Ambiguity aversion and the expected cost of nuclear power accidents

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The paper

Observation	Conflicting assessments of the nuclear risk
Questions	How to make good decisions in this situation? Is cost-benefit analysis appropriate when facing catastrophic risks?
Method	Use of a growing literature on ambiguity-aversion
Results	A method that accounts for attitudes towards uncertainty Expected-cost of nuclear accidents 1.7€/MWh

Two strands of literature

Expertise regarding the risks of nuclear accidents:

- Statistical analyses of past events (Hofert, 2011; Rangel, 2014; Wheatley, 2016)
- Probabilistic risk assessments (ExternE, 1995; EPRI, 2008)

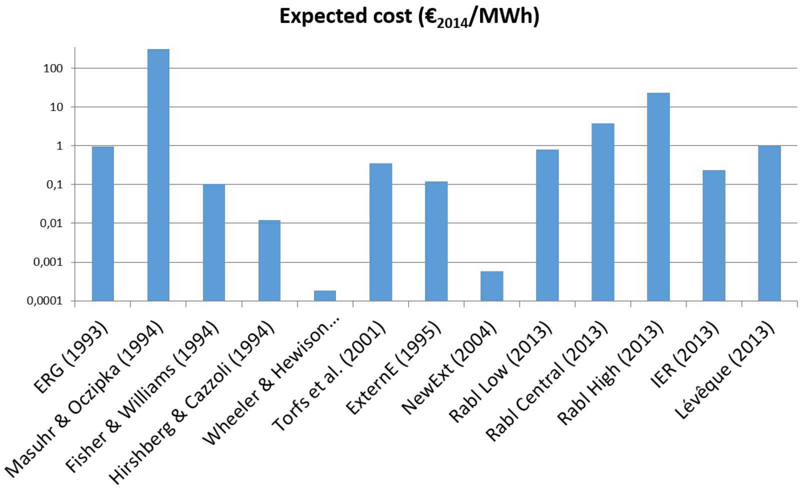
Applied decision theory:

- Risk-aversion and nuclear accidents (Eeckhoudt, 2000)
- Policy-making under uncertainty (Henry, 2002; Crès, 2011)
- Climate change and model uncertainty (Millner, 2013; Berger, 2016)

Motivations

- A need to estimate the cost of nuclear accidents
  - To better inform policy/investment decisions
  - examples: nuclear share in the energy mix, location of nuclear stations, phase-out schedules
- An estimation facing important methodological challenges
  - Rare events whose frequencies are not probabilities
  - Absence of consensus on the expected-cost of accidents

A review of expected-costs assessments



No consensus on the probabilities of accidents

Figure: Existing studies assessing nuclear accident probabilities

Source	Year	Core melts	Large releases	Method
ExternE	1995	5.10^{-5}	1.10^{-5}	PSA
NEA	2003	10^{-5}	10^{-6}	ExternE (PSA)
Hofert, Wuthricht	2011	1.10^{-5}	NS	Poisson law
IRSN	2012	NS	10^{-5}-10^{-6}	IAEA standards
Rabl	2013	NS	10^{-4}	Observed frequencies
IER	2013	NS	10^{-7}	NS
D'Haeseleer	2013	$1,7.10^{-4}$	$1,7.10^{-5}$	Bayesian update
Rangel, Lévêque	2014	$4,4.10^{-5}$	NS	PEWMA model

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Interpretation for a 400-reactor fleet

- $p_{PastEvents} = 10^{-4}$: one major accident every 25 years
- $p_{PSA} = 10^{-6}$: one major accident every 2500 years

Nuclear accidents are ambiguous

Multiplicity of information regarding accidents probabilities

Probabilistic Risk Assessments: 10^{-7}

Observed frequency of large accidents: 10^{-4}

What about public perceptions ? $> 10^{-4}$?

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Multiplicity of information regarding accidents probabilities

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- Observed frequency of large accidents: 10^{-4}
- What about public perceptions ? $> 10^{-4}$?

Which information should a DM consider?

- PRAs assume perfect compliance with safety standards
- Accident frequencies are not objective probabilities
- Public perceptions are distorted

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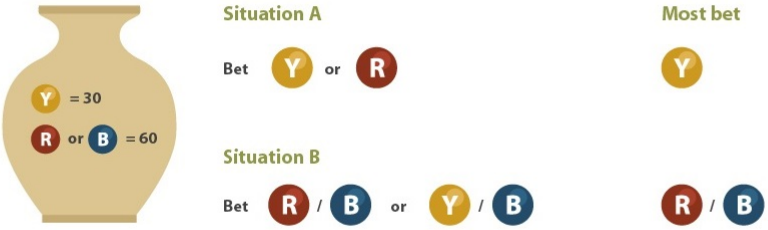
In this situation, how can we make good decisions?

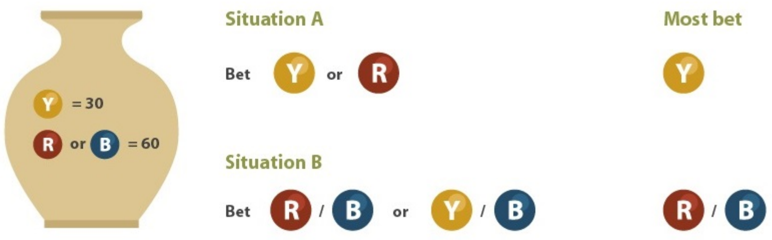
Ambiguity - Ellsberg's paradoxes

Figure: The one-urn Ellsberg paradox



Ambiguity - Ellsberg's paradoxes

Figure: The one-urn Ellsberg paradox

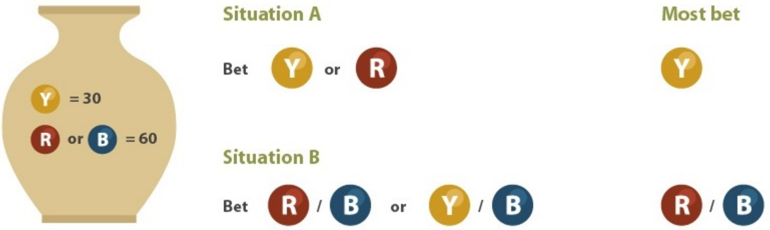


Situation A $\mathbb{P}(Y) > \mathbb{P}(R)$

Situation B $\mathbb{P}(Y \cup B) < \mathbb{P}(R \cup B) \Rightarrow \mathbb{P}(Y) < \mathbb{P}(R)$

Ambiguity - Ellsberg's paradoxes

Figure: The one-urn Ellsberg paradox



- People prefer bets described by known probabilities
- Ambiguity-aversion is not accounted for in classical cost-benefit analysis

The expected cost of nuclear accidents

A theoretical decision criterion : Ghirardato et al. (2004)

1. Ambiguity is embodied by multiple probability distributions
2. Ambiguity-aversion is represented by $\alpha \in [0; 1]$
3. Decisions should minimize an α-maxmin expected cost

$$\alpha \mathbb{E}_{\textit{worst case}}[C] + (1 - \alpha)\, \mathbb{E}_{\textit{best case}}[C]$$

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Applied to rare nuclear disasters :

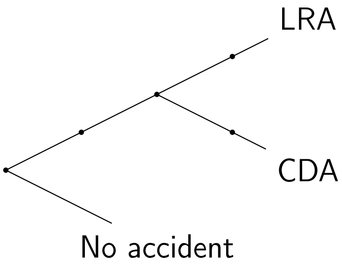
- Multiple sources of information suggest different probabilities of occurrence
- Ambiguity aversion: increased level of pessimism

An application to nuclear new-builds (1/2)

Two categories of accidents

- Core Damage Accident without releases (CDA)
- Large-Release Accident (LRA)

Figure: A simplified event-tree structure for nuclear accidents



An application to nuclear new-builds (2/2)

	Probability (per r.y)		Damage (10^9€)	
	best-case	worst-case	benchmark	macro
Core-damage	10^{-6}	10^{-3}	$2,6$	52
Large-release	10^{-7}	10^{-4}	170	359
Source	AREVA (HSE PSA)	Past events	Sovacool (08) Jap. Gvt.	IRSN (13) Rabl (13)

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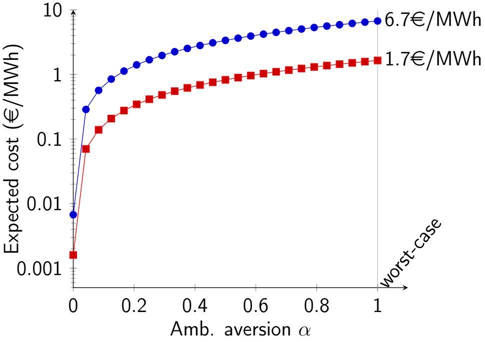

including image costs

no image cost

load factor: 90%

nom. power: 1650 MW

Policy implications

Policy: Assessments of the costs of technologies should account for public perceptions as well as experts analyses

Nuclear: Our result is *small* when compared to the LCOE of nuclear power new builds ($\sim$ 100€/MWh)

Method: Other uses to assess the cost of other rare disasters (oil spills, dam failures, nuclear safety standards or accident mitigation plans...)

Limits

Damage: are also prone to uncertainties

Completeness: All states of the world not known *ex ante*

Flexibility: Decisions are good *ex ante*

What happens when new information is obtained?

Is *ex post* flexibility valuable? (Kreps (1979))

Social choice: Implicit assumption: decision-maker is a rational individual (firm CEO, banker, median voter...)

No aggregation of preferences (equity concerns)

Thank you for your attention !

Presentation materials and references :

- www.cerna.mines-paristech.fr/bizet
- www.cerna.mines-paristech.fr/leveque
- www.cerna.mines-paristech.fr/nuclearpower

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References III

Wheatley, S., Sovacool, B. K., and Sornette, D. (2016). Reassessing the safety of nuclear power. *Energy Research & Social Science*, 15:96–100.

Axiomatic foundation

- We apply a decision criterion (GMM, 2004)
- Decision Maker is assumed to behave according to six axioms:

Ghirardato's "rationality" (2004)

- **GMM1:** Transitive Weak-order (usual)

$$\mathbf{a} \succeq \mathbf{b} \textit{ and } \mathbf{b} \succeq \mathbf{c} \Rightarrow \mathbf{a} \succeq \mathbf{c}$$

- **GMM2:** Certainty Independence (new)
- **GMM3:** Continuity (technical, usual)
- **GMM4:** Monotonicity (usual)
- **GMM5:** Non-degeneracy (usual)
- **GMM6:** Certainty-equivalence (new, technical)

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- **GMM1:** Transitive Weak-order (usual)
- **GMM2:** Certainty Independence (new) "*risk hedging*":

$$\mathbf{a} \preceq \mathbf{b} \Leftrightarrow \lambda\mathbf{a} + (1-\lambda)\mathbf{c} \preceq \lambda\mathbf{b} + (1-\lambda)\mathbf{c}, \ \mathbf{c} \textit{ constant}$$

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- **GMM3:** Continuity (technical, usual) "*no extreme*"

$$\mathbf{a} \prec \mathbf{b} \prec \mathbf{c} \Rightarrow \lambda_1 \mathbf{a} + (1-\lambda_1)\mathbf{c} \prec \mathbf{b} \prec \lambda_2 \mathbf{a} + (1-\lambda_2)\mathbf{c}$$

- **GMM4:** Monotonicity (usual)
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- **GMM4:** Monotonicity (usual) "*state dominance*"

$$\forall s \in \mathcal{S}, b(s) \preceq a(s) \Rightarrow \mathbf{b} \preceq \mathbf{a}$$

- **GMM5:** Non-degeneracy (usual)
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$$\exists \mathbf{a}, \mathbf{b}, \ \mathbf{a} \preceq \mathbf{b}$$

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$$\forall \mathbf{a}, \mathbf{b} \in \mathbf{A}, C^*(\mathbf{a}) = C^*(\mathbf{b}) \Rightarrow \mathbf{a} \sim \mathbf{b}.$$