Meta-analysis of expert elicitations of future technology outcomes for nuclear power

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Overview

Developing energy policies that are robust to a broad set of possible future conditions requires explicit characterization of the anticipated performance of individual energy technologies. While representing future technological change introduces considerable uncertainty into decision-making, we know from past data that energy technologies have been dynamic, and that these changes have had substantial affects on the entire energy system, the economy, the environment, and society. And even though future change is uncertain, we are not completely ignorant; dispersed researchers have produced data and developed tools that, in combination, provide the basis for probabilistic estimates of future improvements in technology.

In this paper we make use of expert elicitations of the future performance of nuclear fission technology conditional on public R&D investment. Multiple groups, in Europe and in the U.S., have collected responses from experts. We apply meta-analysis techniques to generate elicitation results that are consistent across the studies and can be combined. The variation in approaches to elicitation across studies allows us to understand what characteristics of elicitation design most affect elicited technology outcomes.

Methods

Our data are several hundred expert responses collected by different research groups around the world about the future costs of nuclear power conditional on specified levels of R&D investment. These were obtained via expert elicitation. Expert elicitation is a formal process for obtaining experts' judgments about uncertain values, and quantifying those judgments in terms of probabilities that can be used in further analyses. The process is more intensive than surveys and more structured than simply collecting informed opinions.

We analyze our data through the use of meta-analysis, namely a set of statistical techniques used to aggregate the results of multiple studies testing similar hypotheses and to thus enhance the overall reliability of findings (Glass 1976; Borenstein, Hedges et al. 2009). It accounts for differences across studies and provides results that are dependent on a consistent set of conditions across observations. This technique has been used in environmental economics since the 1990s (Nelson and Kennedy 2009), with more recent applications in energy (Barker and Jenkins 2007; Zamparini and Reggiani 2007; Havranek, Irsova et al. 2011; Rose and Dormady 2011)

In this paper we provide an analytical basis with which to combine results from multiple expert elicitations into a single data set. A particular focus for this study is on normalizing the R&D characteristics across various elicitation questions, e.g. timing and levels of funding. We use meta-analysis: (1) to identify how differences in research design across elicitation studies contribute to variation in the elicited estimates, (2) to better understand the shape of the R&D productivity function, and (3) to develop a combined dataset of consistent estimates of future technology performance.

The proposed meta-analysis is novel in three respects. First, the data we use are not observed variables but elicited values from experts of the anticipated effects of R&D investments on technology performance.

Second, our geographic scope is international, presently including the U.S. and Europe. Third, we use both aggregated study results and individual participant data (IPD). The use of primary data avoids many of the shortcomings of aggregate meta-analysis: it enables controlling for confounding factors at the individual level and for treatment differences between studies. While the use of IPD has been described as the 'gold standard' for systematic reviews, we are in a unique position to compare the result of meta-analysis on two different level of aggregation, thus providing useful methodological insights.

Results

This paper presents 3 sets of outcomes. First, the descriptive statistics about the independent variables across studies and the estimated effects of the independent variables on overnight capital cost are informative on their own and useful for designing future elicitations. Such information is very valuable given the extreme economy required in including questions on both surveys and in interviews.

Second, data aggregation via meta-analysis provides a basis for understanding the shape of the returns to R&D. Whether the returns to R&D are increasing or decreasing is itself an important energy policy question. For the purposes of this study, such information is also important for controlling for variation in elicited technology performance resulting from differences in assumed R&D investments. The questions we address in the paper are: (1) should we assume linearity or flexible functional forms for adjusting R&D levels? And (2) is R&D investment actually better represented as a dichotomous variable—e.g. high investment vs. low investment—because experts have limited insight on the shape of the R&D productivity function? A prior hypothesis is that technology outcomes at R&D levels *within* the range of elicited R&D values are insensitive to the shape of the R&D productivity curve—while R&D levels *above* the levels elicited probably are sensitive to the shape of this function.

Third, the results will increase the reliability of the elicited technology performance values. By expanding the number of observations, considering experts from different geographical areas and then using the estimated values for technology performance so that they are consistent across observations we generate a set of technology performance values and distributions that provide a basis for data harmonization and the subsequent integrated assessment modeling steps included in the larger project to which this paper contributes.

Conclusions

This study is part of a larger effort to characterize the effects of technological change involving many other technologies. Our paper discusses what factors affect elicitation results and informs future elicitations on the role of important protocol design characteristics (such as in-person versus online interviews). It also provides insights on the consistency of elicited experts' estimates across countries and protocol designs. We discuss applicability of these results to other energy technologies as well as their incorporation in integrated assessment models as a way to account for the uncertainty linked with energy technology cost reductions.

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