WORKING PAPER
ITS-WP-03-17

Valuing Noise Level Reductions in a Residential Location Context

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August, 2003

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ISSN 1440-3501

INSTITUTE OF TRANSPORT STUDIES
The Australian Key Centre
in Transport Management

The University of Sydney
and Monash University

Established under the Australian Research Council's Key Centre Program.

NUMBER: Working Paper ITS-WP-03-17

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ABSTRACT: The noise levels measured in metropolitan streets are on many occasions over the norms but the consequences of this as a health hazard are only starting to be questioned; this is obviously worse in the large cities of the second and third worlds. A stated preference (SP) experiment was designed to estimate the willingness-to-pay (WTP) for reducing the noise level in a group based residential location context. Important issues were the proper definition of the context and the variable metric for the environmental attribute. The experiment considered variations of the attributes travel time to work, monthly house rent, position of the dwelling with respect to the sun and subjective noise level inside it; objective levels were also measured after the experiment. With this data we estimated Multinomial Logit and Mixed Logit (ML) models based on a consistent microeconomic framework, with linear and non-linear utility functions and allowing for various stratifications of the data. The more flexible ML models also allow to treat the repeated observations problem common to SP data and, as expected, gave a better fit to the data. Based on these models we estimated subjective values of time, that were consistent with previous values obtained in the country, and also sensible values for the WTP for reductions in the subjective noise level at a given location.

KEY WORDS: Noise valuation, willingness-to-pay, stated preference, discrete choice modelling, value of time, mixed logit

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DATE: August 2003

1. Introduction

As transport systems evolve, particularly in large cities, several externalities become important. It is safe to say that nowadays the social evaluation of transport projects includes the benefits associated to time savings almost everywhere; however, the benefits due to reductions in the number and severity of accidents are only considered seriously in first world nations, and the potentially large benefits associated to reductions in pollution and noise are yet to found patrons even in the developed world.

There are at least two ways to incorporate the social valuation of external effects. The first attempts to quantify the change in the aggregate product value in terms of the impact on social or individual productivity (the social accounting or shadow price approach). The second consists on estimating the perception of users about the damage inflicted, either through observations of their own actions (revealed preference) or through analysis of their stated willingness-to-pay (WTP), the so-called questionnaire methods. Freeman (1993) examines and classifies the various methods that have been proposed in the literature.

In this paper we deal with the problem of valuing reductions in noise levels which is an endemic problem of large metropolis and one which so far has received relatively little attention as a potential health hazard for their citizens in the developing world. Measurements carried out in 1999 by the Metropolitan Environmental Health Service (SESMA; 1999) showed that in most areas of Santiago de Chile not only the European norm (ie noise levels over 45 dB(A) are damaging to health), but the much more lax Chilean norm of 55dB(A), was violated during many hours of the day.

However, this is a complex subject due to the diffused nature of the contribution of each agent and also to the causality relation of noise on health. Several methods have been applied to deal with this problem in the past, including hedonic pricing (Nelson, 1980; Abelson and Markandya, 1985; Vainio, 2001), the avoided cost method (Whitbread; 1978) and contingent valuation (Feitelson *et al*, 1996); interested readers may wish to check the comprehensive reviews provided by Arsenio (2002) and Navrud (2002). Nonetheless, all these methods have well-known deficiencies (Hausman, 1993; Azqueta, 1994).

On the other hand, Stated Preference (SP) methods have been widely used in transport research and in marketing to identify responses to choice situations that are not clearly revealed in the market. As such they appear to be a promising tool to estimate monetary values for improvements to the environment. In this paper we report the first experience in using SP data to estimate the WTP for reducing noise levels in Chile, and note that precious few experiences have been reported in the literature (Wardman *et al*, 1998; Saelensminde, 1999; Daniels and Hensher, 2000; Arsenio *et al*, 2002).

We decided to study household location choice for theoretical reasons. In valuation experiments it is important to induce a direct perception of damages by the individual and this cannot be achieved in a mode or route choice context. In order to interpret the results of our SP approach correctly, we based our work on the micro-economic model of residential location originally proposed by Jara Díaz and Martínez (1999) and further developed by Pérez *et al* (2003); however, we are not interested in residential location *per se*. Incidentally, note that we used a group-based approach (ie making the whole family to participate in the SP game) that has been shown to give different and better results than the more traditional individual – based studies (Molin *et al*, 1999). Also note that we have applied successfully similar experiments in the country, for measuring the WTP for improving accessibility and for reducing environmental pollution (Ortúzar *et al*, 2000a; Ortúzar and Rodríguez, 2002).

The rest of the paper is organized as follows. Section 2 describes the survey design in some detail; section 3 describes the data collection exercise and discusses the results of the preliminary data screening. Section 4 gives a glimpse of the vast array of models estimated during the work, including the powerful and flexible Mixed Logit model, and derives subjective values of time and willingness-to-pay values for reducing noise from each modelling structure. Finally, section 5 summarizes our main conclusions.

2. SURVEY DESIGN

The first steps in a SP survey design are defining the choice context and the attributes that characterize each available option. Because the valuation of noise reductions is not an everyday matter of thought for individuals, we had to be especially rigorous in selecting an appropriate choice context where this effect could be measured, and the specific way (variable metric) in which it would be presented in the survey.

2.1 The choice context

To estimate the WTP for reducing noise we needed a setting where a family could be exposed, credibly, to different noise levels. Because previous experience with related problems had been very successful, we believed that a realistic context would be to offer respondents the choice of different residential locations associated with different noise levels. It is well-known that when people choose a place to live, they consider not only the dwelling characteristics but also the features of its location (Hunt *et al*, 1994), including noise levels and accessibility conditions.

In the case of Santiago's acoustic pollution problem there are different noise levels in various part of the city as evidenced by the noise surveillance done by the Metropolitan Environmental Health Service (SESMA; 1999); not surprisingly, the louder noise levels are experienced near major roads. This suggests that families who have made their residential location choice recently have implicitly decided on the noise exposure level they would accept during their home activities, and that this may have been contrasted with other attributes associated to the selected dwelling, such as rent and accessibility.

Residential location represents a medium/long term decision and can be labelled a complex decision process. As mentioned, we had found that the rank-order format is particularly appropriate in these cases as it requires ordering options based on attractiveness criteria, instead of choosing a particular one[1]. This allows for in-depth family discussions and had proved an asset in previous studies (Ortúzar, 2000; Ortúzar and Rodriguez, 2002; Perez *et al*, 2003). Maintaining the context and format also had the advantage of allowing us to compare results with our previous studies (in particular, subjective values of time) and in this way checking if respondents seem to have played the game with the required rigour.

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[1] Although the use of rank-order data is disliked by some scholars (Louviere, 2002), we have always find it a very useful method and it is obviously alive and well (Jones and Hensher, 2003).

2.2 Use of focus group

We conducted focus group and pre-tests in order to identify the set of attributes to be presented to respondents and the best way to present them. Our samples were conformed by individuals (of different age, gender and socio-economic conditions) who fulfilled the requirements of living in a flat where they had moved to recently. We had studied this requirement in previous studies, reaching the conclusion that for owners or people who have been renting flat at a given location for more than a year, it is very difficult to put themselves in the context of an hypothetical experiment that requires them thinking about changing their residential location.

Identification of the set of attributes

The first attribute revealed as relevant when a family is choosing a flat is its location. In this sense it is worth mentioning that Santiago is an extremely segregated city; the rich and the poor live in different areas and very seldom mix. In second place comes the rent/mortgage and then the apartment quality. In the particular case of this experience, after some prodding focus group participants recognized that the noise level was indeed important, but also emerged as very relevant the orientation of the flat with respect to the sun (incidentally, we found that sun orientation preferences are not universal; some prefer sun in the morning and others in the evening). Based on these results, the attributes finally chosen for the stated preference experiment were: rent or mortgage paid, noise level, travel time to work and sun orientation. In common with our previous studies, the quality of the apartment was assumed to be the same in all choices.

Selection of measurements units

This task is trivial for attributes related with time and money because they are familiar to all kind of people. Unfortunately, this is not the case for variables such as pollution, noise level or sun orientation (see the discussion in Ortúzar and Rodriguez, 2002). At the focus group we confirmed our suspicion that although noise levels are measured in practice using the decibel scale (dB), people do not know what it means and neither do they know that it is logarithmic. We tested presenting the noise variable in relation to recalled levels at different intersections in Santiago (e.g. some objectively louder than others). For this, participants were asked to rank them using a five-point scale; however, the results did not reflect a clear pattern and none of the respondents was close to the objective data in their assessments.

Laboratory experiences were discarded in spite of the fact that they would allow to simulate a wide range of situations because, as Arsenio *et al* (2000) explain, the experiments are costly and there is no way to know if respondents feel ‘at home’ in this simulation or if they would be really annoyed by that noise level in practice. Finally, we settled for using a rating scale (we started with the seven-point scale used for school and college marking in Chile, but eventually ended with a more traditional 10-point scale). In the case of sun orientation we used the cardinal points; this is not only the natural way of presenting the attribute but was easily understood by the focus group participants and this was confirmed at the subsequent pre-tests.

2.3 Experimental design

Once the attributes and the way to represent them were chosen, the next step was to select the number of levels for each attribute. Although more attribute levels allow to test for non linearities (ie quadratic effects and interactions between variables), the number of choice situations increases and so does respondent burden (Ampt, 2003).

The factorial design chosen for this survey was a 2^4 experiment (Street *et al,* 2001[2]). A full factorial needs 16 choice situations but this had been observed to test respondent's patience in previous focus groups. For this reason we decided to use two blocks with eight treatments each, confounding the four-way interaction AxBxCxD. Although we can estimate all the two-way and three-way interactions, quadratic effects cannot be estimated as this is a 2^k design (Louviere *et al*, 2000).

2.4 Statistical design

The two blocks with eight treatments each, shown below, were generated by solving the following equations (see Hicks, 1973)[3]:

Block 1: A + B + C + D = 0 (mod2)	Block 2: A + B + C + D = 1 (mod 2)
0000 (alternative 1)	0001 (alternative 6)
1100 (alternative 8)	0010 (alternative 5)
1001 (alternative 7)	0100 (alternative 2)
1010 (alternative 3)	1000 (alternative 3)
0110 (alternative 5)	1110 (alternative 4)
0101 (alternative 4)	1101 (alternative 7)
0011 (alternative 2)	1011 (alternative 8)
1111 (alternative 6)	0111 (alternative 1)[4]

Table 1 presents this result in terms of the attributes. If a respondent answers block 1 seriously, s/he should rank alternative 8 first and alternative 2 last. On the other hand, a respondent answering block 2 seriously should put alternative 3 before alternatives 1, 5, 6 and 8. These are just examples; in fact, blocks 1 and 2 imply 12 and nine dominated pairs of options[5] respectively. This knowledge enabled us to check the data for inconsistencies.

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[2] We are grateful to Jordan Louviere for having pointed out this excellent reference to us.

[3] As the variables have two levels of variation they are represented by zero at the lower level and by one at the higher level.

[4] This option was modified, as seen in Table 1, and replaced by (0000) to introduce more realism at the cost of loosing complete orthogonality.

[5] A dominant pair of options appears when every attribute of an option is in an equal or better level than those of the other; therefore, the former option should be placed always higher than the latter in the ranking.

	Block 1				Block 2			
	Attribute levels				Attribute levels			
Alternative	Time	Noise	Sun	Rent	Time	Noise	Sun	Rent
1	High	High	Best	Low	High	High	Best	Low
2	High	High	Worst	High	High	Low	Best	Low
3	Low	High	Worst	Low	Low	High	Best	Low
4	High	Low	Best	High	Low	Low	Worst	Low
5	High	Low	Worst	Low	High	High	Worst	Low
6	Low	Low	Worst	High	High	High	Best	High
7	Low	High	Best	High	Low	Low	Best	High
8	Low	Low	Best	Low	Low	High	Worst	High

Table 1: Attributes levels in each block

2.5 Pilot study

A pilot study was conducted for a sample of households including one, two, four, five and eight family members. The pilot allowed us to detect that the seven-point scale originally proposed for the noise variable confused the respondents; many family members forgot that grade seven (ie the best mark in the Chilean system) represented a “good” noise level (almost silence) and assumed that it implied the highest noise level. For this reason a more traditional ten-point scale was finally chosen, where grade one represented a noise level “as in the countryside” and grade ten an unbearable noise. So each household indicated to us, using the 10-point scale, the noise level grade they thought their dwelling occupied; this is the “actual level” that we refer to below.

The pilot study also helped us to defining the variations in attribute levels for the final survey, as shown in Table 2. As the sun orientation variable cannot be varied in percentage terms we decided to ask each household for their best and worst orientations and used these as levels; although this definition worked well in the pre-tests, it was found to be a little over dramatic in our final results.

	Variation over the actual level	
Attribute	**Level 0**	**Level 1**
Time travel to work (TTW)	15%	-15%
Monthly rent (MR)	-10%	10%
Noise Level (NL)	15%	-15%

Table 2: Variation levels for each attribute

Finally, the pilot study was helpful in defining minimum levels and threshold variations for some attributes (note that some ground work had been covered here because we had conducted similar studies before); for example, it was found that a variation of less than 10 minutes in travel time between two situations was insignificant (in comparison with variations in the other variables). We also were able to establish that the minimum noise level should be grade two and that the minimum travel time should be eight minutes (for further information the interested reader should consult Galilea, 2002).

3. DATA COLLECTION AND PRELIMINARY ANALYSIS

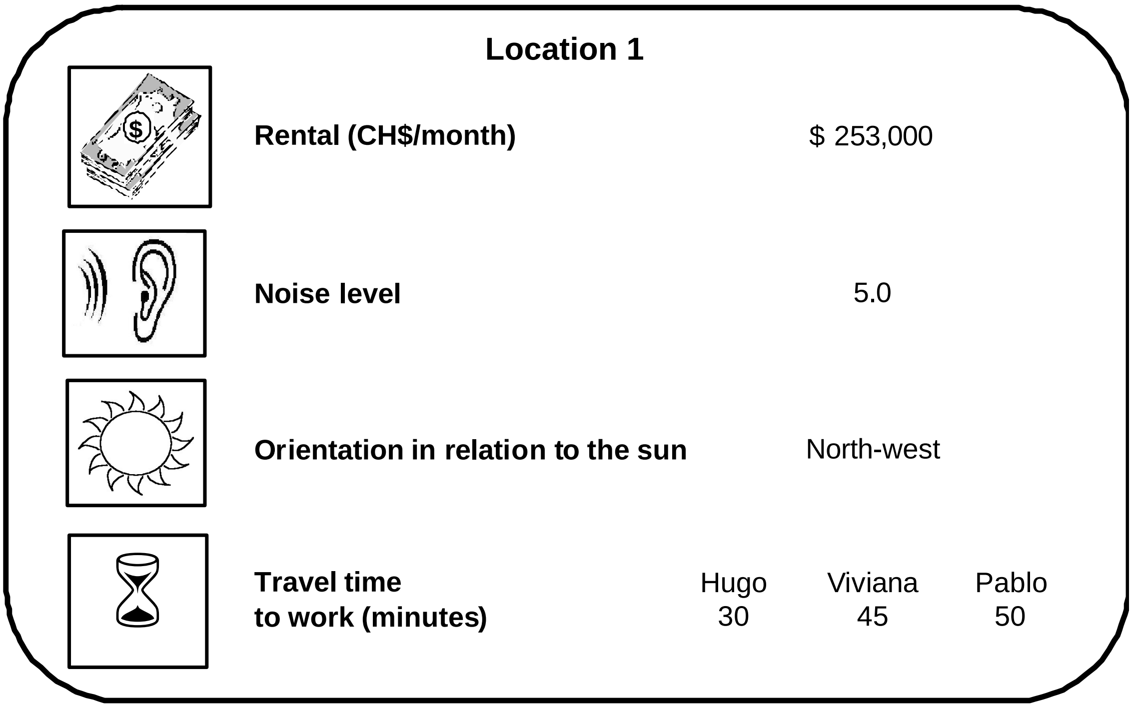
3.1 Sample strategy

The same data collection strategy that had proved successful previously (Ortúzar *et al*, 2000a; Ortúzar and Rodríguez, 2002) was used. It has two stages involving a small group of well-trained interviewers making personal visits to each family contacted. At the first stage, the main characteristics of the dwelling and basic information about the family members (ie identification and travel attributes) are sought. Each interviewer was provided with a survey form to register the household data and an interviewer manual containing the precise set of questions to be formulated and an exact definition of the data required. The manual specified that an adult family member should be the first to be contacted in order to ask him/her the general household information.

The socio-economic characteristics required from each person were: first name, relation to the household head, gender, age, educational level, possession of a driving license and occupation. The general household and dwelling data gathered were: borough where the dwelling was located, nearest street intersection, monthly rent/mortgage paid, origin of this money, number of household vehicles and family income. The interviewer also gathered trip data from every worker in the family: travel modes used, borough where the work place was located, nearest street intersection to the work-place, and current travel time and weekly number of trips to work. Finally, the interviewer asked the family which sun orientations were considered best and worst respectively, and requested them to grade the current level of noise inside the dwelling according to the ten-point scale.

Once this data was processed, the interviewer made a second visit (two days later) where a customized SP exercise was presented to the household. The SP experiment was generated on the basis of the data collected at the first stage and included a set of complementary questions. Once a introductory description of the rank-order exercise context and the varying attributes was made, the interviewer delivered eight cards to the family (Figure 1), each representing a different residential location. The family had to rank these cards and after completing the process the interviewer formulated some questions designed to detect how consistently the family had played the game, how important they considered the variable noise, and to investigate if the attribute levels had been considered realistic (Galilea, 2002).

Because the main purpose of the exercise was to value reductions in noise levels, it was important to measure each household noise level objectively. Due to the high cost of this measurement (done by outside professional experts), we decided to interview only families living in predetermined buildings. An important step was to get permission to do the survey in each of these buildings; a registry of noise levels was offered in return.



Location 1

Rental (CH$/month) $ 253,000

Noise level 5.0

Orientation in relation to the sun North-west

Travel time to work (minutes)	Hugo	Viviana	Pablo
	30	45	50

Figure 1: Example of personalized ranking card

We finally surveyed flats in a total of nine buildings located in different areas of Santiago (four in the high income district, two in a medium-high income sector and three in the exact boundary between middle and low income sectors of the city); the buildings were selected on the basis of their socio-economic characteristics and noise levels. The number of households interviewed at each building varied from three and four (in high income buildings) to 27 and 33 (in low-medium income buildings). The sampling strategy was simply to get as many households as possible in each building because our interest was mainly exploratory and not policy oriented; for this same reason we did not keep records of response rates[6].

Households in 150 flats were finally interviewed with a high level of supervision on the interviewing process. Socio-economic information was representative of middle and high-income people in Santiago. Table 3 shows the sample distribution by rent paid and family income; as can be seen 63.5% of households answering the income question stated that their income was over 850 000 Ch$/month. This is easily over the highest 10% of income in the country, the minimum wage being little over 100 000 Ch$/month (at the time of the survey 1 US$ = Ch$ 650).

The campaign for measuring noise levels started as soon as the second visit was over for every home. We tried to measure inside each flat to spot any differences due to street-level height or orientation. However, only 96 flats (64%) were eventually measured, the rest either refused entrance or nobody was there when the noise specialist arrived.

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[6] The only type of response rate we can quote is that out of 12 preliminary selected buildings, we were given permission to conduct our survey in nine (ie a 75% acceptance rate).

Rent/Mortgage (10^3 Ch$/month)	**Family Income** (10^3 Ch$/month)						**Total**
	100-350	351-550	551-850	851-1250	Over 1250	No answer	
0 - 99	3	2	1	1	1	1	9
100 - 199	5	15	24	21	11	4	80
200 - 299	2	2	4	9	14	3	34
300 - 399	-	1	1	4	11	4	21
Over 400	-	-	-	-	5	1	6
Total	10	20	30	35	42	13	150

Table 3: Rent/mortgage distribution by family income

3.2 Consistency and lexicographic behaviour

Prior to modelling, it is important to detect observations that are not internally consistent or that do not correspond to the assumed population behaviour. One first task was to identify those households that did not make the rank-order exercise as carefully as required. A second task was to identify those cases where responses suggested that the household decision strategy was not coherent with the compensatory decision making protocol assumed by our estimated models (Williams and Ortúzar, 1982).

Internal consistency

Given the complexity involved in simultaneously comparing eight alternatives containing four attributes each, it should be expected that some households might commit mistakes giving not entirely consistent responses. Following usual practice (Pearmain *et al*, 1991), we allowed for a maximum of two inconsistent responses per household as a reasonable indicator of a carefully done ranking exercise. As a result of this we eliminated all observations from 18 households; in addition, in those cases with an acceptable degree of inconsistency we eliminated only the inconsistent responses

Lexicographic behaviour

Household responses were identified where the ranking was consistent with always preferring options with the highest level of a single attribute. Even if this behaviour effectively corresponded to the respondent preferences, it is not consistent with the compensatory decision structure of the estimated models. We detected 40 households exhibiting lexicographic behaviour; 16 on the attribute rent, 23 on the attribute sun orientation, and one on the attribute time to work; this proportion is slightly lower than that reported in previous studies (Saelensminde, 2001; Ortúzar and Rodríguez, 2002; Iragüen and Ortúzar, 2003; Rizzi and Ortúzar, 2003a). The relatively high presence of lexicographic households with respect to sun orientation may be due to two reasons: first, a real concern of the families for this attribute, and second (and more probable), maybe our idea of using the best and worst orientations as levels for this qualitative attribute was just too drastic.

We decided to include the lexicographic responses in the final estimation process for various reasons. First, there is never certainty that respondents are truly lexicographic (they just may seem to be, given the variation levels of the experiment). Second, their inclusion allows to compare SP results with those of revealed preference (RP) surveys, where lexicographic answers cannot be detected. Finally, and as we will show below, the models including lexicographic answers fit the data as well as those excluding them.

4. Discrete Choice Modelling

Ortúzar and Willumsen (2001) provide a convenient summary of the economic and statistical background for analysing discrete choice data. In what follows in this section, and as it is recommended experience (Louviere *et al*, 2000), we will first search for the best Multinomial Logit (MNL) model specification. Then we will relax the assumptions of fixed coefficients and independence of observations by the same household required by this model, and estimate the more flexible but complex Mixed Logit (ML) model (Train, 2003); we will proceed, as recommended, from simple specifications to more interesting structures allowing for interaction effects and parameterised main effects.

The definition of the variables used at the modelling stage is the following:

NL_i : noise level in location *i* (one to ten, where ten is an unbearable level of noise)
RM_i : value of the flat rent or mortgage (thousand of Ch$ per month)
SUN_i :dummy which takes the value one if option *i* has the best orientation in relation to the sun, as declared by household *h*, and zero if it has the worse.

A household accessibility variable, given by the travel time to work by all workers in the family, was also defined following Pérez *et al* (2003):

$$TTW_i = \sum_{h \in H_i} f_{ih} TTW_{hi} \qquad (1)$$

where TTW_{hi} is the travel time to work by individual *h* from location *i* (minutes per trip) and f_{ih} is the frequency of trips to work by individual *h*, from location *i* (trips per week).

Other variables used, such as interaction terms and additional (socio-economic and trip related) attributes, will be defined later as needed.

4.1 Linear MNL models

The first models tested were based on a linear-in-parameters indirect utility function:

$$V_i = q_{RM} RM_i + q_{NL} NL_i + q_{SUN} SUN_i + q_{TTW} TTW_i \qquad (2)$$

Two MNL models were estimated with this specification; the first included all consistent responses by every household (MNL-1) and the second excluded households exhibiting lexicographic behaviour (MNL-2). The maximum likelihood estimation results are shown in Table 4; as can be seen, both models have a satisfactory adjustment in comparison to the market shares model, correct signs and significant parameters.

Although it is not appropriate to compare both models statistically, it is fair to say that MNL-1 has certainly no worse fit than MNL-2. This is intriguing and different from previous experience; normally models without lexicographic responses are clearly superior (Iragüen and Ortúzar, 2003; Ortúzar and Rodríguez, 2002; Rizzi and Ortúzar, 2003a). For this reason, in the rest of the paper we will just present models for the complete sample.

The importance of a variable in the utility function can be gauged by looking at the product of its coefficient and its mean sample value. Doing this it can be shown that in both cases the most important variables are clearly the rent and the noise level, followed distantly by the sun orientation and finally travel time. So, at this level of analysis there was no indication that the "drastic" way of presenting the sun orientation had a notorious influence in the results.

Attributes	**Parameters** (t-test)	
	MNL-1	**MNL-2**
RM (10^3 Ch$)	-0.0432 (-16.3)	-0.0397 (-13.0)
NL	-0.6609 (-14.3)	-0.7091 (-12.3)
SUN	1.697 (16.2)	1.407 (11.9)
TTW (min)	-0.00628 (-7.3)	-0.00639 (-5.5)
l(?)	-967.03	-702.09
$?^2_c$	0.213	0.171
Sample size	859	601

Table 4: Estimated models with and without lexicographic individuals

Table 5 presents willingness-to-pay (WTP) values[7] and their 95% confidence intervals calculated using the methodology proposed by Armstrong *et al* (2000). A number of points are worth making from Table 5. The first is that the SVT values are in complete agreement with values estimated in previous projects (Ortúzar *et al*, 2000a; Ortúzar and Rodríguez, 2002; Pérez *et* al, 2002). This gives much credibility to the experiment, in the sense that not only it must have been well designed and understood, but also that respondents answered it with serious intent.

Attributes	**Subjective Values** (95% confidence interval)	
	MNL-1	**MNL-2**
Noise Level (US$/NL per month)	23.54 (20.26 – 27.24)	27.51 (22.96 – 32.87)
Travel Time to Work (US$/hr)	3.14 (2.30 – 3.97)	3.42 (2.30 – 4.62)

At the time of the survey, 1US$ = 650 Chilean $

Table 5: Subjective valuations with and without lexicographic individuals

The second is that the WTP values for reducing noise have the same order of magnitude than the monetary values that should be invested to put double glazing in the dwellings. Finally, recall that these are values based on people's perceptions of noise (ie based on a 10-point scale) and not based on objective (ie decibel scale) values. We will come back to this issue below.

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[7] To obtain the SVT figures (in Ch$/min), the ratio of the parameters of time (min/week) and rent (thousand Ch$/month) from Table 3 has to be multiplied by the factor (12 000/52). To obtain the WTP for reducing the noise level (in Ch$/NL per month), the ratio of the parameters NL and RM has to be multiplied by 1000.

4.2 Stratified MNL models

Segmentation was performed to quantify the influence of certain household characteristics in the valuation of attributes. Given our modest sample size we considered more sensible to stratify according to one feature at a time. To identify the best specification at each stratum, we used the step-by-step methodology proposed by Ortúzar and Rodríguez (2002):

- Estimate a general model with different parameters in both segments; identify statistical similarity between parameters considering magnitudes and t-tests.
- Estimate a restricted model under the null hypothesis that the most similar pair of parameters can be replaced by a single parameter in the estimation process.
- Perform a likelihood-ratio test to ensure that both models (general and restricted) are statistically equivalent and that, consequently, there is a gain in parsimony.
- Re-check parameter similarity, identify the most similar pair of parameters remaining as specific and go back to step 3.
- Stop when no potential pair similarities or model reductions are found.

Stratification by flat ownership

Two groups were considered here: owners and tenants. Although their respective numbers were not equivalent (43 and 107 respectively), the results shown in Table 6 are conclusive. A likelihood ratio-test with two degrees of freedom shows that MNL-3 is significantly superior to MNL-1, the original model without stratification.

Attributes		**Parameters (t-test)**	
		MNL-1	**MNL-3**
RM (10^3 Ch$)		-0.0432 (-15.4)	-0.0436 (-16.4)
NL		-0.6609 (-14.3)	-0.6646 (-14.3)
SUN	Tenants	1.697 (16.2)	1.566 (13.5)
	Owners		2.142 (10.4)
TTW (min)	Tenants	-0.00628 (-7.3)	-0.00575 -(6.1)
	Owners		-0.00907 (-4.5)
l(?)		-967.03	-963.28
$?_c^2$		0.213	0.216
Sample size		859	859

Table 6: Models stratified by dwelling’s ownership

Model MNL-3 implies that flat owners value sun orientation and travel time higher than flat tenants, but the perception of noise and of the value of the rent are not significantly different. The first result can be explained by considering that when a person is buying an apartment s/he is entering in a longer term commitment than when s/he is choosing one to rent, so the orientation in relation to the sun should be more important On the other hand, the much higher parameter associated to the owners’ travel times to work is probably due to their higher income level. Table 7 presents points estimates and 95% confidence intervals for the subjective values of noise (SVN) and time (SVT) estimated from both models. Although the confidence intervals for the SVT overlap, the interval for the tenants does not include the owners' point estimate. Their confidence interval being wider could be explained by the fact that although most owners had a higher income level than the tenants, this was not true for every owner.

Attributes		**Subjective Values** (95% confidence interval)	
		MNL-1	**MNL-3**
Noise Level (US$/NL per month)		23.54 (20.26 – 27.24)	23.43 (20.17 – 27.09)
TTW (US$/hr)	Tenants	3.14 (2.31 – 3.97)	2.77 (1.94 – 3.69)
	Owners		4.43 (2.49 – 6.37)

Table 7: Subjective values by dwelling's ownership stratification

We tried several additional sensitivity groupings in an attempt to find different valuations for the noise variable, but to no avail (Galilea, 2002).

4.3 MNL models including interaction effects[8]

Our factorial design allowed us to estimate models with interactions between variables. We started the specification searches from a general model including all main effects, two-way and three-way interactions. Then, the less significant effects were taken out, one by one, until we reached a model with significant variables and correct signs. The final result (MNL-4 in Table 8) was checked by choosing different ways to take out the less significant effects; as can be seen, it has a much better fit than MNL-1, thanks to the interactions (the likelihood ratio test with five degrees of freedom was firmly rejected).

It was surprising to find the same number of three-way than two-way effects present in the preferred specification, as it has been generally assumed that the latter explain a greater proportion of the data variation (Louviere *et al*, 2000); but hard as we tried, models with only two-way interactions were clearly inferior (Galilea, 2002).

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[8] All models with interactions and with parameterised main effects were estimated deviating each variable by its mean. These helped estimating the confidence intervals and did not change the results. The variable means were calculated based on the attributes effectively available for each observation at the estimation process.

Attributes	**Parameters** (t-test)	
	MNL-1	**MNL-4**
RM (10^3 Ch$)	-0.0432 (-16.3)	-0.0464 (-16.4)
NL	-0.6609 (-14.3)	-0.7021 (-14.5)
SUN	1.697 (16.2)	1.759 (16.3)
TTW (min)	-0.00628 (-7.3)	-0.00686 (-7.3)
RM x NL	-	-0.00151 (-2.8)
RM x TTW	-	-0.0000263 (-2.5)
NL x SUN x TTW	-	-0.000551 (-1.9)
RM x SUN x TTW	-	-0.0000159 (-1.5)
l(?)	-967.03	-956.75
?^2_c	0.213	0.221
Sample size	859	859

Table 8: Models with interactions

It is also interesting to note that sun orientation appears this time to be more important, as it features in all the three-way interactions. Table 9 presents estimates for the subjective values derived from MNL-4; as can be seen although the specification is much improved, the results remain almost invariant.

Attributes	**Subjective Value**	
	MNL-1	**MNL-4**
Noise Level (US$/NL per month)	23.54 (20.26 – 27.24)	23.74 (20.20 – 27.70)
Travel Time to Work (US$/hr)	3.14	3.14
	(2.31 – 3.97)	(2.40 – 3.97)

Table 9: Subjective value for models with interactions

Note that these values had to be computed taking into account the interactions, so it was necessary to derive utility with respect to the attributes as in equations (3)-(5):

$$\partial U / \partial RM = q_{RM} + q_{RMxNL} xNL + q_{RMxNLxSUN} xNLxSUN + q_{RMxSUNxTTW} xSUNxTTW \qquad (3)$$

$$\partial U / \partial NL = q_{NL} + q_{RMxNL} xRM + q_{RMxNLxSUN} xRMxSUN + q_{NLxSUNxTTW} xSUNxTTW \qquad (4)$$

$$\partial U / \partial TTW = q_{TTW} + q_{SUNxTTW} xSUN + q_{NLxSUNxTTW} xNLxSUN + q_{RMxSUNxTTW} xRMxSUN \; (5)$$

Then, the subjective values of time and noise level (Table 9) were calculated as:

$$SVT = \frac{\partial U / \partial TTW}{\partial U / \partial RM} \cdot \frac{12\,000}{52} \cdot \frac{60}{650} \left[\frac{US\,\$}{hr} \right] \tag{6}$$

$$SVN = \frac{\partial U / \partial NL}{\partial U / \partial RM} \cdot \frac{1000}{650} \left[\frac{\text{US\$}}{\text{degree}} \right] \tag{7}$$

It is important to mention that the SVT and SVN values were positive for all individual households, as this is not always the case in models of this type (Brownstone, 2001; Daniels and Hensher, 2000 and see the discussion in Rizzi and Ortuzar, 2003b).

4.4 MNL models with parameterised main effect variables

Equation (2) does not allow to incorporate individual tastes in a MNL. One way of doing this is to parameterise the coefficients of the main effects variables by means of the socio-economic and journey characteristics of each individual, as in equation (8). In contrast with the traditional specification of socio-economic variables, this specification applies to both alternatives; also, since the same additional variable can be related to more than one attribute, it can be specified with different coefficients in each case. Therefore, as every individual has different socio-economic and journey characteristics, each may end up with different valuations for the same attributes. Rizzi and Ortúzar (2003a) provide a microeconomic rationale for equation (8):

$$V_{ij} = (a_0 + \sum_l a_l s_{lj})RM_{ij} + (b_0 + \sum_l b_l s_{lj})NL_{ij} + (g_0 + \sum_l l_l s_{lj})SUN_{ij} + (d_0 + \sum_l d_l s_{lj})TTW_{ij} \tag{8}$$

The binary variable s_{lj} represents either the socio-economic (SE) or trip characteristic l of individual j. This is an interesting way of incorporating additional variables and allows to use additional individual data to estimate the subjective values. As there may be different coefficients for each attribute depending on the special features of each household, this specification allows estimating models that are almost unique to each household helping to reduce the problem of taste variations. After a detailed specification search the variables finally selected were (Galilea, 2002):

$N°People/Income_{RM}$: Number of household members divided by family income level; as it was added to the rent coefficient its value should be negative, if the number of members increases or if income decreases (*ceteris paribus*), an increase in rent should affect them more.

$Importance_{NL}$: Equals one if the household declared that the noise level was important in choosing where to live. Its value should be negative, as an increase in noise level should make utility decrease.

$Floor^2_{NL}$: Takes the quadratic value of the floor where the apartment is located. Its value should be negative, because the noise level is higher in the ground floor (closer to the source of noise) and in the upper floors (no shield from other houses or smaller buildings), so people living in these floors should be more sensitive to higher noise levels.

$AgeIncome_{TTW}$: Takes the value of the age of the household's head multiplied by the income level. Its value should be negative, because if either income or age increase, time should be more highly valued.

The best model found (MNL-6) is shown in Table 10. In order to compare it with the linear MNL we had to estimate a new model (MNL-5) using only data from families reporting their income and who passed the consistency test (119 households). As can be seen, all parameters have correct signs and although the significance of some additional variables seems low (given their t-tests), a likelihood-ratio test rejected comfortably the null hypothesis that both models were equivalent (ie LR = 13.92 > $?^{2}_{4;95\%}$= 9.49).

Attributes	Parameters (t-test)	
	MNL-5	**MNL-6**
RM (10^3 Ch\$)	-0.0447 (-15.9)	-0.0327 (-6.3)
N°People/Income$_{RM}$		-0.0322 (-2.8)
NL	-0.6789 (-13.8)	-0.5113 (-4.2)
Importance $_{NL}$		-0.1278 (-1.1)
Floor$^2_{NL}$		-0.00214 (-1.8)
SUN	1.743 (15.7)	1.773 (15.8)
TTW (min)	-0.00621 (-6.9)	-0.00307 (-1.4)
AgeIncome$_{TTW}$		-0.0000169 (-1.7)
l(?)	-877.63	-870.67
$?^2_c$	0.222	0.228
Sample size	786	786

Table 10: Models with parameterised main effects attributes

The results obtained indicate that, for example, a household with a given income level will increase its valuation of the rent in 0.032 (ie almost 100%) for each new member added to it. On the other hand, those households that declared noise to be an important element in the search for a new flat, value noise 25% higher (ie 0.5113 plus 0.1278 over 0.5113) than those who stated it was not important. Finally, a 50 year old head of household whose family income level is 2, would value time 22% higher than a 30 year old in the same income bracket.

Table 11 presents SVT and SVN for the model with additional variables. As can be seen, although the new specification is clearly superior to the linear MNL, the WTP estimates are almost identical and the confidence intervals contain the other model's point estimates in all cases. The much wider confidence intervals for the model with parameterised effects is due to its lower t-ratios.

Attributes	Subjective Values	
	MNL-5	**MNL-6**
Noise Level (US\$/NL per month)	23.37	23.38
	(20.46 – 27.70)	(12.07 – 41.54)
Travel Time to Work (US\$/hr)	2.95	3.14
	(2.22 – 3.88)	(0.00 – 5.26)

Table 11: Subjective values for models with parameterised main effects

It is important to mention that once again no individual household resulted with negative SVN or SVT.

4.5 Estimation of Mixed Logit models

Mixed Logit (ML) models were finally estimated in order to examine the importance of including heterogeneity in individuals tastes explicitly, as well as a correct treatment of the repeated observations problem associated to SP data (Ortúzar *et al*, 2000b). In the ML model, apart from the random errors (ie white noise) that distribute independent and identically (iid) Gumbel as in the MNL, the systematic part of the utility function, V_{iq}, may also have randomly distributed parameters. This flexible specification allows to consider heteroscedasticity, correlation and variations in tastes (see Train, 2003).

To estimate the ML we used a non-commercial code implemented in GAUSS (it can be downloaded from the web page of Kenneth Train: http://elsa.berkeley.edu/~train). We considered independent Normal distributions for the attributes as previous experience with multivariate functions had shown results to vary little but at non negligible cost (Sillano and Ortúzar, 2003); for the simulated maximum likelihood search we used sequences of 125 Halton numbers. To identify the best specification for each type of model we carried out another step-by-step methodology.

- For the best specification found in each case, estimate a general model where all parameters are random variables; examine the significance of the mean and standard deviation of each estimated coefficient using their associated t-tests.
- Estimate a restricted model under the null hypothesis that the parameter with least significance is equal to zero; this implies estimating a fixed coefficient when its standard deviation is close to zero. Perform a likelihood-ratio test to ensure that both models (general and restricted) are statistically equivalent and that, consequently, there is an improvement for parsimony reasons.
- Re-check parameter significance and go back to step 3; stop when there are no more potentially insignificant parameters.

Table 12 compares a ML model with main effects only (ML-1) with MNL-1. As can be seen, ML-1 has a clearly superior fit. Note also the high significance of each standard deviation, specially for the variables NL and (in particular) SUN. This is consistent with the subjective nature of these variables, and with the fact that there is no consensus about their importance within the sample.

Attributes	**Parameters** (t-test)		
	MNL-1	**ML-1**	
		Mean	Std. Dev.
RM	-0.0432 (-16.3)	-0.1398 (-5.5)	0.0863 (4.7)
NL	-0.6609 (-14.3)	-2.2852 (-10.3)	1.1504 (8.0)
SUN	1.697 (16.2)	3.718 (9.4)	4.699 (7.9)
TTW	-0.00628 (-7.3)	-0.0241 (-7.4)	0.0137 (5.4)
l(?)	-967.03	-787.74	
$?^{2}_{c}$	0.213	0.359	
Sample size	859	859	

Table 12: Mixed Logit with main effects only

The mean values of the ML parameters correctly increase in size due to the scale factor effect. As in this case we are allowing for random parameters the white noise variance (inversely related to the scale factor) decreases significantly (Sillano and Ortúzar, 2003).

Table 13 compares the subjective values for the linear MNL and ML models. The two willingness-to-pay point estimates increase in ML-1 due to the non-uniform increase in the mean estimates of its parameters with respect to MNL-1 (we have found that as sample size increases the scale factor effect becomes more uniform).

	Subjective Values	
	MNL-1	**ML-1**
Noise Level (US$/NL per month)	23.54	25.14
	(20.26 – 27.37)	(18.56 – 37.63)
Travel Time to Work (US$/hr)	3.14	3.69
	(2.31 – 3.97)	(2.58 – 5.63)

Table 13: Subjective values for the linear ML

A second Mixed Logit model was estimated based on the results for model MNL-3 (household ownership stratified model). However, we found that segmenting the variables was not warranted in this case; indeed, a likelihood-ratio test allowed us to accept the null hypothesis that this model was not dissimilar to ML-1.

A third ML was estimated based on MNL-4 and included interactions. The results in Table 14 show that the new ML version is clearly superior to both MNL-4 and to the linear ML-1. Interestingly, most interactions finally received fixed parameters but the main effects remained consistently variable among individuals. Table 15 presents the willingness-to-pay point estimates for ML-4. As can be seen, they are even larger than those of ML-1 but still the confidence intervals for each model contain practically all the point estimates of the competing functions. It is also very important to mention that, again, we found that no households had individual subjective values with an incorrect sign. This is so often *not* the case (Brownstone, 2001; Rizzi and Ortuzar, 2003b), that calls have been made to include among the model assessment check-list, if the microeconomic conditions implied by the postulated indirect utility function are violated or not (Cherchi and Ortuzar, 2003).

Attributes	**Parameters** (t-test)				
	MNL-4	**ML-1**		**ML-4**	
		Mean	Std.Dev.	Mean	Std.Dev
RM	-0.04644 (-16.4)	-0.1398 (-5.5)	0.0863 (4.7)	-0.120 (-8.6)	0.0888 (6.9)
NL	-0.7021 (-14.5)	-2.2852 (-10.3)	1.1504 (8.0)	-2.570 (-8.6)	1.283 (7.8)
SUN	1.759 (16.3)	3.718 (9.4)	4.699 (7.9)	4.566 (7.5)	5.052 (7.0)
TTW	-0.00686 (-7.3)	-0.0241 (-7.4)	0.0137 (5.4)	-0.0284 (-8.4)	0.0097 (5.7)
RM x NL	-0.00151 (-2.8)	-	-	-0.00456 (-2.6)	0.00662 (3.8)
RM x TTW	-0.0000262 (-2.5)	-	-	-0.00007 (-3.5)	0.00013 (6.5)
NL x SUN x TTW	-0.000551 (-1.9)	-	-	-	-
RM x SUNx TTW	-0.0000159 (-1.5)	-	-	-	-
l(?)	-956.75	-787.74		-777.62	
$?^2_c$	0.221	0.359		0.367	

Table 14: Mixed Logit model including interactions

	Subjective Values		
	MNL-4	**ML-1**	**ML-4**
Noise Level (US$/NL per month)	23.74 (20.20 – 26.67)	25.14 (18.56 – 37.63)	33.98 (23.74 – 45.96)
Travel Time to Work (US$/hr)	3.14 (2.40 – 3.97)	3.69 (2.58 – 5.63)	5.17 (3.60 – 7.02)

Table 15: Subjective values for Mixed Logit model including interactions

A final Mixed Logit specification (ML-6) was estimated based on model MNL-6 which incorporated parameterised taste variations. The estimation results are shown in Table 16. Although these two models cannot be compared under a likelihood-ratio test (because none is a restricted version of the other), it is pretty obvious that ML-6 is superior, due to its much better fit. Note that ML-6 is not comparable with the previous ML models either, because it has a smaller sample size. Nonetheless, because of its remarkable goodness-of-fit we feel safe to label it as the preferred specification.

Attributes	**Parameters** (t-test)		
	MNL-6	**ML-6**	
		Mean	Std. Dev.
RM	-0.0327 (-6.3)	-0.0776 (-4.3)	0.0574 (3.7)
N°People/Income$_{RM}$	-0.0322 (-2.8)	-0.120 (-2.6)	0.170 (2.9)
NL	-0.5113 (-4.2)	-1.481 (-3.6)	-
Importance $_{NL}$	-0.1278 (-1.1)	-0.924 (-2.2)	1.108 (5.5)
Floor$^{2}_{NL}$	-0.00214 (-1.8)	-0.0111 (-2.4)	0.0290 (3.7)
SUN	1.773 (15.8)	4.520 (8.8)	4.947 (5.9)
TTW	-0.00307 (-1.4)	-0.0287 (-5.7)	0.0155 (2.5)
AgeIncome$_{TTW}$	-1.69E-05 (-1.7)	-	-
l(?)	-870.6714	-700.772	
$?^{2}_{c}$	0.2277	0.3784	
Sample size	786	786	

Table 16: Mixed Logit model with parameterised main effects

It is worth making the point that the results in Table 16 confirm that data sets (perhaps particularly of the SP variety) tend to have implicit taste variations over and above those associated to observable individual characteristics (Iraguen and Ortuzar, 2003). Table 17 presents the willingness-to-pay point estimates for model ML-6. Again, they are even larger than those of ML-1 and exactly for the same reasons, but once more well within each other confidence intervals.

	Subjective Value	
	MNL-6	**ML-6**
Noise Level (US$/NL per month)	23.38 (12.07 – 41.59)	32.60 (12.38 – 61.84)
Travel Time to Work (US$/min)	3.14 (0.00 – 5.26)	4.89 (4.43 – 15.42)

Table 17: WTP for Mixed Logit model with parameterised main effects

4.6 Subjective v/s objective (dB) perceptions of noise level

As the final objective of any exercise in valuation should be to estimate an objective monetary value, in this case for noise levels reductions, we attempted to relate our ten-point scale subjective values with the decibel scale measurements taken at the 96 dwellings where we succeeded in performing this task.

An important problem was that the dB(A) measures were in general fairly high whilst its range was not wide (ie from 37 to nearly 61 dB); this meant that many respondents with a “low” objective noise level reported a “high” grade as their subjective noise level. So a simple linear regression did not achieve a reasonable fit (Galilea, 2002), not even when separate regressions were estimated for each building; in this latter case only one building gave a more satisfactory fit but the number of respondents was too low to use only them for further analysis.

To improve estimation we decided to incorporate the extra information provided by the households at the interview stage in order to achieve *ceteris paribus* conditions. In particular, we used the results of two questions: (i) whether they were aware that their dwelling had a significant noise level and, (ii) if they thought that noise level was an important attribute when searching for a place to live. Thus, a multiple regression was estimated using the ten-point scale subjective grades as the dependent variable, and the decibel scale plus two dummies representing *Awareness* (one, if the household was aware that the dwelling had a significant noise level) and *Importance* (one, if the household thought that noise level was an important attribute) as independent variables. The results of this regression are shown in Table 18; as can be seen they appear quite reasonable. With these results, we were able to transform the estimated parameter for the noise level, simply by multiplying it by the coefficient for dB(A) in Table 18, as it is obviously not necessary to re-estimate the model with the transformed variable.

Attribute	**Parameter**	**(t-test)**
dB(A)	0.0893	(6.1)
Awareness	2.1295	(3.6)
Importance	1.3184	(2.3)
Multiple correlation coefficient	0.5124	
Sample size	96	

Table 18: Multiple regression results for the ten-point scale

The transformed noise level parameters allowed us to derive new subjective values of noise level (SVN) for each model (Table 19). These represent the willingness-to-pay, in US$, associated to decreasing the noise level inside a dwelling in one dB(A) per month. Although the values seem reasonable, a caveat related to their use in social project evaluation is that there are other terms and elements that should form part of the total WTP for reducing noise level; for example, the health costs incurred as an effect on human health because of noise.

The importance of establishing a relationship between noise perception and dB(A) is clear for cost-benefit analysis. For instance, if noise levels in a central business district are high and as a consequence most households and offices were incorporating double glazing as a personal protection against noise, it could be more efficient to coordinate a central double glazing programme, for example, to attack the noise problem but this should be evaluated. Such a programme could even attract some other agents which, otherwise, could not afford the cost of double glazing.

	SVN (US$/dB(A) per month)		
	Lower bound	Mean	Upper bound
MNL-1	1.81	2.10	2.43
MNL-3	1.80	2.09	2.42
MNL-4	1.80	2.12	2.38
MNL-6	1.08	2.09	3.68
ML-1	1.66	2.25	3.36
ML-4	2.12	3.03	4.10
ML-6	1.10	2.91	5.52

Table 19: Subjective values for noise level reduction in dB

As a caveat, we must recall that the relationship established above has to be considered tentative in so far as we did not conduct any kind of external validity of our results.

Therefore, it is debatable whether it could be adopted immediately by the environmental authority. More work should follow in this direction.

5. Conclusions

The successful application of SP techniques to such a complex problem as valuing noise level reductions in Chile, shows great promise for the use of this methodology in other countries. Two important results emerged from the design stage of the survey: (i) the identification of residential location as an appropriate experimental framework, and (ii) the formulation of a variable metric for noise level (although only related to family perceptions) that was clearly understood by the participants in the exercise.

We also found that the statistical design was able to represent the respondents' preferences for the variables included in the experiment. This is supported not only by the good general fit of the estimated models, but also by the anticipated parameter signs and reasonable significance t-tests. Equally, the subjective values of time obtained from the various models estimated turned out to be consistent with prior studies. This is, in our opinion, a clear indication that respondents understood the experiment which included two new variables in relation to previous experiences: noise level and sun orientation. So in spite of its complexity, the SP experiment was able to capture individual preferences adequately.

In terms of modelling results, we found that individual households do not necessarily have linear utility functions. Not only several interaction terms were significant but also the introduction of additional variables (socio-economic and related to noise level) affected the coefficients of the main-effects variables importantly. These latter variables allowed us to note, for example, the significance of age and income in the valuation of travel time. We were also able to confirm that the flexible and powerful Mixed Logit model easily outperformed the simple MNL; this may be due to the fact that it accepts the presence of random taste variations among individuals (which indeed appeared as an effect) or just because it allows to treat consistently the problem of repeated observations by each individual, which is a feature of stated preference and panel data. We also found that ML models incorporating non-random variation (ie parameterised effects) prior to allowing for random coefficients achieved the best fit to the data. This is consistent with the recommendations of Ortúzar and Garrido (2002).

In relation to our estimated values for reducing noise levels and given all the caveats mentioned above, we would tend to recommend a conservative value of US$ 1.1 per decibel per month, which corresponds to the lower bound of the confidence interval associated to the ML model with parameterised taste variation effects, as this was the structure which clearly achieved the best fit to the data.

It is first important to mention that this value (and most values estimated) appear to be reasonable when compared (although the comparison is *per force* not strict) with the real costs[9] associated to reducing noise by physical means (ie double glazing). Second, it is important to insist that there are some caveats related to its potential use in social project evaluation, since there are other terms and elements that should form part of the total willingness-to-pay for reducing noise level; for example, the health costs incurred by the effects of noise on human health. The estimation of such other factors that may affect SVN is left for other studies.

Acknowledgements

The final version of this paper was written during a six-week stay of the second author at the Institute for Transport Studies, University of Sydney. We wish to thank Ana María Ivelic for having helped us at the survey form design stage, Luis Ignacio Rizzi for his invaluable help and knowledge throughout the whole work and Mauricio Sillano for his useful pointers in relation to mixed logit estimation. Thanks are also due to Luis Cifuentes, David Hensher, Sergio Jara-Diaz and Huw Williams for their knowledge and availability every time we required their advice. The research was supported by the National Fund for Scientific and Technological Development (FONDECYT) through Project 1000616. We are also grateful for the dedicated work of our interviewers and to those responsible for the noise level measurement campaign.

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[9] The cost of double glazing is roughly US$ 130 per square meter. If, for example, the noise level was near 70 dB(A) double glazing would reduce it to approximately 40 dB(A). However, there would also be a reduction of approximately 40% in central heating costs.

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