Endogenous Technological Change in Power Market Models

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Sneak Peak

1. We extend a numerical model of the European power market by learning-by-doing of renewables

2. We develop a novel framework extension for experience depreciation in learning-by-doing (forgetting)

$\Rightarrow$ Qualitative model behaviour with provisional learning calibration

Motivation

Power market models

- Important tool to evaluate system impacts of climate and energy policies
- Paris Agreement, European Green Deal
- Scenario evaluation $\Rightarrow$ system outcomes

Important driver: cost developments of generation technologies

Exogenous technological change

- Purely time-dependent unit costs reductions
- Unrealistic regional bang-bang solutions

Literature

Learning curves, organisational forgetting, spillovers

Wright (1936), McDonald and Schrattenholzer (2001), Rubin et al. (2015), Argote and Epple (1990), Benkard (2000), Nemet (2012)

Endogenous learning in numerical power market models

Messner (1997), Kypreos et al. (2000), Barreto and Kypreos (2004), Miketa and Schrattenholzer (2004), Heuberger et al. (2017)

The Project

Endogenous technological change (ETC)

We extend the numerical EUREGEN Power Market Model

- by **regional LBD**
- for **solar, wind onshore, wind offshore**

... perfect recall (base case ETC)

⇒ Application of existing LBD framework

... forgetting

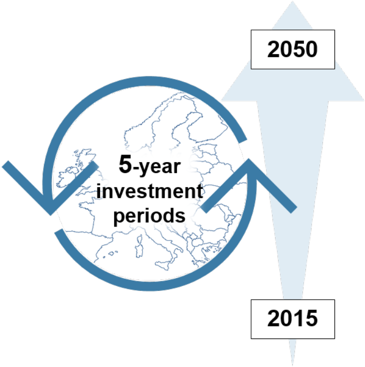
⇒ Novel framework extension by experience depreciation in LBD

We also explore spillover effects, different learning specifications, and different numerical specifications (not covered today)

The EUREGEN European Power Market Model

Partial equilibrium model with resolution of up to 28 countries:

- 16 generation technologies
- Storage and transmission
- Emissions and carbon price
- Hourly market clearing



Intertemporal optimisation:

- Investment cost
- Fixed cost and dispatch cost
- Policy cost (subsidies/ taxes for capacity and generation)

See Blanford and Weissbart (2019) and Weissbart (2020)

Numerical Strategy

Unit cost learning curve as starting point:

$$c_{i,r,t} \quad = \quad c^0_{i,r} \times QS^{b_{i,r}}_{i,r,t}$$

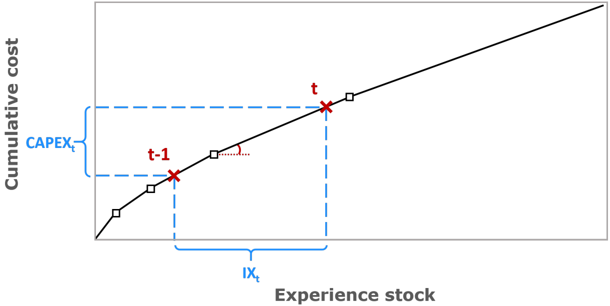
i, r, t	technology, region, period
c	unit cost
c^0	initial unit cost
QS	experience stock
b	negative learning elasticity

⇒ Linearise **non-linear** learning curve as **Mixed-Integer-Program**
⇒ Get capacity expansion IX and associated **capital expenditure** $CAPEX$ **per period**

Numerical Strategy (cont.)

Two-step linearisation procedure (Kypreos et al., 2000)

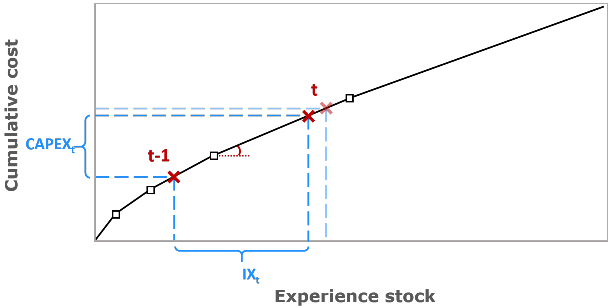
1. Integrate unit cost curve over experience stock
   ⇒ cumulative cost curve
2. Variable length segmentation of cumulative cost curve into piece-wise linear line segments



Forgetting-by-not-doing

Introduce a depreciation factor δ:

$$QS_{i,r,t} = (1-\delta) \times QS_{i,r,t-1} + IX_{i,r,t}$$

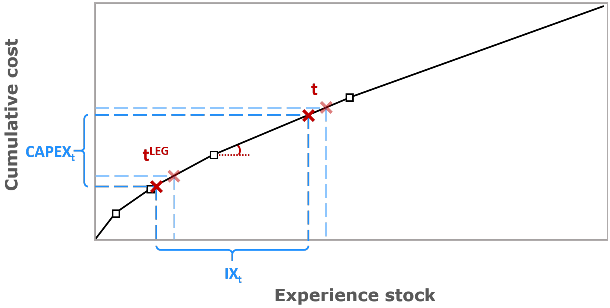


Naive implementation $\Rightarrow$ Negative bias of *CAPEX* and *IX*

Forgetting-by-not-doing (cont.)

Calculate the inherited (legacy) part of the experience stock while accounting for depreciation

$$QS_{i,r,t}^{LEG} = (1 - \delta) \times QS_{i,r,t-1}$$



⇒ **Add unbiased CAPEX to objective function**

Default implementation

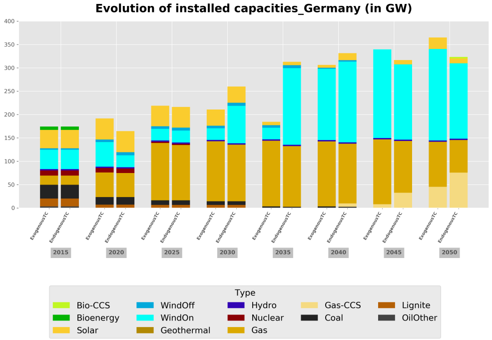
Model specification

- Number of line segments: 5
- Regional learning (12 regions)

Provisional calibration

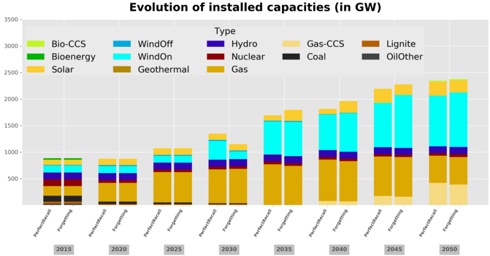
- Learning elasticity: 9% for solar, wind onshore, offshore
- (Forgetting rate: 3% p.a.)

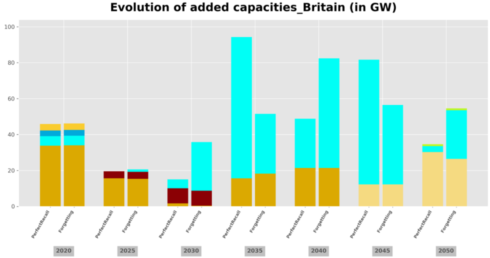
Results: Exogenous TC vs. Base Case ETC



- Gas-CCS to compensate for less renewables expansion
- Earlier investments
- Partial reduction of bang-bangs
- Heterogenous effects and interdependencies

Results: Base Case ETC vs. Forgetting





Aggregate level:

- Increased expansion to compensate forgetting
  $\Rightarrow$ Off-setting effect

Regional level:

- Condensed/smoothed expansion waves

General insights

Model outcomes

- High sensitivity to learning parametres
- Relevant impact of line segmentation

Computational feasibility

- Strong increase in computational complexity
  $\Rightarrow$ solving time and feasibility
- Computional limits to segmentation resolution

Next Steps

- Fine-tune calibration, sensitivity (forgetting rates, CO2 prices)
- Optimal number of line segments
- Learning technologies
- Learning-by-searching, spillovers

Challenges

- Non-linear implementations (feasibility, local optima)
- Adequate learning specification (technologies, mechanisms)
- Data availability

Conclusion

- Constant trade-off: complexity vs. feasibility of ETC specification
- ETC leads to more realistic expansion behaviour
  $\Rightarrow$ policy design!
- Regional perspective behind aggregate values is relevant
- Careful calibration is crucial
- Potential for more sophisticated learning features
  $\Rightarrow$ data availability

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