Fuelling the Future?

INPRO Dialogue Forum 8

Toward Nuclear Energy System Sustainability: Economics, Resource Availability, and Institutional Arrangements

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Context

*Less sophisticated*: When will we run out of uranium?

*More sophisticated*: 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

IAEA
Ore grade trajectory

Ore grade (ppm)

Cumulative uranium output (MtU)
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

\[ \beta = 1, 0.78, 2.25 \]

Low demand growth
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.
Dynamic model: productivity growth

\( \beta = 1 \)

Low demand growth

Productivity = 0.1%, 0.3% per annum
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
Dynamic model: learning

Learning effect

$\beta = 1$

- Low demand growth

Learning = 100% (“no learning”), 95%, 85%

Productivity = 0% per annum
Dynamic model: history matters

\[ \beta = 1 \]

- **A**: Low demand growth, 100% learning, 0.0% pa productivity growth
- **B**: Low demand growth, 95% learning, 0.3% pa productivity growth
- **C**: High demand growth, 95% learning, 0.3% pa productivity growth
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.
Fuelling the Future?

Thanks!

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