *House of Representatives*
- Hartley P. and K. Medlock III (2005): Carbon Dioxide: A Limit to Growth? Manuscript
- Kammen D.M. and G.F. Nemet (2005): Reversing the incredible shrinking US energy R&D budget. *Issues in Science and Technology* 22(1), 84-88
- Margolis R.M. (2003): Photovoltaic Technology Experience Curves and Markets
- Nemet G.F. (2007): Learning Curves for Photovoltaics
- Popp D. (2009): Where Does Energy R&D Come From?