Ambiguity Aversion and the Expected Cost of Rare Energy Disasters: An Application to Nuclear Power Accidents

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OVERVIEW

Assessing the risks of rare disasters due to the production of energy is of paramount importance when making energy policy decisions. Yet, the costs associated with these risks are most often not calculable due to the high uncertainties that characterize their potential consequences. In this paper, we try to shed light on this issue by giving an axiomatic representation of preferences among portfolios of energy production technologies. We derive from this representation a non-Bayesian method for the calculation of the expected cost of rare energy disasters that accounts for the ambiguity that characterizes the probabilities of these events. Ambiguity is embodied by the existence of multiple and conflicting sources of information regarding these probabilities. We then apply this method to the particular case of nuclear accidents in new builds. Our results suggest that the expected cost of a nuclear accident in an EPR reactor is approximately 1.7 €/MWh, which confirms the results of most recent estimates. This expected cost rises to 7 €/MWh when the macroeconomic damage caused by a nuclear accident is taken into account. This paper follows the efforts of Eeckhoudt et al (2000), who tried to account for risk aversion in the assessment of the cost of nuclear power accident. It provides a non-Bayesian method, which can be compared to the more traditional statistical methods applied to the cost and probabilities of nuclear accidents that can be found in Hofert and Wüthrich (2011) or Escobar Rangel and Lévêque (2014).

METHODS

Our paper develops a method for the evaluation of the expected cost of rare disasters characterized by ambiguous probabilities. Indeed, rare catastrophes related to the production of energy often fail to be well described by a single probability distribution over their potential outcomes. First, the frequency of observed past events fail to meet Savage's definition of an objective probability (1954). Besides, other sources of information regarding these events are available, such as subjective probabilities perceived by the public, or probabilistic safety assessments. When these sources of information are contradictory, performing cost-benefit analysis with respect to either of these may seem like an *ad hoc* choice rather than a rational calculation on which sound decisions may be made. Therefore, we propose a new method that accounts for this ambiguity. The method is based on the α-maxmin rule of decision making under uncertainty derived by Ghirardato et al (2004). It consists in calculating a weighted sum of the minimum and maximum expected costs of a given accident, calculated with respect to a worst-case and a best-case probability distributions. From a normative standpoint, the rule is appealing because of its axiomatic foundation: a firm or social planner who would want his energy choices to follow Ghirardato's axioms should feel compelled to using our rule. It also generalizes cost-benefit analysis. Indeed, when facing a situation characterized by a single (objective or subjective) probability distribution, our rule boils down to cost-benefit analysis. Finally, the rule embodies rather well the prescriptions of the precautionary principle: the existence of ambiguity over the probabilities of an event is translated by an increased level of pessimism (characterized by α) in the decision rule.

In order to apply this rule to the particular case of nuclear accidents, we use the state-of-the-art literature on the damage and probabilities of nuclear power acidents in order to identify the parameters of the model (the various types of accidents, their associated damage, or the "best-case" and "worst-case" probability distributions). We account for two distinct categories of nuclear accidents. We distinguish core-damage accidents, in which the core of a reactor is damaged, but lead to no radioactive leakage (but may cause outside damage such as a widespread panic among local residents); and large-release accidents, in which the containment of a nuclear reactor is breached, and large amounts of radioactive materials are released into the environment. The damage associated with each type of accidents is taken from recent post-Fukushima estimates and reviews. Regarding the probabilities associated with these accidents, the frequency of past nuclear accidents is taken as the worst-case prior, and the best-case prior is derived from the industry's probabilistic safety assessments. The rationale for these choices

	Damage (b€)	Probability best-case	Probability worst-case
Core Damage Accident	2.6	10^{-3}	10^{-4}
Large Release Accident	180	10^{-4}	10^{-7}
Other parameters	Ambiguity-aversion	Nominal power	Load factor
	1	1650 MW	90%

Table 1: Parameters of the numerical application

is the following. Probabilistic safety assessments conducted by the industry capture the work of fourty years of nuclear engineering, yet this method is based on simulations and event trees. It also assumes that operators are complying with safety regulations. As compliance may be imperfect, and event trees may not account for all potential triggering factors, this source of information may underestimate the probabilities of nuclear accidents. Regarding the worst-case prior, past events were witnessed on existing reactors that do not share the design basis of new builds. Therefore, this source of information is likely to be an overestimation of the probabilities of nuclear accidents. The values chosen for the different parameters are listed on tables 1. The results of our calculations are presented in the next paragraph.

RESULTS AND POLICY IMPLICATIONS

The results of this paper are twofold. First, we present a new method that generalizes cost-benefit analysis to situations of uncertainty characterized by ambiguous probability distributions: it provides a rational way of accounting for the existence of multiple probability distributions that may characterize rare energy disasters. Second, our application of this method to nuclear power accidents in new builds suggests that the expected cost of such accidents is approximately 1.7€/MWh, which is consistent with most of the recent estimates reviewed in the D'Haeseleer report for the European Commission (2013). Some sensitivity tests are carried out on this result, and show that this number is particularly sensitive to the damage associated with large release accidents. Furthermore, when we account for a potential macroeconomic shock induced by a large release of radioactive materials, we obtain an expected cost of 7€\MWh. This estimation is based on the assessment of macroeconomic damage performed by the French Institute for Radioprotection and Nuclear Safety (IRSN) for the hypothetical case of a major nuclear accident occurring in France. This number is to be interpreted with caution, as the estimation of the macroeconomic damage depends highly on the location of the accident.

The cost provided by this method is no longer the result of the aggregation of the different damage incurred by society in the aftermath of an accident, but an index associated with any decision that may bring about a nuclear accident. The relevance of this index lies in its axiomatic foundation: a decision-maker who would want her choices related to energy to be consistent with our axioms should evaluate rare disasters according to the rule we derived. The main policy implication of this paper is that public perceptions as well as technical expertise ought to be taken into account by policy-makers. This paper provides a tool that allows the combination of these two sources of information. More practically, the method we propose could also be used to assess other catastrophic risks, such as oil spills or dam failures; or in the elaboration of other policies, such as nuclear mitigation plans or safety standards. Our numerical results suggest that, even under maximum pessimism, the expected costs of nuclear accidents remain small when compared to the total LCOE of nuclear new builds.

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