Learning-by-doing in wind electricity production –

Who learns and why does it matter to differentiate?

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Introduction

- Technological progress crucial for climate policy
- Alternative approaches to modeling technological change
  - autonomous
  - R+D induced learning
  - Learning-by-doing: reduction of production costs with growing “experience” (cumulative production or capital stock)
- Political relevance:
  - timing of emissions reduction
    - autonomous or R+D-induced progress: (research now), act later
    - learning-by-doing: early action
  - optimal reduction targets
  - strategic behavior of individual countries (first-mover vs. leap-frogging)

Introduction

Focus of our paper:

- learning-by-doing
- wind energy
- where does learning take place and why is it important to distinguish?

- Distinguish between learning in renewable energy **equipment** production and learning in renewable electricity **generation**
- ‘Explorative exercise’ in modeling
  - introduce learning-by-doing in energy economy CGE model
  - introduce renewable energy equipment production
  - analyze economic and international trade effects of mitigating CO2 emissions with alternative assumptions about learning

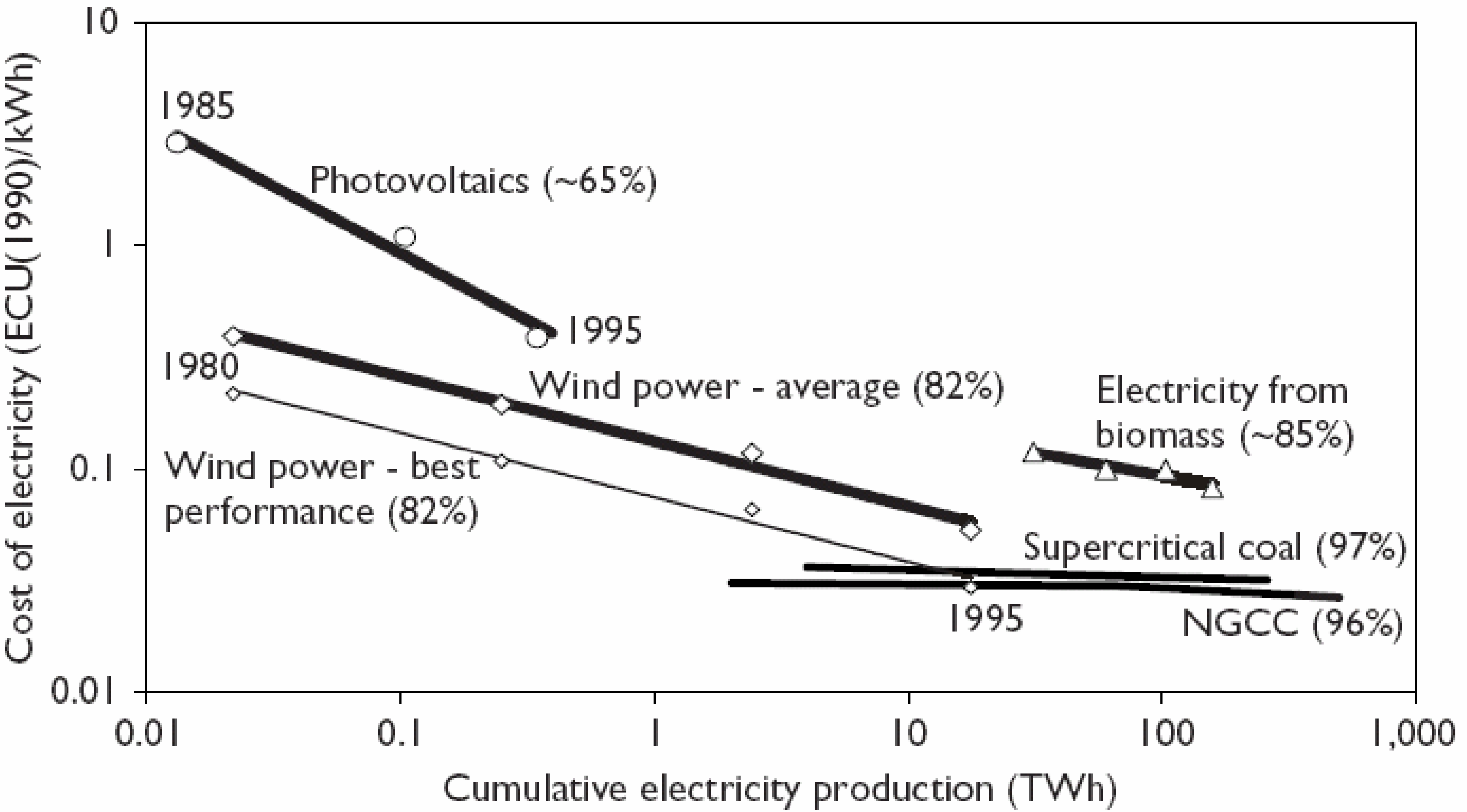
Learning-by-doing

- Costs of output (C) decrease with cumulative experience (X) of producing this output

$$C = \alpha \quad X^{-\beta}$$

  - α normalization parameter, β learning elasticity
  - Doubling of X leads to specific cost reduction of $2^{-\beta}$ (PR); learning rate = 1- $2^{-\beta}$
- Proxy for experience: cumulative output or investment

Learning-by-doing



Learning-by-doing…

- ...in renewable energy equipment & machinery
  - improvement in machinery and equipment components
  - such as for wind turbines: hub height, rotor blades, foundation and site preparation etc.
  - learning curve relates unit cost of energy equipment (€/kW) to output produced in industry (kW)

- ...in renewable electricity generation
  - improvement in identifying and making use of most favorable locations, better information technology, improved operation and maintenance, energy management, plant lifetime
  - learning curve relates levelized cost (=average unit costs) of electricity generation (€/kWh) to electricity output (kWh)

Modeling tool

- LEAN_2000 (developed by Prof. H. Welsch, Oldenburg)
- Top down CGE energy economy model
- Dynamic recursive model with 1 year time steps and myopic expectations
- Time horizon up to 2030
- Two regions: Germany, Rest of Europe
- 15 sectors, thereof 7 energy sectors

- 3 tasks:
  - introduce learning-by-doing
  - introduce renewable energy equipment production
  - develop 3 scenarios

Technological Change in LEAN - previously

- Exogenous productivity change
- Factor saving technological change
- Xt (RNBL) = f(gKt*Kt, gLt*Lt)
  - f(x,y) = output function of inputs measured in efficiency units
  - gK efficiency of capital stock/investment
  - gL labor efficiency
- Efficiency of capital stock is weighted average of efficiency of last year‘s capital stock and efficiency of new investment (latest vintage)

$$gK_t = \frac{(1-\delta)K_{t-1}}{K_t} gK_{t-1} + \frac{I_{t-1}}{K_t} gI_{t-1}$$

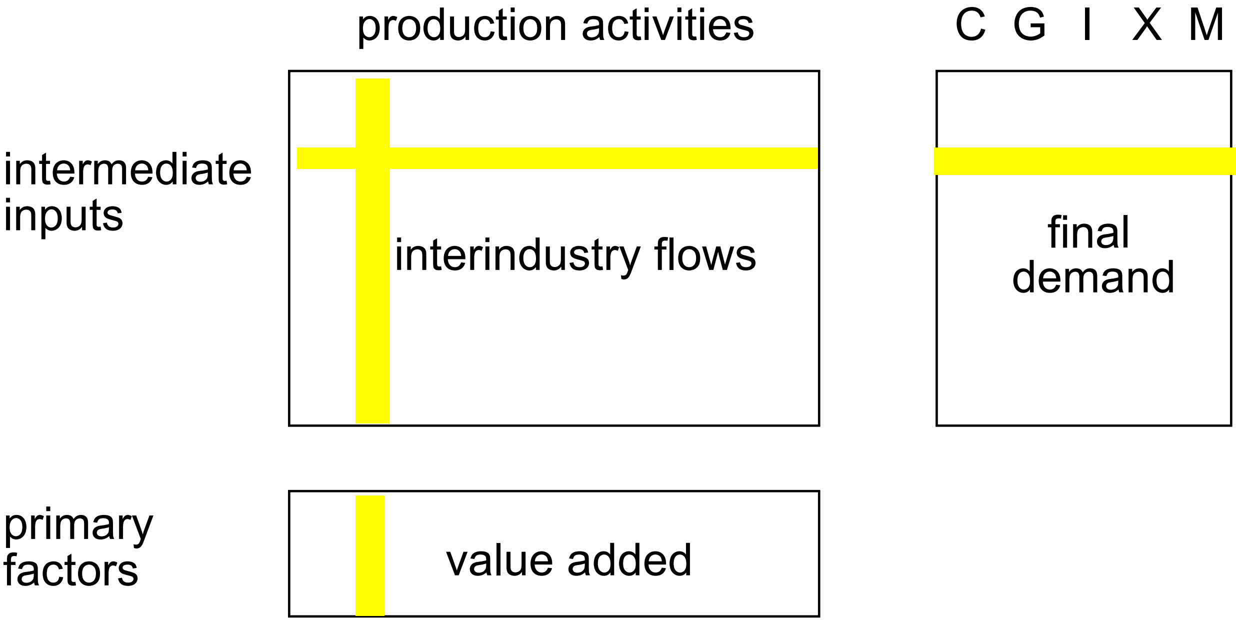
Implementation of LbD in LEAN

- Efficiency of factor input (gL, gI) as function of cumulated output (Xcum)
- LbD can be applied to both capital and labor efficiency, i.e. gL and gI
- LbD induces efficiency increase of new investment not total capital stock (embodied tech change)

$$gI = \left(\frac{X_{cum,t}}{X_{cum,0}} \right)^{\beta}$$

Renewable energy equipment in LEAN

- Introduce new sector called renewable energy equipment
- Add line and row to input/output table EQRN as fraction (0.5%) of machinery and equipment sector



Scenarios of model analysis

- Base case: No learning takes place in either sector
- Scenario lbd_elec: Learning-by-doing takes place in renewable electricity generation
- Scenario lbd_eqip: Learning-by-doing takes place in renewable energy equipment. It applies to the efficiency of both capital and labor.

Renewable energy in Germany

- Renewable energy law:
  - goal of 12.5% of electricity produced by renewable energy by 2010, 20% by 2020
  - fixed compensation for power fed into the grid and priority purchase requirement by renewable energy law
- Installed capacity:
  - quadrupled between 1994 and 2004 to 24 GW, mainly wind power
- Export of wind turbines:
  - about 50% of domestic produced capacity in 2004
- Costs of wind power:
  - investment costs (80%), installation costs (foundation, installation work, site preparation, roads, grid)

Scenario assumptions

- CO_2 price 20€/t CO_2 in 2005, linear increase to 40€/t CO_2 in 2010
- Energy:
  - Renewable energy 1.3GW in 1995, 31GW in 2030, high initial increase that tapers off over time
  - nuclear power phase out
  - exogenous assumptions for hard coal
- Learning rates:
  - 10% in renewable electricity generation
  - 10% in renewable energy equipment

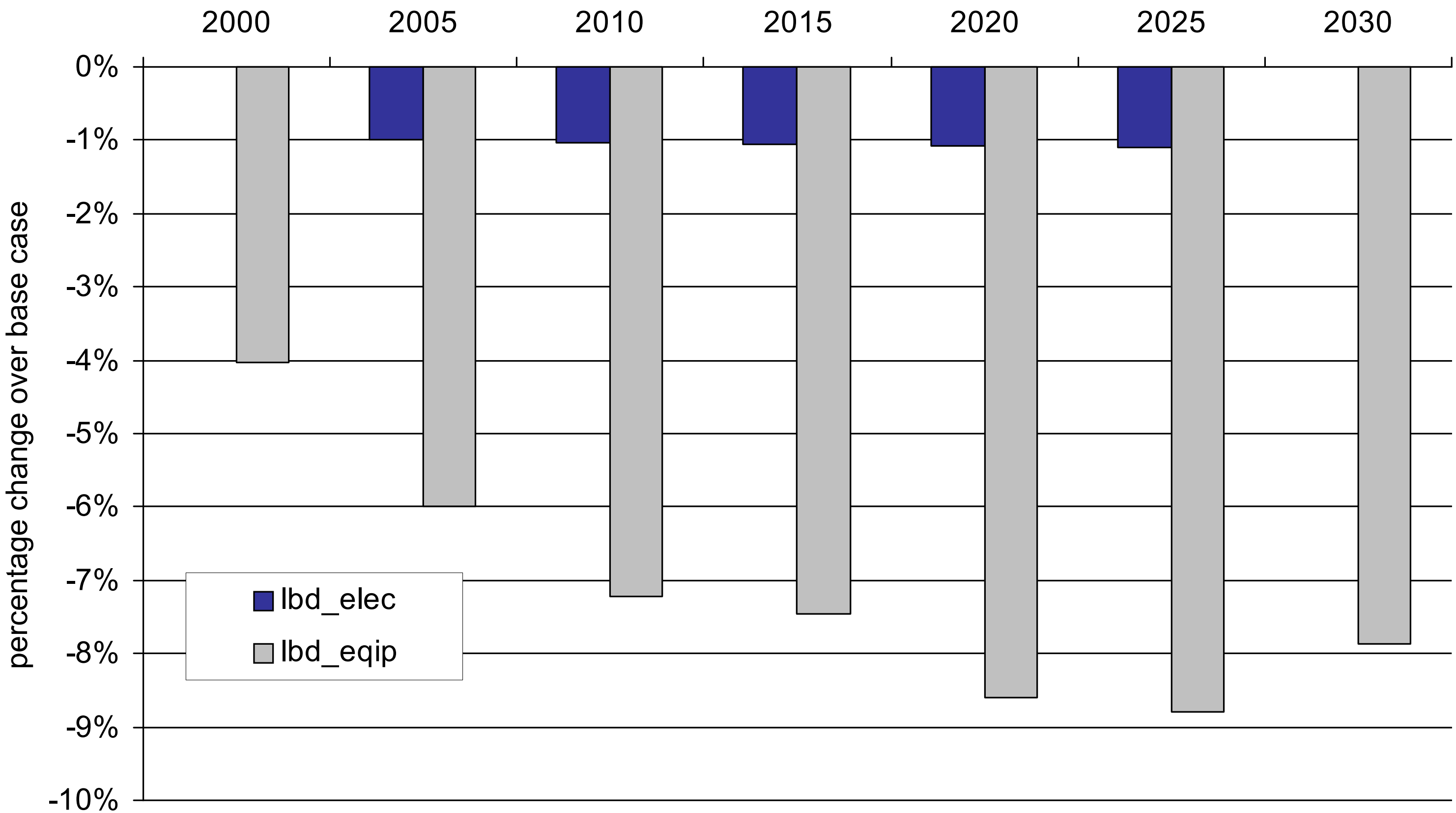
Some qualitative results

- Both policy scenarios
  - Quantity of renewable electricity output determined by policy objectives and measures
  - LbD reduces the costs of renewable electricity

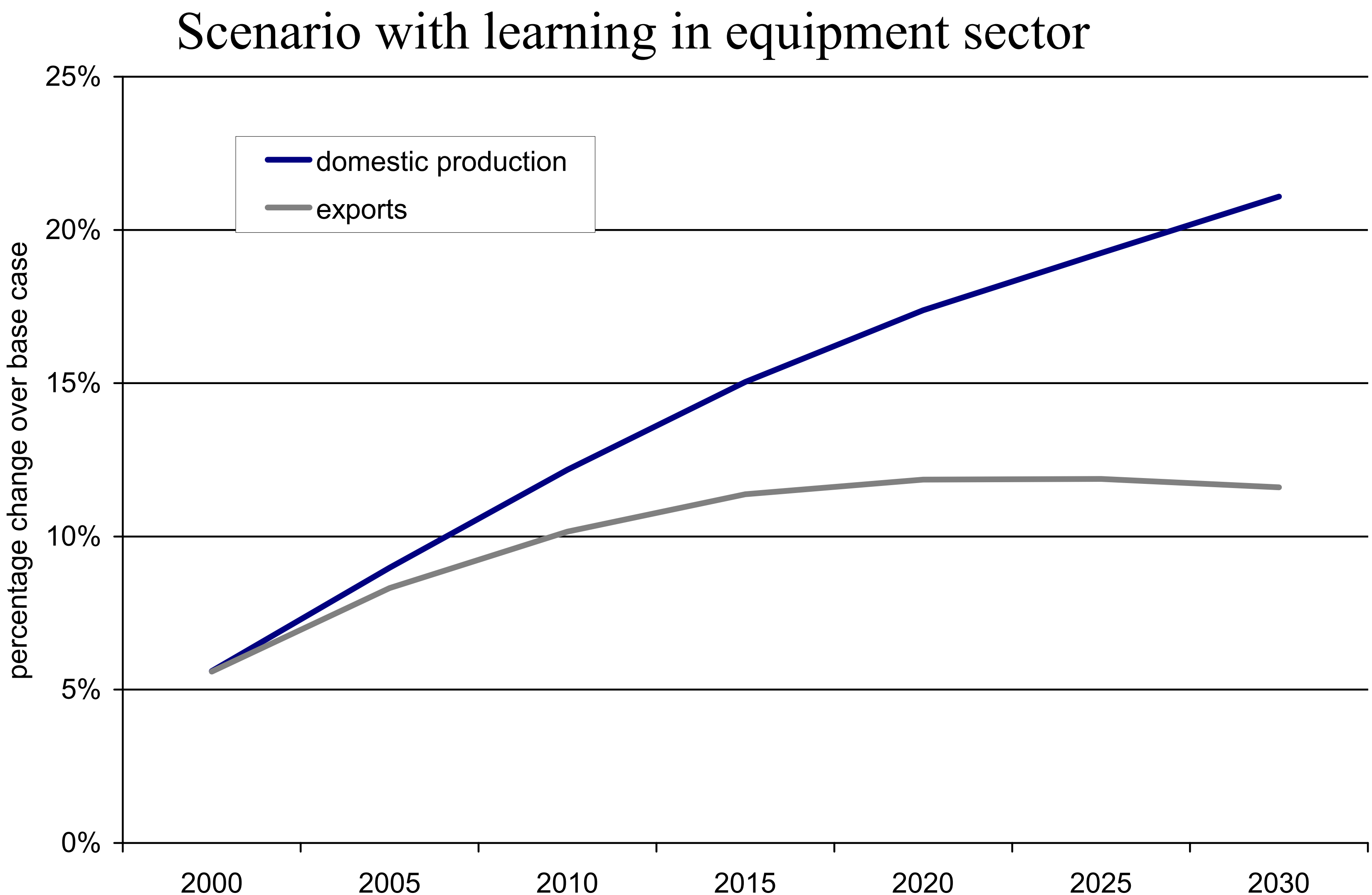
- Differences between the policy scenarios
  - LbD_equip spurs exports and output of equipment sector substantially
  - With renewable electricity quantities fixes, LbD_elec actually reduces demand for equipment

Renewable energy equipment

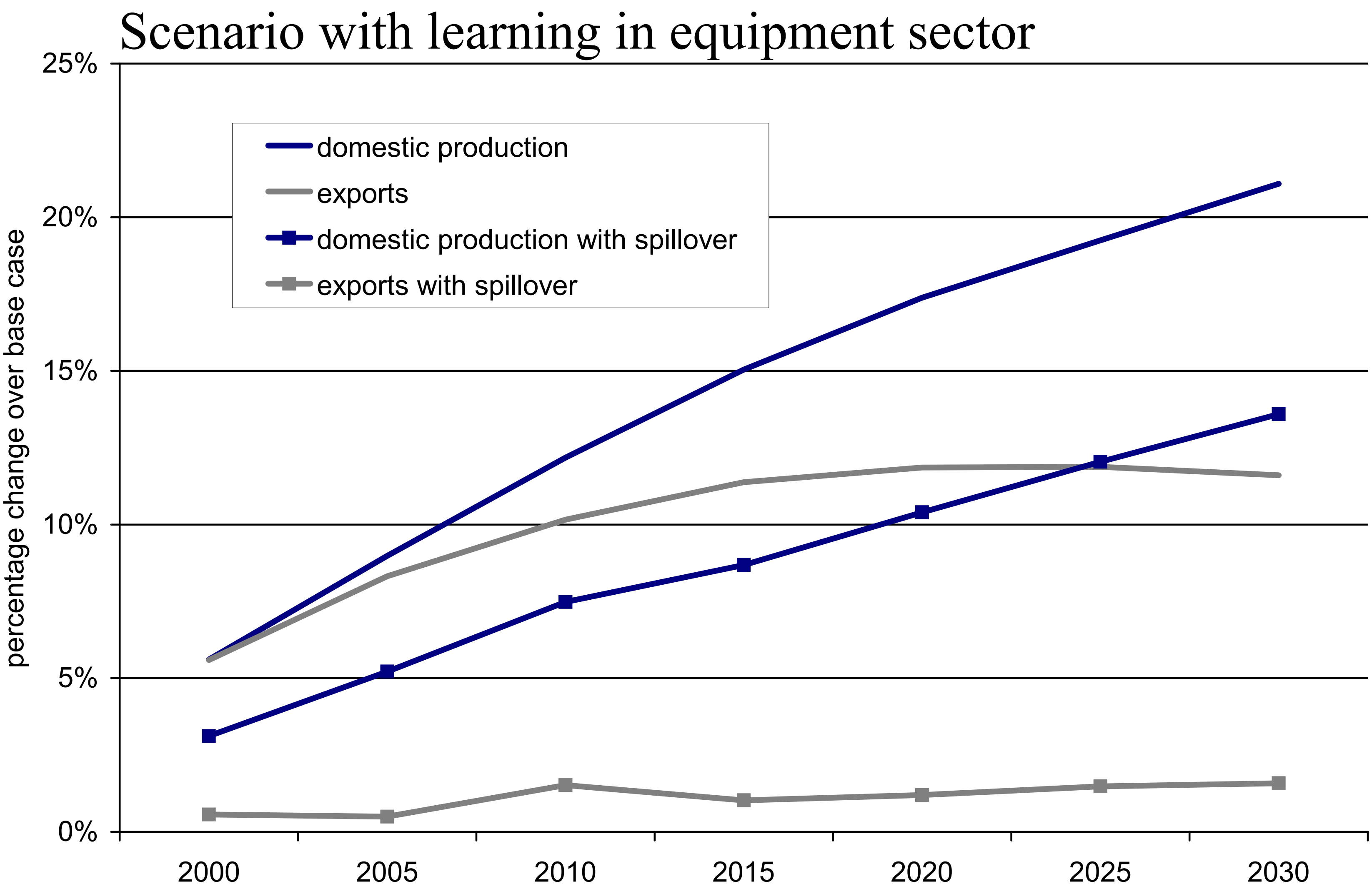
Price of output, change over base case



Renewable energy equipment



Renewable energy equipment



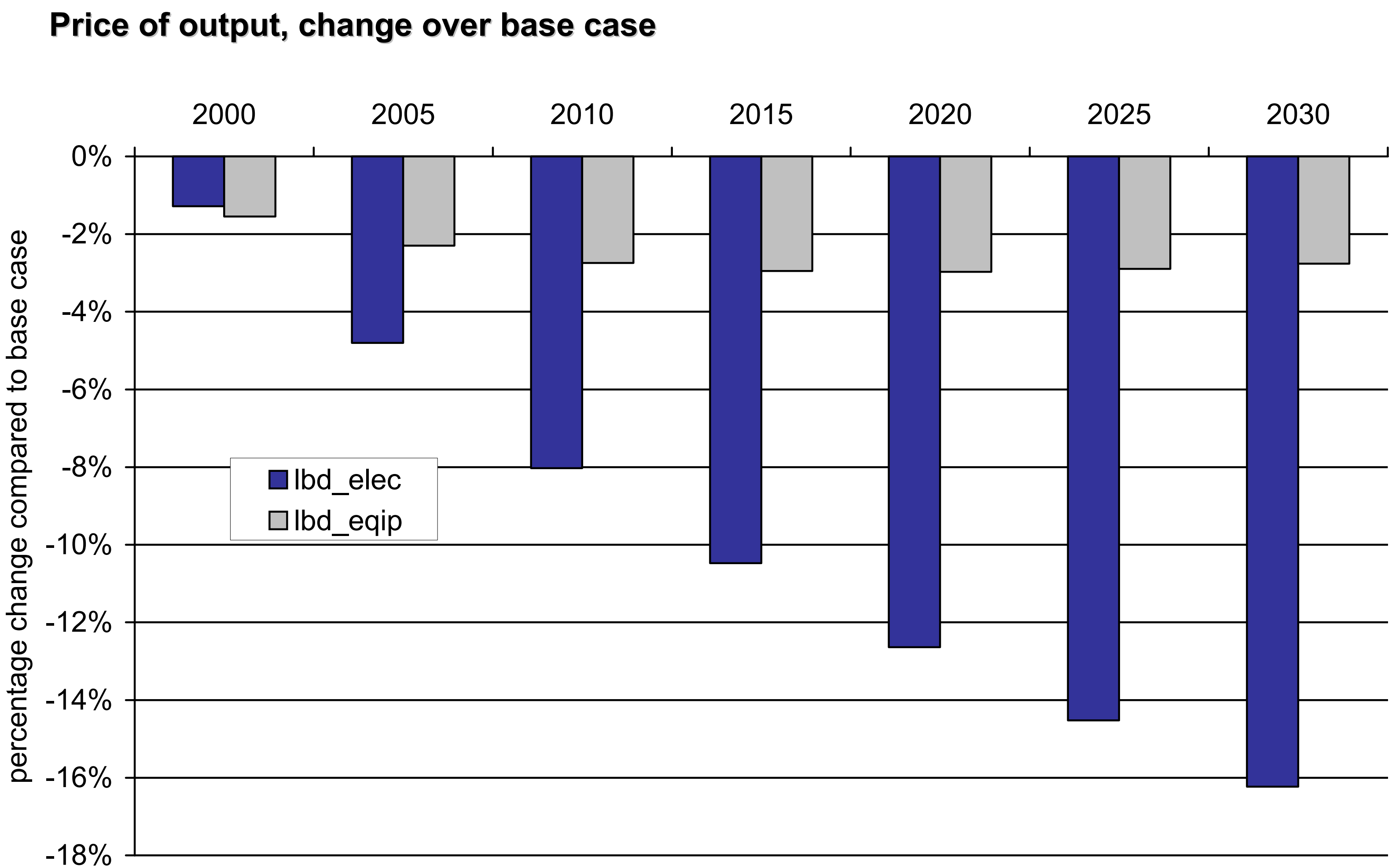
Conclusions

- It does matter to differentiate between learning-by-doing in the renewable energy equipment and in renewable electricity generation.
  - Substantial international trade effects associated with learning-by-doing in the machinery & equipment sector.
- If learning-by-doing affects export sectors and improves international competitiveness this has consequences for the costs and the optimal timing of climate policy.
- Further analyses may profit from literature on international trade and its dynamics in the context of learning-by-doing (see for example Young 1991).
- Different types of learning should be distinguished for parameter estimation as well

Thank you for your attention!

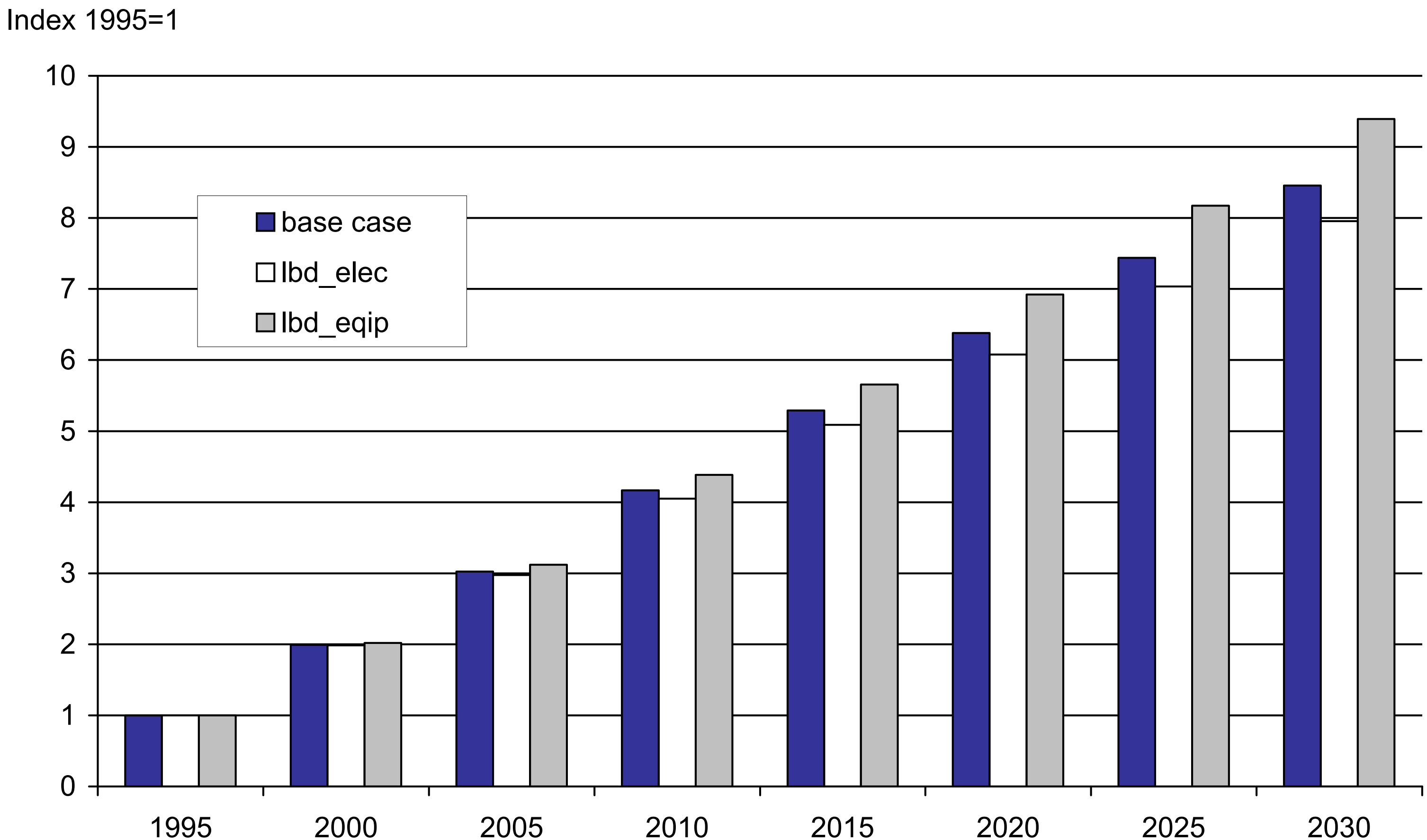
Extra Slides

Electricity generation renewables

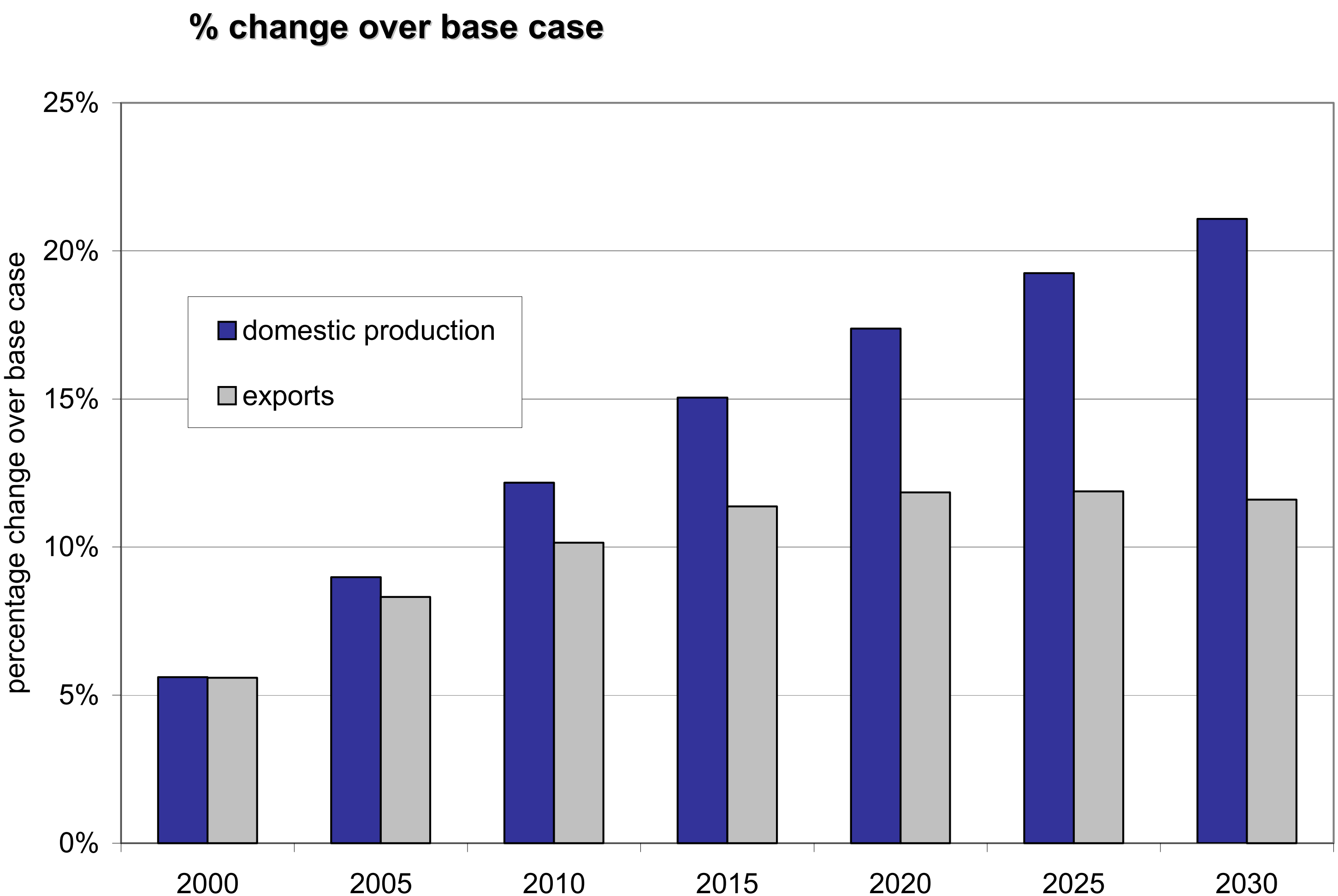


Renewable energy equipment

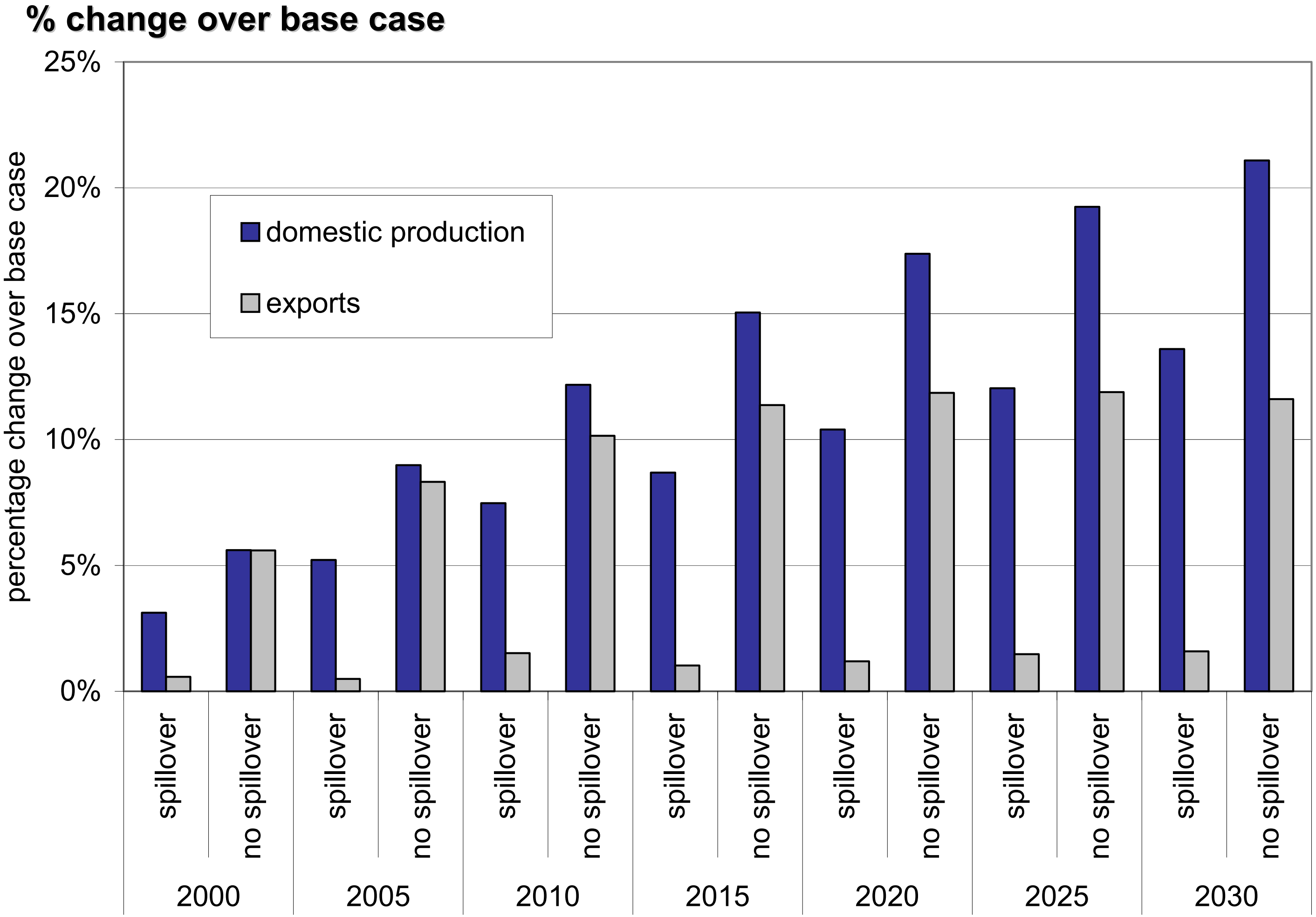
Cumulative output



Domestic production and exports of renewable energy equipment



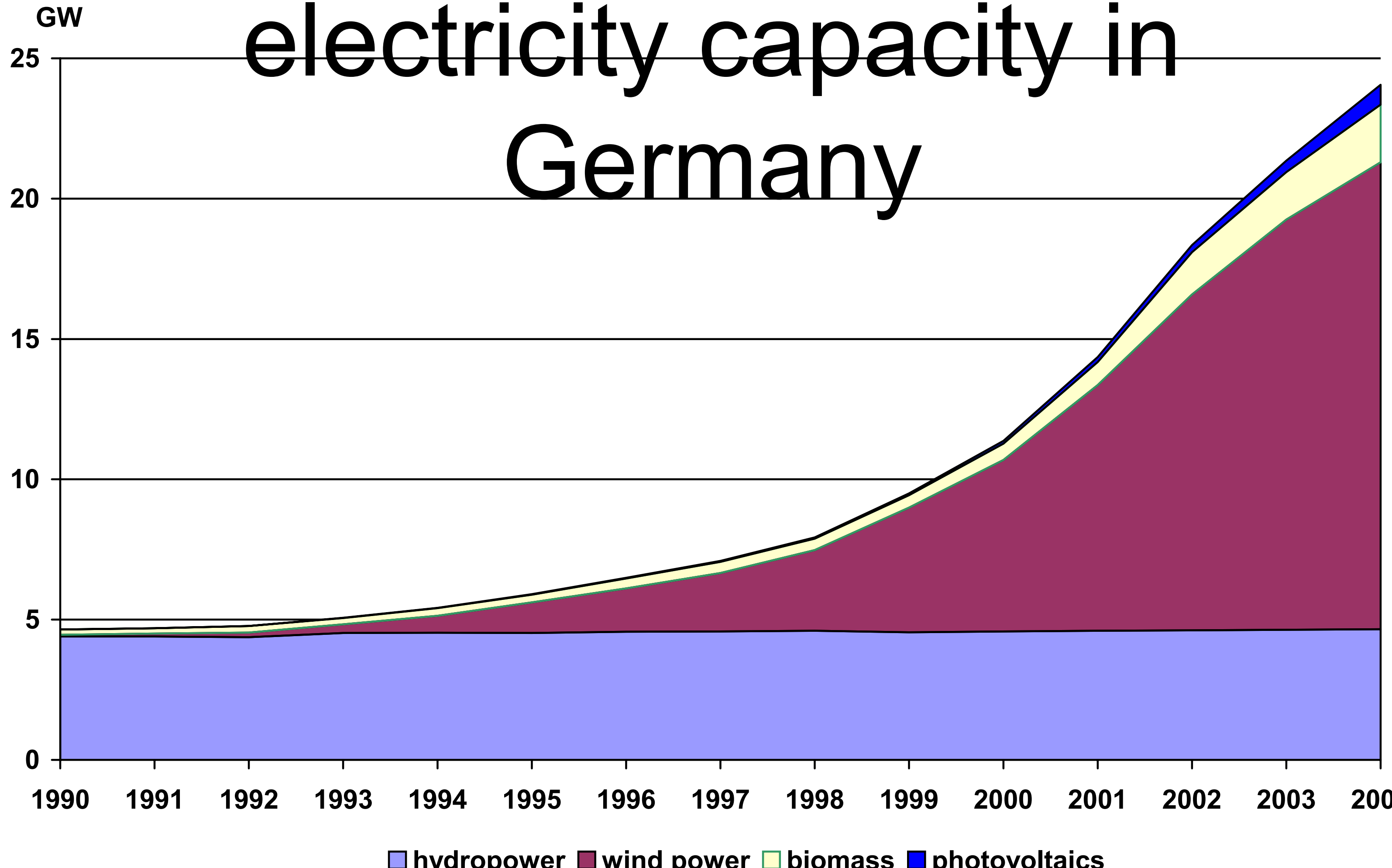
Germany renewable energy equipment: Domestic production and exports with and without knowledge spillover



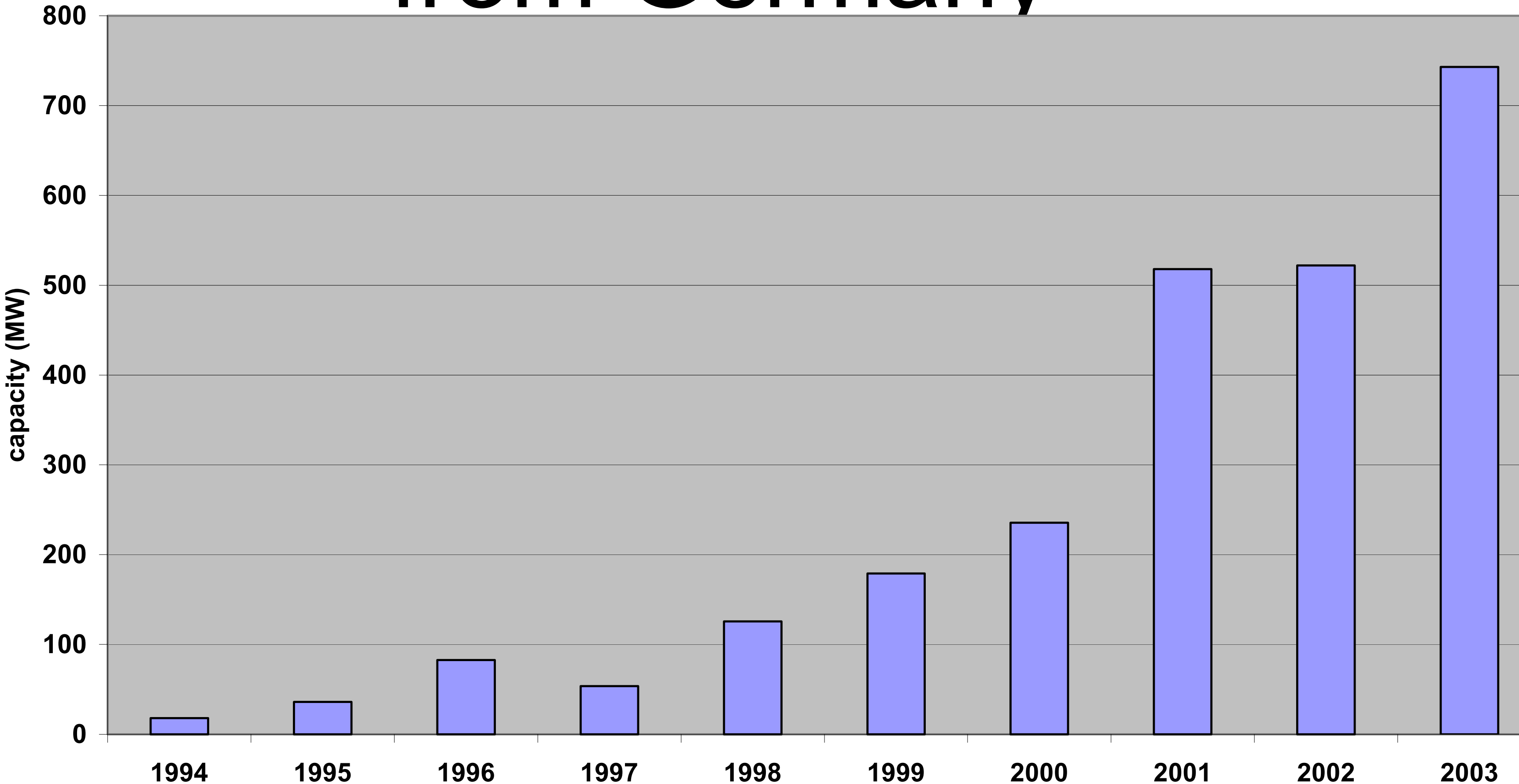
Sensitivity analysis of spillover effects

- No knowledge spillover: Germany first-mover country that profits from learning within its own borders, no learning in EU
- No knowledge spillover: GER and EU learning depends on experience with own borders
- Knowledge spillover from Germany to other countries (learning in EU and GER based on cum output in Germany)
- Knowledge spillover: Germany and EU profit from experience gained in all of EU (learning in GER and EU based on cum overall output in EU)

Total installed renewable electricity capacity in Germany



Annual export of wind turbines from Germany



Costs of wind power

Cost of wind turbines

Cost of components such as blades, towers etc