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Abstract: Many countries are facing a dilemma over whether to extend the lives of their old reactors or make costly capital investments on Renewable Energy (RE). This paper explores the determinants of Willingness-To-Pay (WTP) for RE in France by means of a contingent valuation question that was included in a large web survey organized by the OECD. The main contribution of our paper is to test whether people living close to a reactor are sensitive to the age of the reactor. We find that the age of the reactor has a positive effect on WTP for RE.

Keywords: Contingent valuation, nuclear power plant, renewable energy

JEL classification JEL: C82, Q21, I10

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1 Introduction

In France, the number of reactors per inhabitant is the highest in the world. However, most of the reactors are expected to close in the next two decades. In total, 80% of the 58 French reactors were commissioned between 1977 and 1987 and will therefore reach the end of their 40-year lifespans between 2017 and 2027. These aging reactors provide more than 60% of France electricity (Schneider [2013]).

Policy makers might be tempted to extend the lives of the old reactors rather than massively invest into new reactors or Renewable Energy (RE). However, this option is not necessarily cheap. There might be "indirect costs" when extending the life of old reactors. The number of accidents may increase. For instance, the US nuclear regulatory commission found a correlation between the age of the reactors and the number of degradation occurrences, based on a review of nearly 500 degradation occurrences in US Nuclear Power Plant (NPP) (Braverman *et al*. [2000]). Furthermore, the subjective risk of the accidents may increase with the age of the reactor. Accordingly, extending the life of the reactor could affect people's welfare, even in the absence of future accidents.

We use a large web-based survey to test whether the value that people living close to a reactor place on RE depends on the age of the reactor in France. Several studies have explored the determinants of WTP for RE but none of them examined the combined effect of the distance and the age of the reactor[1]. Our study represents the first large-scale study of the NPP outside the US, Japan and Germany. The main results suggest that the age of the reactor WTP has a positive effect on WTP for RE.

The remainder of the paper is structured as follows: Section 2 presents some background information on nuclear energy and RE. Section 3 provides an overview of the valuation studies dealing with nuclear energy and RE. Section 4 describes the methodology used. Section 5 presents the econometric models, while the results are provided in Section 6. Section 7 highlights the limitations of the study. Finally, Section 8 concludes with some policy implications.

2 Background

Nuclear accidents can have very serious consequences on the health of the population. For instance, the accident at Chernobyl is thought to be responsible for 4,000 cancer occurrence among people who were exposed to elevated doses of radiation. Thus, people living close to operating NPPs might be tempted to support the development of other sources of energy,

[1] For a survey of this literature, see OECD (2011)

especially if the reactor is old. On the other hand, people may derive some benefits from their proximity to a NPP (e.g., job, tax, school, to name a few, see Bezdek and Wendling [2006]). These benefits might be related to the size of the NPP (e.g. number of jobs).

On February 2012, the French President Nicolas Sarkozy decided to extend the life of existing reactors, with the support of the French operator EDF ("Electricité de France") which advocates a 20 year extension, from 40 to 60-years. A few months later, the new French President François Hollande launched a national debate about energy transition options. In the concluding national conference which took place on September 2013, he reiterated his pledge in the 2012 election to close the oldest NPP in Fessenheim by the end of 2016 and reduce the share of energy power from 75% to 50% by 2025. However, no decision was made about the other old reactors. There are still ongoing discussions on whether or not to extend the life of the latter.

3 Prior valuation studies

The Hedonic Pricing (HP) method, which relates the price of a marketed goods to its characteristics, has been used to study the effect of a NPP on property prices (for a more comprehensive review, see Bezdek and Wendling [2006]), although the combined effect of the distance and the age has never been studied. The HP literature suggests either no effect or a positive effect on property prices from living close to a NPP. Clark *et al*. [1997] focused on two NPPs in California. By means of the HP method and geographic information system, the authors found that housing located nearby the Diablo Canyon plants or the Rancho Seco plants imply a premium in the market. Similar results have been found by Metz *et al*. [1997] for the Rancho Seco plant.

In a more recent study, Bezdek and Wendling [2006] used information on four NPPs located throughout the United States (South Texas Project, River Bend Nuclear Generating Station, Callaway Nuclear Power Plant, Wolf Creek Generating Station) and found a positive relationship between the housing price and proximity to NPPs. Job, school and property tax are some of the factors which may explain this positive relationship according to the authors. Finally, some studies found no effect; for instance, Nelson [1981] found no difference between prices in the area close to the Three Mile Island and two control areas. Similar results have been found by Gamble and Downing [1982].

Contingent valuation has also been used to study RE and nuclear energy. For instance, Jun *et al*. [2010] showed in a split sample survey that informed people were more in favor of nuclear energy than uniformed people: informed people declared higher WTP to develop this energy than the rest of the participants. Liao *et al*. [2010] explored energy nuclear support in Taiwan and found that the number of supporters and opponents of nuclear power was about the same, as was their WTP for RE. Hansla *et al*. [2008] used a mail survey to study the effect of attitude towards green electricity in Sweden. Bigerna and Polinori [2011] explored WTP for green electricity in Italy to attain a 17% share of electricity production from RE sources by 2020. Whitehead and Cherry [2007] estimated the annual benefits of regional amenities associated with a green energy program in North Carolina. Finally, choice experiment has also been employed for RE and nuclear energy (e.g. Scarpa and Willis [2010]).

4 Data

An internet-based survey was organized in January-February 2008 by OECD in 10 countries (Australia, Canada, Czech Republic, France, Italy, Korea, Mexico, Netherlands, Norway and Sweden) to investigate the behavior of people on five different topics including energy use, water consumption, and organic food expenditure. In each country, a representative sample of the population was surveyed[2]. The questionnaire was identical across countries. Socioeconomic questions were asked to the respondents followed by the five key areas[3]. The one devoted to energy use was structured as follows (for more information, see Kriström [2008], Shi *et al*. [2011]). People were asked general questions related to their habit in terms of energy use. The valuation question, in a payment card format, was worded as follows (after explaining that RE corresponded to energy sources such as wind, solar, geothermal and hydro):

What is the maximum percentage increase on your annual electricity bill that you are willing to pay to use only renewable energy, assuming that your electricity consumption is constant.

1 I would not pay anything additional
2 Less than 5%
3 5%-15%
4 16%-30%
5 More than 30%
6 Don't Know

No particular question or information was included in the questionnaire on nuclear energy. The third part of the energy section concerned "green" behavior. For instance, respondents were to state how often they turn off lights when leaving a room in their own residence.

We focused on France[4]. For each of the 19 NPPs, we collected information on the age of the reactor and their number (see Table 1). For instance, the NPP in Fessenheim has two reactors

[2] The number of participants was about 1000 in each country.

[3] The order of the question and/or categories was not randomized.

[4] In the other countries, with the exception of Sweden, too few participants live close to a NPP because the study is based on a representative sample of the national population. This mainly explains why we only focused on

which started providing electricity in 1978. For each of the 1075 respondents, the distance as the crow flies between the 19 NPPs (see Figure 1) and their "primary residence" were estimated using the software R. A program was set up to automatically retrieve information on the distance using the zip codes. Based on this zonal information[5], the distance between the primary residence and the closest plant was estimated for each individual. The variable distance was used to create dummy variables. In past HP studies, the chosen distance threshold is typically 40 kilometers or 25 miles (Gamble and Downing [1982], Bauer *et al*. [2013], Fink and Stratmann [2013]). Rather than creating a single variable, we created several variables to detect a possible threshold effect: *Close10*, *Close20*, *Close30*,…, up to *Close100*. *Close*10 is equal to 0.009 (see Table 2), which means that less than 1% of the participants live less than 1 kilometer from a reactor. *Close*100 corresponds to 0.610 which implies that the majority of the respondents live less than 100 kilometers from a reactor.

[Tables 1-2 about here]

[Figure 1 about here]

We collected information on the level of soil contamination after the Tchernobyl catastrophe in each of the 27 administrative regions of France (see Figure 2), since people living in the contaminated area are probably more aware of the health effects of nuclear accidents. The mean of the variable associated to contamination was 2,403 which suggested that the level of contamination was on average 2,403 becquerel per square meter. We also collected information on the proportion of electricity produced from wind, solar and biomass in each of the regions of France in 2009 (see Appendix A). On average, 3.16% of electricity was from a renewable source.

[Figure 2 about here]

Table 3 shows that the proportion of respondents refusing to pay is high (43.16%). We will take this into account in the empirical analysis, to which we now turn.

[Table 3 about here]

France. Incidentally, Sweden has decommissioned a plant (Barsebäck 1 in 1999 and Barsebäck 2 in 2005) in a highly populated area.

[5] We do not have information on the exact address of the participants (e.g. name of street)

5 Econometric models

The log-normal distribution is often used in contingent valuation because it avoids negative WTP. However, this distribution rules out zeroes. A mixture model is an alternative. Andersson *et al*. [2013] used such a model in a recent study using the double-bounded dichotomous choice elicitation format. Kriström [1997] applied such approach in a single-bounded choice application. The mixture model can also be applied to the payment card format. Following Andersson *et al*. [2013], we present both conventional and mixture models, although we will only use the mixing model because a sizeable part of the participants ($\rho = 0.43$) chose the zero WTP option ("I would not pay anything additional").

5.1 Conventional model

People are displayed with positive amounts and are asked to indicate all the amounts from the payment card they are willing to pay. Let b_i^L denote the lowest amount of the card the individual *i* would pay and b_i^U the next higher amount in the card. The respondent's answer is represented by the following three indicator variables[6]:

$I_{1i} = 1$ if $WTP_i < b_i^U$

$I_{2i} = 1$ if $WTP_i \geq b_i^L$

$I_{3i} = 1$ if $b_i^L \leq WTP_i < b_i^U$

If the individual is not willing to pay the lowest amount on the card, A, then $I_{1i} = 1$; $I_{2i} = I_{3i} = 0$; $b_i^U = A$; $b_i^L = \emptyset$. If the individual is willing to pay the highest amount on the card *B*, $I_{2i} = 1$; $I_{1i} = I_{3i} = 0$; $b_i^U = \emptyset$; $b_i^L = B$. If the individual is willing to pay *C* but not the next higher amount *D*, $I_{3i} = 1$; $I_{1i} = I_{2i} = 0$; $b_i^L = C$; $b_i^U = D$.

Let $F(x; \theta)$ denote the Cumulative Distribution Function (CDF) for x with parameter θ. The log-likelihood function for the conventional model is:

[6] Andersson et al (2013) include four indicator variables for the double-bounded dichotomous choice, which correspond to: "yes-no", "no-yes", "no-no", "yes-yes"

$$l(\theta) = \sum_{i=1}^{N} \{ I_{1i} \ln[F(\mathrm{b}_\mathrm{i}^\mathrm{U};\theta)] + I_{2i} \ln[1 - F(\mathrm{b}_\mathrm{i}^\mathrm{L};\theta)] + I_{3i} \ln[F(\mathrm{b}_\mathrm{i}^\mathrm{U};\theta) - F(\mathrm{b}_\mathrm{i}^\mathrm{L};\theta)] \}$$

5.2 Mixture model

The value zero (or similar expression such as "I would not pay anything additional") is now available in the payment card. The CDF of x in the mixture model is:

$G(x; \rho, \theta) = \rho$ if $x = 0$ and $G(x; \rho, \theta) = \rho + (1 - \rho)F(x; \theta)$ if $x > 0$,

where ρ is the proportion of participants picking the value zero. Including a new indicator variable I_{0i} which takes the value one if WTP is equal to zero the log-likelihood with full information is then:

$$l(\theta) = \sum_{i=1}^{N} \{ I_{0i} \ln[\rho] + (I_{1i} - I_{0i}) \ln[(1 - p). F(\mathrm{b}_\mathrm{i}^\mathrm{U};\theta)] + I_{2i} \ln[(1 - \rho)(1 - F(\mathrm{b}_\mathrm{i}^\mathrm{L};\theta))] + I_{3i} \ln[(1 - \rho)(F(\mathrm{b}_\mathrm{i}^\mathrm{U};\theta) - F(\mathrm{b}_\mathrm{i}^\mathrm{L};\theta))] \}$$

If the individual is willing to pay zero, then $I_{0i} = I_{1i} = 1$; $I_{2i} = I_{3i} = 1$. If the individual is willing to pay the lowest positive amount on the scale, *A*, and no higher amounts, then $I_{1i} = 1; I_{0i} = I_{2i} = I_{3i} = 0$; $b_i^U = A$; $b_i^L = \emptyset$.

6 Results

First, we focused on the persons living less than 10 kilometers from a reactor by including the variables *Close10×Age*, *Close10×Reactor* and *Close10* in the mixture model. However, the model could not be estimated in STATA because too few persons live less than 10 kilometers from a reactor. Then, we explored distances of 20 kilometers, 30 kilometers, etc…. The parameters related to *Close40×Age*, *Close50×Age* and *Close60×Age* were found to be positive and statistically significant at 10% level, implying that as the NPPs get older, respondents living near the NPPs are more inclined to support RE. However, *Close70×Age*, *Close80×Age*, *Close90×Age* and *Close100×Age* were not found to be statistically significant, although the sign of the coefficients remain positive. The variables *Close20×Age* and *Close30×Age* also failed to be statistically significant, which was probably due to the low number of participants living less than 30 kilometers from a reactor. Overall, our results suggest a threshold effect at a distance between 60 and 70 kilometers.

[Table 4 about here]

We re-estimated the mixture model with the interaction variables *Close61×Age*, *Close62×Age* and so on. The interaction variables *Close61×Age*, *Close62×Age …*, *Close67×Age* are statistically significant at 10% level, unlike the variable *Close68×Age*, which indicates that people living less than 68 kilometers from a reactor are sensitive to the age of the reactor. In past valuation studies, the threshold effect was seldom found at distances larger than 40 kilometers. For instance, Clark *et al*. [1997] found a housing price premium at a distance of about 23 miles from the Diablo Canyon plant. Because past studies did not include interaction variables it is not easy to compare them with our study. By excluding the interaction variables (*CloseA×Year* and *CloseA×Reactor*) *Close10,…,Close34* are statistically significant at 10% level, unlike *Close35*. This is in line with past studies.

The negative sign of *Close40×Reactor* suggests that the number of reactors increases the benefits of being located close to a reactor (e.g. number of jobs). However, the coefficient fails to be statistically significant for some of the considered models (e.g. *Close50×Reactor*, see Table 4).

The results from all the models suggest that participating in an environmental organization has a positive effect on WTP for RE, which is consistent with Bethke and Traub [2009]; see also Kiran and Kriström [2013]. Furthermore, females report lower WTP than males in the model involving *Close40* which is consistent with Akcura [2011]. However, Zarnikau [2003] and Bigerna and Polinori [2011] found the opposite result. We also find that WTP does not increase with income, although this result has been found in several studies (e.g. Zografakis *et al*. [2010]). The results also reveal that WTP does not increase with the level of concern for climate change. This is in sharp contrast to the study of Zografakis *et al*. [2010] who conducted a study in Crete and found that people having a higher level of awareness for climate change reported higher amounts. Finally, the mean WTP of the sample for RE is 3.36%. This is in line with what has been found in many studies of the price premium, see e.g. the review in Kriström [2012].

7 Limitations

Our study suffers from some limitations, which are mainly due to the survey and questionnaire design. (i) No follow-up questions were introduced after the valuation question to better understand why some people refused to pay for RE. (ii) The scenario was relatively straightforward in our study (100% renewable energy). However, no information was available on the nuclear energy (e.g. the age of the reactor). Furthermore, it was not explained what type of RE would be developed. (iii) We do not have information about the annual consumption and/or the electricity bill on household level. Households with a low annual consumption (e.g. due to environmental concerns) could state a high percentage premium, but still have a small annual premium in absolute monetary terms. (iv) We have little information about respondents' moving patterns, so we cannot investigate how the construction of the NPPs could affect respondents' locational decisions. This endogeneity problem is thus difficult to resolve with this data.

Finally, (v) we cannot explore whether the results would have been different if the study had been carried out after the accident in Fukushima. A few valuation studies have been conducted on the effects of Fukushima, although they did not focus on the characteristics of the plant. Morita [2012] conducted a HP study in Japan and found a reduction (about 4%) in housing prices near the NPP. Bauer *et al*. [2013] checked the effects of the Fukushima on the German housing market and found that house prices near operating NPPs decreased by 6%. On the other hand, Fink and Stratmann [2013] performed the same study as Bauer for the US market and found that prices near NPP were not affected by Fukushima. If the OECD survey is carried out in 2014 (which tentative plans do suggest), WTP might be more sensitive to the age of the reactor, because some people may believe that Fukushima accident was partly due to the age of the reactors. The Fukushima NPP started producing electricity in 1971, and was thus older than any NPP operating in France.

8 Conclusions and policy implications

A multi-country survey was conducted by OECD in 2008 to study the behavior of people in five key areas, including energy use. In the energy part of the questionnaire, one question was related to how much people would be willing to pay for RE. This paper investigates whether the response provided by the respondents living close to a reactor was sensitive to the age of the reactor. The results of the study suggest that the age of the reactor affects WTP.

Policy makers may want to consider both the subjective and objective risks of nuclear accidents, when considering whether to extend the life of nuclear energy or massively invest into RE. The results from our study suggest that the age of the reactor can have a negative effect on people's welfare. Extending the life of the reactor might thus affect people's welfare. If not taken into account, the comparison between prolonging NPP and developing RE might not be fully accurate.

In Germany, the coalition government decided in September 2010 to extend the life of nuclear reactors by an average of 12 years. A few months later, after the Fukushima accidents, the coalition closed the oldest reactors: eight out of the 17 reactors. The government also announced the phasing out of the nine remaining reactors by 2022 and an increased effort to develop RE. Germany is the largest economy that seems destined to close out nuclear energy. Other countries may follow.

Appendix A. Production of electricity from wind, solar and biomass/consumption of electricity in 2009

Department	Percentage
Alsace	0.7%
Aquitaine	2%
Auvergne	2.5%
Basse-Normandie	2.5%
Bourgogne	0.3%
Bretagne	4.1%
Centre	6.3%
Champagne-Ardenne	6.2%
Corse	1.6%
Franche-Comté	1%
Haute-Normandie	3.7%
Île-de-France	1.1%
Languedoc-Roussillon	6.9%
Limousin	6%
Lorraine	5%
Midi-Pyrénées	4.7%
Nord-Pas-de-Calais	2.3%
Pays de la Loire	2.3%
Picardie	8.5%
Poitou-Charentes	1.4%
Provence-Alpes-Côte d'Azur	1.2%
Rhône-Alpes	1%

Table 1 Descriptive information on nuclear power plants

Name	Starting date of the first reactor	Closest Town[1]	Distance from the plant in km[1]
Fessenheim (2)	1978	Strasbourg	85
Bugey (4)	1979	Lyon	20
Dampierre (4)	1980	Orléans	44
Gravelines (6)	1980	Lille	74
Tricastin (4)	1980	Marseille	120
Blayais (4)	1981	Bordeaux	42
St. Laurent (2)	1983	Tours	71
Chinon-B (4)	1984	Nantes	130
Cruas (4)	1984	Valence	31
Paluel (4)	1985	Le Havre	50
Saint-Alban (2)	1986	Lyon	30
Flamanville (2)	1986	Rennes	160
Cattenom (4)	1987	Metz	33
Nogent (2)	1988	Paris	95
Belleville (2)	1988	Clermont Ferrand	183
Penly (2)	1990	Rouen	55
Golfech (2)	1991	Toulouse	73
Chooz-B (2)	2000	Charleroi	41
Civaux (2)	2002	Limoges	79

Notes: The number of reactors is in brackets. The column reports the proportion of respondents from the OECD study. For instance, 1.67% of the respondents live closer to the Belleville power plant than to any other power plants. Sources (except for the last column): www.santepublique-editions.fr, march 2013

Table 2 Descriptive information on the explanatory variables

Variables	Description	Mean
Information related to the characteristics of the respondents		
Income	Continuous variable = midpoint bracket expressed in annual ten thousands of dollar for the household	2.028 (0.751)
Female	Binary variable = 1 if the respondent is a female; 0 otherwise	0.496 (0.500)
Organization	Binary variable = 1 if the respondent is a member of an environmental organization; 0 otherwise	0.102 (0.303)
Climate change	Continuous variable: response to a verbal scale: "not concerned" = 1, "fairly concerned" = 2, "concerned" = 3, "very concerned" = 4	3.163 (0.868)
Information related to nuclear power plant and energy		
Year	Continuous variable: age of the closest power plant	23.104 (5.086)
Close**A**	Binary variable = 1 if the zonal distance between the zip codes related to home and the nearest power plant is inferior to **A** kilometres	A=10: 0.009 (0.095) A=20: 0.031 (0.172) A=30: 0.091 (0.287) A=40: 0.162 (0.369) A=50: 0.239 (0.427) A=60: 0.293 (0.456) A=70: 0.334 (0.472) A=80: 0.429 (0.495) A=90: 0.525 (0.500) A=100: 0.610 (0.488)
Contamination	Continuous variable: soil contamination expressed in number of thousands of becquerels per square meter in the administrative department where the respondent lives	2.403 (1.961)
Percentage of RE	Continuous variable: percentage of electricity from wind, solar and biomass/consumption of electricity in 2009	3.163 (0.868)
Notes: N = 883. Standard deviations are in brackets. Incomplete questionnaires and people who did not know about their WTP were removed from the dataset.		

Table 3 Descriptive information on the response to the contingent valuation question

Available responses	Percentage
“I would pay nothing additional”	43.16%
“Less than 5%”	26.33%
“5%-15%”	11.35%
“16%-30%”	1.77%
“More than 30%”	1.02%
“Do not know”	16.37%

Table 4 Mixture model

Variables				
	A=40	**A**=50	**A**=60	**A**=70
Log Income	0.276 (0.199)	0.281 (0.199)	0.299 (0.199)	0.288 (0.199)
Female	-0.253 (0.155)	-0.267* (0.155)	-0.250 (0.155)	-0.265 (0.155)
Organization	0.550*** (0.193)	0.546*** (0.193)	0.541*** (0.193)	0.547*** (0.193)
Climate change	0.045 (0.091)	0.053 (0.091)	0.508 (0.091)	0.045 (0.091)
Contamination	-0.033 (0.039)	-0.031 (0.038)	-0.038 (0.039)	-0.034 (0.039)
Percentage of RE	-0.030 (0.037)	-0.029 (0.037)	-0.032 (0.037)	-0.041 (0.037)
Close**A**	-1.677 (1.205)	-1.478 (1.027)	-0.774 (0.824)	0.298 (0.573)
Close**A**×Year	0.114** (0.053)	0.079* (0.043)	0.063* (0.035)	0.020 (0.027)
Close**A**×Reactor	-0.394* (0.211)	-0.133 (0.164)	-0.224 (0.150)	-0.202 (0.139)
Constant	-5.568*** (2.066)	-5.634*** (2.057)	-5.792*** (2.058)	-5.663*** (2.058)
N	883	883	883	883
χ^2	23.45	21.30	21.68	20.54

Notes: *, ** and *** refer to statistically significant at 10%, 5% and 1%. Standard errors are in brackets. $\chi2$ is the likelihood ratio Chi-Square test and N the total number of observations.

Figure 1 Map of the nuclear energy plants that operate in France and the representative sample of the French population (N=1075)

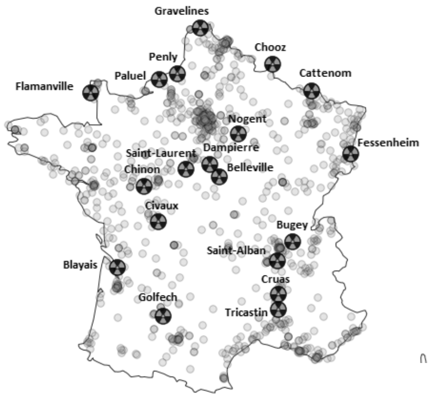
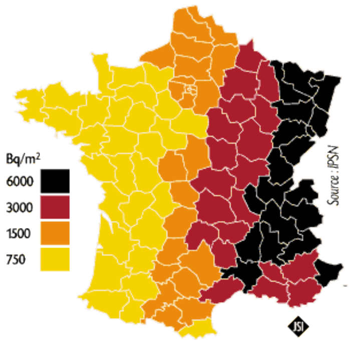


Figure 2 Map of soil contamination in radiocaesium in France



Source: ISPN98

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