



Quantifying the social costs of nuclear energy: Perceived risk of accident at nuclear power plants[☆]



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ABSTRACT

The preferences expressed in voting on nuclear reactor licenses and the risk perceptions of citizens provide insights into social costs of nuclear power and decision making in energy policy. We show analytically that these costs consist of disutility caused by unnecessary anxiety - due to misperceived risks relating to existing reactors - and where licenses for new nuclear reactors are not granted, delayed or totally lost energy production. Empirical evidence is derived from Finnish surveys eliciting explicitly the importance of risk perceptions on preferences regarding nuclear power and its environmental and economic impacts. We show that the estimated marginal impact of a high perceived risk of nuclear accident is statistically significant and that such a perception considerably decreases the probability of a person supporting nuclear power. This result holds across a number of robustness checks including an instrumental variable estimation and a model validation by observed voting behavior of the members of Parliament. The public's risk perceptions translate into a significant social cost, and are likely to affect the revenues, costs and financing conditions in the nuclear power sector in the future.

1. Introduction

Nuclear power is a contentious subject in energy policy. It supplies base-load energy with low operational costs and does so without CO₂ emissions, a feature that appeals to the international community in tackling climate change. However, the technology is plagued by apprehension related to radioactivity. Because of concerns about nuclear accidents and the handling and storage of spent fuel, nuclear power has long been controversial among the public. Safety risks have typically been considered the most challenging external costs of nuclear power (e.g., Kessides, 2010). For these reasons, in most countries, the licensing process for nuclear power is subject to political control and, to ensure risk management, production is strictly regulated by nuclear safety authorities.

We study the costs to society of the risks of nuclear power plant accidents. These costs are considerably harder to quantify than the costs of storage of spent fuel (Davis, 2012). How should such external costs be assessed? Two salient elements must be considered in doing so. The first is the objective probability of accidents at nuclear power plants. These probabilities are small, but the consequences of a large-scale catastrophe are potentially vast and long-lasting. Interestingly in this regard, private insurance companies will not provide full-coverage insurance against accidents. This policy can be attributed to a choice made in the beginning of nuclear programs worldwide to implement a rule strictly limiting civil liability in order to allow the growth of the nuclear industry (Faure and Fiore, 2009). In the case of an extreme emergency, clean-up and compensation to victims for damage and

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injury are ultimately the responsibility of government.¹

The second element is the impact on welfare of the perceived risks of a nuclear power plant accident. This is the focus of our paper. As the probability of a large-scale accident is very small, but the resulting damage may be enormous, the likelihood of an accident and the scope of the ensuing damage may become confounded in people's minds and result in exaggerated perceptions of risk.² It is thus likely that the perceived risks of an accident deviate from the objectively estimated probabilities and may play a weightier role in final decisions on licenses for new nuclear reactors, for example. Moreover, politicians' decisions may be influenced by their own risk perceptions, their views of their constituents' perceptions and the opinions of citizens or voters at large.³

We introduce an analytical framework for measuring the social costs of nuclear power resulting from perceived risks of a nuclear accident. Our investigation of risk perceptions reveals insights into their welfare consequences, which become capitalized in political decisions in licensing processes. In earlier work, [Salanie and Treich \(2009\)](#) have provided an economic rationale for over-regulation when risks are misperceived and citizens make choices according to their beliefs. We show analytically that if people's risk perceptions affect their stand on nuclear power, biased perceptions of accident probabilities pose a cost to society. These costs show up in two forms: unnecessary anxiety due to misperceived or exaggerated risks of existing reactors and, where licenses for new nuclear reactors are not granted, delayed or totally lost energy production. Understanding people's risk perceptions can help reduce expenditures, delays and enmity, and improve risk management and social welfare.

Based on the welfare components identified in the analytical model, we measure perceived risks of nuclear accident using surveys targeting the general public in Finland. Finland is a particularly interesting country in which to study nuclear power and risk perceptions. During the past 30 years, there has been a parliamentary vote on licenses for new nuclear reactors every decade, and the risks of nuclear power have been discussed in public debates in connection with each vote.⁴ Moreover, one of the world's most keenly followed and latest reactor technologies, the European Pressurized Water Reactor (EPR), has been under construction in Finland for over ten years. As the media frequently reported the opinion polls on nuclear power conducted in connection with each vote in Parliament and, more recently, have covered delays in the start-up of energy production at the new reactor, the public is familiar with the issue of nuclear power. We investigate the extent to which the public's risk perceptions affect their stand on nuclear power and their stated behavior in a putative referendum on new reactor licenses.

Our empirical modelling draws on the extensive previous research on risk perceptions. There is a vast literature in cognitive psychology on

risk perceptions (e.g., [Fischhoff et al., 1978](#); [Slovic, 1999](#); [Slovic et al., 2004](#); [Sjöberg, 2000](#)). Economics as well has a comprehensive literature studying the determinants of risk attitudes and perceptions in different domains and contexts (e.g., [Harrison et al., 2007](#), [Dohmen et al., 2011, 2012](#)). A recent study has investigated the effect of the Fukushima nuclear accident on the risk perception of residents near a nuclear power plant in China ([Huang et al., 2013](#)). We measure perceptions of risks based on responses to multiple survey items eliciting perceived risks in the context of a referendum-type vote on nuclear power licenses and in the context of personal risks in everyday life. As we have responses to several risk questions and risk rating scales, we can observe the use of the risk scale in separate items by every individual and control for the risk perceptions when explaining preferences in voting.⁵ We study the impacts of a set of demographics and risk perceptions on voting for or against license applications for new nuclear power reactors in Finland, and provide well-identified evidence on whether perceived risk or fear of accident affects voters' preferences. In the survey, the wording of the vote on license applications was exactly the same as the one used in the Finnish Parliament in July 2010.

Obviously, those who oppose nuclear power are likely to perceive its risks high. This raises the concern of reverse causality.⁶ We show that our results on the impacts on voting of perceived risks of a nuclear accident are robust to a series of specification checks. In particular, our instrumental variable estimation strengthens our confidence in perceived risk of accident being a strong determinant of respondents' voting decision. Moreover, we validate our model of hypothetical voting by analyzing the observed voting behavior of the members of Parliament who voted on the reactor licenses in Parliament in 2010. There, too, predicted perception of the risk of an accident turns out to be a statistically significant determinant of voting decision.

Finally, drawing on the survey data, we can estimate how important a factor risk perceptions are for calculations of the social costs of nuclear power. Our focus on risk perceptions is motivated by the fact that previous studies have shown rather low external costs in the case of a potential large-scale nuclear accident per produced MWh (e.g., [Laes et al., 2011](#)). Still, nuclear power continues to be a highly contested issue in energy policy. The growing literature on the long-term physical and psychological health effects of nuclear catastrophes on well-being (e.g., [Almond et al., 2009](#), [Danzer and Danzer, 2016](#), [Goebel et al., 2014](#)) stresses the importance of analyzing the impacts of risk perceptions on the choices of technology in energy policy, where externalities and social costs play a crucial role. Our results show that risk perceptions increase the social costs of nuclear power considerably, and provide a case for policies that mitigate real risks and reduce fear. Although one should be cautious when drawing conclusions for other countries from the experience in Finland, we believe that the results of our study may significantly improve the understanding about the risk perceptions and their importance in the external costs associated with energy production and implications for policy making in other countries.

In the following, we first provide the political and social context of our study by discussing issues of nuclear power safety and reviewing the relevant literature on the calculation of probabilities of nuclear accidents and elicitation of risk perceptions. Thereafter, we present the simple analytical framework that underlies the statistical analysis of the voting behavior. In [Section 4](#), we briefly motivate the issues queried in the survey and describe the data collected. [Section 5](#) presents the results and [Section 6](#) puts forward a monetary estimate of the social cost of perceived accident risk and discusses its policy implications. [Section 7](#) concludes.

¹ International conventions limit the liabilities of operators of nuclear power plants such that beyond the limit the state can accept responsibility as insurer of last resort. For example, the Fukushima I Nuclear Power Plant was insured for some tens of millions of euros with the German Nuclear Insurance Association; yet, no insurance was provided for damage caused by earthquakes, tsunamis, and volcanic eruptions, and the insurer had no liability to Tokyo Electric Power Company. The clean-up costs of Fukushima have been estimated at USD 50–250 billion during the upcoming decades.

² "Risk perception is the *subjective assessment of the probability of a specified type of accident* happening and how concerned we are with the consequences. To perceive risk includes evaluations of the probability as well as the consequences of a negative outcome." ([Sjöberg et al., 2004](#) p. 8) The tendency to overestimate small probabilities has been widely discussed in the context of prospect theory ([Kahneman and Tversky, 1979](#); see also [Barberis, 2013](#)).

³ See, e.g., [Levitt \(1996\)](#), [Lee et al. \(2004\)](#), [Washington \(2008\)](#) and, for political decision making in environmental issues, [Nelson \(2002\)](#).

⁴ According to the Finnish Nuclear Energy Act (11.12.1987/990), Parliament has to evaluate whether the use of nuclear energy, taking into account its various effects, is "in line with the overall good of society". In Finnish parliamentary politics, nuclear energy is what is known as an 'issue of conscience', in which voting outcomes often split along other than established party lines.

⁵ In fact, for a sample of the members of the Finnish Parliament we have observed stated risk perceptions and actual voting behavior in Parliament regarding licenses.

⁶ A potential endogeneity bias has also been investigated by [Riddell \(2011\)](#) in her model of perceived mortality risk and acceptance of the risk associated with nuclear waste transport.

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