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

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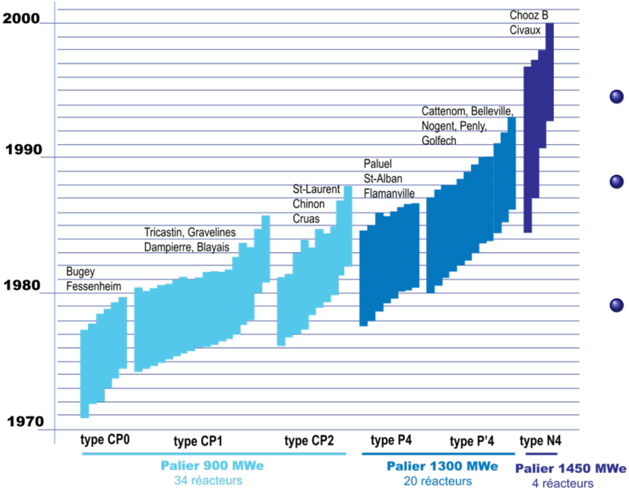
Introduction

- 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

The French fleet

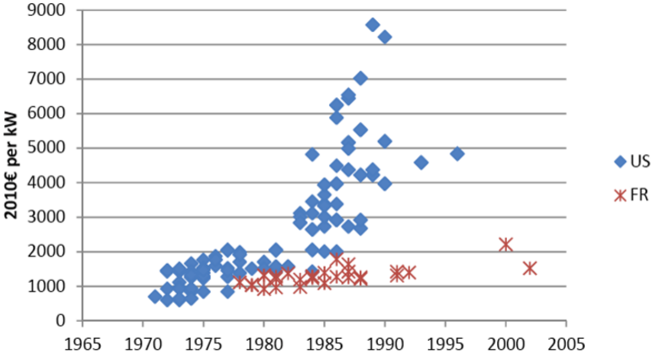


- Construction between 1970 and 1990
- One technology: Pressurized water reactors
- Several technologies: 900, 1300, 1450 MWe

Current status of the fleet

- 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

Comparison of French and US construction costs



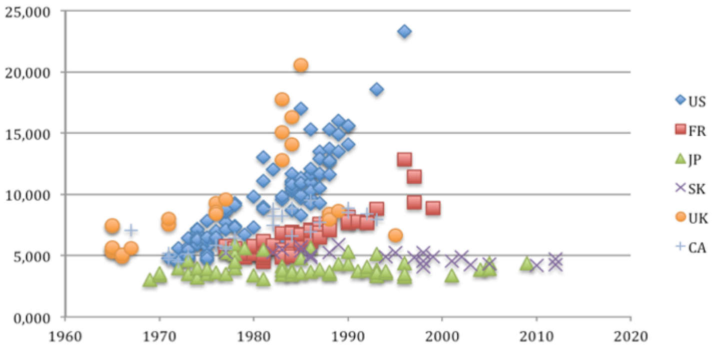
- The cost escalation is steeper in the US (blue) than in France (red)

Existing empirical findings regarding the US fleet

Effect	Komanoff (1981)	Zimmerman (1982)	Cantor &Hewlett (1988)	McCabe (1996)	Cooper(2010)
Scale	-0.2%	+0.17%	+0.13% offsetting by leadtime effect	-0.22% but no significant	+0.94%offsetting by leadtime effect
Learning	-7.0% by doubing the experience	-11.8% first unit -4% second unit	-42% first unit -18% second unit Only for utilities	-9% by 1 unit of builders experience added	0.9% by 1% increase in builders experience
Regulatory	+15.4% +24%	+14% time trend	+10%time trend	Not included	+0.179% NCR Rules +0.096% ΔNCR Rules

- 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?

Variable	Model 1		Model 2	
	Cost	Lead-time	Cost	Lead-time
$\ln LT_i$	2.177***		1.825***	
	(0.468)		(0.465)	
$\ln EDem_i$		−0.404***		−0.404***
		(0.079)		(0.079)
$\ln ExpArqMo_i$	−0.152***	0.022	−0.166***	0.022
	(0.034)	(0.015)	(0.033)	(0.015)
$\ln ExpArqNoMo_i$	−0.036	0.039**	−0.025	0.039**
	(0.035)	(0.012)	(0.033)	(0.012)
$\ln ExpNoArqMo_i$	0.021	0.035*	0.008	0.035*
	(0.036)	(0.015)	(0.035)	(0.015)
$\ln ExpNoArqNoMo_i$	−0.296*	0.156***	−0.223*	0.156***
	(0.099)	(0.023)	(0.096)	(0.023)
$HHI. Mo_i$	0.917	−0.415*	0.865	−0.415*
	(0.468)	(0.207)	(0.463)	(0.207)
$KNOW_i$			1.464***	
			(0.438)	
$\ln CAP_i$	−0.897***	0.188**	−0.793***	0.188**
	(0.175)	(0.068)	(0.170)	(0.068)
$ArqUtility_i$	−0.332***	0.052	−0.340***	0.052
	(0.084)	(0.037)	(0.081)	(0.037)
$\ln NPP. UC_i$	0.429**	−0.102**	0.356***	−0.102**
	(0.102)	(0.045)	(0.099)	(0.045)
$\ln Cement_i$	−0.214		−0.230	
	(0.405)		(0.394)	
$\ln Labour_i$	0.873		0.154	
	(0.409)		(0.413)	
TMI.US	−0.847**	0.436***	−0.504*	0.436***
	(0.248)	(0.050)	(0.246)	(0.050)
TMI.FR	−0.328	0.040	−0.230	0.040
	(0.216)	(0.096)	(0.209)	(0.096)
CHERNO	−0.348*	0.168***	−0.331	0.168***
	(0.142)	(0.037)	(0.137)*	(0.037)
Constant	4.829***	−0.449	−0.828	−0.449
	(1.573)	(0.510)	(2.714)	(0.510)
Country FE	Yes	Yes	Yes	Yes
Trend + trend^2	Yes	Yes	Yes	Yes
Obs.	128	128	128	128
Adj. R^2	0.856	0.914	0.865	0.914

Note: ***, ** and * indicate that results are significant at respectively 1%, 5% and 10
confidence level. Robust standard errors are reported in bracket.

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

The learning effect (France)

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%

Variable	Cost		Leadtime	
ln . *Leadtime*	1.064	*		
	(0.622)			
ln *Cap*	-0.624	***	0.125	**
	(0.182)		(0.053)	

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

France and US data

Variable	Cost	Leadtime
ln.*Leadtime*	1.064 *	
	(0.622)	
HHI_{mo}	0.374	-0.566 ***
	(0.485)	(0.160)

OECD data

Variables	(1) (ln LT)	(2) (ln LT)
$HHI.Mo_{l}$	-0.291 **	-0.472 ***
	(0.135)	(0.182)

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.

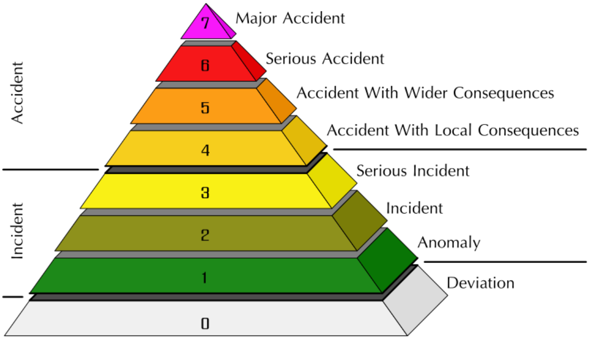
Innovation : participates to the increase in the costs of construction of nuclear stations

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

INES	3	4	5	6	7
World	20	13	5	1	2
France	1	2	0	0	0

Measuring the risks of nuclear accidents

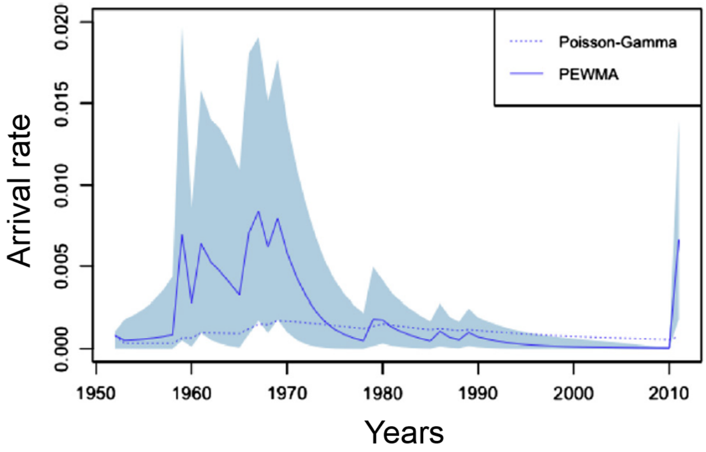
Several sources of information:

- 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

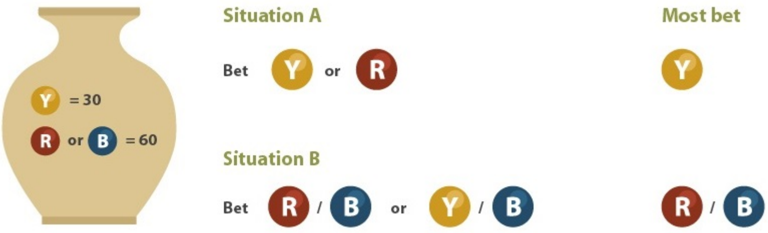
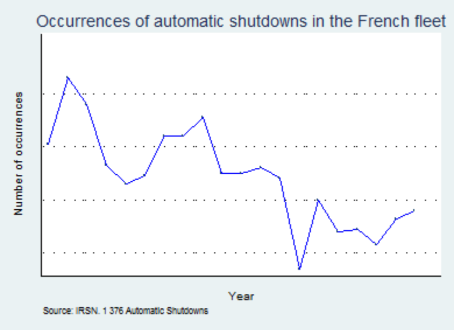


Figure: The one-urn Ellsberg paradox

- 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

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

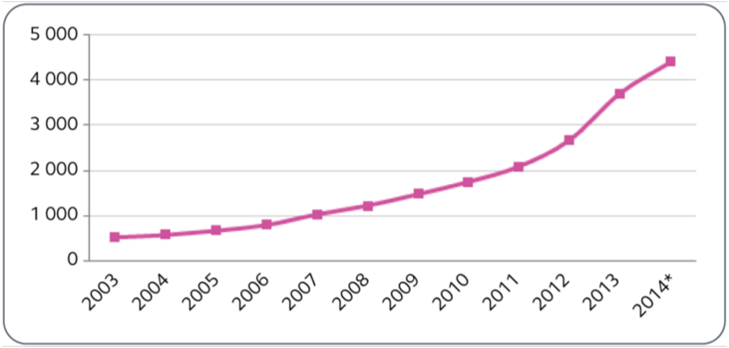
The economics of the existing fleet

- 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

	€/MWh	Source
Fuel (including WM)	5,7	Cour des comptes (2014)
Opex	24,4	Cour des comptes (2014)
Cash cost	32	E. Macron (2016)
Considered costs to set the regulated access tariff to EDF nuclear MWhs	39	Champsaur Commission (2011)
Average cost 2010	49,6	Cour des comptes (2012)
Average cost 2013	59,8	Cour des comptes (2014)

Investment and maintenance costs



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

Cost of life extensions

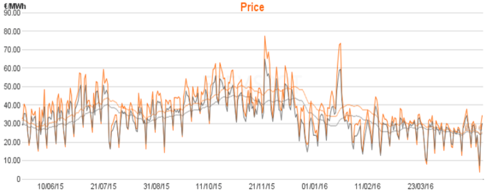
- Multiple, but coherent sources
  - EDF (2014) : €55 billion in capex (1 b€$_{2013}$ /reactor) for 2014-2025
  - Court of Auditors (2016): €100 billion in capex + opex (1.7 b€$_{2013}$/reactor) for 2014-2030
- Remarks
  - Figures include Fukushima-Daiichi upgrades
  - equivalent LCOE for 15-year operation (900 MW, 80% load): 18 €$_{2013}$/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 (63,2$\tilde{M}$W):
    - 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)

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?

Short-term issues

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 adress 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
    - CO_2 prices
    - stability of French nuclear and energy public policies

Concluding remarks

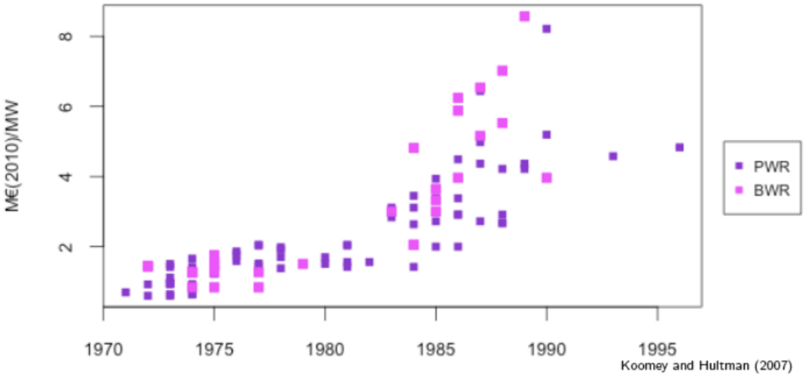
- The French nuclear industry is at a crossroad
  - Past success-story vs. "change or die" future
- Stakes for existing NPPs
  - Ensure constant safety to benefit from cheap extensions
  - Counteract political forces in favor of early phase outs
- Stakes for new builds
  - Context of present European 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