# Spatial Effects in Willingness-to-Pay:

# The Case of Nuclear Risks*

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This paper examines the spatial dimension of responses to the external effects of nuclear power. Most people would agree that these effects decrease – ceteris paribus – with distance from a nuclear power plant. They would therefore expect willingness-to-pay (WTP) for coverage against the financial risks of a nuclear accident to decrease with distance from plant. However, 'ceteris paribus' may not hold because homeowners and tenants can choose where to locate. If those who believe to be little affected by the externality settle in the vicinity of the plant, WTP for financial safety may well increase rather than decrease with distance. Still another spatial relationship is predicted for waste disposal, a second externality associated with nuclear power. As long as the (national) site of waste disposal is not determined yet but could be anywhere in the country where geological conditions are favorable, putting more distance between the plant and one's residence does not make much of a difference. Thus, WTP for getting

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rid of this externality is predicted to have no relation with distance (except in the very neighborhood of the plant, where all eligible train lines and truck routes necessarily originate).

The present study purports to test these predictions using data from a stated choice experiment (SCE) with Swiss individuals. It is of particular interest for two reasons. First, most of the existing published work concerned with the effect of distance on the WTP for reducing a negative externality 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. As noted above however, such a relocation usually proves ineffective when it comes to escaping nuclear waste; in fact, Switzerland does not yet have a long-term repository for spent nuclear fuel and high-level radioactive waste[1]. A large fraction of nuclear material is kept at the respective power plants before being shipped to either France or Great Britain.

The SCE was conducted in 2001. Some 370 respondents were asked to choose between the status quo and an alternative type of electricity, defined by a changed number of blackouts, problems with the disposal of nuclear waste, severity of (financial) damage in case of accident, and degree of coverage through 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 ≅ CHF 1.25 at 2003 exchange rates]), 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 comes from hydro power).

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 II describes the SCE that was applied to measure WTP of the Swiss population for reducing these externalities. Section III develops the hypotheses to be tested, mainly with regard to the effect of distance on measured WTP. The econometric specification, based on the Random Utility Model, is presented in section IV. Estimation results and hypothesis tests follow in section V, while concluding remarks are offered in section VI.

## I. 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. Isaac Ehrlich and Gary S. 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 Georges Dionne and Louis Eeckhoudt, 1985). Therefore, more strongly risk-averse individuals are predicted to spend more resources on loss mitigation than less risk-averse consumers.

The experiment conducted in the present study introduces a hypothetical insurance market. Respondents in this experiment evidently 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 (Mary Kelly and Anne E. 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 Jon P. Nelson (1981) and Hays B. Gamble and Roger H. 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. Sherman Folland and Robin 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, Kishore Gawande and Hank 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 Stephen 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 David E. Clark and Tim 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 III.

Most of these studies rely on hedonic modeling, linking price data to a set of characteristics of real estate property. In a recent contribution to this journal, Lucas W. Davis (2005) applies this method to estimate marginal WTP to avoid pediatric leukemia risk. 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 may thus complement information gleaned from market data.

For example, V. Kerry Smith and Desvouges (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 Mary Riddel et al. (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 et al. (2003), this study does not consider a planned and not yet effected 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.[2] Respondents had ample opportunity to relocate according to their preferences regarding nuclear power plants. The present investigation therefore estimates the net disutility caused by nuclear power plants, given the respondents' amount of self-insurance through locational choice.

## II. The Stated Choice Experiment

### A. 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 that is allowed to differ 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 alternative started with Daniel McFadden (1974) and was further developed by Jordan J. Louvière and David A. Hensher (1982). More recently, it has become popular in energy and health economics (F. Reed Johnson and William H. Desvousges, 1997, Johnson et al. 1998, Harry Telser and Peter Zweifel, 2002). In the context of nuclear energy risks, SCE have been found to yield qualitatively and quantitatively plausible results (Yves Schneider and Zweifel, 2004). However, that study neglected the spatial dimension of risk associated both with the operation and waste disposal of nuclear plants.

### B. Experimental Design

In the present context, the ‘stated choice’ method allows individuals to choose among different types of electricity. During the decision process, the attributes (among them price) of electricity are traded off against each other. Participants in the experiment are asked to pairwise evaluate several different electricity products[3] by indicating their preferred choice. By observing a number of choices, it is possible to approximate an

**Table 1. Levels of attributes.**

| Attribute | Levels (Coding) | Unit | Status quo |
|---|---|---|---|
| price | 0; 10; 30; 60 (0;...;60) | percent increase | 0 |
| blackout | 2; 14 (0;1) | number/year | 2 |
| waste | unresolved problems (1)<br>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 (0;...;100) | percent | 1 |

a) Maximum loss in US$ per household: 21; 2,100; 21,000; 42,000 (at 2002 exchange rates)
b) Nuclear insurance coverage in percent of loss

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 (WASTE), reliability (BLACKOUT, low frequency of blackouts), 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. The relevant attributes are summarized in Table 1.

**Table 2. Sample description of explanatory variables.**

| | Description | Mean | Median | Std. |
|---|---|---|---|---|
| DISTANCE | distance in kilometers from respondents 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 |
| OWNER | = 1 if respondent owns his or her dwelling | 0.35 | 0 | 0.48 |
| SEXM | = 1 if respondent is male, = 0 if female | 0.52 | 1 | 0.50 |
| 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 was missing | 0.44 | 0 | 0.50 |

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 (see the appendix for exact wording). 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 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.

Face-to-face interviews were performed 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.

## III. Expected Effects of Distance on Willingness-to-Pay

### A. The Confounding Effect of Locational Choice

Given the possibility of choosing residential location according to attitudes towards nuclear power plants, one would expect respondents to be sorted according to distance to nuclear power plants, with the more skeptical types to be found farther away from the plant. Therefore, people located farther away from the plant might be willing to pay more for additional insurance coverage than those located in the vicinity of the plant. Whether the distance gradient of WTP for risk reduction is positive or negative thus depends on the degree of sorting that took place. For without sorting, living farther away from the plant does serve as self-insurance, reducing the risk of radiation and causing a lowered WTP for coverage of financial loss.

Since the cost of relocating is not trivial, sorting is expected to be less than perfect. Thus, the combined effect of self-insurance and sorting is ambiguous. However, 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 plants.

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 (3) male sex (SEXM). The last indicator is based on several studies. Joop Hartog et al. (2002) analyze the influence of individual characteristics on risk aversion and find survey evidence that men are less risk averse than women. Jesper B. Nielsen et al. (2003) present evidence that men have a lower perception of risks than women. SEXM is therefore predicted to display a negative relationship with WTP. Furthermore, to the extent that locational decisions concerning residence more strongly reflect main breadwinners' preferences (who are still predominantly men in Switzerland), interacting SEXM with DISTANCE controls for sorting. Thus, the net effect of DISTANCE on WTP is predicted to be less strongly negative for men than women.

## B. The Difference Between Radiation and Waste Disposal Risks

The risk of nuclear waste disposal differs importantly from that of plant operation. In view of the fact that a national site for nuclear waste disposal has not been designated yet, putting more distance between one's residence and a nuclear plant has little effect. 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. For geological reasons, a future disposal site is unlikely to be near existing plants (which are all located on rivers). Therefore, being located at a great DISTANCE to the plant does not protect individuals from the risk associated with the shipping and disposal of nuclear waste. Yet transports of radioactive waste and spent fuel necessarily originate from plants, from where they will be directed to whatever national disposal site will be chosen (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.

## C. 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 sorting effect prevails. (2) By controlling for respondents' attitude, parts of the pure risk effect can be estimated and is expected to be negative. (3) WTP for solving the waste problem ($WTP_W$) is predicted not to depend on distance. (4) Ceteris paribus, increasing values of $MWP_C$ and $WPT_W$ are expected with higher income since the marginal utility loss caused by an increase in the price of power should be decreasing in income.

Since some 40 percent of respondents refused to indicate their income, restricting the sample to those individuals with information on income has 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.

## IV. Econometric Specification

An individual may be confronted with a discrete choice, e.g. whether to buy a certain product or not. Given this choice, individuals maximize their utility with respect to their budget constraints, obtaining certain utility values. These values define an indirect utility function (conditional on the alternative selected) that depends on individuals' characteristics, their incomes, on the particular attributes of the alternative (including price) as well as on various unobservable and therefore random effects (random utility specification, see Daniel 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 to one if respondents chose the alternative and zero if they stayed with the status quo. Respondent $i$'s utility of the alternative in choice situation $j$ is denoted by $V_{ij}$; the one of the status quo, by $V_{im}$. Respondents therefore chose the alternative ($y_i$ = 1) if $V_{ij} - V_{im} \geq 0$. The utility function to be estimated thus reads

$$\begin{aligned} V_{ij} \;=\; & \beta_0 + \beta_1 \cdot \text{COVERAGE}_j + \beta_2 \cdot \text{NOWASTE}_j + \beta_3 \cdot \text{BLACKOUT}_j + \beta_4 \cdot \text{DAMAGE}_j \\ & + \beta_5 \cdot \text{OUTLAY}_j + \beta_6 \cdot \text{OUTLAY}_j^2 + \beta_7 \cdot \text{DIST}_i \cdot \text{COVERAGE}_j + \beta_8 \cdot \text{DIST}_i \cdot \text{NOWASTE}_j \\ & + \beta_9 \cdot \text{DIST}_i \cdot \text{DAMAGE}_j + \beta_{13} \cdot \text{DIST}_i \cdot \text{PESS}_i \cdot \text{COVERAGE}_j + \beta_{34} \cdot \text{INCOME}_i \cdot \text{OUTLAY}_j \\ & + \ldots + \varepsilon_{ij}, \end{aligned} \tag{1}$$

where $\varepsilon_{ij} = u_i + v_{ij}$ has a two-way random specification to account for the fact that the same individual $i$ decides in the several situations $j$. Note that $\text{INCOME}_i \cdot \text{OUTLAY}_j$ and $\text{OUTLAY}_j^2$ permit marginal utility of income to vary with income (since $\Delta\, \text{OUTLAY}_j = -\Delta\, \text{INCOME}_i$). Since only differences $V_{ij}$ - $V_{im}$ are relevant for an individual's decision, regressors such as $\text{OUTLAY}_j$ 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, at least under the random utility specification. The random effects probit model was estimated using maximum likelihood. The estimated utility function, $\hat{V}_i$, 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,

$$MWP_i(\text{COVERAGE}) := -\frac{\partial \hat{V}_i / \partial \text{COVERAGE}}{\partial \hat{V}_i / \partial \text{OUTLAY}}. \tag{2}$$

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

$$WP_i(\text{NOWASTE}) := -\frac{\hat{V}_i[\text{NOWASTE} = 1] - \hat{V}_i[\text{NOWASTE} = 0]}{\partial \hat{V}_i / \partial \text{OUTLAY}}. \tag{3}$$

MWP values reported are in US$ per year. Using the delta method (see William H. Greene 2003, p. 70), standard errors of MWP are derived using the standard errors of the parameters contained in the estimated utility function.

## V. Results

Selected estimation results are displayed in Table 3 (full results are relegated to Table 5 in the appendix). All coefficients of product attributes (COVERAGE, NOWASTE, BLACKOUT, OUTLAY, OUTLAY$^2$) with the exception of DAMAGE show the expected sign and are highly significant, indicating that respondents were (on average) willing to make tradeoffs 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. Multiplying the coefficient of COVERAGE (0.001) by 100 for making it roughly comparable to that of NOWASTE (0.52), one obtains 1.00, suggesting that the two attributes are valued similarly. Moreover, there are first indications that the hypotheses formulated in section III.C may be confirmed. (1) While DIST·COVERAGE has a negative coefficient, the one of DIST·PESS·COVERAGE is positive, turning the overall effect of DISTANCE around. (2) The effect of DISTANCE interacted with COVERAGE again changes sign when further interacted with OPPONENT. (3) The coefficient of DIST·NOWASTE is insignificant, in contradistinction to that of DIST·COVERAGE. (4) Higher

**Table 3: Selected estimation results. Dependent variable is the probability of accepting the alternative type of power.**[a)]

| | Sign[b)] | | Coefficient | | Std.Err. | z |
|---|---|---|---|---|---|---|
| COVERAGE | + | $\beta_1$ | 0.009887 | *** | 0.002264 | 4.37 |
| NOWASTE | + | $\beta_2$ | 0.516774 | *** | 0.168756 | 3.06 |
| BLACKOUT | - | $\beta_3$ | -0.362759 | *** | 0.049799 | -7.28 |
| DAMAGE | - | $\beta_4$ | 0.001445 | | 0.000939 | 1.54 |
| OUTLAY | - | $\beta_5$ | -0.003341 | *** | 0.000303 | -11.04 |
| OUTLAY2 | + | $\beta_6$ | 1.19E-7 | *** | 0.000000 | 11.06 |
| DIST·COVERAGE | - | $\beta_7$ | -1.03E-4 | ** | 0.000042 | -2.47 |
| DIST·NOWASTE | 0 | $\beta_8$ | -0.001138 | | 0.003068 | -0.37 |
| DIST·SEXM·COVERAGE | ? | $\beta_{10}$ | 1.54E-4 | *** | 0.000044 | 3.47 |
| DIST·SEXM·NOWASTE | 0 | $\beta_{11}$ | 0.005323 | | 0.003347 | 1.59 |
| DIST·PESS·COVERAGE | + | $\beta_{13}$ | 1.22E-4 | ** | 0.000049 | 2.49 |
| DIST·PESS·NOWASTE | 0 | $\beta_{14}$ | -0.004200 | | 0.003589 | -1.17 |
| DIST·OPP·COVERAGE | + | $\beta_{16}$ | -0.77E-4 | | 0.000060 | -1.29 |
| DIST·OPP·NOWASTE | 0 | $\beta_{17}$ | 0.002981 | | 0.004520 | 0.66 |
| SEXM·COVERAGE | - | $\beta_{22}$ | -0.008248 | *** | 0.002285 | -3.61 |
| SEXM·NOWASTE | - | $\beta_{23}$ | -0.427121 | ** | 0.173976 | -2.46 |
| PESS·COVERAGE | + | $\beta_{25}$ | -0.005563 | ** | 0.002417 | -2.30 |
| PESS·NOWASTE | ? | $\beta_{26}$ | 0.285538 | | 0.181611 | 1.57 |
| OPP·COVERAGE | + | $\beta_{28}$ | 0.003360 | | 0.003009 | 1.12 |
| OPP·NOWASTE | + | $\beta_{29}$ | 0.273641 | | 0.224882 | 1.22 |
| INCOME·OUTLAY | + | $\beta_{34}$ | 7.19E-009 | *** | 0.000000 | 2.52 |
| Log likelihood = -2,178.2026, N=4,613, 376 respondents | | | | | | |

a) Estimation for the full equation (containing 37 rather than 21 explanatory variables) are given in the appendix.
b) Theoretically expected sign.

income mitigates the disutility caused by higher outlay on electricity, pointing to diminishing marginal utility of income.

Therefore, 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 costs of electricity (OUTLAY and $OUTLAY^2$), with the positive coefficient of $OUTLAY^2$ pointing to a diminishing marginal disutility of loss of income and hence decreasing marginal utility of income.

## A. The effect of attitudinal variables on WTP

Using eq. (1), 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 3. Men (SEXM=1) do not value both additional insurance coverage and solving the waste disposal problem as much as women (SEXM=0). WTP values reported in Table 4 confirm this finding. Pessimistic women are willing to pay more than twice as much as comparable men for a marginal increase in insurance coverage (1.47 US$/year compared to 0.62 US$/year) and roughly 50 percent more than men for solving the waste disposal problem (182 US$/year compared to 111 US$/year).

The relative differential is less for non-PESSIMISTIC women w.r.t. coverage, viz. some 85 percent, but the same (100 percent) w.r.t. waste disposal. This may be surprising at first sight. Respondents who perceive a nuclear accident to be at least ten times more probable than experts (PESSIMIST=1) are expected to be willing to pay more for coverage

**Table 4: Marginal willingness-to-pay for increased coverage ($MWP_C$) and for solving the waste disposal problem ($WTP_W$), evaluated at median distance (35 km) in US$ per year.**

| | Value | s.e. | z |
|---|---|---|---|
| **$MWP_C$ *)** | | | |
| pessimistic men | 0.6198 | 0.3660 | 1.69 |
| pessimistic women | 1.4677 | 0.4031 | 3.64 |
| non-pessimistic men | 1.0357 | 0.3706 | 2.80 |
| non-pessimistic women | 1.8837 | 0.4085 | 4.61 |
| **$WTP_W$** | | | |
| pessimistic men | 110.6924 | 27.8928 | 3.97 |
| pessimistic women | 181.9186 | 31.7356 | 5.73 |
| non-pessimistic men | 71.5003 | 28.5781 | 2.50 |
| non-pessimistic women | 142.7264 | 31.0601 | 4.60 |

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

than non-pessimistic individuals. In fact, PESSIMIST is the one item of the questionnaire permitting respondents who do not want to be openly against nuclear power (OPPONENT=1, chosen by only 21 percent, see Table 1) to express their skepticism. However, skeptical individuals likely are more concerned about the non-financial risks associated with nuclear power such as the disposal of radiating waste.

The results in Table 4 thus suggest that PESSIMIST more likely serves as an indicator of individuals' general attitude towards nuclear energy rather than of their perceived accident probability. Therefore, it makes sense that their WTP for additional coverage should be somewhat lower than that of non-PESSIMISTIC respondents, while their WTP for the solution of the waste problem is much higher.

## B. The Effect of Distance on WTP

Returning to Table 3 for estimation results, one can see that the hypotheses formulated in III.C are confirmed. In keeping with hypothesis (1), the coefficient of DIST·COVERAGE, reflecting the risk effect, is significantly negative. By way of contrast, the coefficient of DIST·NOWASTE lacks significance, suggesting that WTP for solving the waste problem does not depend on distance from the nearest nuclear plant, as predicted by hypothesis (3).

Prediction (2) states that these rather clear-cut results are due to the fact that the effect of sorting is controlled for by attitudinal variables in the regression. This in turn means that PESSIMISTS should exhibit a smaller distance gradient w.r.t. MWP for coverage. And indeed, DIST·PESS·COVERAGE has a positive coefficient (+ 1.22 E-4), which even more than counterbalances the negative one of DIST·COVERAGE (- 1.03 E-4). The same effect can be observed for men (who are hypothesized to decide about residential location in a family), for DIST·SEXM·COVERAGE also has a countervailing positive coefficient, amounting to 1.54 E-4. And while DIST·OPP·COVERAGE has a negative partial effect (-0.77 E-4), it is not significant.

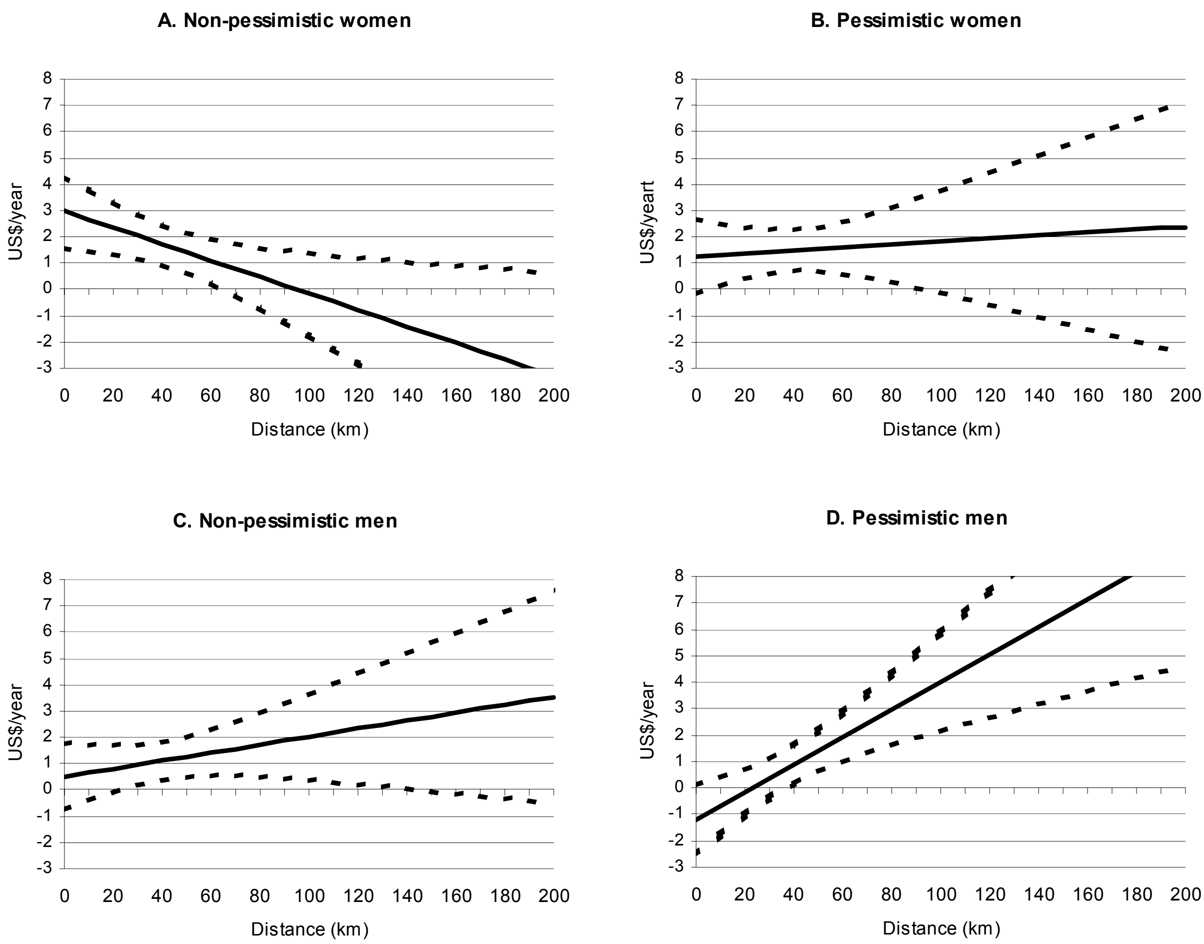
However, hypothesis (3) also states that sorting should not make a difference w.r.t. WTP for having the waste problem resolved. Indeed, DIST·SEXM·NOWASTE, DIST·PESS·NOWASTE, and DIST·OPP·NOWASTE all fail to attain statistical significance. Finally, prediction (4) states that marginal WTP for safety is an increasing function of income because of decreasing marginal utility of income. In Table 3, the negative coefficient of OUTLAY (and the much smaller coefficient of $\text{OUTLAY}^2$) indicate that the probability of accepting the alternative to the status quo (and hence utility) decreases because of the reduction in disposable income caused by outlay on electricity. However, the positive coefficient of INCOME·OUTLAY means that this loss of utility weighs less heavily when income is high.

This certainly constitutes a sign of decreasing marginal utility derived from income. Moreover, the fact that INC_MISSG·OUTLAY lacks significance (see bottom of Table 5 in the appendix) suggests that the 40 percent of respondents who refused to provide information on their income (see section III.C) do not differ systematically from the others w.r.t. their marginal utility. Thus, hypothesis (4) is confirmed as well.

Since the indicators SEXM, PESSIMIST, and OPPONENT are designed to capture the sorting effect, the WTP of non-PESSIMISTIC women not opposed to nuclear energy (SEXM=0, PESSIMIST=0, OPPONENT=0) represents the pure risk effect. By hypothesis (2) of section III.C, their WTP for more comprehensive insurance coverage should be decreasing in distance from plant. Panel A of Figure 4 shows that non-PESSIMISTIC women who do not oppose nuclear energy exhibit positive MWP for coverage at small distances from plant. However, $MWP_C$ becomes indistinguishable from zero (at the 5 percent significance level) at 65 kilometers, turning negative farther away.

Pessimistic women, by way of contrast, may be claimed to have sorted themselves away from nuclear plants, resulting in a slightly positive distance gradient of MWP (which however itself is significantly positive only between 0 and 85 kilometers, see panel B of Figure 4). Among pessimistic men, this positive gradient is far more marked (panel D), in accordance with the view that they are the ones who decide about residential location.

**Figure 2: Effect of distance from nearest nuclear power plant on marginal WTP for increased insurance coverage (OPPONENT = 0; other variables at sample median values).**




Finally, non-PESSIMISTIC men (panel C) exhibit a much weaker positive gradient than the PESSIMISTS of panel D, combined with positive WTP for coverage between distance of 20 and 135 kilometers from plant. The two groups seem to differ in terms of their sorting w.r.t. distance, in accordance with hypothesis (1) of section III.C.

By way of contrast, the distance gradients of WTP for solving the waste disposal problems are flat in all cases (not shown). Evaluating $WTP_W$ it at median sample values (which includes a remaining life expectancy of some 44 years for women and discounting at 15 percent[4]), one obtains a lifetime $WTP_W$ of $1,087 for a distance of 35 kilometers. The hundredfold of MWP for insurance coverage also corresponds to the full solution of a problem, this time the one of financial risk associated with operation of the plant. In this case, lifetime WTP at a distance of 35 km amounts to $1,439, suggesting that (full) financial coverage is valued 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 $2,280. It decreases by $24 per km, or $15 per mile, much less than the $200 to 300 per mile reported by Faber (1998) for the United States.

## VI. Conclusions

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 survey evidence. 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. This could result in a positive rather than negative distance gradient in their marginal WTP for risk reduction. In the case of nuclear waste disposal, however, distance from plant is predicted to be irrelevant as long as the final disposal site is not decided (as 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 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 attitudes towards nuclear energy and nuclear sorting in space, the distance gradient turns out to be significantly negative with regard to marginal WTP for increased insurance coverage. Starting with WTP for full insurance coverage of $2,280 at zero distance from nuclear power plants, WTP decreases by $24 per km [$15 per mile, compared to $200 to 300 according to Faber (1998) for the United States] and eventually falls to zero at a distance of 95 km.

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

**References**


Clark, David E. and Allison, Tim (1999). “Spent Nuclear Fuel and Residential Property Values: The Influence of Proximity, Visual Cues and Public Information”. *Papers in Regional Science* 78, 403-421.

Coller, Maribeth and Melonie B. Williams (1999). “Eliciting Individual Discount Rates”. *Experimental Economics* 2, 107-127.

Davis, Lucas W.(2005). “The Effect of Health Risk on Housing Values: Evidence from a Cancer Cluster”. *American Economic Review* 94, 1693-1704.

Dionne, Georges and Louis Eeckhoudt (1985). “Self-Insurance, Self-Protection and Increased Risk Aversion”. *Economic Letters* 17, 39-42.

Ehrlich, Isaac and Becker, Gary S. (1972). „Market Insurance, Self-Insurance, and Self-Protection“. *The Journal of Political Economy* 80, 623-648.

Faber, Stephen (1998). “Undesirable Facilities and Property Values: A Summary of Empirical Studies”. *Ecological Economics* 24, 1-14.

Folland, Sherman and Hough, Robin (2000). “Externalities of Nuclear Power Plants: Further Evidence”. *Journal of Regional Science* 40, 735-753.

Gamble, Hays B. and Downing, Roger H. (1982). “Effects of Nuclear Power Plants on Residential Property Values”. *Journal of Regional Science* 22, 457-478.

Gawande, Kishore and Jenkins-Smith, Hank (2001). "Nuclear Waste Transport and Residential Property Values: Estimating the Effects of Perceived Risks". *Journal of Environmental Economics and Management* 42, 207-233.

Greene, William H. (2003). "Econometric Analysis". Prentice Hall International, Fifth Edition.

Hartog, Joop; Ferrer-i-Carbonell, Ada, and Nicole Jonker (2002). "Linking Measured Risk Aversion to Individual Characteristics". *Kyklos* 55, 3-26.

Johnson, F. Reed and William. H. Desvousges (1997). "Estimating Stated Preferences with Rated-Pair Data: Environmental, Health, and Employment Effects of Energy Programs". *Journal of Environmental Economics and Management* 34, 79-99.

Johnson, F. Reed; M. C. Ruby and W. H. Desvousges (1998). "Using Stated Preference Measurement and Health-State Classification to Estimate the Value of Health Effects of Air Pollution". Working Paper T-9807, Triangle Economic Research.

Kelly, Mary and Anne E. Kleffner (2003). "Optimal Loss Mitigation and Contract Design". *The Journal of Risk and Insurance* 70, 53-72.

Lawrance, Emily C. (1991). "Poverty and the Rate of Time Preference: Evidence from Panel Data". *Journal of Political Economy* 99, 54-77.

Louvière, Jordan J. and Hensher, David A. (1982). "On the Design and Analysis of Simulated or Allocation Experiments in Travel Choice Modeling". *Transportation Research Record* 890, 11–17.

McFadden, Daniel (2001). “Economic Choices”. *American Economic Review* 91(3), 351-378.

McFadden, Daniel (1974). “The Measurement of Urban Travel Demand”. *Journal of Public Economics* 3(4), 303-28.

Nelson, Jon P. (1981). “Three Mile Island and Residential Property Values: Empirical Analysis and Policy Implications”. *Land Economics* 57, 363-372.

Nielsen, Jesper B.; Gyrd-Hansen, Dorte; Kristiansen, Ivar Sonbo and Nexoe, Jorgen (2003). “Impact of Socio-demographic Factors on Willingness to Pay for the Reduction of Future Health Risk”. *Journal of Environmental Planning and Management* 46, 39-47.

Riddel, Mary; Dwyer, Christine and Shaw, W. Douglas (2003). “Environmental Risk and Uncertainty: Insights from Yucca Mountain”. *Journal of Regional Science* 43(3), 435-457.

Schneider, Yves and Zweifel, Peter (2004). „How Much Internalization of Risk Through Liability Insurance?“. *Journal of Risk and Uncertainty* 29(3), Dec., 219-240.

Smith, V. Kerry and Desvousges, William H. (1986). “The Value of Avoiding a Lulu: Hazardous Waste Disposal Sites.” *The Review of Economics and Statistics* 68 (2), 293-299.

Telser, Harry and Zweifel, Peter (2002). “Measuring Willingness-to-Pay for Risk Reduction: An Application of Conjoint Analysis”, *Health Economics* 11, 129-139.

# VII. Appendix

**Table 5: Full estimation results. Dependent variable is the probability of accepting the alternative type of power.**

| | | Coefficient | Std.Err. | z | P>\|z\| |
|---|---|---|---|---|---|
| COVERAGE | $\beta_1$ | 0.009887 | 0.002264 | 4.37 | 0.00 |
| NOWASTE | $\beta_2$ | 0.516774 | 0.168756 | 3.06 | 0.00 |
| BLACKOUT | $\beta_3$ | -0.362759 | 0.049799 | -7.28 | 0.00 |
| DAMAGE | $\beta_4$ | 0.001445 | 0.000939 | 1.54 | 0.12 |
| OUTLAY | $\beta_5$ | -0.003341 | 0.000303 | -11.04 | 0.00 |
| OUTLAY2 | $\beta_6$ | 0.000000 | 0.000000 | 11.06 | 0.00 |
| DIST·COVERAGE | $\beta_7$ | -0.000103 | 0.000042 | -2.47 | 0.01 |
| DIST·NOWASTE | $\beta_8$ | -0.001138 | 0.003068 | -0.37 | 0.71 |
| DIST·DAM | $\beta_9$ | -0.000050 | 0.000016 | -3.06 | 0.00 |
| DIST·SEXM·COVERAGE | $\beta_{10}$ | 0.000154 | 0.000044 | 3.47 | 0.00 |
| DIST·SEXM·NOWASTE | $\beta_{11}$ | 0.005323 | 0.003347 | 1.59 | 0.11 |
| DIST·SEXM·DAMAGE | $\beta_{12}$ | 0.000038 | 0.000018 | 2.10 | 0.04 |
| DIST·PESS·COVERAGE | $\beta_{13}$ | 0.000122 | 0.000049 | 2.49 | 0.01 |
| DIST·PESS·NOWASTE | $\beta_{14}$ | -0.004200 | 0.003589 | -1.17 | 0.24 |
| DIST·PESS·DAMAGE | $\beta_{15}$ | -0.000029 | 0.000019 | -1.47 | 0.14 |
| DIST·OPP·COVERAGE | $\beta_{16}$ | -0.000077 | 0.000060 | -1.29 | 0.20 |
| DIST·OPP·NOWASTE | $\beta_{17}$ | 0.002981 | 0.004520 | 0.66 | 0.51 |
| DIST·OPP·DAMAGE | $\beta_{18}$ | 0.000092 | 0.000024 | 3.89 | 0.00 |
| DIST·OWN·COVERAGE | $\beta_{19}$ | -0.000055 | 0.000050 | -1.11 | 0.27 |
| DIST·OWN·NOWASTE | $\beta_{20}$ | 0.006622 | 0.003738 | 1.77 | 0.08 |
| DIST·OWN·DAMAGEE | $\beta_{21}$ | 0.000031 | 0.000020 | 1.51 | 0.13 |
| SEXM·COVERAGE | $\beta_{22}$ | -0.008248 | 0.002285 | -3.61 | 0.00 |
| SEXM·NOWASTE | $\beta_{23}$ | -0.427121 | 0.173976 | -2.46 | 0.01 |
| SEXM·DAMAGE | $\beta_{24}$ | -0.000822 | 0.000950 | -0.86 | 0.39 |
| PESS·COVERAGE | $\beta_{25}$ | -0.005563 | 0.002417 | -2.30 | 0.02 |
| PESS·NOWASTE | $\beta_{26}$ | 0.285538 | 0.181611 | 1.57 | 0.12 |
| PESS·DAMAGE | $\beta_{27}$ | -0.000379 | 0.000987 | -0.38 | 0.70 |
| OPP·COVERAGE | $\beta_{28}$ | 0.003360 | 0.003009 | 1.12 | 0.26 |
| OPP·NOWASTE | $\beta_{29}$ | 0.273641 | 0.224882 | 1.22 | 0.22 |
| OPP·DAMAGE | $\beta_{30}$ | -0.003633 | 0.001204 | -3.02 | 0.00 |
| OWNER·COVERAGE | $\beta_{31}$ | 0.003946 | 0.002528 | 1.56 | 0.12 |
| OWNER·NOWASTE | $\beta_{32}$ | -0.167968 | 0.193440 | -0.87 | 0.39 |
| OWNER·DAMAGE | $\beta_{33}$ | -0.002436 | 0.001071 | -2.27 | 0.02 |
| INCOME·OUTLAY | $\beta_{34}$ | 0.000000 | 0.000000 | 2.52 | 0.01 |
| INC_MISSG·OUTLAY | $\beta_{35}$ | 0.000601 | 0.000328 | 1.83 | 0.07 |
| CONST | $\beta_0$ | 0.659389 | 0.085810 | 7.68 | 0.00 |
| LOG LIKELIHOOD = -2,178.2026, N=4,613, 376 RESPONDENTS | | | | | |

## Footnotes

[1] Since June 2001, there exists a temporary storage facility (Zentrales Zwischenlager, ZZL).

[2] The most recent Swiss nuclear power plant became operational in 1984.

[3] A product is a specific combination of attribute levels. Different types of a product have the same attributes but at different levels. A scenario is a pair of products from which respondents have to choose their preferred alternative.

[4] Emily C. Lawrance (1991) estimates discount rates ranging from 12 to 19 percent. Maribeth Coller and Melonie B. Williams (1999) elicit individual discount rates ranging from 15 to 17.5 percent.