Technology learning curves for energy policy support

Summary of a JRC/ECN Workshop

AMPERE-ADVANCE-PIAMDDI
Technology Workshop

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www.jrc.ec.europa.eu

Overview

I. Background and context

II. JRC policy assessment applying the Two Factor Learning Curve

III. Technology learning workshop

  I. Objectives and research questions

  II. The One-Factor-Learning Curve: Status quo and improvements

  III. The Two-Factor-Learning Curve

  IV. Applying endogenous technology learning in models

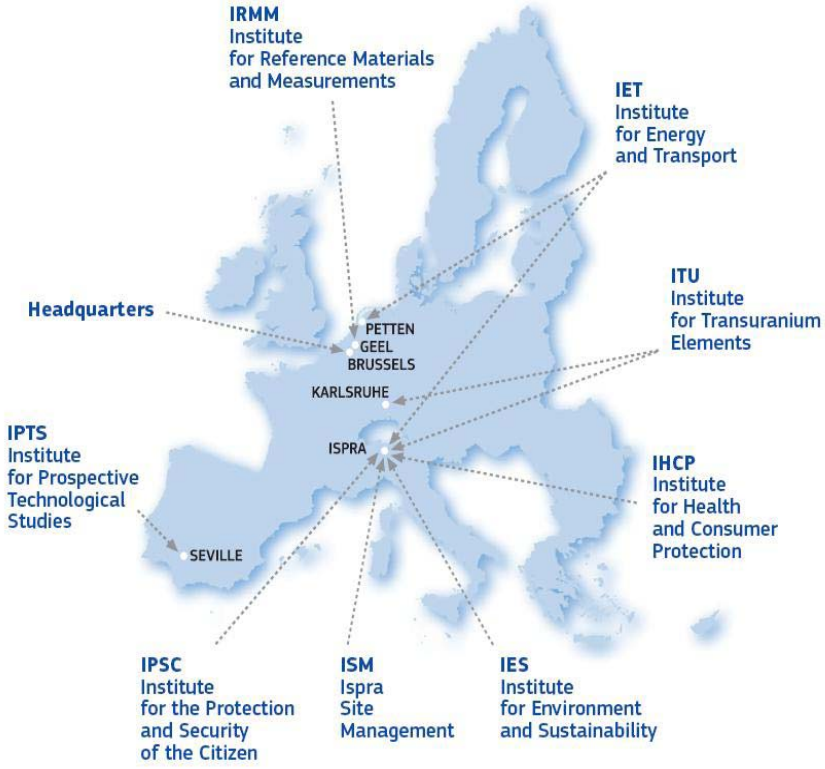
Introduction: the JRC

European Commission

Mission: provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Established 1957

- 7 institutes in 5 countries
- 2 822 scientific, technical and administrative personnel
- 1 200 contributions to EU Policy
- 650 peer-reviewed scientific publications in 2012
- Budget: €356 million annually, plus €62 million earned income



JRC's structure

Joint Research Centre

Introduction: IPTS and ECCET

The EC Joint Research Centre is 'the European Commission's in-house science service'

IPTS (ECCET unit)

IET (Energy systems evaluation unit)

Economics of Climate Change, Energy and Transport unit:

'Support policy formulation related to energy, transport and climate change mitigation'

- by developing and maintaining a solid toolbox of quantitative modelling instruments, databases and analytical capabilities (e.g. POLES, GEM-E3, Transtools), and
- by applying this know-how for policy studies internal to the Commission in these fields (e.g. DG ENER, DG CLIMA, DG MOVE, DG RTD…)

Background: The European Strategic Energy Technology Plan and JRC assessment of impacts

SET-Plan adopted in 2008: The EU Energy and Climate Technology Pillar; aims at accelerating the development of low-carbon technologies

Communication on investing in the development of low carbon technologies COM(2009) 519: Technology Roadmaps and 10 year costing of the SET-Plan Efforts

→ "**Assess the impact of increasing RD&D efforts on several SET-Plan priority technologies at the same time in Europe"** on

… technology costs &

… costs of achieving EU's energy/cc targets

… by applying the Two-Factor-Learning Curve linked to POLES

$$C(Q, KS) = aQ^{-\alpha} KS^{-\beta}$$

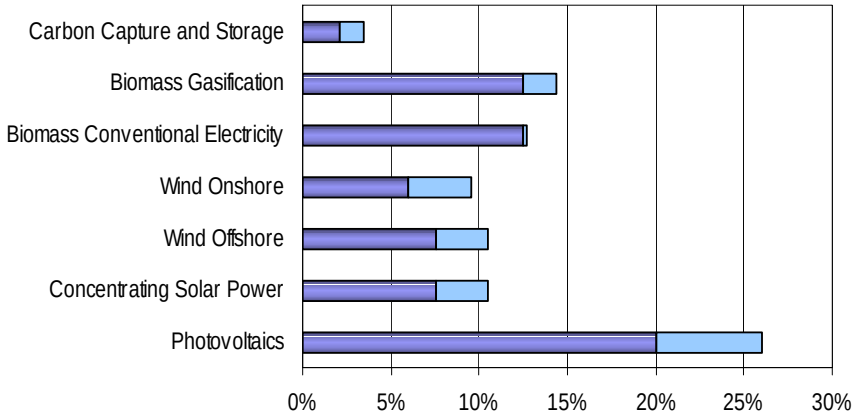
With C = Costs of unit production
a = Costs of the first unit produced
Q = Cumulative Production
α = Elasticity of learning by doing
KS = Knowledge stock
β = Elasticity of learning by researching

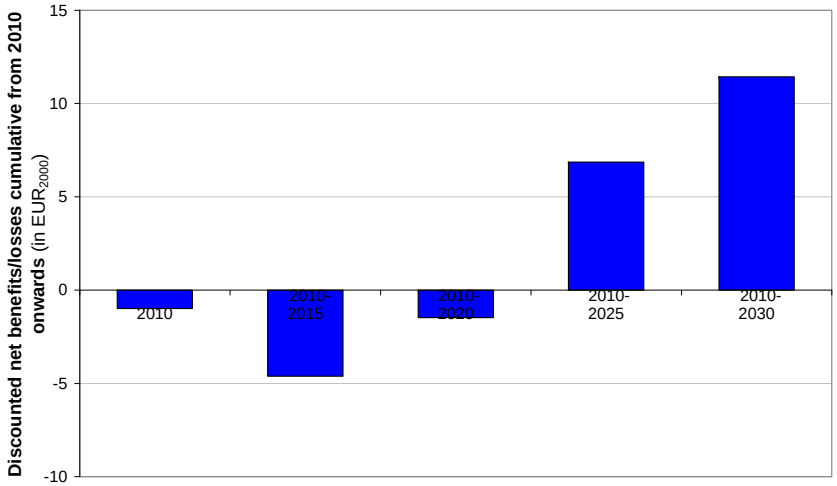
JRC Assessment on Impacts of increased R&D efforts

http://setis.ec.europa.eu/

European Commission

- Additional global RD&D investments (ca. € 60bn), in line with the SET-Plan can reduce costs of new low-carbon technologies by 4% - 13%
- Accelerated market penetration of innovative low-carbon technologies (e.g. PV, CSP, wind offshore)
- Over the period 2010-2030, the additional R&D efforts assumed would result in a positive IRR of some 15%





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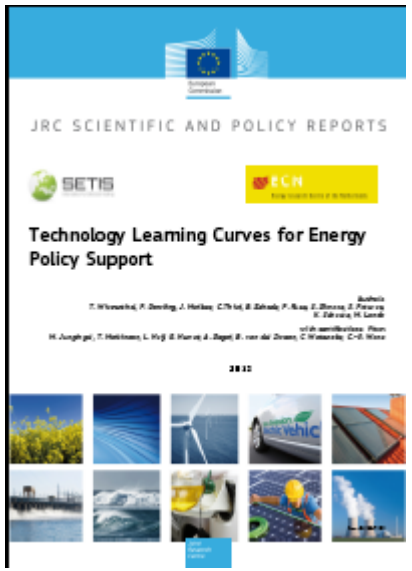
European Commission

"Technology Learning Curves for Policy Support"

- Status quo of the One-Factor-Learning Curve: proven concept, applicability?
- Is the concept of the Two-Factor-Learning-Curve reliable enough to use for policy-advice?
  - Linking knowledge stock to reduction in technology costs? Importance of whole innovation chain
  - Approximating knowledge stock by R&D? Non-linear relation between R&D input and output; knowledge spillovers
- Do uncertainties in data impede meaningful results
  - Are learning rates reliable? Do they vary over time?
  - How about the impact of raw material prices?
  - Problem of R&D investment data
- How best to include learning in modelling?
  - Limit to learning (floor costs)?
  - Global or regional (link to data problem)?
  - Learning by technology/sector/component?



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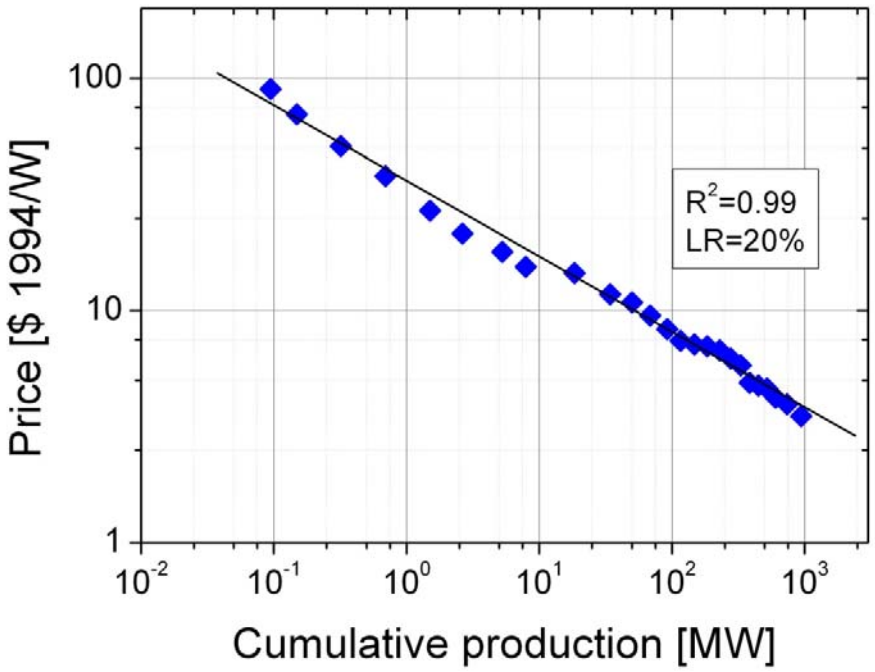
One-Factor-Learning Curve: Introduction

$$C_{t,y} = mQ_{t,y}^{-\varepsilon}$$

PV learning curve



Source: taken from the presentation of B. van der Zwaan

- Proven, well-observed concept
- Data (easily) available
- Does not try to disentangle the mechanisms behind, combines
  - Learning by doing
  - Learning by researching
  - Economies of scale
- Some improvements possible and necessary in particular when using for projections

One-Factor-Learning Curve Improvements (1)

European Commission

1) Component learning:

Ferioli et al. (2009) shows better fit for gas turbine prices assuming that only one of two components learn.

→ Importance for scenario projections

$$C(x) = \alpha C(x_0)\left(\frac{x}{x_0}\right)^{-L} + (1-\alpha)C(x_0)$$

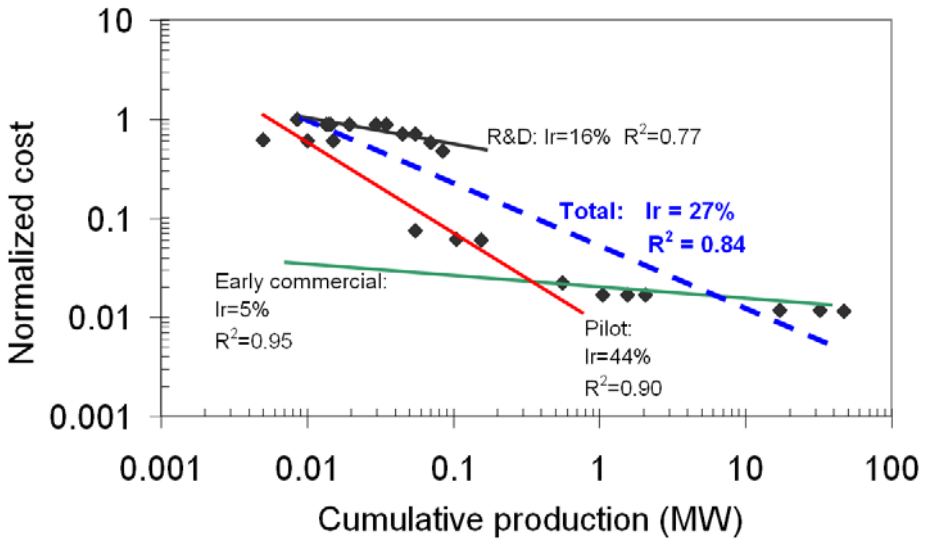
2) Piecewise learning:

Better fit if piecewise learning is assumed, Rivera-Tinoco et al. (2012) for SOFC and Ferioli et al for gas turbines

→ Reflects distinct stages in the innovation cycle

→ High importance for modelling

SOFC in different stages



Source: Rivera-Tinoco et al. (2012); taken from the presentation of B. van der Zwaan

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One-Factor-Learning Curve Improvements (2)

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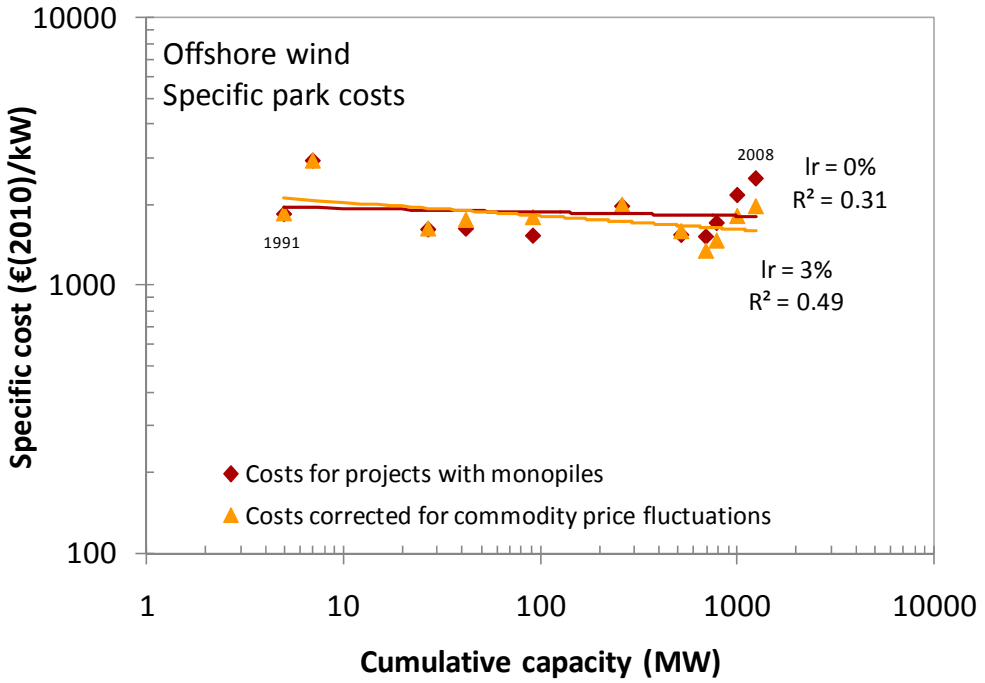
3) Impact of other factors, incl. energy & material prices

→ Tomorrow morning

3) Expansion of learning to performance, not only costs

→ Technology learning can be aimed at improving LCOE, including efficiency, safety etc.

→ In a wider context, the product functionality develops (Watanabe et al., 2009)



Source: B. van der Zwaan (2011)

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Two-Factor-Learning Curve: Introduction

$$C(Q, KS) = aQ^{-\alpha} KS^{-\beta}$$

Explicit consideration of the knowledge stock and cumulative production

Assets

One of few approaches to directly quantify the impact of research investments on technology learning

→ High (political) relevance!

Problems

1. TFLC less well proven than OFLC
2. R&D and market formation (plus other factors) drive technological progress, not any of them alone
   I. Strong interaction between the two factors – difficult to separate them;
   II. Even worse so: (mis-) use of results to assess R&D *versus* market-introduction mechanisms
3. Quantification of R&D impacts very difficult (random outcome; breakthroughs; spillovers)
4. Poor data availability

Two-Factor-Learning Curve: The innovation system

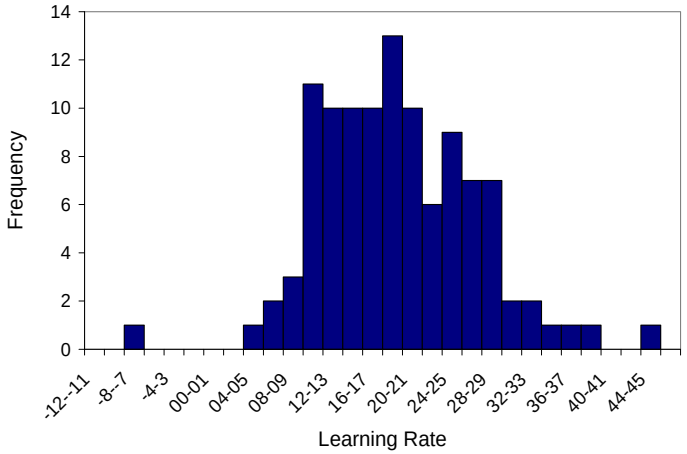
Learning by researching and learning by doing (incl. market formation) **effects are linked; they depend on each other and occur simultaneously**

→ Example of wind energy uptake in Germany/US compared to Denmark

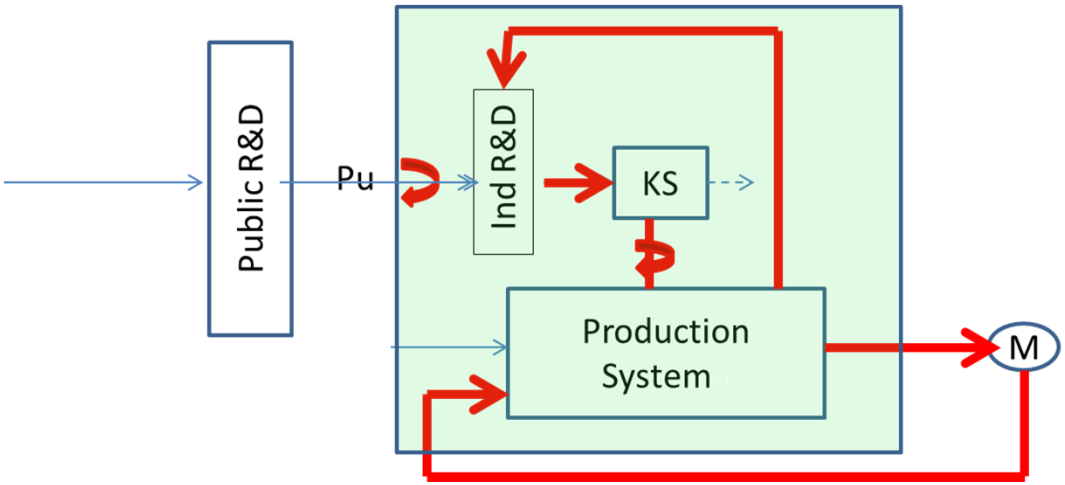
→ Impossible to disentangle them.

→ Policy message: complementary rather than competing

Distribution of learning rates



Source: Dutton and Thomas, 1984; taken from the presentation of C.O. Wene



Strongly interconnected learning system:

Operationally closed system with technology learning as 'Eigenbehaviour' (C.O. Wene)

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Two-Factor-Learning Curve: Approximation of the knowledge stock

Traditional approximation of the knowledge stock through R&D investments poses problems:

1) R&D investments fall short of characterizing R&D input because soft factors (collaboration; feedback loops; see Grübler 2012) not included.

2) Relationship between R&D input and output not fully predictable:

→ More predictable for incremental innovation; but

→ Radical innovations more random AND more important

→ However, relationship between R&D and patents exist in energy sector (Margolis and Kammen, 1999)

3) Do corporate and public R&D contribute to the KS in the same way?

→ Alternative? Patent data as proxy for the knowledge stock (Popp, Santen et al., 2012)

- Technology-specific data easier to obtain
- Knowledge spillovers easier to be handled

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Learning Curves: Implementation in models

1) Is there a limit to technology learning?

Implementation through floor costs?

Pro:
+ There is an end to learning
+ Learning describes dynamics…
+ …but technology potential via technology perspective analysis

Contra:
- No end to learning
- Technology experts too conservative
- Hides opportunities
- Excludes possibilities for breakthroughs from other areas

2) Do learning rates vary over time and/or across scenarios

- Piecewise learning curve suggests so
- Extreme technology scenarios may have other LRs (more R&D etc.)
- Difficulties in defining them

Learning Curves: Implementation in models

3) Use of multi-component learning in order to

- better adapt to the learning parts of a system, and
- better grasp the future potential for learning

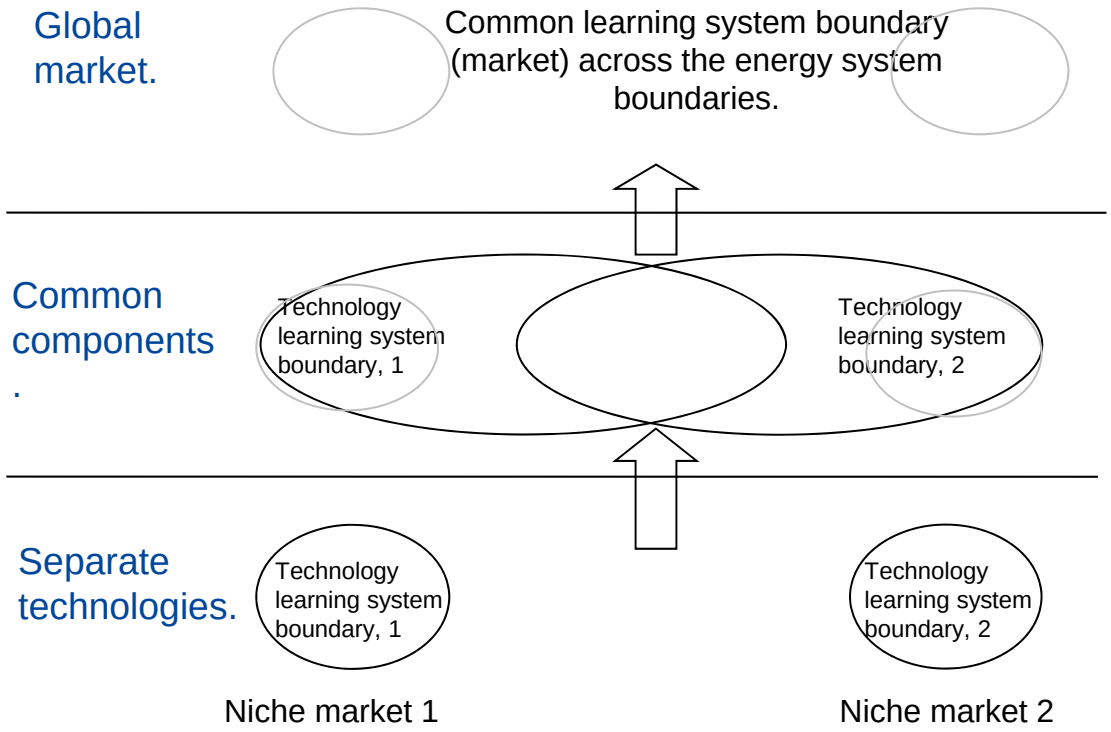
4) Single out the effect of raw material and energy prices

- better approximation of the pure learning effect
- If possible use technology costs instead of prices

5) Explore the expansion of learning on parameters beyond cost

(moving from $/kW to $/kWh)

6) How to set the system boundaries? Global/regional – technology/sector?



Source: Martinsen, 2011

7) Apply care when using the (and communicating about results of the) Two-Factor-Learning Curve in models

- Explore the approximation of the knowledge stock by patents
- Set up 'consistent' scenarios avoiding the competition between technology-push and market-pull mechanisms
- Combine with complementary studies, expert elicitations

Thank you for your attention

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