Fuelling the Future?

INPRO Dialogue Forum 8

Toward Nuclear Energy System Sustainability:

Economics, Resource Availability, and Institutional Arrangements

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International Atomic Energy Agency

Context

<u>Less sophisticated</u>: When will we run out of uranium?

<u>More sophisticated</u>: How will the need to mine lower grades of uranium influence the cost of uranium in the future?

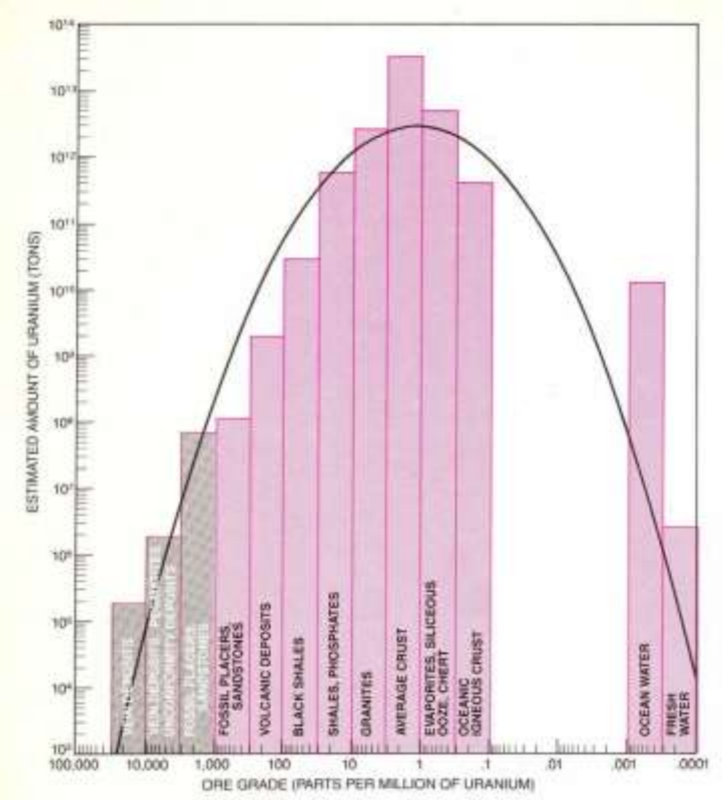
- Previous attempts to answer this second question have neglected forces which tend to reduce costs
  - Productivity growth
  - Learning

Plan of presentation

- Presentation will be in 3 parts:
  1. Deffeyes & MacGregor
  2. Development of a *static* model encompassing:
     - Ore grades
     - Cost structures
     - Demand growth
  3. Development of a *dynamic* model, augmenting the static model with
     - Productivity growth
     - Learning

Deffeyes & MacGregor

- Cost of extracting uranium from successively exploited deposits is likely to *increase* as the concentration of uranium in those deposits *decreases*
  - **Distribution of ore grades is crucial for economics**
- Deffeyes & MacGregor (1980) suggest that the distribution of ore grades can be characterised by a lognormal distribution function



- Parameterization of this function allows development of an ore grade *trajectory*
  - ***Reduction in ore grade as a function of total extracted uranium***

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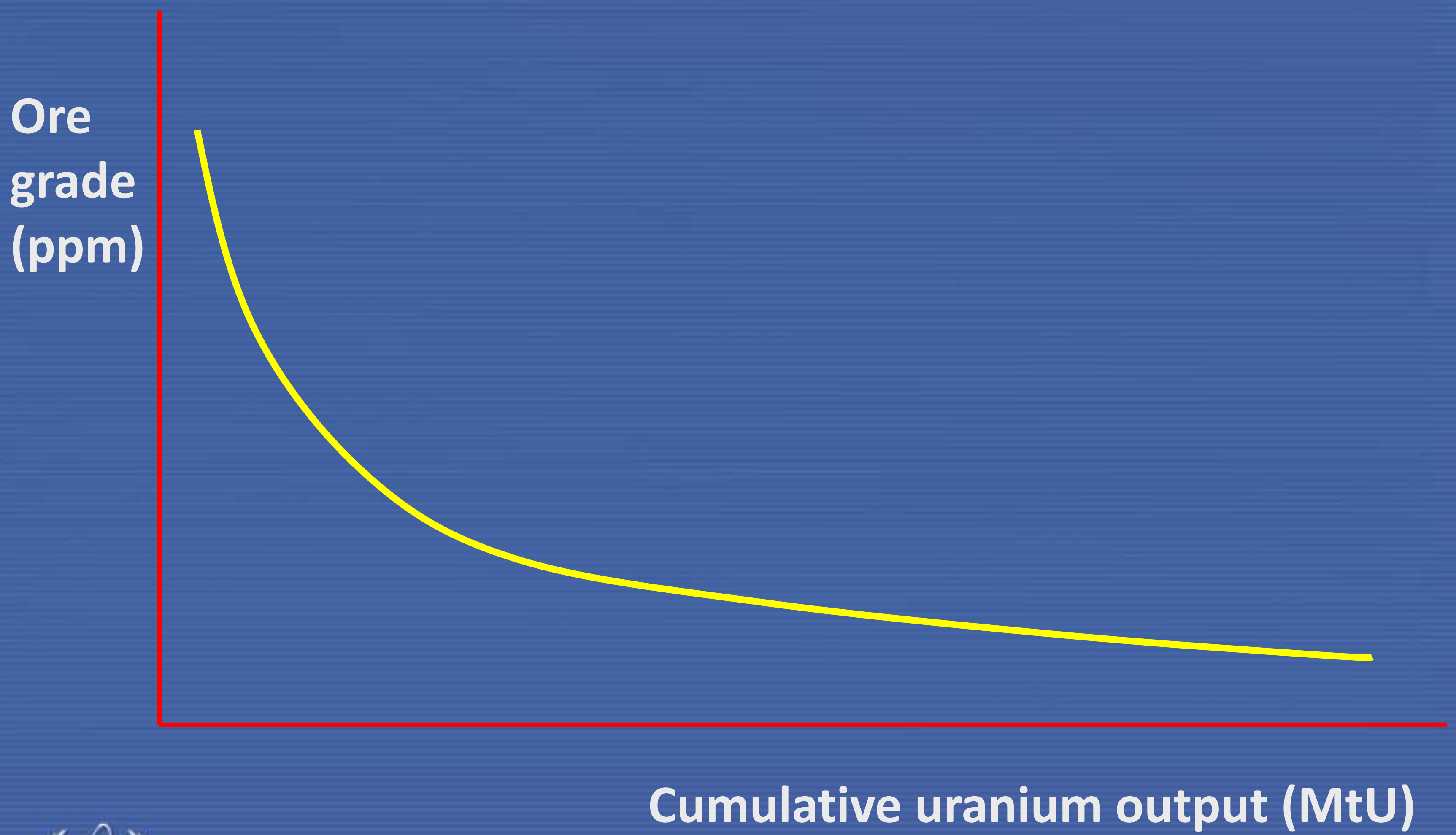
Ore grade trajectory



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Static model: cost structures

- Development of a *static* model will draw on ore grade trajectory mapping from accumulated uranium ore extraction to ore grade
- We need a mapping from ore grade (g) to cost per kg of U (c):

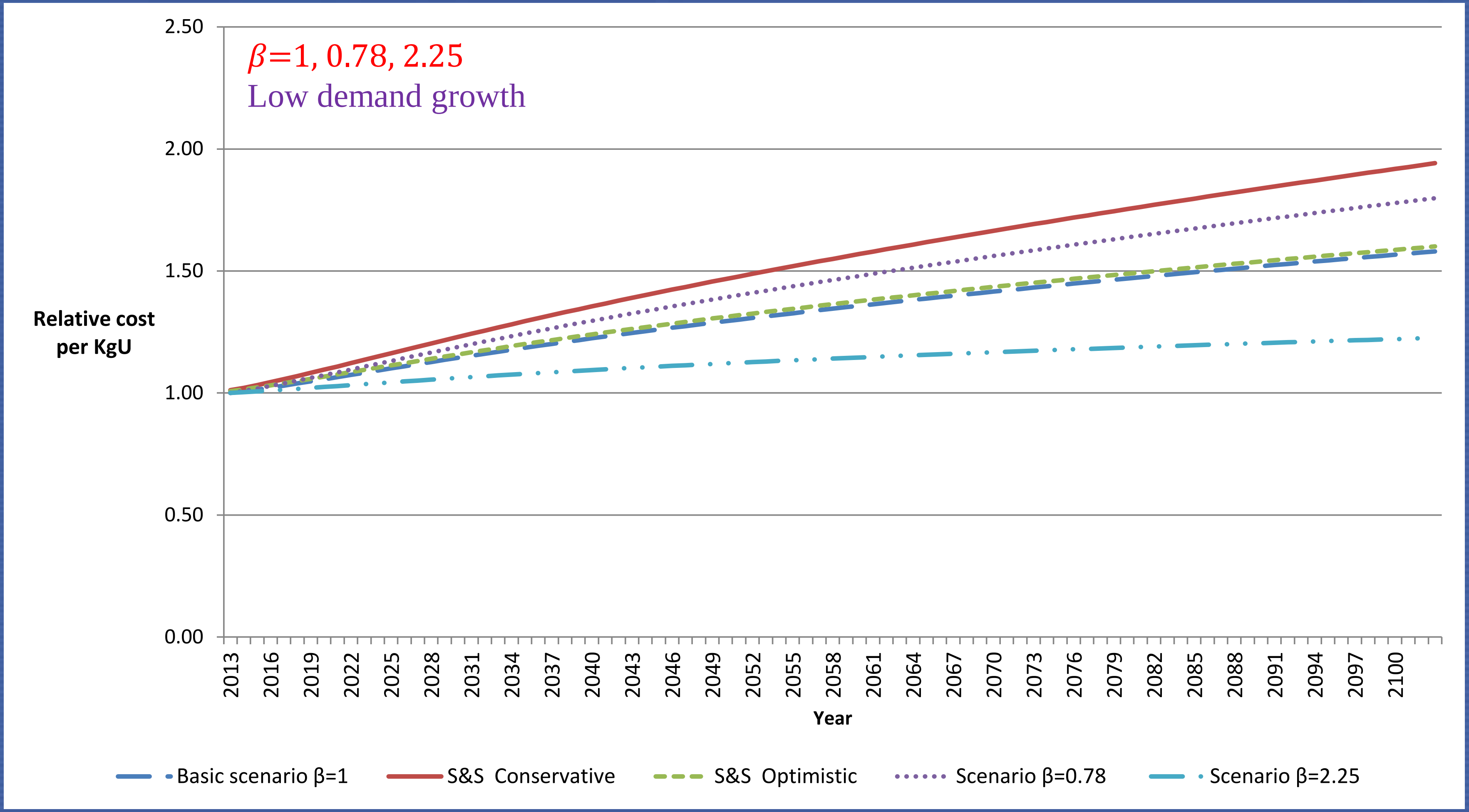
$$\left(\frac{g}{g_0}\right) = \left(\frac{c_0}{c}\right)^{\beta}$$

  - If $\beta = 1$ a halving of ore grade results in a doubling of unit costs
  - If $\beta > 1$ a halving of ore grade results in unit costs increasing by a factor of less than two
  - If $\beta < 1$ a halving of ore grade results in unit costs increasing by a factor of more than two

Static model: demand growth

- Use IAEA's Reference Data Series No. 1 (IAEA, 2013) to project U demand
  - RDS-1 projects nuclear electricity generation
    - We translate nuclear generation to U demand using 30K kWh per kg U
- 2 scenarios:
  - Low estimate: "conservative but plausible" case
    - Nuclear electricity expected to grow to 3548 TWh in 2050
  - High estimate projections relax some assumptions of the low estimate
    - Nuclear power generation to 5689 TWh in 2030 to reach 8971 TWh in 2050
  - Growth rates extrapolated out to 2100

Static model: cost vs time



Dynamic model: productivity growth

- As declining ore grades will tend to *increase* costs, so productivity growth will tend to *reduce* them
- Three important aspects of integrating productivity growth in the model:
  - Use data on productivity growth in the mining sector
  - Use mining productivity growth estimate *adjusted for ore quality*
  - Use adjusted productivity growth estimate *relative* to economy wide productivity growth
- Productivity growth is a time dependent process

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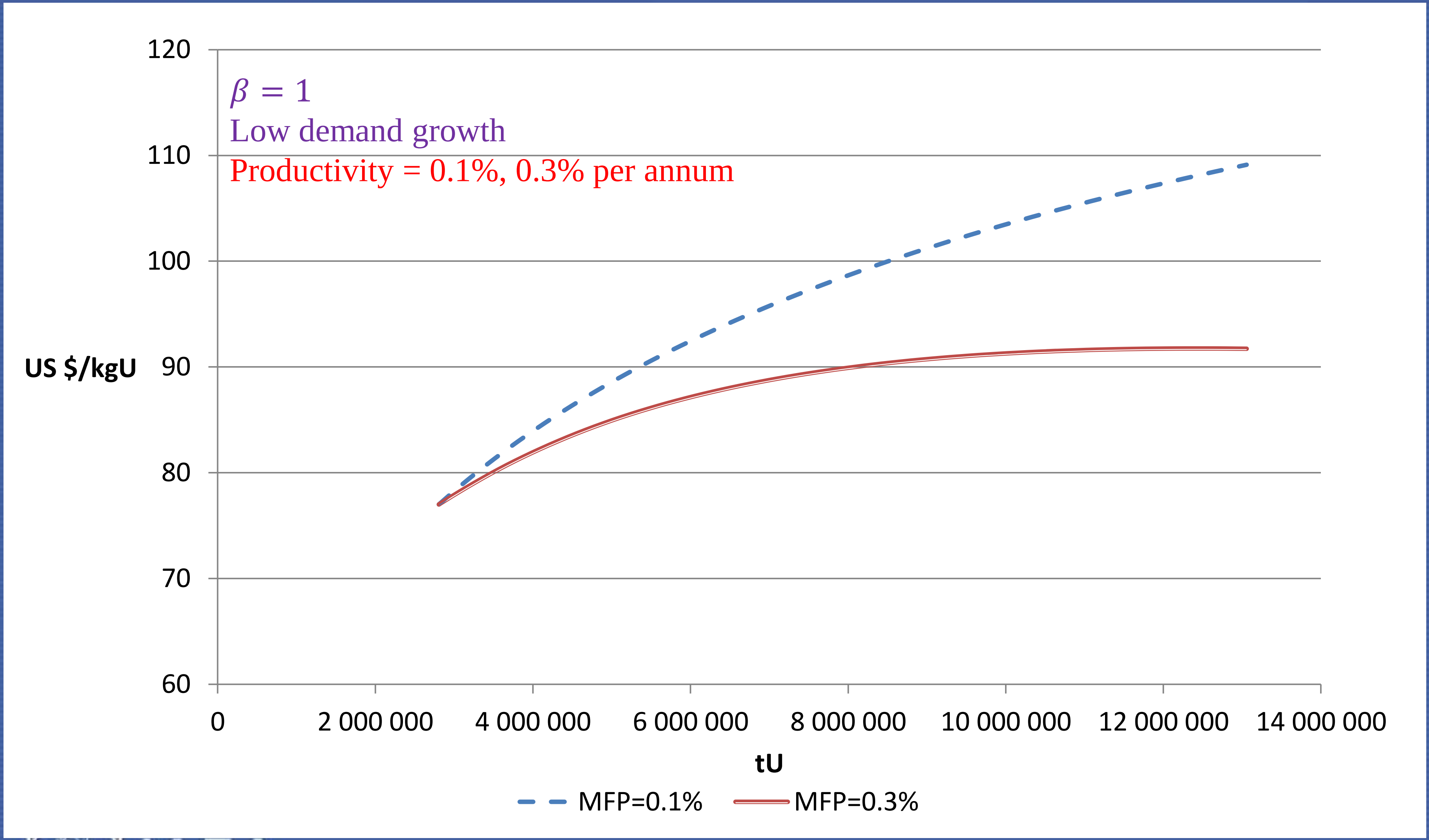
Dynamic model: productivity growth



Dynamic model: learning

- Learning will also tend to reduce costs (even as declining ore grades tend to increase them)
- Learning captures cost reductions arising from *experience*
  - Research suggests learning is best modelled as a function of *accumulated output*
- Parameterizations for 95% and 85% learning:
  - *95% learning:* costs reduced by 5% for every doubling of accumulated output
  - *85% learning:* costs reduced by 15% for every doubling of accumulated output

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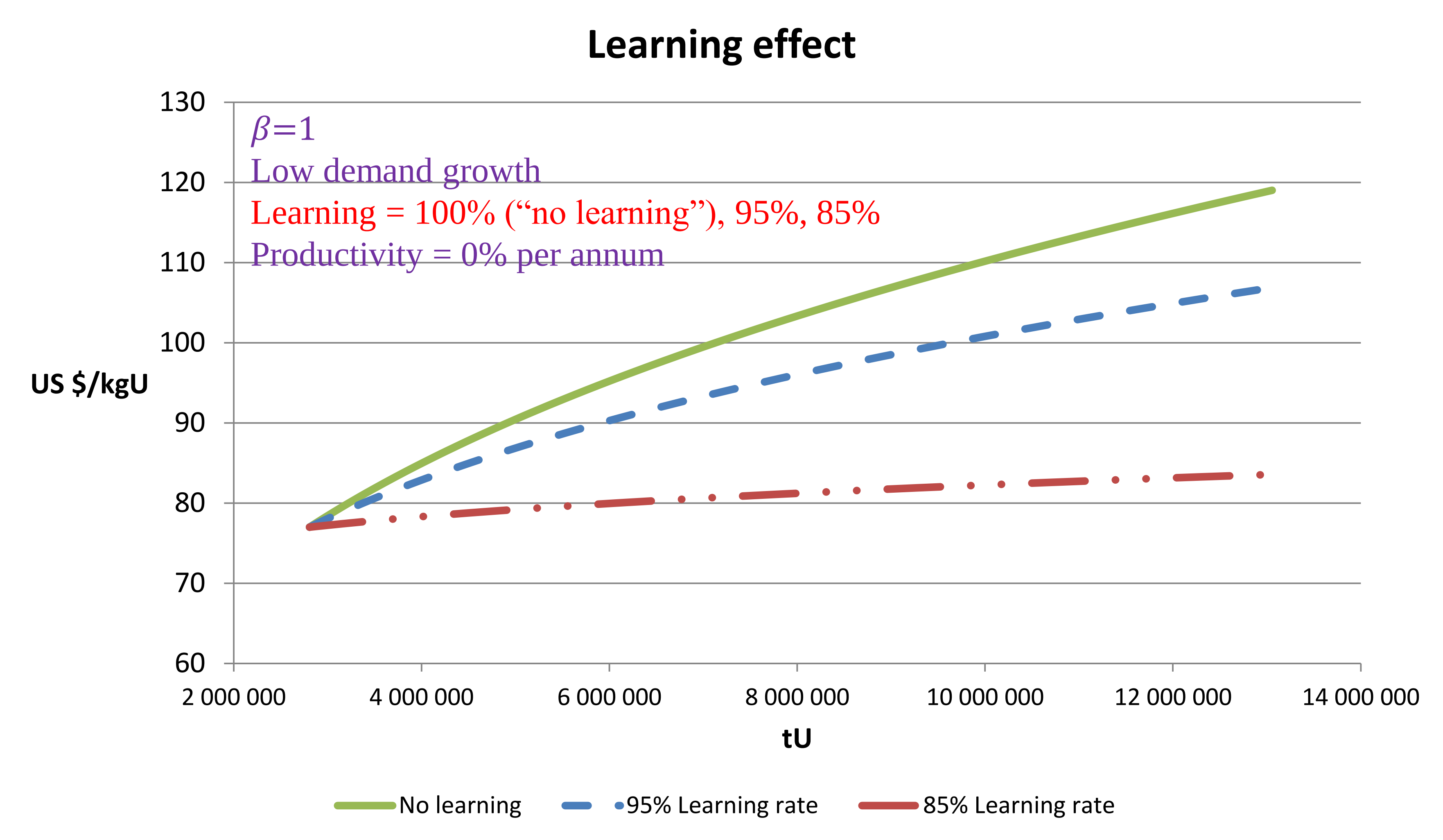
Dynamic model: learning



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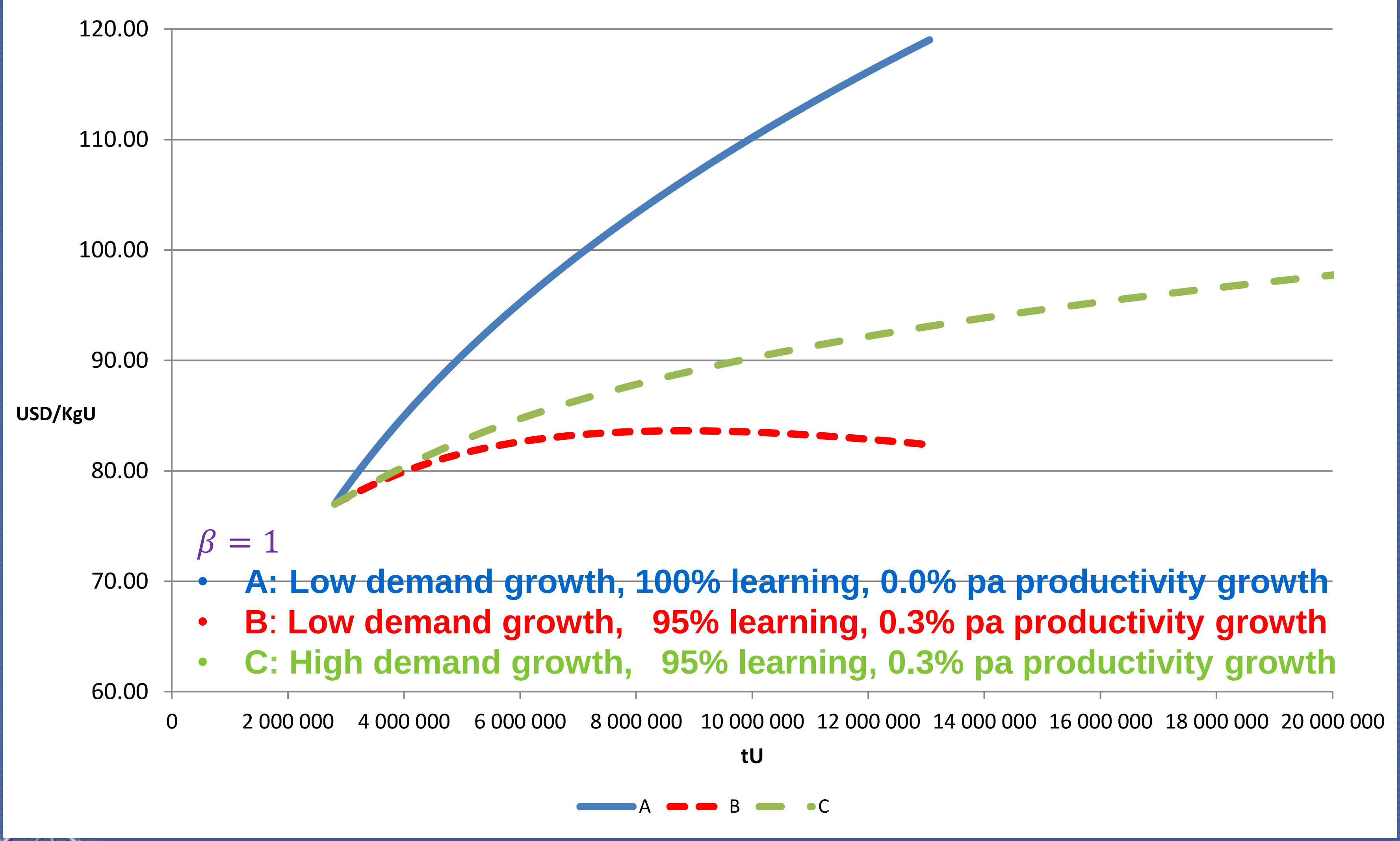
Dynamic model: history matters



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Fuelling the future?

- The issue is not whether we will run out of uranium resource, but what will happen to its price
  - Higher ore grade **depletion** will tend to drive extraction cost **up**
  - But two opposing forces will tend to **reduce cost**:
    - **Productivity growth** in mining
    - **Learning** effect
- **Dynamic** model incorporates these effects

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Thanks!

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