Electricity Policy Research Group

UNIVERSITY OF CAMBRIDGE

Technical Change Theory & Learning Curves:

Progress and Patterns in Energy Technologies

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SUPERGEN

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Overview

- Technical change
- Learning curves
- Empirical analysis
- Conclusions

Technical Change - Basic Concepts

Theory	**Invention**	**Innovation**	**Diffusion**
Practice	**Basic research**	**Applied research / demonstration**	**Commercial-isation**
Policy	**Technology push**	**Market pull**	

Single-Factor Learning Curves

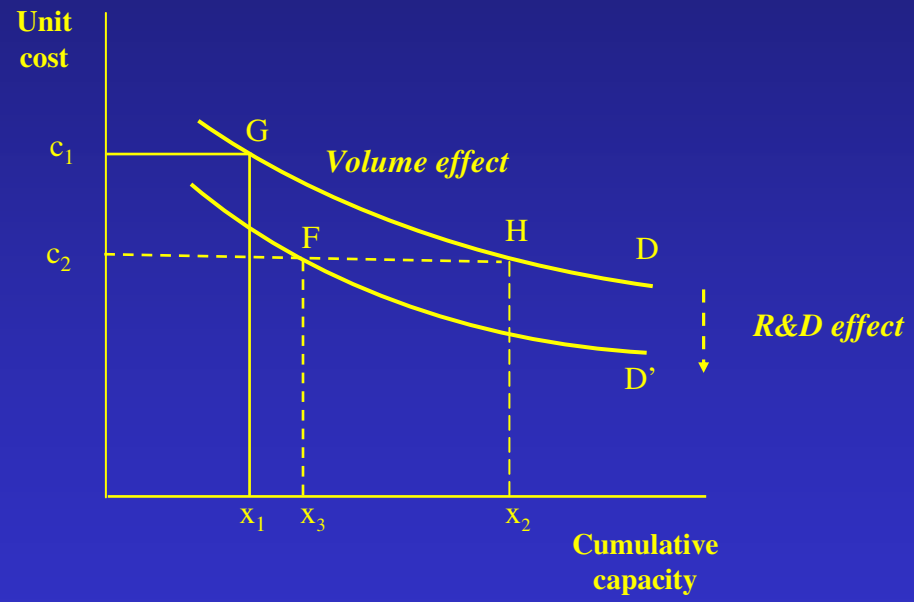
$$C = \alpha * K^{\varepsilon}$$

$$LR = 1 - 2^{-\varepsilon}$$

where:

C	**Unit cost of technology**
K	**Cumulative capacity (or production, etc.)**
LR	**Learning rate**

Cost Effects of Learning by Doing and Learning by Research



Two-Factor Learning-Diffusion Learning Curves

$$LogC = \alpha + \beta * LogRD + \kappa * LogCap$$

$$LogCap = \mu + \omega * LogC + \chi * LogTime$$

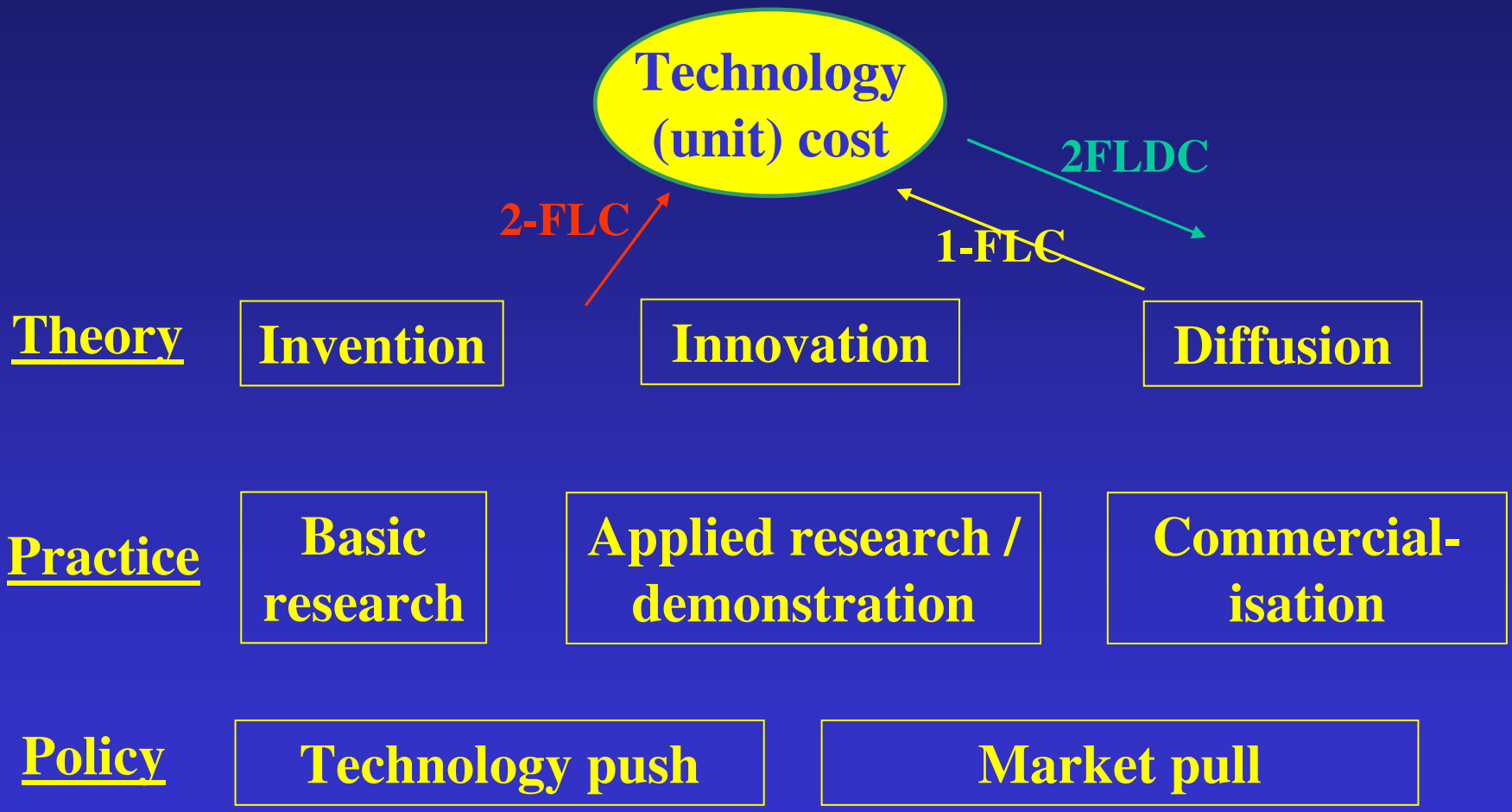
Exogenous variables : LogRD, LogPat, LogTime

Endogenous variables : LogC, LogCap

where:

C	**Total unit cost of technology (€1999/KW)**
RD	**Cumulative private and public R&D spending (mill. €1999)**
Cap	**Cumulative installed generation capacity (MW)**
Time	**Year**
Pat	**Cumulative number of technology patents**

Technical Change - Basic Terms



Learning Curves – Some Issues

- Single-factor learning curves:
  - Only partially reflect innovation (learning-by-doing)
  - Do not reflect technology diffusion
- Thus, only partially useful for "mature" technologies

- Strong trends in time-series data
- Possibility of endogeneity of capacity
- => 2FLCs and simultaneous learning-diffusion models

Technologies and Data Used

	Technology	Year
1	Pulverised fuel supercritical coal	1990-1998
2	Coal conventional technology	1980-1998
3	Lignite conventional technology	1980-2001
4	Gas in GTCC	1980-1989 1990-1998
5	Large hydro	1980-2001
6	Combined heat and power	1980-1998
7	Small hydro	1988-2001
8	Waste to electricity	1990-1998
9	Nuclear LWR	1989-1998
10	Wind	1980-1998
11	Solar thermal power	1985-2001
12	Offshore wind	1994-2001

Learning Rates for "Mature" Technologies

		Learning Model				Diffusion Model	
Technology	Method	Capacity Elasticity	Learning by Doing	Research Elasticity	Learning by Research	Diffusion	Year
Pulverised fuel supercritical coal	3SLS	-0.0551***	3.75%	-0.0897	6.03%	-11.052*	0.0454*
Coal conventional technology	3SLS	-0.1909*	12.39%	-0.0182	1.25%	-2.330*	0.151*
Lignite conventional technology	2FLC	-0.0842*	5.67%	-0.0250***	1.72%	-	-
Combined cycle gas turbine 1990-98	3SLS	-0.0321*	2.20%	-0.0347*	2.38%	-16.465	0.601
Large hydropower	2FLC	-0.0285*	1.96%	-0.0384	2.63%	-	-
* 5% significance ** 10% significance *** 15% significance							

Learning Rates for "Reviving" Technologies

		Learning Model				Diffusion Model	
Technology	Method	Capacity Elasticity	Learning by Doing	Research Elasticity	Learning by Research	Diffusion	Year
Combined cycle gas turbine 1980-89	3SLS	-0.0094*	0.65%	-0.2815*	17.7%	-8.451	0.227
Combined heat and power	3SLS	-0.0033*	0.23%	-0.1351*	8.9%	-26.23*	-
Small hydropower	2FLC	-0.0070*	0.48%	-0.3333*	20.6%	-	-
* 5% significance ** 10% significance *** 15% significance							

Learning Rates for "New" Technologies

		Learning Model				Diffusion Model	
Technology	Method	Capacity Elasticity	Learning by Doing	Research Elasticity	Learning by Research	Diffusion	Year
Nuclear power (light water reactor)	3SLS	-0.6517*	36.3%	-0.4485*	26.7%	-0.910*	-
Waste to electricity	3SLS	-0.7738*	41.5%	-0.8286*	43.7%	-0.762*	-
Wind energy	3SLS	-0.2021*	13.1%	-0.4502**	26.8%	-3.458*	-

* 5% significance ** 10% significance *** 15% significance

Learning Rates for "Emerging" Technologies

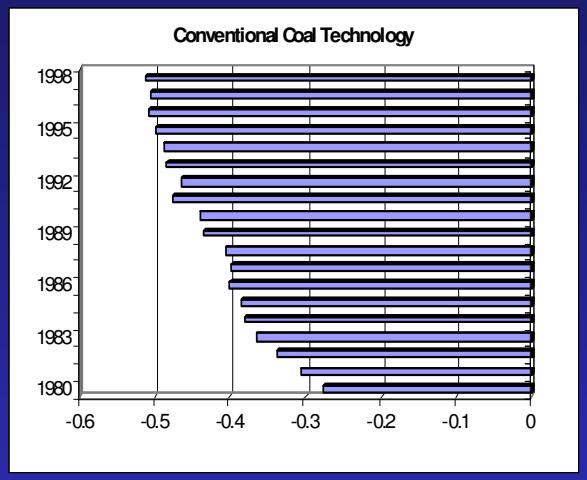
		Learning Model				Diffusion Model	
Technology	Method	Capacity Elasticity	Learning by Doing	Research Elasticity	Learning by Research	Diffusion	Year
Solar power – thermal	2FLC	-0.0320*	2.2%	-0.0779*	5.3%	-	-
Wind energy – offshore	2FLC (instrumental variable R&D = year)	-0.0151	1.0%	-0.0720*	4.9%	-	-

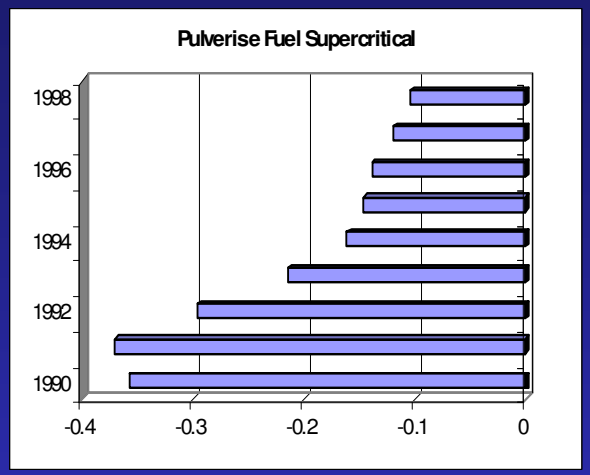
* 5% significance ** 10% significance *** 15% significance

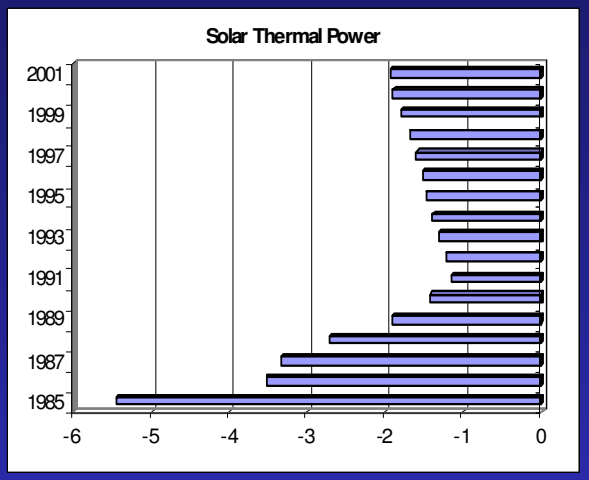
Technology Development Stage, Learning Rate, Capital Intensity, and Market

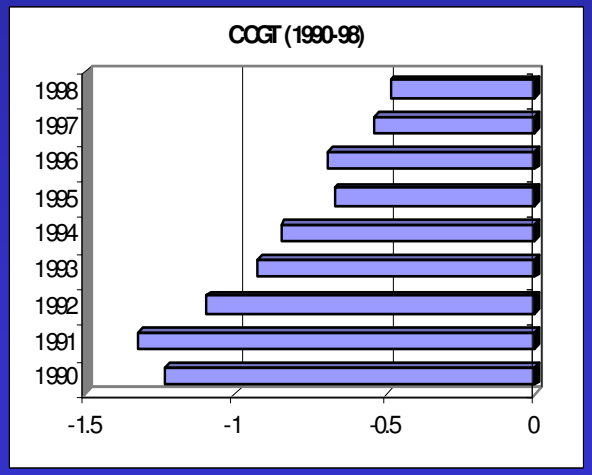
	Learning by Doing	Learning by Research	Capital Intensity	Market Opportunity / Constraint
Mature technologies	Low	Low	Low	High
Reviving technologies	Low	High	Low	High
New technologies	High	High	High	Low
Emerging technologies	Low	Low	High	Low

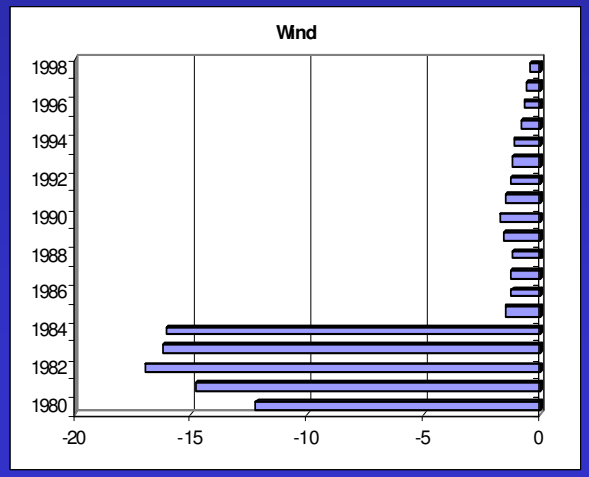
Elasticity of Substitution between R&D and Capacity Expansion

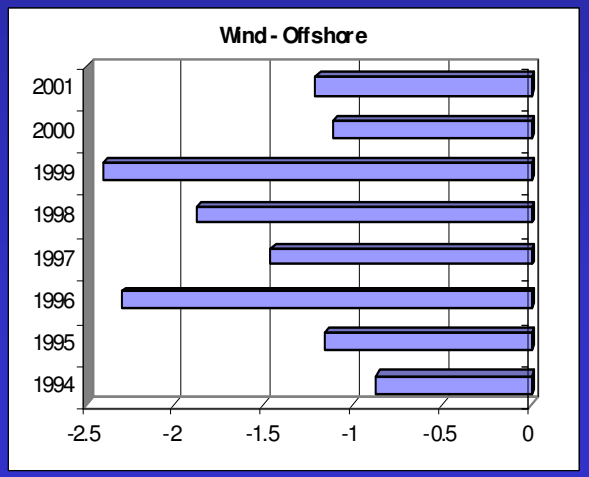












Conclusions

- Two-factor learning-diffusion models preferable
- Learning patterns broadly in line with perceived view of technical change process
- Learning-by-research stronger than by doing for most technologies
- No progress stage dominated by learning-by-doing
- Market constraints limit progress of (capital intensive) emerging and new technologies
- Limited substitution between R&D and capacity

- How to help technologies from one development stage to another?

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