Past trends, present situation and future outlooks of the French nuclear industry

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Mines ParisTech - CERNA

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Introduction

- The European context
  - Depressed spot prices
  - Over-capacities
  - Rising costs of nuclear power
  - Enhanced competition with renewable sources

- What are the prospects of nuclear power?

- This presentation
  - Past trends in France: cost and safety
  - Present policies in France and early shutdowns
  - Future stakes for the nuclear industry
Outline

1. Past trends in France and OECD countries
   - The evolution of the construction costs
   - The evolution of safety

2. Present situation
   - Operating costs and life-extension costs
   - The French energy policy

3. Future outlooks of the French nuclear industry
The French fleet

- Construction between 1970 and 1990
- One technology: Pressurized water reactors
- Several technologies: 900, 1300, 1450 MWe
A mature fleet...
- 32-years old on average

...built at a reasonable cost...
- Standardization (only PWR on Westinghouse license)
- Single supplier and buyer (Framatome and EDF)
- Smooth and steady safety regulation

... and without subsidies
- paid by consumers, not taxpayers
- unlike fundamental nuclear R&D
The cost escalation is steeper in the US (blue) than in France (red)
Existing empirical findings regarding the US fleet

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Scale</td>
<td>-0.2%</td>
<td>+0.17%</td>
<td>+0.13% offsetting by leadtime effect</td>
<td>-0.22% but no significant</td>
<td>+0.94% offsetting by leadtime effect</td>
</tr>
<tr>
<td>Learning</td>
<td>-7.0% by doubling the experience</td>
<td>-11.8% first unit -4% second unit</td>
<td>-42% first unit -18% second unit Only for utilities</td>
<td>-9% by 1 unit of builders experience added</td>
<td>0.9% by 1% increase in builders experience</td>
</tr>
<tr>
<td>Regulatory</td>
<td>+15.4% +24% trend</td>
<td>+14% time trend</td>
<td>+10% time trend</td>
<td>Not included</td>
<td>+0.179% NCR Rules +0.096% ΔNCR Rules</td>
</tr>
</tbody>
</table>

- Regulatory requirements are the main driver of cost escalation
- Mixed findings regarding scale effects
- No evidence that supports learning-effects at the industry level
OECD construction lead-times (source: IAEA)
What do econometrics tell us?

Two papers

- Rangel and Lévêque (2015, Energy economics and Environmental Policy)
- Rangel and Berthelemy (2015, Energy Policy)

Three main findings

- A learning effect
- A scale effect
- A variety effect
Rangel and Leveque (2015):

- Positive learning effects occur within constructors and reactor technologies.
- On average, the second unit of a reactor built by the same firm would benefit from a 14% construction cost reduction.
- There is no evidence for other learning transfers (among technologies or firms).

Rangel and Berthélemy (2015):

- Innovation participates to the increase in the costs of construction of nuclear stations.
The scale effect

- Larger reactors are cheaper per MWe
- But they are longer to build, and lead time increases costs
- The net effect remains positive: a 10% increase in capacity reduces the cost by 4.9%

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cost</th>
<th>Leadtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>In ( \text{Leadtime} )</td>
<td>1.064</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>(0.622)</td>
<td></td>
</tr>
<tr>
<td>In ( \text{Cap} )</td>
<td>-0.624</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td>(0.182)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.125</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.053)</td>
</tr>
</tbody>
</table>
The effect of variety

- Homogeneity is measured by a market share index
- Homogeneity of the fleet reduces lead time
- True for France, the US, and OECD data

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cost</th>
<th>Leadtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>In. Leadtime</td>
<td>1.064 * (0.622)</td>
<td>-0.566 *** (0.160)</td>
</tr>
<tr>
<td>HHI_{mo}</td>
<td>0.374 (0.485)</td>
<td>-</td>
</tr>
</tbody>
</table>

France and US data

<table>
<thead>
<tr>
<th>Variables</th>
<th>(1) In LT</th>
<th>(2) In LT</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHI_{Mo}</td>
<td>-0.291 ** (0.135)</td>
<td>-0.472 *** (0.182)</td>
</tr>
</tbody>
</table>
Other findings

**France** : Lead times and labour costs are the most important determinant in the construction cost: longer construction periods lead to higher costs

**OECD** : Diversity is the main difference between countries that exhibit low or high construction periods

**Accidents** : TMI and Chernobyl have had significant structural consequences on construction lead times.

**Innovation** : participates to the increase in the costs of construction of nuclear stations
Policy implications

Future competitiveness of nuclear power will depend on:
- reduced lead times and overnight costs
- enhanced standardization and learning effects

These stakes imply the following trade-offs:
- standardization vs. innovation: to benefit from standardization without missing out on better and safer new technologies
- industry concentration vs. market power: to benefit from spillovers
The evolution of safety

- Severe events around the world

<table>
<thead>
<tr>
<th>INES</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>20</td>
<td>13</td>
<td>5</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>France</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Measuring the risks of nuclear accidents

Several sources of information:

- Probabilistic risk assessments: $10^{-5} - 10^{-7}$
- Observed events: $10^{-4} - 10^{-5}$
- Public perceptions: $> 10^{-4}$?

How to account for all these sources?

- Combining PSAs with observed events: Rangel and Lévêque (2014, Safety Science)
- Combining technical expertise with public perceptions: Bizet and Lévêque (2016)
Combining observations and PSAs

Poisson Exponentially Weighted with Moving Average model, Rangel and Lévêque (Safety Science, 2014).
Accounting for perceptions of the nuclear risks

Figure: The one-urn Ellsberg paradox

- Bizet and Lévêque (2016, Working paper)
- People prefer to bet with known probabilities
- How to account for ambiguity-aversion when making policy decisions?
Safety as measured by incident data

- French data on nuclear incidents (small events)
- Increasing operator transparency and regulatory stringency
- Decreasing rate of occurrence of automatic shutdowns
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3. Future outlooks of the French nuclear industry
In France, existing NPPs are cost competitive and will likely remain so, even if costs continue to increase
- construction costs have been amortized
- life extension investment is a cheap investment

The safety regulatory framework is satisficing
- Independency, transparency and competency of the ASN

However, the context has changed and EDF needs a new business model
- Less political emphasis on nuclear power, more on renewables
- Erosion of regulated tariffs and depression of wholesale market price
- Financial constraints and huge needs in investment
## Cost of the existing fleet

<table>
<thead>
<tr>
<th>Cost Description</th>
<th>€/MWh</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel (including WM)</td>
<td>5.7</td>
<td>Cour des comptes (2014)</td>
</tr>
<tr>
<td>Opex</td>
<td>24.4</td>
<td>Cour des comptes (2014)</td>
</tr>
<tr>
<td>Cash cost</td>
<td>32</td>
<td>E. Macron (2016)</td>
</tr>
<tr>
<td>Considered costs to set the regulated access tariff to EDF nuclear MWhs</td>
<td>39</td>
<td>Champsaur Commission (2011)</td>
</tr>
<tr>
<td>Average cost 2010</td>
<td>49.6</td>
<td>Cour des comptes (2012)</td>
</tr>
<tr>
<td>Average cost 2013</td>
<td>59.8</td>
<td>Cour des comptes (2014)</td>
</tr>
</tbody>
</table>
Investment and maintenance costs

(Source: Annual report of the French Court of Auditors, 2016)
Cost of life extensions

- Multiple, but coherent sources
  - EDF (2014): €55 billion in capex (1 b€\textsubscript{2013} /reactor) for 2014-2025
  - Court of Auditors (2016): €100 billion in capex + opex (1.7 b€\textsubscript{2013}/reactor) for 2014-2030

- Remarks
  - Figures include Fukushima-Daiichi upgrades
  - Equivalent LCOE for 15-year operation (900 MW, 80% load): 18 €\textsubscript{2013}/MWh

- Early closures under constant safety
  - Incentives for early phase-outs are mostly political
  - They are economically inefficient as the MWh from existing NPPs is cheaper than any other technology and than investments in energy efficiency
The French energy transition law

- Voted in October 2014
- Focus on renewables, energy efficiency, long-term planning
- Nuclear aspects and their consequences
  - A capacity cap at the current capacity (63,2GW):
    - FL3 completion will require to phase-out two existing reactors
  - A 50% share in the electricity mix “at the 2025 horizon”:
    - Current share is 75%
    - Vague objective with highly uncertain consequences
    - From no changes in case of new political majority in 2017 to the shutdown of up to 20 reactors (Cour des Comptes, 2016)
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3 Future outlooks of the French nuclear industry
The need for a new business model

- Depressed spot prices
  - EU spot prices are inferior to French regulated tariffs
  - EDF’s nuclear output is no longer sold at regulated tariffs

- Financial constraints
  - Broke but greedy shareholder
  - Small free cash-flow
  - Risk of derating

- How to finance the huge needed investments?
EDF is facing short-term issues

- Becoming a manufacturer: the AREVA NP acquisition
- Designing a new EPR with shorter lead times and lower costs
- Finishing the FL3 project
  - uncertainties pertaining to the reactor pressure vessel steel
- The Hinkley-Point C project
  - HPC now vs new EPR later vs nothing?
  - Opportunities of learning-by-doing before new projects in France?
Long-term issues

- EDF also has to address global stakes...
  - life extension
  - new business model
  - cost tightening for new builds

- ...that will depend on multiple factors
  - Internal factors
    - human resources management
    - engineering capabilities
  - External factors
    - future power prices
    - $\text{CO}_2$ prices
    - stability of French nuclear and energy public policies
Concluding remarks

- The French nuclear industry is at a crossroad
  - Past success-story vs. “change or die” future
- Stakes for existing NPPs
  - Ensure constant safety to benefit from cheap extensions
  - Counteract political forces in favor of early phase outs
- Stakes for new builds
  - Context of present European over-capacity
  - Convince financial markets
  - Overcome the cost-escalation curse
Thank you for your attention!

More information and references:

- www.cerna.mines-paristech.fr/fr/leveque/
- www.cerna.mines-paristech.fr/fr/bizet/
- www.cerna.mines-paristech.fr/fr/recherche/economics-nuclear
The US case

- Latest reactors were seven times as expensive as the oldest ones
- What are the drivers of this cost-escalation curse?
Disentangling construction costs and lead times

The simultaneity issue:

Lead-times and construction are determined simultaneously by the buyer and seller of a nuclear power station.

Rothwell (1986) proposed a model and a statistical method to account for this bias.

Statistical method (Rangel and Berthélemy, 2015):

Two-stage least square method to account for simultaneity.
Use of expected electricity demand as a proxy for lead-times.