ANALYSIS

Measuring nuclear power plant externalities using life satisfaction data: A spatial analysis for Switzerland

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A B S T R A C T

We investigate the relationship between Swiss citizens' life satisfaction (understood as a proxy of utility) and the distance of their place of residence from the nearest nuclear power plant. Using survey data for up to 12,264 Swiss citizens, elicited in February–August 2011, and several specifications of distance, we find a statistically and economically significant satisfaction-distance gradient. The gradient is smaller for those who may feel protected by wind direction and topographical conditions, and it differs by age, sex, and the level of education. The satisfaction-distance gradient has changed significantly after the nuclear disaster at Fukushima, Japan, indicating a reassessment of distance-dependent nuclear risk due to an information shock.

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1. Introduction

The future role of nuclear power is high on the agenda in many countries around the world, in particular in the aftermath of the Fukushima-Daiichi nuclear meltdown in March 2011. While the governments of France, the UK and Australia adhere to nuclear power or plan to expand it, Germany, Italy and Switzerland announced to phase out their nuclear power plants, and the Chinese government decided to postpone approvals for new nuclear reactors (Davis, 2012).

Similar as other electricity generation technologies, nuclear power has its specific advantages and disadvantages. Advantages typically invoked in public debates on nuclear power are security of supply, the absence of air pollution and greenhouse gas emissions, and low operating costs (whereas construction and decommissioning costs may be high). On the downside, there is the risk of nuclear accidents, as well as the issue of nuclear waste disposal.

While the advantages of nuclear power tend to benefit citizens regardless of their location, the damage expected to arise from a nuclear accident has an explicit spatial dimension. Specifically, damage can be expected to increase with proximity to nuclear plants. This suggests

that *ceteris paribus* people prefer more distant places to less distant ones. Nuclear risk, however, is not the only factor in people's locational preference function. Important other factors are wages (incomes) and housing costs, and these may vary with location. Hedonic spatial equilibrium theory suggests that people sort across locations according to location-specific (perceived) nuclear risk, wages and housing costs, and, as a consequence of locational choice, wages and housing costs adjust such as to capitalize the externality from nuclear risk and to eliminate any location-dependent differences in utility.

This paper studies nuclear risk as an externality in Swiss citizens' utility function using reported life satisfaction as a proxy for utility. Conceptualizing externalities from perceived nuclear risk as being related to distance from nuclear facilities, we estimate the relationship between Swiss citizens' life satisfaction and the distance of their place of residence from the nearest nuclear power plant (NPP). Framing our analysis within a model of locational choice, we investigate the following questions: (1) Does citizens' life satisfaction vary with distance to NPPs *ceteris paribus*, that is, when income and housing costs are kept fixed? (2) Does citizens' life satisfaction vary with distance if income and housing costs are allowed to vary with distance? (3) Did the relationship between life satisfaction and distance change after the Fukushima nuclear disaster? As it will be explained in section 2, an increase of life satisfaction with distance when income and housing costs are included in the

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regression will be interpreted as a measure of the NPP externality, whereas a variation of life satisfaction with distance when those factors are allowed to vary with distance will be taken to suggest an absence of locational equilibrium. A change in the satisfaction-distance relationship after the Fukushima disaster will be taken to represent a reassessment of nuclear risk triggered by an information shock.

Our empirical analysis uses survey data for up to 12,264 Swiss citizens elicited in February–August 2011. The data includes information on respondents' distance to the nearest existing Swiss NPP and the language region where respondents live. The latter are a specific feature of Switzerland which allows us to differentiate our analysis with respect to regions and to interpret our results in the light of topographical and meteorological conditions characteristic of those regions (see subsection 3.2). Since more detailed information on respondents' location is unavailable we cannot, however, control for local characteristics. Our results should be viewed in the light of these limitations.

Using several parametric and non-parametric specifications for the distance variable and controlling for a rich set of life satisfaction factors, we find a statistically and economically significant satisfaction-distance gradient at fixed income and housing costs. The gradient is smaller for those who may feel protected by wind direction and topographical conditions, and it differs by age, sex, and the level of education. These findings suggest the existence of significant nuclear power plant externalities in Switzerland. The satisfaction-distance relationships remain significant when incomes and housing costs are omitted from the regressions, indicating a violation of the condition for locational equilibrium. Finally, the satisfaction-distance gradient has changed significantly after the nuclear disaster at Fukushima, Japan, suggesting a reassessment of distance-dependent nuclear risk. This reassessment of nuclear risk mainly refers to people living at an intermediate distance from NPPs, for whom the possible spatial extent of a nuclear disaster became apparent through the Fukushima event, whereas the risk perception of people living closer to NPPs was not changed by the event.

The present paper is the first to use life satisfaction data to measure nuclear power plant externalities within an explicit locational choice framework. It is organized as follows. Section 2 reviews the related literature. Section 3 presents the conceptual and empirical background. Section 4 describes the methodology. Section 5 reports and section 6 discusses the results. Section 7 concludes.

2. Related Literature

The extant literature on preference for distance to NPPs mainly comprises revealed preference (property value) studies and to a smaller extent stated preference (stated choice) studies. Nelson (1981); Gamble and Downing (1982); Clark, Michelbrink, Allison, and Metz (1997), and Folland and Hough (2000) find no or ambiguous effects of distance on property values in the US, whereas Farber (1998) reports a positive relationship between property values and the distance from NPPs. Clark and Allison (1999) find that the distance effect weakens over time, possibly due to relocation, or to preference adaptation attenuating initial price decreases.[1] Yamane, Ohgaki, and Asano (2013); Fink and Stratmann (2013) and Bauer, Braun, and Kvasnicka (2013) studied property price changes in Japan, the US and in Germany, respectively, after the Fukushima disaster. Yamane et al. (2013) found that property values around the Fukushima-Daiichi plant decreased with increasing levels of local nuclear contamination, but not with proximity to the plant. Fink and Stratmann (2013) found no change of property prices in the proximity of NPPs in the US, whereas Bauer et al. (2013) found that house prices near NPPs in Germany dropped by up to 11%. Schneider and Zweifel (2013) report the results of a stated choice experiment conducted in Switzerland in 2001. Their main result is that stated willingness to pay for increased insurance coverage against

nuclear accidents decreases with distance from plant once attitudes influencing choice of residential location are controlled for.

Other papers focused on nuclear waste shipment routes rather than nuclear power plants. Gawande and Jenkins-Smith (2001) found that being 5 miles away from a nuclear waste transportation route was associated with a 3% increase of average house value compared to property on the route. Riddel, Dwyer, and Shaw (2003) found in a stated choice experiment that perceived risk decreases with distance to a planned nuclear waste transportation route and that higher perceived risk resulted in a higher probability of moving away from the route.

Our paper is an application of the life satisfaction (or happiness) approach to non-market valuation. This method of preference elicitation uses people's reported life satisfaction as a proxy for utility and estimates the statistical association between life satisfaction and the non-market good in question as well as people's income. The implied utility-constant tradeoff of income for the good is then used as a measure of the monetary value of the latter.

Life satisfaction data have been used in environmental economics (for surveys see Welsch and Kühling, 2009; Frey, Luechinger, and Stutzer, 2010; MacKerron, 2012) and, to a smaller extent, with respect to energy issues. In environment-related studies the spatial resolution ranges from whole nations (Welsch, 2002; Rehdanz and Maddison, 2005) over postcode areas (Levinson, 2012) to GPS coordinates (MacKerron and Mourato, 2013). Ferreira and Moro (2010) used spatially explicit life satisfaction data from Ireland to test the existence of hedonic spatial equilibrium.

With respect to energy, Welsch and Biermann (2014a) used life satisfaction data to study European citizens' preferences for alternative structures of their national electricity supply system. A number of life satisfaction studies considered the Fukushima nuclear disaster and found that it caused mental distress not only among people directly affected (Ohtake and Yamada, 2013; Rehdanz, Welsch, Narita, and Okubo, 2015) but, due to news media coverage, in people thousands of miles away from the place of the event. Goebel, Krekel, Tiefenbach, and Ziebarth (2013) found an increase in environmental concern in Germany after the Fukushima nuclear disaster, but no change in life satisfaction.[2] Welsch and Biermann (2014b) found a change in the relationship between European citizens' life satisfaction and their countries' nuclear electricity share. Out of the energy-related life satisfaction studies, only Rehdanz et al. (2015) and Goebel et al. (2013) incorporated measures of distance from power plants.

3. Conceptual and Empirical Background

3.1. Conceptual Model and Hypotheses

We consider an economy with two marketable goods: housing and a numeraire. An individual derives utility from these goods and disutility from (perceived) nuclear risk. Her indirect utility function specifies the maximum utility she can attain by allocating income optimally to the marketable goods at a given housing price and a given level of nuclear risk. The indirect utility function of an individual with personal characteristics θ, takes the following form:

$$u = v(p, y, R, \theta) \tag{1}$$

where p, y and R denote the price of housing, income, and nuclear risk, respectively. The indirect utility function is decreasing in the first and third arguments and increasing in the second argument.

Perceived nuclear risk is conceptualized as the expected value of damage from a nuclear accident: $R = \pi * D$, where π denotes the subjective probability of an accident and D the subjective expected damage

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[1] Folland and Hough (2000) and Davis (2011) document that at the time of installation, as well as following the installation, land prices in the proximity of NPPs fell.

[2] Similarly, an increase in German people's concern about the environment but no change in life satisfaction was found after the Chernobyl nuclear accident in 1986 (Berger, 2010).