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Spatial Effects in Willingness to Pay: The Case of Two Nuclear Risks

Yves Schneider and Peter Zweifel*

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Abstract

This paper examines the spatial dimension of marginal willingness to pay (MWP) for reduction of nuclear risks through increased insurance coverage. The effect of distance from a nuclear power plant on individuals' MWP is ambiguous. MWP is expected to decrease with distance because the risk of being affected by an accident decreases. However, if individuals choose their residential location taking the operational risk into account, MWP is predicted to first increase and later decrease with distance from the nuclear power plant. On the other hand, there are risks associated with transportation and disposal of nuclear waste where distance should matter only in the vicinity of the plant. These theoretical predictions are tested with data collected using a stated choice experiment. The predictions are largely confirmed by the evidence.

Keywords: discrete-choice experiment, liability insurance, nuclear accident, willingness to pay

JEL-Classification: C25, K13, L94

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1 Introduction

There are various risks associated with nuclear energy. The two most notable risks at the energy production stage are accidents at the power plant and waste disposal. We employ a stated choice experiment in order to elicit individuals' willingness to pay (WTP) for reducing these risks. The importance of these risks is reflected in a significant WTP for their reduction. Economic theory predicts that WTP for reducing the risk of a nuclear power plant accident depends on an individuals' location. Especially, individuals with high risk aversion or high subjective risk estimates will tend to locate farther away from nuclear power plants. Because there are many other factors that determine an individual's residential location, distance from the plant is expected to have an effect only on those individuals' WTP who judge nuclear risks to be important enough. It is shown that the WTP estimates do indeed depend in a subtle way on distance from the plant conforming the theoretical predictions.

The present study purports to test these predictions using data from a stated choice experiment (SCE) conducted in 2001 with Swiss individuals. It is of particular interest for two reasons. First, most of the existing published work dealing with the effect of distance on the WTP for externality mitigation focuses on housing prices. By way of contrast, this contribution reports on WTP values derived from market experiments yielding measurements of demand uncontaminated by supply conditions. Second, the evidence comes from Switzerland, a country where residents have been having full opportunity to choose their location in response to nuclear externalities.

Decreasing the (financial) risk of nuclear power plant accidents was framed in terms of increasing mandatory liability insurance carried by nuclear plant operators. At present, operators are obliged to insure for CHF 1 billion (bn.) (approx. US$ 0.8 bn. [US$ 1 $\approx$ CHF 1.2), an amount that will hardly be sufficient to compensate the victims of a major accident. However, an extension of coverage will c.p. result in higher consumer prices for electricity. This also holds true for any conceivable solution to the problem of nuclear waste, since in Switzerland 35 percent of electricity is provided through nuclear power (most of the remainder comimg from hydro sources).

The remainder of this paper is structured as follows. After a review of the literature dealing with the spatial effects of externalities associated with nuclear power, section 3 presents a model of locational choice and develops the hypotheses to be tested. Next, section 4 describes the SCE that was applied to measure WTP of the Swiss population for reducing nuclear externalities. The econometric specification, based on the Random Utility Model, is presented in section 5. Estimation results and hypothesis tests follow in section 6, while concluding remarks are offered in section 7.

2 Review of the Literature

Choosing one's optimal location with respect to the risk of being affected by an externality can be viewed as self-insurance. By locating farther away from a nuclear power plant, individuals reduce their losses e.g. due to radiation in case of a severe accident. Ehrlich and Becker (1972) analyze the effect of the simultaneous availability of self-insurance and market insurance and conclude that both ``technologies" are substitutes as long as the price of market insurance is independent of the amount of self-insurance.

Since up to now it has not been possible for Swiss citizens to buy insurance against nuclear risks, the only option available is self-insurance. In the absence of an insurance market, the optimal level of self-insurance thus increases with increased risk aversion (see for instance Dionne and Eeckhoudt, 1985). Therefore, more strongly risk-averse individuals are predicted to spend more resources on loss mitigation than do less risk-averse consumers.

The experiment conducted in the present study introduces a hypothetical insurance market. Evidently, respondents in this experiment state their WTP for nuclear insurance after having set their optimal level of self-insurance through their residential choice. Although there is no need to account for strategic interaction between market insurance and self-insurance (Kelly and Kleffner, 2003), it is necessary to account for self-insurance that has taken place prior to the experiment. Thus, estimated WTP for insurance coverage is expected to vary systematically with the degree of self-insurance, i.e. residential location in the present context.

There is a large body of empirical work estimating the effect of proximity to a source of disamenity on property values. The case of nuclear power plants was first studied by Nelson (1981) and Gamble and Downing (1982). In the wake of the 1979 incident at Three Mile Island, they find weak or even reversed distance effects, viz. higher property values in the vicinity of the plant. Folland and Hough (2000) extend their focus beyond a single power plant, analyzing a panel data set of broad market areas across the United States. Their evidence points to a negative impact of nuclear power plants on land prices, with distance again having an ambiguous effect.

However, Gawande and Jenkins-Smith (2001) find that being five miles away from a nuclear waste shipment route was associated with a 3 percent increase of average house value compared to property on the route.

While important, nuclear power is only one of several sources of disamenities. In their review, Gawande and Jenkins-Smith (2001) conclude that a wide range of disamenities such as Superfund sites and polluted water negatively influence the value of residential property. More specifically Faber (1998), collecting evidence on the effects of distance, finds that their magnitude depends on the type of facility, community characteristics, and setting (rural or urban). Chemical refineries and nuclear power plants seem to have roughly comparable (positive) gradients, amounting to $200-300 per mile of distance (in 1993 dollars). Compared to other facilities, this is a rather small effect, as a proposed radioactive waste disposal site was associated with a gradient of $4,440 per mile. As Clark and Allison (1999) found in their study, the distance effect weakens over time, suggesting that relocation of individuals may replenish demand for property close to the source of the externality by those who believe to be little affected, a consideration taken up in section 3.

Most of these studies rely on hedonic modeling, linking price data to a set of characteristics of real estate property. Davis (2005) applies this method to estimate marginal WTP to avoid the risk of leukemia in children. As he points out, the heterogeneity of individuals (with respect to income or preferences in general) contaminates housing price data. Furthermore, the cost of changing location, which constitutes the cost of this particular self-insurance technology, is arguably not trivial. Moreover, market prices also depend on supply which in turn is affected by zoning laws and building regulations. For these reasons, estimates of individual WTP derived from analyzing the compensating differentials contained in market data are potentially distorted and incomplete. Experimental evidence, while having its own drawbacks (see Diamond and Hausmann, 1994), may thus complement information gleaned from market data.

For example, Smith and Desvousges (1986) analyze the impact of a waste disposal facility on the subjective value of a residential site using a contingent valuation experiment. For hazardous waste, they obtain a positive distance gradient of $330-$495 per mile. A study related to the present paper is by Riddel, Dwyer, and Shaw (2003), who estimate the effect of several planned nuclear waste transportation routes from power plants to the Yucca Mountain (Nevada) repository. They find evidence that perceived risk decreases with distance to the planned transportation route and that higher perceived risk results in a higher probability of moving away from the route.

As opposed to Riddel, Dwyer, and Shaw (2003), this study does not consider a planned future change in the environment. Rather, it seeks to measure WTP for a reduction of two risks emanating from nuclear power plants that have been effective for at least two decades.

Respondents had ample opportunity to relocate according to their preferences regarding nuclear risks. The present investigation therefore estimates the net disutility caused by two types of nuclear risk (one associated with current operation, the other with transportation of waste) given the respondents' amount of self-insurance through locational choice.

3 A Model of Locational Choice

This section is devoted to the formulation of a simple model of locational choice designed to predict the spatial distribution of marginal willingness to pay for risk reduction.

Assume a linear space with a nuclear power plant located at point $s = 0$ and maximum distance, $s = 1$. An individual i is characterized by its position s_i on the interval and his or her perceived (subjective) probability p_i of an accident at the plant. Initially, individuals are uniformly distributed in space, resulting in a bivariate uniform distribution (s_i, p_i) of distances and probabilities in the $[0, 1] \times [0, 1]$ plane.

In case of accident, individual i suffers a financial loss that depends on distance from plant. For simplicity, let this loss be $(1 - s_i)L$ such that an individual located at $s_i = 1$ suffers no loss. With m denoting money wealth, expected utility of individual i is

$$V(p_i, s_i) = (1 - p_i)u(m) + p_i u\left(m - (1 - s_i)L\right). \tag{1}$$

Note that $u(m)$ is assumed to be the same for all individuals. Heterogeneity is thus uniquely captured by differences in the subjective assessment of p_i, the probability of an accident, and s_i, the location in space.

If individuals in this situation were given the possibility to buy a marginal loss reduction, they would be willing to pay

$$W(p_i, s_i) \equiv -\frac{\partial V_i/\partial L}{\partial V_i/\partial m}. \tag{2}$$

Using (1), this leads to

$$W(p_i, s_i) = \frac{p_i(1-s_i)\cdot u'\left[m-(1-s_i)L\right]}{(1-p_i)\cdot u'\left[m\right] + p_i \cdot u'\left[m-(1-s_i)L\right]}. \tag{3}$$

Note that for concave u ($u' > 0$ and $u'' < 0$) we have $\partial W/\partial s_i \leq 0$ but $\partial W/\partial p_i \geq 0$. For given p_i, the marginal WTP for loss reduction is thus decreasing with distance, while for a given distance s_i, marginal WTP increases with subjective accident probability p_i. The spatial pattern of marginal WTP values is thus predicted to exhibit a negative distance gradient ($\partial W/\partial s_i < 0$).

However, since individuals differ with respect to location and type, the initial (uniform) distribution of types allows for mutually beneficial trade. An individual of type (s_i, p_i) will trade with individual j if $s_i \leq s_j$ but $p_i \geq p_j$, with at least one inequality being strict. Thus if i is located closer to the plant but has higher subjective accident probability than j, both individuals gain from switching locations.

Suppose that individuals are pairwise matched randomly. If individual i meets individual j, who is located at a greater distance ($s_j > s_i$) to the power plant but has a lower estimate of nuclear risk ($p_j < p_i$),

By switching location with i, individual j on the other hand loses $V(p_j, s_i) - V(p_j, s_j) < 0$. But since $p_j < p_i$, the utility loss of individual j is smaller than the utility gain of individual i. Assuming that no individual faces a wealth constraint, such a mutually beneficial trade will take place and i and j thus switch location. Summing up, whenever two individuals i and $j \neq i$ with

$$\rho_{ij} \equiv (p_i - p_j)(s_i - s_j) < 0 \tag{4}$$

are matched, they switch location and realize a positive net gain from doing so. Note that $sign(\rho_{ij})$ reflects the correlation of the two individuals i and j. Before they switch location

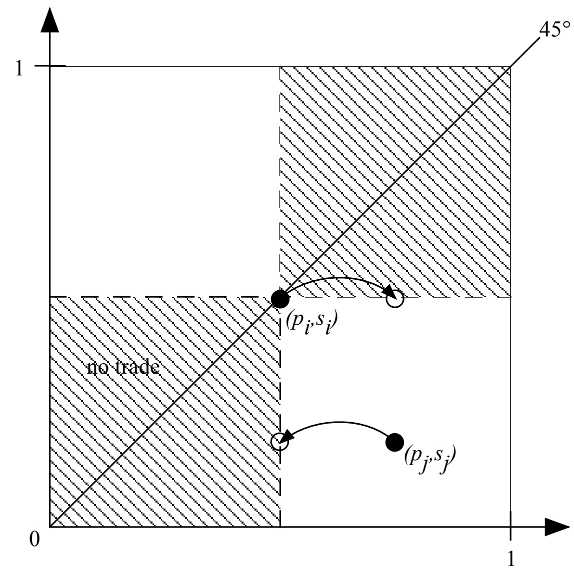

Figure 1: Trading opportunities of individual i with endowment (p_i, s_i).

we have $sign(\rho_{ij}) = -1$ while after the switch we have $sign(\rho_{ij}) = +1$. A repeated process of pairwise random matching gradually leads to more and more individuals being positively correlated. When all individuals are positively correlated with all other individuals then there are no more opportunities for trade left. The following Lemma summarizes this argument.

Lemma 1. *The final allocation has all individuals distributed on the 45-degree line in (p, s)-space, i.e. $s_k = p_k$ for every individual k.*

Proof. As long as there are two individuals i and j for which $(p_i - p_j)(s_i - s_j) < 0$, they will switch locations. Only if all individuals are on the 45-degree line, i.e. if $p_k = s_k$ for all k, are opportunities for mutually beneficial trade exhausted. □

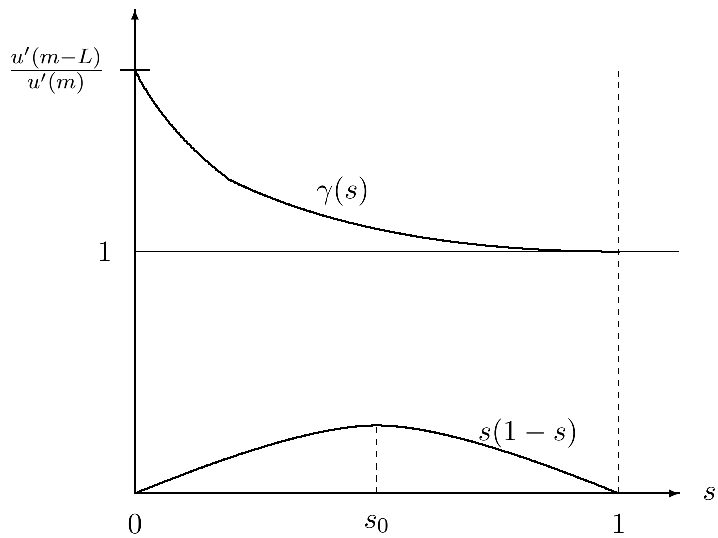

Figure 2: Marginal willingness to pay ($\hat{W}(s)$) in the general case: $\hat{W}(s) = \gamma(s) \cdot s(1-s)$.

Lemma 1 assumes zero relocation costs. If there are costs to relocation, the main point still carries over.[1] Exhausting all profitable opportunities for trade still results in a positive but no longer perfect correlation between location and subjective accident probability.

Consider next, how marginal willingness to pay varies with distance *after* sorting. Using Lemma 1, equation (3) now reads

$$W(p_i = s_i, s_i) = \frac{s_i(1-s_i) \cdot u'\left[m - (1-s_i)L\right]}{(1-s_i) \cdot u'\left[m\right] + s_i \cdot u'\left[m - (1-s_i)L\right]}. \quad (5)$$

To illustrate the consequences of Lemma 1, consider the case of risk neutrality. In this case, equation (5) simplifies to

$$W(p_i = s_i, s_i) = s_i(1-s_i). \quad (6)$$

[1] Clearly, if costs are so high as to render trade unprofitable, this model no longer applies.

This is a quadratic function which is zero at $s_i = 0$ and $s_i = 1$ and attains its maximum at $s_i = \frac{1}{2}$. After sorting, MWP is thus no longer a decreasing function of distance but shows an inverted U-shaped relationship. Lemma 2 shows that this property holds for any concave utility function.

Lemma 2. *If u is concave then marginal willingness to pay after sorting is*

$$\hat{W}(s) \equiv W(p = s, s) = s(1-s) \cdot \gamma(s), \tag{7}$$

with

$$\gamma(s) \equiv \frac{u'\left(m-(1-s)L\right)}{(1-s)\cdot u'\left(m\right) + s \cdot u'\left(m-(1-s)L\right)}. \tag{8}$$

$\hat{W}(s)$ has inverted U shape.

Proof. The first term of $\hat{W}(s) = s(1-s)\cdot\gamma(s)$ is inverted U shape. Since $u'\left[m-(1-s)L\right] \geq u'[m]$, it follows that $\gamma(s) \geq 1$. Furthermore, $\gamma[0] = \frac{u'(m-L)}{u'(m)} > 1$ and $\gamma[1] = 1$.

Let $k(s) \equiv \{(1-s)u'[m] + su'\left[m-(1-s)L\right]\}^2$. The sign of the derivative of $\gamma(s)$ with respect to s is then equal to the sign of

$$\begin{aligned}
&\gamma'(s)k(s) = \\
&\qquad u''[m-(1-s)L]L\cdot\left[(1-s)u'[m] + su'[m-(1-s)L]\right] \\
&\qquad - u'[m-(1-s)L]\left[-u'[m] + u'[m-(1-s)L] + su''[m-(1-s)L]L\right].
\end{aligned}$$

This expression can be rewritten as

$$\gamma'(s)k(s) = \overbrace{u''[m-(1-s)L]}^{<0} L(1-s)u'[m] \\ - u'[m-(1-s)L]\underbrace{[u'[m-(1-s)L] - u'[m]]}_{\geq 0} \leq 0.$$

$\gamma'(s)$ is smaller than zero because $u'' < 0$ and $u' > 0$ due to concavity of u. In sum, $\gamma(s)$ is always greater or equal to one and is strictly decreasing in s. At $s = 1$, γ is one and its slope is zero.

Recall that $\hat{W}(s) = \gamma(s)f(s)$ with $f(s) = s(1-s)$. Then $\hat{W}'(s) = \gamma'(s)f(s) + \gamma(s)f'(s)$. Let s_0 denote the distance at which $f'[s_0] = 0$, i.e. where f is maximum. At this point, $\hat{W}'[s_0] = \gamma'[s_0]f[s_0] < 0$ since $\gamma'[s_0] < 0$. Furthermore, $\hat{W}'[0] = \gamma[0]f'[0] > 0$ since $\gamma \geq 1$ and $f'[0] > 0$. Consequently, $\hat{W}(s)$ must attain a maximum in $(0, s_0)$. Note that this maximum is at $s < s_0$. Refer to Figure 2 for an illustration.

□

3.1 Simulation With a CARA Utility Function

Up to this point, the analysis neglected wealth effects. When individuals carry out all these mutually beneficial trades, they not only switch location but they also transfer wealth. More specifically, individuals benefiting from the switch of location transfer wealth to the other individuals in order to compensate them for the loss in utility associated with living closer to the nuclear power plant. Therefore, each switch of locations also changes wealth endowments. This section reports simulation results which take these wealth effects into account. It is shown that all the previous results remain valid.

Let $u(m) = -e^{-\frac{1}{\gamma}m}$. In this case, the coefficient for (absolute) risk aversion is $-\frac{u'}{u''} = \gamma$. Consider the case where $s_j > s_i$ and $p_j < p_i$. Then individual i's gain in utility from switching location with j can be offset by a decrease in wealth by t_i, with t_i defined by

$$t_i = (1-p_i)u(m_i-t_i)+p_i u\left(m_i - (1-s_j)L - t_i\right) = (1-p_i)u(m_i)+p_i u\left(m_i - (1-s_i)L\right). \quad (9)$$

Substituting for $u(m)$ and solving for t_i, one obtains

$$t_i = \gamma \ln \left[\frac{(1-p_i) + p_i e^{\frac{1}{\gamma}(1-s_i)L}}{(1-p_i) + p_i e^{\frac{1}{\gamma}(1-s_j)L}} \right] > 0. \quad (10)$$

Analogously, individual j can be compensated by an increase in wealth so that he or she is just indifferent between switching location and not switching. Put differently, j's loss in utility from switching location with i is equal to a reduction of wealth by t_j, with

$$t_j = \gamma \ln \left[\frac{(1-p_j) + p_j e^{\frac{1}{\gamma}(1-s_j)L}}{(1-p_j) + p_j e^{\frac{1}{\gamma}(1-s_i)L}} \right] < 0. \quad (11)$$

Since $p_i > p_j$, the net gain from switching location is

$$\Delta \equiv t_i + t_j > 0. \quad (12)$$

We do not consider how the two individuals bargain over the distribution of this net gain but simply assume that they split it equally. Wealth after trade (m_i', m_j') is then given by

$$m_i' = m_i + t_j + \tfrac{t_i+t_j}{2} \quad (13)$$

$$m_j' = m_j - t_j + \tfrac{t_i+t_j}{2}. \quad (14)$$

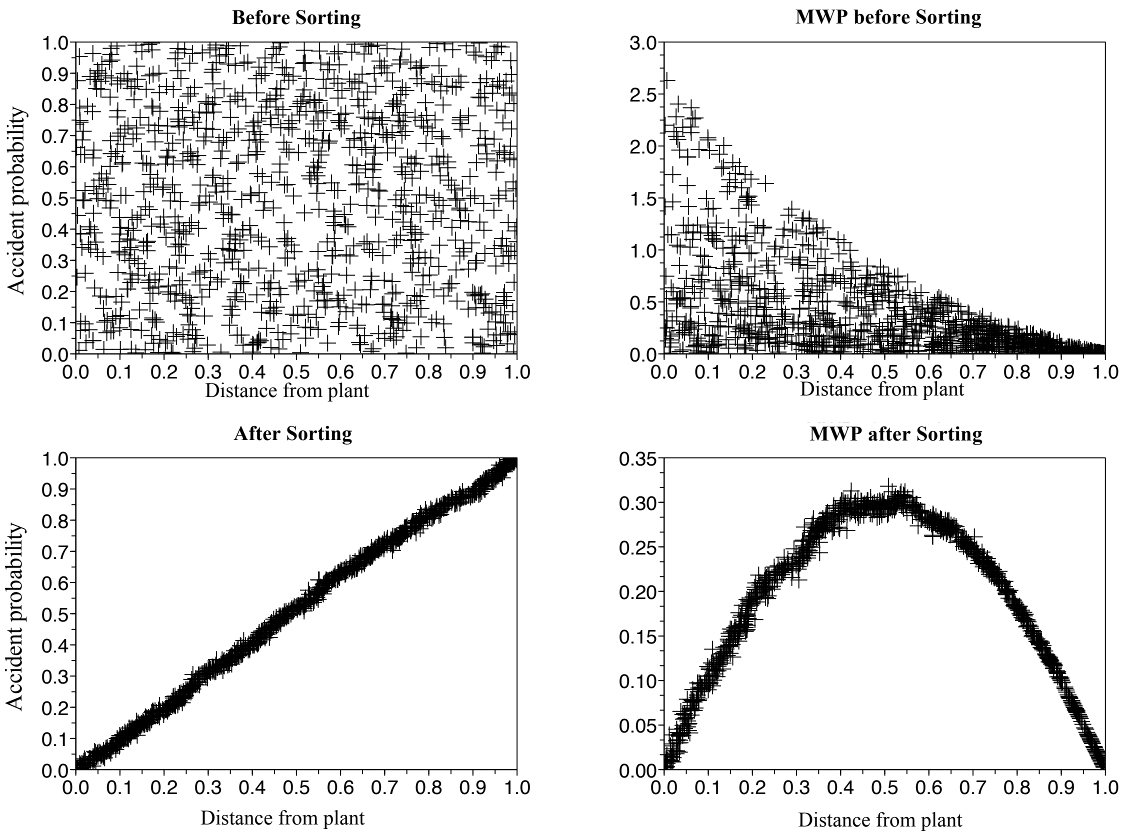

Figure 3: Simulation results with a CARA utility function.

The simulation proceeds as follows.[2] Initially n individuals are randomly allocated to a point in $[0, 1] \times [0, 1]$. Moreover, all individuals are endowed with the same level of wealth. Next, two individuals are chosen randomly. If there are potential gains from switching location, i.e. if condition (4) holds, they switch locations and transfer wealth according to eqs. (13) and (14). After this transaction is concluded, a new pair of individuals is matched. This process continues until there have been no profitable matches for a predetermined number of rounds.

Figure 3 depicts the result of this simulation. The top left panel shows the initial distribution of individuals in (p, s)-space. Taking this allocation as given, the top right panel shows each individuals marginal willingness to pay with distance from the power plant on the x-axis. The lower left panel then shows the allocation of individuals in (p, s)-space after sorting. It is in accordance with Lemma 1 which states that all individuals are concentrated on the 45-degree line. As a consequence, marginal willingness to pay after sorting is inverted U-shaped, as depicted in the lower right panel (this confirms Lemma 2).

3.2 The Confounding Effect of Locational Choice

The analysis in the previous section predicts respondents to be sorted according to distance from nuclear power plants, with the more skeptical types to be found farther away from the plant. Therefore, people located farther away from the plant may well be willing to pay more for additional insurance coverage against operational risk than those located in its vicinity. Whether the distance gradient of WTP for risk reduction w.r.t operational risk is positive or negative thus depends on the amount of sorting that took place. Prior to sorting, those living farther away from the plant would be characterized by a low risk of radiation, causing their WTP for coverage of financial loss to be reduced.

[2]The SciLab code is available from the authors upon request.

Nuclear risk is but one of many factors governing the choice of residential location. Employment opportunities, proximity to the family, recreational considerations, etc. all affect the choice of one's residence. Hence, there is a significant cost associated with relocating, and sorting with respect to operational risk is expected to be less than perfect. However, the stronger a person's attitude towards nuclear risk, the greater is the weight this risk obtains in consumer's decisions. Only persons with a strong negative attitude, high perceived risk or marked risk aversion are expected to rank operational risks high enough so that the sorting-effect becomes measurable in the available data. Put differently, to the extent that estimation succeeds in controlling for attitude and perceived risk, the distance gradient should be negative, i.e. WTP for additional insurance coverage should decrease with distance from plant. If, on the other hand, rsik selection is not controlled for then an inverted U shape relationship between distance from the plant and WTP for coverage of financial loss is expected.

Three indicators for respondents' attitude towards nuclear power plant are used in the estimation, (1) whether they perceive nuclear accidents to be much more likely than experts' best estimates (PESSIMIST), (2) whether they state to be opposed to nuclear energy in principle (OPPONENT), and as an inverse indicator, (3) male sex (SEXM). The last indicator is based on several studies. Hartog, i Carbonell, and Jonker (2002) analyze the influence of individual characteristics on risk aversion and find survey evidence that men are less risk-averse than women. Nielsen, Gyrd-Hansen, Kristiansen, and Nexoe (2003) conclude that men have a lower perception of risks than women. SEXM is therefore predicted to display a negative relationship with WTP.

There is possibly another effect of gender on WTP.[3] Recognizing that households rather than individuals choose their residential location, the intra-household decision process affects the degree of sorting of its constituting individuals. Suppose that on average the main bread-

[3] In Section 6 we show that women do indeed have significantly higher WTP for risk reduction than men. However, their WTP monotonically decreases with distance from the plant as opposed to men's WTP.

winners' preferences are reflected in a household's locational decision concerning residence. In this case, only the main breadwinner's WTP for reduction of risk due to operational risk is expected to be inverted U-shaped, while the other household members' (who did not sort) WTP should be decreasing with distance. Because in Switzerland the main breadwinners are predominantly men and until recently had the legal authority to decide about the residential location of a household, it is expected that they are more strongly sorted than women. Interacting SEXM with DISTANCE controls for this effect.

Unlike with operational risks, individuals who fear the risk from nuclear waste transport or disposal gain little from putting more distance between their residence and a nuclear power plant.[4] Therefore, DISTANCE should not be a relevant predictor of WTP for solving the problem of nuclear waste (WTP_W). This statement needs to be qualified in the following way. Shippings of radioactive waste and spent fuel necessarily originate from plants, from where they will be directed to the future national disposal site (at present, destinations are Le Hague in France and Sellafield in Great Britain). This implies that there is and will be an increased exposure to the risk of nuclear waste in the vicinity of the plant. For most values of DISTANCE, however, the effect of distance on WTP_W is expected to be zero.

3.3 Hypotheses to Be Tested

The preceding arguments may be summed up as follows. (1) Marginal WTP for higher liability insurance coverage (MWP_C) may decrease or increase with distance from the nearest nuclear plant, depending on whether the direct effect of distance (risk effect) or the indirect sorting effect prevails. If sorting prevails, MWP_C is expected to be inverted U-shaped with respect to distance. (2) By controlling for respondents' attitude and gender, an attempt is made to identify the direct effect of distance. This effect on WTP is predicted to be a negative function of

[4]Although a waste disposal site has not been designated yet, geological considerations make it unlikely that a future waste disposal site will be near existing plants (which are all located on rivers).

distance to plant. (3) WTP for solving the waste (and hence transportation) problem (WTP_W) is predicted not to depend on distance, except in the immediate vicinity of the plant. (4) Ceteris paribus, increasing values of MWP_C and WPT_W are expected with higher income since the marginal utility loss caused by the increase in the price of electricity caused by stepping up liability insurance requirements should be decreasing in income.

4 The Stated Choice Experiment

4.1 Methodology

In stated-choice experiments (SCE), respondents are confronted with hypothetical choice situations where they have to decide whether they prefer the status quo or some alternative product (which potentially differs in all product attributes). For each such choice set, respondents have to indicate their preferred choice, which requires them to trade off one set of attributes against the other, implicitly revealing their preferences regarding the different attributes.

The SCE approach started with McFadden (1974) and was further developed by Louvière and Hensher (1982). An overview is given by Louvière, Hensher, and Swait (2001). More recently, it has become popular in energy and health economics (Johnson and Desvousges, 1997; Johnson, Ruby, and Desvousges, 1998; Telser, 2002). In the context of nuclear energy risks, SCE have been found to yield qualitatively and quantitatively plausible results (Schneider and Zweifel, 2004). However, that study neglects the spatial dimension of risk associated both with the operation and waste disposal of nuclear plants.

4.2 Experimental Design

In the present context, the SCE method has individuals choose among different types of electricity. During the decision process, the attributes (among them price) of electricity are traded

Attribute	Levels (Coding[c])	Unit	Status quo
PRICE	0; 10; 30; 60 (**0**;...;60)	percent	0
BLACKOUTS	2; 14 (**0**;1)	number/year	2
NOWASTE	unresolved problems (**1**); no unresolved problems (0)		unresolved problems
DAMAGE[a]	0.1; 10; 100; 200 (0.1;...;**200**)	CHF bn.	200
COVERAGE[b]	1; 20; 50; 100 (**1**;...;100)	percent	1

[a] Values in US$ bn: 0.065; 6.5; 65; 130 (CHF 1 $\sim US\$1.2$)

[b] Coverage in percent of loss

[c] Bold for status quo

Table 1: Levels of attributes.

off against each other. Participants in the experiment are asked to pairwise evaluate several different electricity products by indicating their preferred choice. By observing a number of choices, it is possible to approximate an indifference curve in attribute space and therefore estimate how much income (through higher electricity prices) respondents are prepared to give up in return for an increased amount of some other desired attribute.

For a SCE, it is necessary to define the product under consideration (here: electricity) by but a few relevant attributes. In a telephone survey preceding the main survey, 500 Swiss residents were asked to indicate how important they considered several electricity attributes. The following five emerged as the most important: size of area exposed to hazard (DAMAGE), secure and sustainable waste disposal (NOWASTE), reliability defined as low frequency of blackouts (BLACKOUT), financial compensation of victims in case of an accident (COVERAGE), and average price per kwh (PRICE). Since the study is concerned with insurance against financial risks of a nuclear accident, DAMAGE was defined as billions of CHF at risk rather than area exposed to hazard. Although this study focusses on financial risks, health risk concerns by respondents are also picked up as long as they are expressed as the desire for increased insurance coverage. The relevant attributes are summarized in Table 1.

	Description	Mean	Median	Std. dev.
DISTANCE	distance in kilometers from respondent's residence to nearest nuclear power plant	45	36	30
PESSIMIST	= 1 if respondent considered a nuclear accident at least ten times more probable than experts	0.59	1	0.49
OPPONENT	= 1 if respondent said to be against nuclear energy even if there was no waste disposal problem	0.21	0	0.41
SEXM	= 1 if respondent is male	0.52	1	0.5
INCOME	yearly income in CHF. Seven income categories were used in the questionnaire. 44 percent did not reveal their income	47,500	60,000	35,400
INC_MISSG	= 1 if income missing	0.44	0	0.5

Table 2: Sample description of explanatory variables.

The questionnaire for the main survey was divided in three parts: warm-up questions, the actual choice experiment, and socioeconomic information. In the first part, data on monthly electricity outlay, attitudes towards nuclear energy, and the importance of choice between different types of electricity was collected. Respondents then had to read a description of the risks of nuclear and hydro power plants (document with exact wording available from the authors). Emphasis was put on possible worst-case scenarios and their financial consequences. Respondents were also told that nuclear power plants were already mandated to have liability insurance but that coverage fell far short of possible financial loss in case of a major accident. The federal government would possibly provide relief by imposing a special tax. Alternatively, mandated insurance coverage could be stepped up to reduce reliance on the tax system.

The second part of the questionnaire consisted of the actual DCE. Respondents were confronted with 14 different choice situations where they had to decide whether they preferred a proposed type of power to the status quo. Note that respondents could always opt out by stating "cannot decide". In the third and last part of the questionnaire, standard socioeconomic data was collected, summarized in Table 2. Specifically, DISTANCE from the nearest nuclear power plant was calculated using Zip codes provided by respondents. PESSIMIST=1 obtains if on a visual analog scale, respondents marked their estimated accident probability at least one order of magnitude higher than experts.

Moreover, respondents were asked to indicate their income. Since more than 40 percent of respondents refused to indicate their income, restricting the sample to those individuals with information on income had to be avoided. The solution retained is to equate missing values to zero (INCOME = 0) while creating a dummy variable INC_MISSG that takes on the value of one if income information is not available. Interaction terms are limited to OUTLAY; this is sufficient to represent differences in marginal utility of income.

Face-to-face interviews were performed with randomly drawn respondents in the German-speaking part of Switzerland during September and October 2001 (in the aftermath of 9/11). In total, 391 persons were interviewed. Each respondent evaluated 14 choice scenarios, resulting in 5,474 recorded decisions. After excluding ``cannot decide" answers and missing values, a total of 4,613 observations were retained.

5 Econometric Specification

Let an individual be confronted with a discrete choice, e.g. whether to buy a certain product or not. Given this choice, individuals maximize their (expected) utility with respect to their budget constraints, obtaining certain utility values. These values define an indirect utility function that depends on individuals' characteristics, their incomes, on the attributes of the alternative (including price) as well as on various unobservable and therefore random effects (random utility specification, see McFadden, 2001).

In the present stated choice experiment (SCE), respondents were confronted with 14 binary choice situations, involving the status quo and an alternative. The dependent variable y_i equals one if respondents chose the alternative and zero if they stayed with the status quo. Respondent i's indirect utility of the alternative in choice situation j is denoted by V_{ij}; the one of the status quo, by V_{mj}. Respondents therefore chose the alternative ($y_i = 1$) if $V_{ij} - V_{im} \geq 0$. In keeping with the theory laid out in section 3, the utility function reads

$$\begin{aligned} V_{ij} = \beta_0 &+ \beta_1 \cdot \text{COVERAGE}_j + \beta_2 \cdot \text{NOWASTE}_j + \beta_3 \cdot \text{BLACKOUT}_j + \beta_4 \cdot \text{DAMAGE}_j \\ &+ \beta_5 \cdot \text{OUTLAY}_j + \beta_6 \cdot \text{OUTLAY}_j^2 + \beta_7 \cdot \text{DIST}_i \cdot \text{NOWASTE}_j + \beta_8 \cdot \text{DIST}_i^2 \cdot \text{NOWASTE}_j \\ &+ \beta_9 \cdot \text{DIST}_i \cdot \text{DAMAGE}_j + \beta_{10} \cdot \text{DIST}_i^2 \cdot \text{DAMAGE}_j + \beta_{11} \cdot \text{DIST}_i \cdot \text{COVERAGE}_j \\ &+ \beta_{12} \cdot \text{DIST}_i^2 \cdot \text{COVERAGE}_j + \ldots + \epsilon_{ij}. \end{aligned} \tag{15}$$

Since the status quo remains the same for each individual during the experiment, the error term ϵ_{im} in the utility function for the status quo does not change. This amounts to an individual-specific error term $\mu_i \equiv \epsilon_{im}$. Since only differences $V_{ij} - V_{im}$ are relevant for an individual's decision, the error term of the estimated function is given by $\mu_i - \epsilon_{ij}$, calling for a random effects specification. Furthermore, regressors such as OUTLAY_j are measured as differences from the status quo, causing socioeconomic variables to drop out of the equation unless interacted with regressors that vary between situations.

The random effects probit model was estimated using maximum likelihood. The estimated utility function permits to calculate marginal WTP for the different product attributes, defined as the marginal utility of the attribute divided by the marginal utility of income,

$$MWP_i(\text{COVERAGE}) := \frac{\partial \hat{V}_i / \partial \text{COVERAGE}}{\partial \hat{V}_i / \partial \text{OUTLAY}}. \tag{16}$$

In the case of WTP for solving the nuclear waste problem, one has

$$WP_i(\textsc{nowaste}) := \frac{\hat{V}_i[\textsc{nowaste} = 1] - \hat{V}_i[\textsc{nowaste} = 0]}{\partial \hat{V}_i / \partial \textsc{outlay}}. \quad (17)$$

MWP values reported are in US$ per year. Note that $\textsc{income}_i \cdot \textsc{outlay}_j$ and $\textsc{outlay}_j^2$ permit marginal utility of income to vary with income. Using the delta method (see Greene, 2003, p. 70), standard errors of MWP are derived from the standard errors of the parameters contained in the estimated utility function.

6 Results

Estimation results are displayed in Table 5. All coefficients of product attributes (COVERAGE, NOWASTE, BLACKOUT, OUTLAY, OUTLAY2) with the exception of DAMAGE show the expected sign and are highly significant, indicating that respondents were (on average) willing to make trade-offs among the different attributes. Furthermore, the relative magnitudes of marginal utilities associated with product attributes are intuitively plausible. Note that COVERAGE measures the increase in insurance coverage in percentage points, whereas NOWASTE is an all-or-nothing variable indicating whether or not there are any problems regarding nuclear waste. There are several indications that the hypotheses formulated in section 3.3 may be confirmed. (1) While DIST·COVERAGE has a negative coefficient, the one of DIST·PESSIMIST·COVERAGE is positive, significantly reducing the overall effect of DISTANCE. (2) Non-pessimistic women (SEXM=0 and PESSIMIST=0) show a strong negative distance gradient for MWP_C whereas pessimistic men show a positive distance gradient for MWP_C. These findings indicate that SEXM and PESSIMIST are able to control for respondents' attitudes. (3) The coefficient of DIST·COVERAGE is significant, that of DIST·NOWASTE not, exactly as predicted. (4) Higher income mitigates the

	Coeff.	**s.e.**	
CONSTANT	0.62489	0.09024	***
COVERAGE	0.02053	0.00424	***
NOWASTE	0.35806	0.17971	**
BLACKOUT	-0.35731	0.04953	***
DAMAGE	-0.00034	0.00087	
OUTLAY	-0.00339	0.00029	***
OUTLAY2	1.17E-07	1.11E-08	***
DIST·NOWASTE	0.00556	0.00637	
DIST^2·NOWASTE	-3.20E-05	5.08E-05	
DIST·DAMAGE	-2.95E-05	3.58E-05	
DIST^2·DAMAGE	3.80E-08	2.95E-07	
DIST·COVERAGE	-5.39E-04	1.74E-04	***
DIST^2·COVERAGE	3.35E-06	1.43E-06	**
SEXM·NOWASTE	-0.18718	0.09561	**
SEXM·COVERAGE	-0.01489	0.00426	***
DIST·SEXM·COV	4.24E-04	1.77E-04	**
DIST^2·SEXM·COV	-2.11E-06	1.47E-06	
PESS·NOWASTE	0.09246	0.09762	
PESS·COVERAGE	-0.01148	0.00451	**
DIST·PESS·COV	4.04E-04	1.86E-04	**
DIST^2·PESS·COV	-2.24E-06	1.54E-06	
OPPONENT·NOWASTE	0.33556	0.12145	***
OPPONENT·COVERAGE	0.00194	0.00528	
DIST·OPP·COV	-1.45E-05	2.11E-04	
DIST^2·OPP·COV	-4.02E-07	1.64E-06	
INCOME·OUTLAY	8.16E-09	2.81E-09	***
NOINCOME·OUTLAY	6.94E-04	3.15E-04	**
$ln\sigma_u^2$	0.10630	0.11006	
σ_u	1.05459	0.05803	
ρ	0.52655	0.02744	

N=$4,613$; 376 respondents; $LogL = -2196.79$; $L_0 = -2596.96$
***, **, * significant at the 1, 5, 10 percent level

Table 3: Random effects probit estimation results. Dependent variable is the probability of accepting the alternative type of power.

	Value	s.e.
$MWP_C^{*)}$		
pessimistic men	0.91	0.38
pessimistic women	1.56	0.41
non-pessimistic men	0.86	0.36
non-pessimistic women	1.52	0.40
WTP_W		
pessimistic men	117.55	25.64
pessimistic women	169.71	28.18
non-pessimistic men	91.79	25.76
non-pessimistic women	143.95	27.37

*) for a percentage point change, e.g. from 1 to 2 percent of maximum loss

Table 4: Marginal willingness to pay for increased coverage (MWP_C) and for solving the waste disposal problem (WTP_W), evaluated at median distance (36 km) in US$ per year.

disutility caused by higher outlay on electricity (INCOME·OUTLAY has a positive coefficient), pointing to diminishing marginal utility of income.

Respondents are not only concerned about the risks associated with nuclear energy (COVERAGE, NOWASTE), but also about the frequency of power outages (BLACKOUT) and about the cost of electricity (OUTLAY and OUTLAY2), with the positive coefficient of OUTLAY2 pointing to a diminishing marginal disutility of loss of income and hence decreasing marginal utility of income.

6.1 The Effect of Attitudinal Variables on WTP

Using eq. (16), MWP is evaluated for different values of SEXM and PESSIMIST while keeping the remaining variables at their median values. The results in Table 4 reproduce the well-known fact of women being more concerned with the well-being of future generations than men. This was already borne out by the negative coefficient of SEXM·COVERAGE in Table 5. Men (SEXM=1) value neither additional insurance coverage nor solving the waste disposal problem as

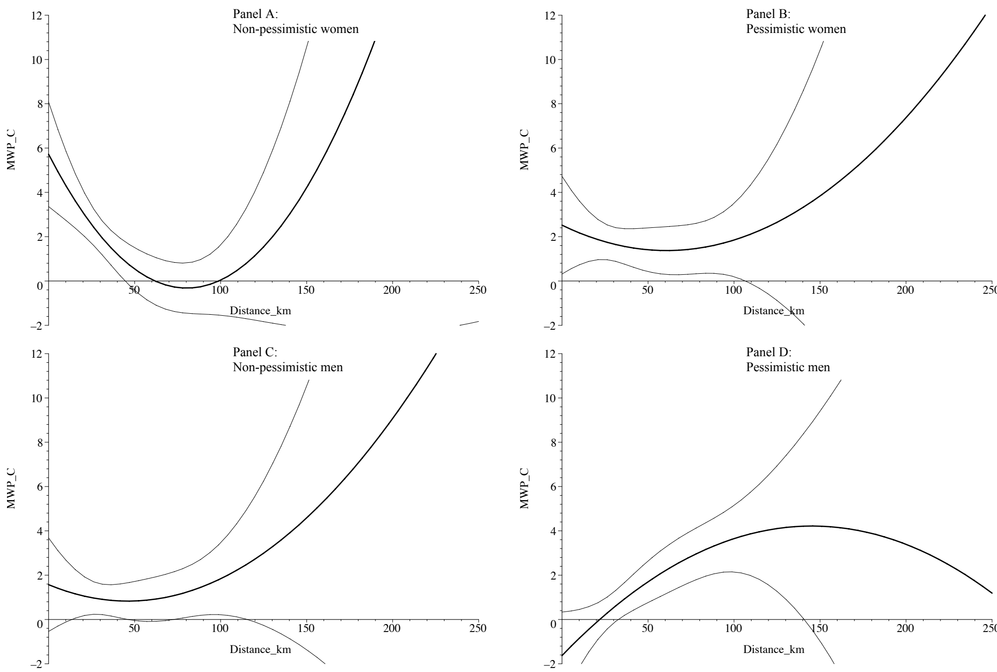

Figure 4: Marginal willingness to pay for increased coverage with respect to distance (measured in km) from nuclear power plant, in US$ per year. The thin lines show the 95 percent confidence intervals.

much as do women (SEXM=0). WTP values reported in Table 4 suggest that pessimistic women are willing to pay 70 percent more than comparable men for a marginal increase in insurance coverage (1.52 US$/year compared to 0.91 US$/year) and roughly 45 percent more than men for solving the waste disposal problem (170 US$/year compared to 118 US$/year). This differential is similar for non-pessimistic women in relative terms, viz. some 75 percent w.r.t. coverage and 55 percent w.r.t. waste disposal.

6.2 The Effect of Distance on WTP

As expounded in section 3, economic theory makes several predictions of considerable detail regarding the effects of DISTANCE on MWP for coverage and WTP for resolving the waste problem. Specifically, prediction (2) states that controlling for attitudinal variables in the regression makes a difference by identifying the (negative) direct effect of distance from plant on MWP_C. This means that pessimists (PESS=1) should exhibit a positive effect (note that the coefficient for DIST·PESS·COVERAGE in Table 5 is positive). In accordance with the argument in Section 3.2, which hypothesized that men are more strongly sorted than women, a positive coefficient of DIST·SEXM·COV is found. Finally, it is expected that opponents (OPPONENT=1) to nuclear energy should exhibit a positive effect as well (here, the coefficient of DIST·OPP·COV is negative but lacks significance). In all, hypothesis (2) is largely confirmed.

Turning to the waste problem, hypothesis (3) states that sorting should not make a difference w.r.t. WTP_W. Indeed, both DIST·NOWASTE and DIST^2·NOWASTE fail to attain statistical significance. Prediction (4) is that higher income should go along with higher value of both MWP_C and WPT_W. Indeed, the negative partial effect of OUTLAY is mitigated by a positive one associated with INCOME·OUTLAY. Therefore, the denominator in equations (16) and (17) goes towards zero with increasing income, causing MWP_C and WTP_W to go up since the numerator is constant. Judging from the positive coefficient of NOINCOME·OUTLAY, this effect is particularly marked among respondents who decline to report their income.

Since the indicators PESSIMIST, OPPONENT and SEXM are designed to capture the sorting effect, the WTP of non-pessimistic women not opposed to nuclear energy (PESSIMIST=0, OPPONENT=0, SEXM=0) for more comprehensive insurance coverage should be decreasing in distance from plant, by hypothesis (2). Panel A of Figure 4 shows that non-pessimistic women do exhibit positive MWP for coverage at first, which decreases with distance from plant. Their MWP_C values become indistinguishable from zero (at the 5 percent significance level) at roughly 50 kilometers away from the plant. In contrast, panel B of Figure 4 reveals a positive but constant MWP_C for pessimistic women. Non-pessimistic men (Panel C of Figure 4) also exhibit constant but lower MWP_C values. Among pessimistic men (panel B), the sorting effect is not only far more marked but also exhibits the inverted U shape predicted by Lemma 2. This constitutes rather strong empirical evidence with regard to the effect of sorting in space.

By way of contrast, the distance gradients of WTP for solving the waste disposal (and transportation) problem are flat in all cases (not shown). Evaluating WTP_W for a non-pessimistic woman at median sample values (which includes a remaining life expectancy of some 44 years for women and discounting at 15 percent), one obtains a lifetime WTP_W of $960 at a distance of 36 kilometers from plant. Likewise, the hundredfold of MWP for insurance coverage corresponds to the full solution of the problem of financial risk associated with operation of the plant. In this case, lifetime WTP at a distance of 36 km amounts to $1,011, suggesting that (full) financial coverage is valued slightly higher than solving the waste disposal problem, at least by the Swiss population. For residents located at the power plant, lifetime WTP is maximum at $3,805. It decreases on average by $63 per km, or $40 per mile, much less than the $200 to 300 per mile reported by Faber (1998) for the United States.

7 Conclusion

The objective of this paper is to analyze the effect of distance from nuclear plant on the WTP for a reduction of two types of risk emanating from these plants, using a stated choice experiment. In the case of Switzerland, respondents had ample opportunity to choose their residential location according to their preferences regarding nuclear power. In the case of radioactive risk associated with the operation of a nuclear plant, this causes distance to play an ambiguous role. If spatial sorting of individuals is indeed important, one would expect to find more strongly concerned people residing at a greater distance from plants. A simple economic model of locational choice predicts that such sorting will result in an inverted U-shaped relationship between marginal WTP for risk reduction and distance. By way of contrast, distance from plant is predicted to be irrelevant for nuclear waste disposal as long as the final disposal site is not decided (as is the case in Switzerland).

In a stated choice experiment, with statistical inference based on the Random Utility Model, the attributes of electric power (degree of coverage by nuclear liability insurance, solution of the waste problem, but also number of blackouts, size of damage, and price of electricity) are found to be valued by respondents as hypothesized. More importantly, distance proves to be a significant predictor of marginal WTP for insurance coverage but not of WTP for having the waste disposal problem solved. Controlling for subjective accident probabilities, the distance gradient of marginal WTP for insurance coverage turns out to display the predicted inverted U profile among men (who until recently had the legal authority to determine a household's location in Switzerland).

On average, WTP for full insurance coverage amounts to $3,805 at zero distance from nuclear power plants, decreasing by $63 per km [$40 per mile, compared to $200 to 300 according to Faber (1998) for the United States], reaching zero at a distance of 60 km (37 miles). WTP for solving the waste disposal problem does not depend on distance from plant, again as predicted.

In sum, this research suggests that distance from an environmental disamenity may have unexpected effects on WTP for risk reduction. Data on real property and housing prices, being contaminated by regional shifts in supply, are unlikely to permit discovering the demand effects caused by the sorting in space performed by individuals when choosing their residential location.

A More Estimation Results

	Specification 1 Coeff.	s.e.		Specification 2 Coeff.	s.e.		Specification 3 Coeff.	s.e.	
CONSTANT	0.62489	0.09024	***	0.60374	0.09093	***	0.60554	0.08967	***
COVERAGE	0.02053	0.00424	***	0.00698	0.00238	***	0.00499	0.00155	***
NOWASTE	0.35806	0.17971	**	0.34859	0.17796	**	0.45605	0.11873	***
BLACKOUT	-0.35731	0.04953	***	-0.35057	0.04924	***	-0.34883	0.04919	***
DAMAGE	-0.00034	0.00087		-0.00025	0.00093		-0.00055	0.00053	
OUTLAY	-0.00339	0.00029	***	-0.00335	0.00029	***	-0.00336	0.00029	***
OUTLAY2	1.17E-07	1.11E-08	***	1.14E-07	1.06E-08	***	1.14E-07	1.05E-08	***
DIST·NOWASTE	0.00556	0.00637		0.00625	0.00639		0.00131	0.00167	
DIST^2·NOWASTE	-3.20E-05	5.08E-05		-4.02E-05	5.09E-05				
DIST·DAMAGE	-2.95E-05	3.58E-05		-3.71E-05	3.98E-05		-2.26E-05	9.84E-06	**
DIST^2·DAMAGE	3.80E-08	2.95E-07		1.24E-07	3.36E-07				
DIST·COVERAGE	-5.39E-04	1.74E-04	***	-7.38E-05	8.59E-05		1.37E-05	2.22E-05	
DIST^2·COVERAGE	3.35E-06	1.43E-06	**	7.06E-07	6.92E-07				
SEXM·NOWASTE	-0.18718	0.09561	**	-0.18769	0.09437	**	-0.18912	0.09449	**
SEXM·COVERAGE	-0.01489	0.00426	***	-0.00207	0.00123	*	-0.00203	0.00123	*
DIST·SEXM·COV	4.24E-04	1.77E-04	**						
DIST^2·SEXM·COV	-2.11E-06	1.47E-06							
PESS·NOWASTE	0.09246	0.09762		0.09554	0.09702		0.09320	0.09696	
PESS·COVERAGE	-0.01148	0.00451	**	0.00027	0.00128		0.00038	0.00128	
DIST·PESS·COV	4.04E-04	1.86E-04	**						
DIST^2·PESS·COV	-2.24E-06	1.54E-06							
OPPONENT·NOWASTE	0.33556	0.12145	***	0.33387	0.12124	***	0.33684	0.12118	***
OPPONENT·COVERAGE	0.00194	0.00528		0.00056	0.00162		0.00051	0.00162	
DIST·OPP·COV	-1.45E-05	2.11E-04							
DIST^2·OPP·COV	-4.02E-07	1.64E-06							
INCOME·OUTLAY	8.16E-09	2.81E-09	***	8.15E-09	2.82E-09	***	8.24E-09	2.80E-09	***
NOINCOME·OUTLAY	6.94E-04	3.15E-04	**	6.75E-04	3.16E-04	**	6.85E-04	3.14E-04	**
$ln\sigma_u^2$	0.10630	0.11006		0.11499	0.11849		0.10655	0.11251	
σ_u	1.05459	0.05803		1.05918	0.06275		1.05472	0.05933	
ρ	0.52655	0.02744		0.52872	0.02952		0.52661	0.02805	
Log Likelihood	-2196.79			-2211.14			-2212.05		

N=4, 613; 376 respondents; $L_0 = -2596.96$; ***, **, * significant at the 1, 5, 10 percent level

Table 5: Random effects probit estimation results. Dependent variable is the probability of accepting the alternative type of power.

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