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Analysing demand for suburban trips: A mixed RP/SP model with latent variables and interaction effects

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Abstract. We analyse mode choice behaviour for suburban trips in the Grand Canary island using mixed revealed preference (RP)/stated preference (SP) information. The SP choice experiment allowed for interactions among the main policy variables: travel cost, travel time and frequency, and also to test the influence of latent variables such as comfort. It also led to discuss additional requirements on the size and sign of the estimated model parameters, to assess model quality when interactions are present. The RP survey produced data on actual trip behaviour and was used to adapt the SP choice experiment. During the specification searches we detected the presence of income effect and were able to derive willingness-to-pay measures, such as the subjective value of time, which varied among individuals. We also studied the systematic heterogeneity in individual tastes through the specification of models allowing for interactions between level-of-service and socio-economic variables. We concluded examining the sensitivity of travellers' behaviour to various policy scenarios. In particular, it seems that contrary to political opinion, in a crowded island policies penalising the use of the private car seem to have a far greater impact in terms of bus patronage than policies implying direct improvements to the public transport service.

Introduction

The use of mixed revealed preference (RP) and stated preference (SP) data has become a recommended practice in many transport demand analyses. RP data are based on individual choices and allow the analyst to characterise actual travel behaviour. SP data are based on individuals' stated behaviour under hypothetical scenarios and are useful when the problem is to examine the demand for new alternatives, measure the effect of latent variables or study the effect of allowing for potential interactions among explanatory variables. The estimation of models combining RP and SP data exploits the advantages and overcomes the limitations of each type of data (Louviere et al. 2000).

Most applied research concerning the value of travel time savings or other willingness-to-pay (WTP) measures is based on formulating simplified models that impose strong restrictions on the distribution of the random error terms (e.g. the independence from irrelevant alternatives property of the MNL model). Also, the specification of systematic utilities does not usually consider the interaction of other variables with the main policy attributes. Thus, WTP measures are simply derived as the ratio between the marginal utility of the corresponding attribute and the marginal utility of income (MUI, which equals minus the marginal utility of cost), and are represented by a fixed value equal to the time (or other attribute) parameter divided by the cost parameter (Gaudry et al. 1989).

The aim of this paper is to analyse travellers' mode choice behaviour for suburban trips under various model specifications using a mixed RP/SP data bank. The SP data were obtained from a choice experiment for car and bus that allowed two-term interactions among the main policy variables: travel cost, travel time and frequency; the experiment also included parking cost and comfort. A previous RP survey gathered information about travel decisions in the two main interurban corridors in Grand Canary, Spain. The RP alternatives were car as driver, car passenger and bus. This information was used to adapt the subsequent SP choice experiment to each respondent's experience.

The modelling strategy considered first an analysis of the model structure and utility specification. We detected the presence of income effect following the theoretical approach proposed by Jara-Díaz and Videla (1989); hence we included income in the utility function dividing travel costs by the expenditure rate (Jara-Díaz & Farah 1987). We analysed the existence of interactions between travel cost and frequency, between socio-economic variables and level-of-service attributes, and between comfort and travel time. Note that when interactions are present WTP is not constant across individuals. As an example, in our analysis we were able to find models in which the subjective value of time (SVT) for the bus mode is expressed in terms of the level of comfort, the frequency, the individual's expenditure rate, and if the person works or not. For car alternatives, SVT is expressed in terms of the expenditure rate, gender and if the individual works or not. In a similar fashion, we could derive WTP for increases in frequency, reductions in walking time and improvements in the level of comfort.

We studied the sensitivity of travellers' behaviour to model specification comparing the results obtained for different modelling strategies. We also analysed the effect of different policy scenarios on demand response. These scenarios favour the use of public transport by considering improvements in the bus level of service, reduction in fares and/or parking cost increases. In general, we found that demand seems to be very sensitive for scenarios that raise significantly the latter attribute.

The rest of the paper is organised as follows. Section 2 describes the main characteristics of the area as well as the RP/SP data banks. Section 3 presents the theoretical framework and Section 4 describes the modelling strategy and shows the estimation results. Section 5 presents the application of the models, yielding different WTP measures and the demand response to several policy scenarios. Finally, our main conclusions are presented in section 6.

The data

We focused on the two main urban/interurban corridors in Grand Canary island. These run through its most densely populated area (ranging from 890 to 3686 inhabitants per squared kilometre) covering a distance of approximately 40 km. Two bus operators provide public transport services: *Guaguas Municipales* and *Global*. The former offers urban services and the latter interurban services. A change in pricing policy implemented after our RP survey achieved fare integration by the two firms and managed to diminish considerably the bus costs (by reducing the interchange fare between the two operators).

The RP survey

This survey collected information about current trip behaviour in both corridors. A total of 922 interviews were completed yielding information about the household, the chosen mode and the main socio-economic characteristics of the individual. A final sample of 710 observations was left after removing captive individuals (i.e. who had only one option available). The final sample had 65.35% car drivers, 13.38% car passengers and 21.27% bus users. Trips were evenly distributed between men and women; 55% were mandatory trips (work and education) and the rest non-mandatory (e.g. 16.76% for shopping, 15.35% for leisure and the rest for various other reasons); also, nearly 46% of trips were made five times per week.

A geographic information system (GIS) was used to transform the survey data into model variables, obtaining very precise measurements of travel time and distance by car. The values of the public transport attributes were provided by the bus operators.

The SP experiment

The SP choice experiment between car and bus allowed for two-term interactions among the main policy variables: *Travel time*, *Cost* and *Frequency*. A focus group managed by a psychologist let us understand the transport context under scrutiny better. The group was equally split between men and women and had both public transport and car users. It took about two and half hours and was recorded in order to check it out later if necessary. On the basis of this survey, six variables were singled out as significant for the SP experiment: travel time, parking time, travel cost, parking cost, the bus service *frequency* and *comfort*. We kept only five in the final SP design to reduce respondent burden (Carson et al. 1994; Caussade et al. 2005); also, if needed both *parking time* and *parking cost* could be included as part of the *travel time* or *travel cost* variables, respectively.

We tried several designs and in each case conducted a thorough pre-test pilot. The first design had the following variables (and number of levels): *travel time* (3), *parking time* (2), *travel cost* (3), *bus frequency* (3) and *comfort* (2). *Parking time* was singled out as a car-specific variable whereas *parking cost* was added to the car costs. A fractional factorial design was used to reduce the number of choice scenarios to 27; the design was subsequently divided into three blocks to reduce respondent burden. After the first pre-test we checked the focus group recording and the psychologist report to fully understand the results. This analysis led us to add parking time to *travel time* and single out *parking cost* as a car-specific variable, changing the design accordingly. The second pre-test gave better results and only the latent variable *comfort* was not so well perceived. For this reason and after talking to the bus operators and to people who had answered the second pre-test, the levels of this variable were increased to three (low, standard and high). Finally, a third pre-test was carried out to check the new definition of *comfort*. As in this case results were reasonable we used this as the final design.

Table 1 shows the set of attribute levels used in the experiment. We used the RP data to adapt the choice experiment to the respondent's experience. t is the time declared by the individual to get to his/her destination; c is the fuel expenditure (considering travel distance and type of car); f is the frequency which would have been experienced if the person had taken the bus (recall that all respondents were current car users) and pc is the parking cost declared in the RP survey. Minimum thresholds

Table 1. Attributes and levels of the SP experiment.

Variables	Levels	Car	Bus	Percentage		Minimum threshold difference
Travel time (t)	0	t	$1.25{\cdot}t$	−25%	<	10 min
	1	t	t	0%	=	–
	2	$1.25{\cdot}t$	t	+25%	>	10 min
Cost (c)	0	$1.15{\cdot}c$	Current[a]	–	≫	1.2€
	1	$1.15{\cdot}c$	Card[b]	–	⋙	1.2€
	2	c	Card	–	>	1.2€
Frequency[c] (f)	0	–	f	0%	=	–
	1	–	$0.75{\cdot}f$	−25%	<	4
	2	–	$0.50{\cdot}f$	−50%	≪	4
Parking cost (pc)	0	pc	–	–	=	–
	1	$1.5{\cdot}pc$	–	+50%	>	–
Comfort	0	High	Low	–	≪	–
	1	High	Standard	–	<	–
	2	High	High	–	=	–

[a] Fare at the time of the RP experiment.
[b] Card is the fare under a fare-integration regime.
[c] Actually the headway (i.e. the time between two consecutive bus services).

were established to define perceptive differences between the car and bus attributes and also between the levels of a given attribute (i.e. bus frequency). For example, given the design in Table 1 if the travel time t by car was 20 min, the bus travel time at level 0 should be 25 min. However, because in this case the difference between both times would be less than the minimum threshold of 10 min, the initial bus travel time in the experiment would be set to 30 min. The same occurs with cost and bus frequency.

Out of an original sample of 345 individuals who had participated in the RP survey, 97 answered the SP survey yielding a total of 871 choice observations. The low response rate (28.12%) was due to the following facts: (i) 21.14% of the sample were not located after four attempts by phone or personal visit; (ii) 21.16% had moved to another residential area; (iii) 29.56% plainly refused to participate in the SP experiment.

We checked the distribution of socio-economic variables between those who responded the SP survey and the original RP sample and found no significant differences between both groups. A detailed analysis of the sample allowed us to detect captive, lexicographic and inconsistent individuals; this in turn allowed us to examine if removing these observations would affect the estimation results.[1] We found 23 potentially *captive*[2] individuals (14 by car and nine by bus[3]); eight who were *inconsistent*[4] and 18 *potentially lexicographic*[5] individuals (seven in travel time, nine in cost and two in low comfort). For more details about the experimental design, see Espino et al. (2004).

Table 2 presents the explanatory variables used. We explain the specification of modal attributes as well as the socio-economic variables below.

Theoretical framework

Disaggregate demand analysis has its theoretical basis on the microeconomics of discrete choice (McFadden 1981). Following Lancaster (1966), utility is assumed to depend on the amount of continuous goods consumed (represented by a vector **X**) as well as on the characteristics or attributes of a set of discrete alternatives (represented by a vector Q_j). Hence, the consumer decision making problem is:

$$\begin{array}{ll} \underset{x,j}{\text{Max}} & U(X, Q_j) \\ \text{s.t.} & \sum_i P_i X_i + c_j \leq I \\ & X_i \geq 0 \quad j \in M \end{array} \tag{1}$$

Table 2. Explanatory variables.

Variable	Units	Model		
		Car driver	Car passenger	Bus
SP Data	Units			
Travel time (*t*)	min	√	–	√
Cost (*c*)	Pts[a]	√	–	√
Parking cost (*pc*)	Pts[a]	√	–	–
Frequency (*f*)	buses/hour	–	–	√
Comfort low (CL)	1 if comfort low	–	–	√
Comfort high (CH)	1 if comfort high	–	–	√
RP Data				
Travel time (in vehicle) (*t*)	min	√	√	√
Walking time (wt)	min	–	–	√
Cost (*c*)	Pts[a]	√	√	√
Parking cost (*pc*)	Pts[a]	√	√	–
Frequency (*f*)	buses/hour	–	–	√
Socio-economic data				
Expenditure rate (*g*)	Pts[a] per available time	√	√	√
Worker (*W*)	1 for workers	√	√	√
Sex (*S*)	1 for men	√	√	√
Mandatory trip (*M*)	1 for mandatory trips	√	√	
Origin of the trip (*O*)	1 if origin is Arucas[b]			√
Age (*A*)	1 if age < 35 years			√

[a] At the time of the survey 1€ = 166.39 pts.

[b] Arucas is the town of origin of the Northern corridor.

Where P_i is the market price of good i, c_j is the cost of alternative j, I is the individual's income and M the set of available alternatives. From the first order conditions of problem (1) for each j we obtain conditional demand functions $X_j(P,I-c_j,Q_j)$ on alternative j. Replacing these functions on the utility expression yields the conditional indirect utility (CIU) on alternative j. The overall indirect utility V^* is obtained by maximising CIU in j, i.e. $V^* = \underset{j}{\text{Max}}\, V_j(P, I - c_j, Q_j)$. The demand function of discrete alternative j is derived from Roy's identity as:

$$\frac{\frac{-\partial V^*}{\partial c_j}}{\frac{\partial V^*}{\partial I}} = \delta_j = \begin{cases} 1 \text{ if } V_j \geq V_i \ \forall i \neq j \\ 0 \text{ otherwise} \end{cases} \tag{2}$$

where $-\frac{\partial V^*}{\partial c_j} = \frac{\partial V^*}{\partial I} = \lambda$ is the marginal utility of income MUI. Dividing the marginal utility of any characteristic or attribute q_{kj} of alternative j by λ, we transform utility units into monetary units and get the subjective value or WTP for a marginal change in this characteristic.

To obtain empirical estimates of these quantities McFadden (1981) shows that, in general, any CIU function satisfying the appropriate mathematical properties can be approximated by a linear-in-parameters specification considering its Taylor expansion around (P,I). First order local approximations of this function coincide with the widely used linear (in the attributes) specification, the main drawback of which is that income does not play any role in the decision of the individual, as it is not specified in the utility expression.

Train and McFadden (1978) considered that individuals could determine their income endogenously by choosing the number of working hours at a wage rate w, and found alternative specifications where w multiplies travel time or divides travel cost. Jara-Díaz and Farah (1987) argued that income is determined exogenously in most situations, especially in developing countries where labour markets are strongly regulated. This hypothesis yields a specification of the CIU where travel cost is divided by the expenditure rate g (income per unit of available time). It also may include second order terms in time and cost when either the share of income or the free time spent in transport are not negligible (Jara-Díaz 1998).

Jara-Díaz and Videla (1989) showed that the choice of mode actually depends on the income level when CIU is approximated by a Taylor expansion of order two or higher. They proposed a simple method to detect the presence of income effect; it implies the specification of a cost-squared term in the linear utility function and estimating the model for different income strata. Then, three properties should be satisfied: (i) the estimated cost coefficient must be negative and decrease with income (in absolute value); (ii) the coefficient of the cost-squared term must be positive and decrease with income; and (iii) the MUI (i.e. minus the cost coefficient) must decrease with income.

We applied the procedure developed by Jara-Díaz and Videla (1989) and detected the presence of income effect, providing the microeconomic foundations to include income in the utility function dividing both travel and parking costs by the expenditure rate; the latter was defined as per capita family income (PCFI) divided by the available time (i.e. 24 h minus the individual's working hours). As in our sample the share of income spent in transport does not exceed 5.77% for car drivers, 1.68% for car passengers and 2.45% for bus users, it was not necessary to include a cost-squared term divided by the expenditure rate in the utility specification (Jara-Díaz 1998). Hence, all models presented below only include travel and parking costs divided by the expenditure rate (see Espino et al. 2003 for more details).

The model

Model specification

Discrete choice models are derived under the assumption of utility-maximizing behaviour by the decision maker. The theoretical basis for the specification of the econometric model is random utility theory (Domencich & McFadden 1975). On the other hand, the joint use of RP/SP data to estimate choice models requires that the variances of the error terms in RP and SP are proportional; thus the quotient between those variances is known as scale parameter and denoted by μ (Ben-Akiva & Morikawa 1990).

Bradley and Daly (1997) proposed an estimation method based on the construction of an artificial nested logit (NL) structure where RP alternatives are placed just below the root and each SP alternative is placed in a single-

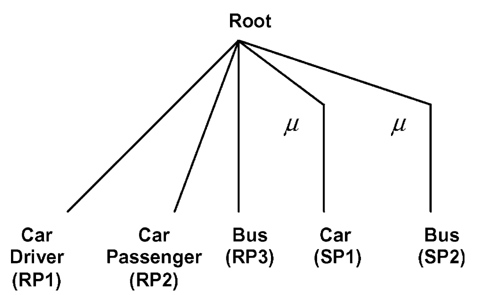

Figure 1. Artificial tree structure for joint RP and SP estimation.

alternative nest with a common scale parameter μ. After testing different substitution patterns between the car options, or between car passenger and bus in the RP data set, we did not find evidence of correlation among the RP modes. Figure 1 shows the artificial tree structure used in our RP/SP model. For more details about this estimation method see Ortúzar and Willumsen (2001).

Specification of latent variables

We were interested in analysing the effect of the latent variable[6] *Comfort*. After defining appropriate levels of comfort for the bus alternative in the SP experiment, the question was how this variable should be specified in the utility function. We considered two alternative specifications. In the first *Comfort* entered as a dummy variable; hence we included the linear term $\theta_{\mathrm{CL}} \cdot \mathrm{CL} + \theta_{\mathrm{CH}} \cdot \mathrm{CH}$, where the low and high (CL and CH) levels of comfort are defined as in Table 3. Note that when these two variables are zero the level of comfort is considered standard. In the second case, *Comfort* was included in the utility function interacting with *Travel time*; therefore, we should be able to obtain different perceptions of travel time depending on the level of comfort as well as perceptions of *Comfort* as a function of trip length.[7] In this case the non-linear term $(\theta_{\mathrm{CL}} \cdot \mathrm{CL} + \theta_{\mathrm{CH}} \cdot \mathrm{CH}) \cdot t$ was included in the utility specification.

Specification of socio-economic variables

To analyse the potential existence of systematic heterogeneity in travellers' tastes we specified socio-economic variables interacting with modal attributes. For a given attribute we defined a base parameter and an incremental additive term including the products of all the socio-economic variables (SEV) allowed to interact with it and their corresponding parameters. Thus, the part of utility corresponding to such an attribute has the following expression (Rizzi & Ortúzar 2003):

$$\left(\theta_{X_i} + \sum_h \theta_{X_i\_\mathrm{SEV}_h} \mathrm{SEV}_h\right) \cdot X_i \tag{3}$$

We found significant interactions of *Worker* (*W*) with *Travel time*, *Sex* (*S*) with *Cost* divided by the expenditure rate *g*, *Mandatory trip* (*M*) with *Parking cost* divided by *g*, *Origin* (*O*) with *Walking time*, and *Age* (*A*) with the bus *Frequency*.

Table 3. Estimation results.

Parameters[a]		NL1	NL2	NL3	NL4
$C^{RP}_{Car-Driver}$	$\theta^{RP}_{C\_D}$	3.321 (6.9)	3.402 (7.1)	3.222 (6.7)	3.378 (6.2)
$C^{RP}_{Car-Pass}$	$\theta^{RP}_{C\_P}$	−0.871 (−2.7)	−0.841 (−2.6)	−0.992 (−2.7)	−0.872 (−2.1)
Travel time (*t*)	θ_t	−0.018 (−1.7)	−0.0156 (−1.4)	–	–
Travel time-Worker (*t***W*)	θ_{t_W}	−0.0549 (−2.9)	−0.0572 (−3.0)	–	–
Travel time car (tc)	θ_{tc}	–	–	−0.0145 (−1.2)	−0.0144 (−1.1)
Travel time car–Worker (tc**W*)	θ_{tc_W}	–	–	−0.0569 (−2.8)	−0.0586 (−2.9)
Travel time bus (tb)	θ_{tb}	–	–	−0.0190 (−1.8)	−0.0157 (−1.4)
Travel time bus–Worker (tb**W*)	θ_{tb_W}	–	–	−0.0542 (−2.8)	−0.0573 (−3.0)
Cost/*g* (*c*/*g*)	$\theta_{c/g}$	−0.3218 (−3.1)	−0.3542 (−3.5)	−0.3261 (−3.2)	−0.3557 (−4.5)
Cost/*g*-Sex (*c*/*g***S*)	θ_{c/g_S}	0.2024 (2.6)	0.2251 (2.8)	0.2013 (2.6)	0.2262 (2.8)
Frequency*Cost/*g* (*f***c*/*g*)	$\theta_{f\cdot c/g}$	−0.0479 (−2.2)	−0.0505 (−2.2)	−0.0450 (−2.1)	−0.0495 (−2.1)
Parking cost/*g* (*pc*/*g*)	$\theta_{pc/g}$	−0.0370 (−0.4)	−0.0175 (−0.2)	−0.0378 (−0.4)	−0.0180 (−0.2)
Parking c/*g*-Mandatory (*pc*/*g***M*)	θ_{pc/g_M}	−0.4391 (−2.5)	−0.4471 (−2.4)	−0.4335 (−2.5)	−0.4422 (−2.3)
Walk time (wt)	θ_{wt}	−0.0790 (−2.0)	−0.0784 (2.0)	−0.0800 (−2.1)	−0.0784 (−2.0)
Walk time–Origin (wt**O*)	θ_{wt_O}	−0.1432 (−2.6)	−0.1426 (−2.5)	−0.1429 (−2.6)	−0.1430 (−2.5)
Frequency (*f*)	θ_f	0.1020 (2.1)	0.0944 (1.8)	0.1021 (2.1)	0.0940 (1.8)
Frequency–Age (*f***A*)	θ_{f_A}	0.1373 (2.3)	0.1606 (2.5)	0.1274 (2.2)	0.1569 (2.4)
Comfort low (CL)	θ_{CL}	−1.929 (−3.4)	–	−1.798 (−3.2)	–
Comfort high (CH)	θ_{CH}	0.5013 (1.5)	–	0.5101 (1.5)	–
Travel time–C. low (*t*∗CL)	$\theta_{t\cdot CL}$	–	−0.0561 (−3.4)	–	−0.0553 (−2.9)
Travel time–C. high (*t*∗CH)	$\theta_{t\cdot CH}$	–	0.0196 (1.8)	–	0.0194 (1.8)
Scale factor[b]	μ	0.7225 (3.3) [1.28]	0.6185 (3.4) [2.11]	0.7641 (3.3) [1.01]	0.6266 (3.2) [1.90]
ρ^2	$\rho^2(C)$	0.1279	0.1247	0.1281	0.1247
Log-Likelihood	$l(\hat{\theta})$	−585.191	−587.302	−584.999	−587.283
No. of observations		1286	1286	1286	1286

[a] *t* statistics; [b]*t* statistics with respect to $\mu = 1$.

Estimation results

The estimation results are shown in Table 3. In models NL1 and NL3 *Comfort* is specified as a dummy variable, and in models NL2 and NL4 it is specified interacting with *Travel time*. Models NL3 and NL4 are more general functions considering specific travel times for the Bus and Car alternatives. All parameter estimates have the expected sign (perhaps with the exception of the Car passenger alternative specific constant - ASC). The ASC for the SP Car alternative was not significantly different from zero and was removed from the final specification. Note that the base parameters of *Travel* time and *Parking cost/g* are not significantly different from zero in all models of Table 3; this is explained by the inclusion of interaction terms with the socio-economic variables (Ortúzar & Willumsen 2001).

Estimation results show, in general, that *Travel time* produces more disutility for workers than for non-workers; in fact, the former have less time available and in general exhibit a higher WTP for travel time savings. There are also differences in the perception of *Cost* between men and women. The parameter corresponding to the interaction term of *Cost* with *Sex* (θ_{c/g_S}) is positive, which means that the last monetary unit spent is more valuable for women. Parking costs produce more disutility for mandatory trips (work and education) than for other motives. Finally, for people older than 35 years of age, improvements in the bus frequency are more valued than for the rest of the travellers.

To check the worth of having specific (NL3 and NL4) rather than generic (NL1 and NL2) *Travel time* parameters, we applied the likelihood ratio test (Ortúzar & Willumsen 2001) considering two linear restrictions. Models NL1 and NL3 are not significantly different so the simpler one (NL1) should be preferred for parsimony; this also happens in the case of models NL2 and NL4, so again the simpler NL2 was preferred. As we lack a statistical test to choose between models NL1 and NL2, both were carried forward to derive WTP measures and to analyse demand response in the next section.

Sign and magnitude of the interaction term parameters

When utilities include interactions or second order terms, a detailed analysis of the sign and magnitude of their parameters is needed to assess if the model explains the individual decision process adequately. This analysis must be based on the microeconomic principles behind the expected signs of the marginal utilities. In our case, the only significant interaction found in all cases was between *Cost*/*g* and *Frequency*. Hence, the conditions that the corresponding parameter, $\theta_{f\cdot c/g}$, must satisfy should be consistent with $\frac{\partial V}{\partial c} < 0$ and $\frac{\partial V}{\partial f} > 0$.

In the case of both models, NL1 and NL2, this yields the following inequalities:

$$\begin{aligned} &\frac{1}{g}(\theta_{c/g} + \theta_{c/g\_S} \cdot S + \theta_{f\cdot c/g} \cdot f) < 0 \\ &(\theta_f + \theta_{f\_A} \cdot A + \theta_{f\cdot c/g} \cdot c/g) > 0 \end{aligned} \tag{4}$$

The conditions for $\theta_{f\cdot c/g}$ depend on the value of the parameters $\theta_{c/g}$, θ_f, θ_{c/g_S} and θ_{f_A} as well as on the value of attributes c/g, f, A and S. Working from inequalities (4) we can obtain that $\theta_{f\cdot\ c/g}$ must belong to the following interval:

$$\theta_{f\cdot c/g} \in \left(-\frac{\theta_f + \theta_{f\_A} \cdot A}{c} \cdot g, \quad -\frac{\theta_{c/g} + \theta_{c/g\_S} \cdot S}{f} \right) \tag{5}$$

As $\theta_f > 0$, $\theta_f + \theta_{f\_A} > 0$, $\theta_{c/g} < 0$ and $\theta_{c/g} + \theta_{c/g\_S} < 0$, the lower bound of the interval should always be negative while the upper bound should always be positive. The magnitude will vary as a function of individual costs, expenditure rate, age and gender. So, individuals who do not satisfy expression (5) are not correctly modelled because their behaviour is not consistent with the microeconomic principles stated in (4). Thus, it would be wise to remove them from the analysis if the model is used for predictive purposes in order to reduce bias.

Policy applications

We derived different WTP measures and also examined the effect of different policy scenarios on demand response. The scenarios favour public transport use, by means of improvements in level-of-service, fare reductions and/or increases in parking costs. All calculations were carried out for individuals in the RP database using a utility function built from common and non-common RP-SP parameters (Louviere et al. 2000). The parameters of attributes defined only for the SP case (i.e. *Comfort*) must be scaled by μ. However, those corresponding to attributes measured in the RP base (i.e. the interaction $\theta_{f\cdot c/g}$:$f\cdot c/g$) do not need to be scaled even if they only appear in the SP utility (Cherchi & Ortúzar 2005).

Willingness-to-pay measures

WTP measures express changes in utility caused by changes in service attributes of the alternatives, in monetary terms. These measures are appropriate only if individuals do not choose a different alternative after q_{kj} changes; this happens when infinitesimal changes in q_{kj} are considered (see the discussion[8] by Lancsar and Savage 2004a, b; Santos Silva 2004; and Ryan 2004). Discrete changes in the characteristics of an alternative may produce changes in the choice probabilities. Lancsar and Savage (2004a) suggest that to consider this uncertainty an accurate measure of welfare must be implicitly weighed by the probability of choosing the alternative. Santos Silva (2004) provides some insight in this respect considering a Taylor expansion of the classical result of Small and Rosen (1981) for the expected compensating variation (ECV).

Although WTP figures should not be used directly to obtain the social benefits of a given project they are interesting instruments to measure welfare changes. Social benefits can be obtained from private benefit measures as shown by Small and Rosen (1981) and Jara-Díaz (1990) for the transport case. In a more recent work, Jara-Díaz et al. (2000) provide a method to calculate social prices for traffic accident reductions following the social appraisal approach developed by Galvez and Jara-Díaz (1998).

In this section we obtain WTP[9] measures for marginal changes in the attribute values. As our model specifications allow for interactions, systematic taste variations and include income in the utility function, we can obtain different WTP measures for each individual in the sample. Aggregate WTP can be computed using the sample enumeration method (Ortúzar & Willumsen 2001). All computations were made including and removing individuals that did not satisfy the interaction condition (5).

Tables 4 and 5 present the WTP measures obtained for models NL1 and NL2 respectively. In general, the WTP for transport system improvements are higher for men than for women. This is consistent with the fact that the MUI is higher for women (note that θ_{c/g_S} is positive). On the other hand, the SVT is higher for workers than for non workers, as well as for car users than for bus users. Improvements in frequency are more valued by people older than 35 years, and walking time savings are more valued by people who travel in the Northern corridor. Note that walking conditions are significantly poorer here than in the Southern corridor, so we believe this fact explains these differences.

The WTP for walking time savings is 2.5 times higher than for travel time savings in the case of model NL1. For model NL2 the WTP for walking time savings is 2.5 times higher when *Comfort* is high, 1.9 times higher when *Comfort* is standard and only 1.5 times higher when *Comfort* is low. In the case of model NL2, the values of travel time savings decrease as comfort improves. This is consistent with the fact that travel time produces more disutility as the level of comfort is reduced.

Table 4. Willingness-to-pay measures from Model NL1.

Alternative	Socio-economic class		All individuals	Only individuals consistent with (13)	Difference[a]%
Willingness-to-pay for travel time savings (€/hour)					
Car	Women	Non-Worker	2.10	2.44	16.37
		Worker	14.70	15.70	6.84
	Men	Non-Worker	5.57	6.83	22.79
		Worker	32.82	33.49	2.03
	Average		14.99	17.40	16.06
Bus	Women	Non-Worker	1.61	1.86	15.42
		Worker	11.51	12.24	6.34
	Men	Non-Worker	3.19	3.89	21.68
		Worker	17.30	17.54	1.37
	Average		8.76	10.08	15.04
Willingness-to-pay for walking time savings (€/min)					
Bus	Women	Southern	0.14	0.16	13.39
		Northern	0.51	0.57	10.82
	Men	Southern	0.25	0.28	8.86
		Northern	0.97	1.06	8.27
	Average		0.36	0.41	12.60
Willingness-to-pay for improvements in frequency (€/bus-hour)					
Bus	Women	Age ≤ 35	0.08	0.13	50.45
		Age > 35	0.33	0.36	8.05
	Men	Age ≤ 35	0.17	0.24	41.35
		Age > 35	0.54	0.57	6.01
	Average		0.28	0.35	24.62
Willingness-to-pay for increasing comfort from low to standard (€)					
Bus	Women		2.67	3.02	13.04
	Men		4.94	5.39	9.08
	Average		3.89	4.32	10.98
Willingness-to-pay for increasing comfort from standard to high (€)					
Bus	Women		0.69	0.78	13.04
	Men		1.28	1.40	9.08
	Average		1.01	1.12	10.98

[a] This difference was calculated using the original figures in pesetas and then transformed into euros so there could be small approximation errors.

Comparing models NL1 and NL2 for individuals consistent with expression (5) only, we observe that the latter predicts an average SVT for bus higher than the former, except when the level of comfort of the Bus is high. Model NL2 also predicts a higher average WTP for improvements in *Com-*

Table 5. Willingness-to-pay Measures from Model NL2.

Alternative	Socio-economic class		All individuals	Only individuals consistent with (5)	Difference[a]%
Willingness-to-pay for travel time savings (€/hour)					
Car	Women	Non-Worker	1.64	1.93	17.62
		Worker	13.31	14.27	7.20
	Men	Non-Worker	4.43	5.58	26.01
		Worker	30.26	31.13	2.86
	Average		13.55	16.10	18.85
Bus comfort High	Women	Non-worker	0.28	0.67	137.23
		Worker	8.78	19.08	117.46
	Men	Non-Worker	0.57	0.72	25.23
		Worker	13.44	13.71	1.98
	Average		6.09	9.26	51.98
Bus comfort standard	Women	Non-Worker	1.27	3.02	137.23
		Worker	10.52	22.89	117.46
	Men	Non-worker	2.57	3.22	25.23
		Worker	16.12	16.44	1.98
	Average		7.98	12.06	51.21
Bus comfort low	Women	Non-worker	4.11	4.78	16.38
		Worker	15.54	16.58	6.65
	Men	Non-worker	8.29	10.38	25.23
		Worker	23.81	24.28	1.98
	Average		13.38	15.45	15.47
Willingness-to-pay for walking time savings (€/min)					
Bus	Women	Southern	0.19	0.14	−22.24
		Northern	0.47	0.53	13.36
	Men	Southern	0.24	0.26	10.21
		Northern	0.91	0.99	9.44
	Average		0.35	0.38	8.15
Willingness-to-pay for improvements in frequency (€/bus-hour)					
Bus	Women	Age ≤ 35	0.06	0.10	62.14
		Age > 35	0.33	0.36	8.05
	Men	Age ≤ 35	0.13	0.20	57.98
		Age > 35	0.54	0.57	6.01
	Average		0.27	0.35	29.82
Willingness-to-pay for increasing comfort from low to standard (€)					
Bus	Women		2.20	2.45	11.17
	Men		4.25	4.59	8.04
	Average		3.31	3.62	9.46

Table 5. Continued

Alternative	Socio-economic class	All individuals	Only individuals consistent with (5)	Difference[a]%
Willingness-to-pay for increasing comfort from standard to high (€)				
Bus	Women	0.77	0.85	11.17
	Men	1.48	1.60	8.04
	Average	1.15	1.26	9.46

[a] This difference was calculated using the original figures in pesetas and then transformed into euros so there could be small approximation errors.

Table 6. Demand response to policy scenarios.

Policy scenario	Percent variation in aggregate share[a] of Bus		
	Comfort high	Comfort standard	Comfort low
Model NL1			
+50% Frequency	7.86	8.96	15.89
+100% Frequency	15.94	18.05	32.83
Reduction in fares (Policy 1)	7.72	8.76	14.24
Reduction in fares (Policy 2)	15.83	18.26	31.03
−10% Travel time (Bus)	4.86	5.15	6.82
+50% Parking cost	37.64	39.28	53.69
Model NL2			
+50% Frequency	7.92	9.15	14.15
+100% Frequency	16.16	18.49	29.01
Reduction in fares (Policy 1)	8.35	9.51	13.11
Reduction in fares (Policy 2)	16.96	19.85	28.55
−10% Travel time (Bus)	2.85	4.81	12.73
+50% Parking cost	35.38	36.70	44.32

[a]With respect to the estimation sample.

fort from standard to high; however, the average WTP for improvements in *Frequency* are similar for both models. In almost all the cases, the inclusion of individuals that do not satisfy condition (5) tends to lower the WTP value. Thus, identifying these individuals could help to reduce underestimation bias in transport project evaluation.

Demand response or policy analysis

Forecasts of changes resulting from the application of different policy scenarios can be represented by the percent change in the aggregate share of alternative j with respect to the initial situation:

$$\Delta P_j = \frac{P_j^1 - P_j^0}{P_j^0} \cdot 100$$

where P_j^1 is the aggregate share of alternative j once the policy is applied and P_j^0 is the initial (do-nothing situation) aggregate share of alternative j. Both aggregate probabilities can be obtained by sample enumeration. Results of the application of various policies are presented in Table 6. Policy scenarios were chosen in order to be consistent with the attribute levels considered in the SP experiment.

We analysed improvements in service frequency, increments in parking costs, reductions in travel time for Bus users and reductions in fares according to the new integrated fare system. In the last case, we considered two policies: the first consists of using a prepaid card that allows a discount of 30% in the first stage of the trip plus a discount of 70% (or 30%) in the second stage for urban (or interurban) trips, respectively. The second allows for discounts of up to 50% in the first stage and of 100% in the second stage, for a fixed number of trips.

These policies were actually implemented in the island and our results (which imply a very small increase in patronage) are slightly higher than the observed effects. It is interesting to mention that political expectations were quite different; in fact, we are currently trying to convince the authorities that parking policies, such as those tested here, seem to be the only way to convince islanders to leave their cars and try the much improved public transport system.

At the time this paper was written the fare reduction policies had just been implemented; the transport planning authorities could now use our models to find out which variables are more relevant in the quest to define the best public transport policy for the island.

Conclusions

The majority of transport empirical applications using SP data are based on simple main-effects-only designs including common level-of-service attributes. Such a modelling strategy may present mis-specification problems when attribute interactions or the effect of latent variables affect individual decisions. In this paper we found two alternative mixed RP/SP model specifications to analyse demand for suburban trips which include latent variables and interaction effects. Besides this, we were able to include non-linear terms in the form of interactions between socio-economic variables and modal attributes, allowing us to study the systematic heterogeneity in individuals' tastes. We also detected the presence of income effect in mode choice decisions and for this reason we included the expenditure rate (dividing the cost terms) in the utility specification.

In relation to the SP choice experiment, special care was taken in the definition of the latent variable *Comfort*. In this sense, focus groups and pilot surveys were determinant in the quality of the final design. A thorough analysis was carried out to detect captive, inconsistent and lexicographic responses. Although removing these observations had a positive effect on the quality of the estimation results when only SP data were used, we found that keeping potentially lexicographic respondents in the mixed RP/SP models produced statistically better results.

The inclusion of interaction terms in the specification requires a detailed analysis of the sign and magnitude of the parameters accompanying them. In our models this analysis allowed us to identify individuals whose behaviour was not adequately captured and to analyse the effect of their inclusion in model applications.

The model results were used to obtain different WTP measures and to analyse demand response to different policy scenarios favouring the use of public transport. These showed that the subjective value of time decreases as comfort is improved; that it is higher for men than for women and for workers than for non workers. Increments in service frequency appear to be more valued for men than for women as well as for people older than 35. Finally, the WTP for improvements in comfort increases with travel time and is higher, again, for men than for women.

We concluded analysing the sensitivity of travel behaviour to model specification. To this end we compared the results obtained after considering different modelling strategies and observed that the inclusion of individuals that did not satisfy the interaction conditions tended to reduce the WTP measures, in the majority of cases. Finally, we examined the effect of different policy scenarios on demand response. The clearest effect is that demand seems to be much more sensitive to raises in parking costs than to fare reductions. Therefore, in spite of public and political expectations, penalising the use of the car seems to be the most effective[10] policy to favour the use of public transport in a wealthy and crowded island.

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Notes

1. We only obtained better models by removing *captive*, *inconsistent* and *potentially lexicographic* individuals when using SP data alone; however, the best models for the mixed RP/SP data set were obtained when we allowed for the presence of the latter; this may be explained because potentially lexicographic individuals cannot be detected when using RP data.
2. *Captive* individuals are defined as those who always chose the same alternative.
3. All individuals who were captive to the bus were also lexicographic in cost (as the bus cost was always defined as lower than the car cost).
4. *Inconsistent* individuals are those who do not behave consistently. The SP choice questions allow to determine logical rules defining consistent choice behaviour. Usual practice allows a maximum of two mistakes by individual; in such cases only the inconsistent observations are eliminated.
5. Potentially lexicographic individuals are those who always choose an alternative which is better in a single attribute. We label them thus because we cannot be sure if they are truly lexicographic or if they behaved that way because the levels of the experiment did not imply a real trade-off for them (see the discussion in Hojman et al. 2005).
6. By latent variable we mean an attribute which is probably considered by individuals but it is not easy (or feasible) to measure in practice.
7. We are grateful to Professor Sergio Jara-Díaz for this suggestion.
8. We are grateful to one of the referees for having pointed this to us.
9. If we do not consider that the marginal utility of income is not constant and it is, we could obtain biased welfare measures (e.g. the compensating variation). However, recent studies show that the bias could be considered negligible in many cases (Bowen et al. 2005).
10. It is important to note that as our sample has a high share of car users this could explain the demand response for increasing parking costs.

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