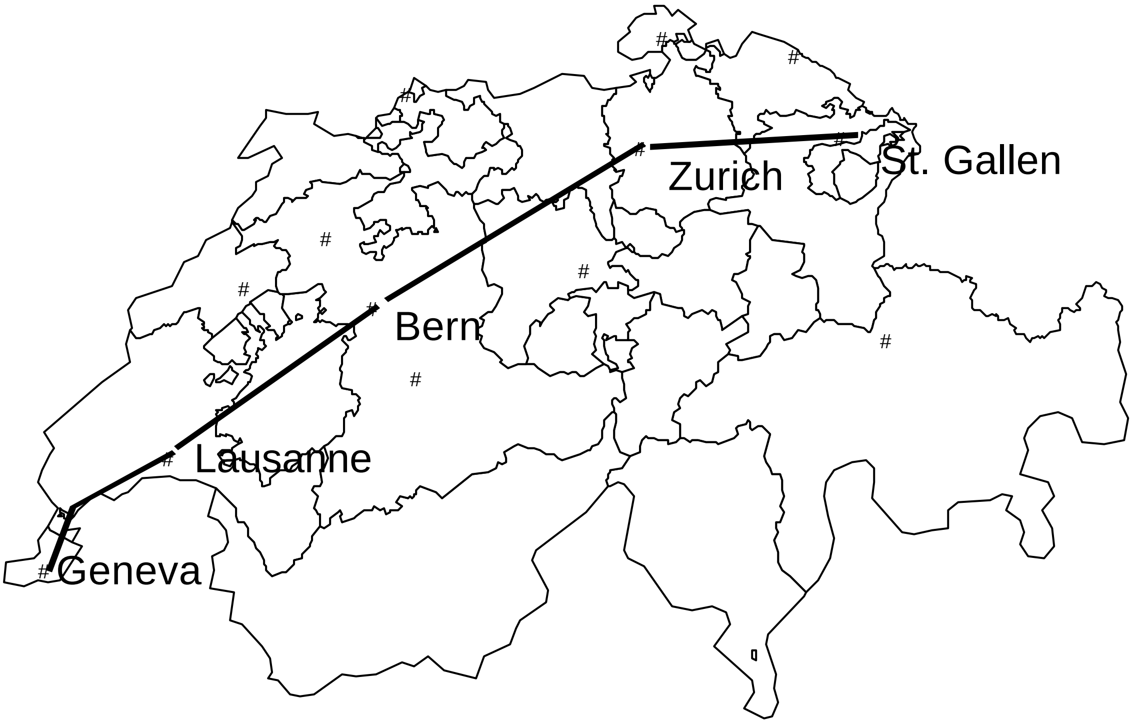
The acceptance of modal innovation

The case of Swissmetro



The acceptance of modal innovation: The case of Swissmetro

M Bierlaire, EPF Lausanne
KW Axhausen, ETH Zürich
G Abay, Abay & Meier, Zürich

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The acceptance of modal innovation: The case of Swissmetro

M Bierlaire
Department of Mathematics
EPFL
Lausanne

KW Axhausen
IVT
ETH
Zürich

G Abay
Abay & Meier
Zürich

Phone: 021- 693 2537
Fax: 021-693 2595
eMail: michel.bierlaire@epfl.ch

Abstract

The SwissMetro is a proposed major innovation to the Swiss transport system : an underground mag-lev system to connect the major urban centres in Switzerland. As part of the various assessment studies carried out so far, Abay (1999) conducted a substantial RP/SP survey of long-distance road and rail travellers using a two-stage survey method. First, the respondents were interviewed or observed about a current trip. Based on this trip SP exercises were generated, which the respondent answered in turn.

This paper explores how stable the modelling results are with respect to different approaches of capturing the heterogeneity in the data : multinominal logit (MNL), MNL with non-linear utility functions, nested logit (NL) and cross-nested logit (CNL). The models were estimated using software written by the first author (see also Bierlaire, 2001).

The results indicate, in this case, a relative stability of the relative parameter values and nearly consistent results with regards to the assessment of parameter significance. Still, the more complex forms account for more of the variance giving more confidence in the results.

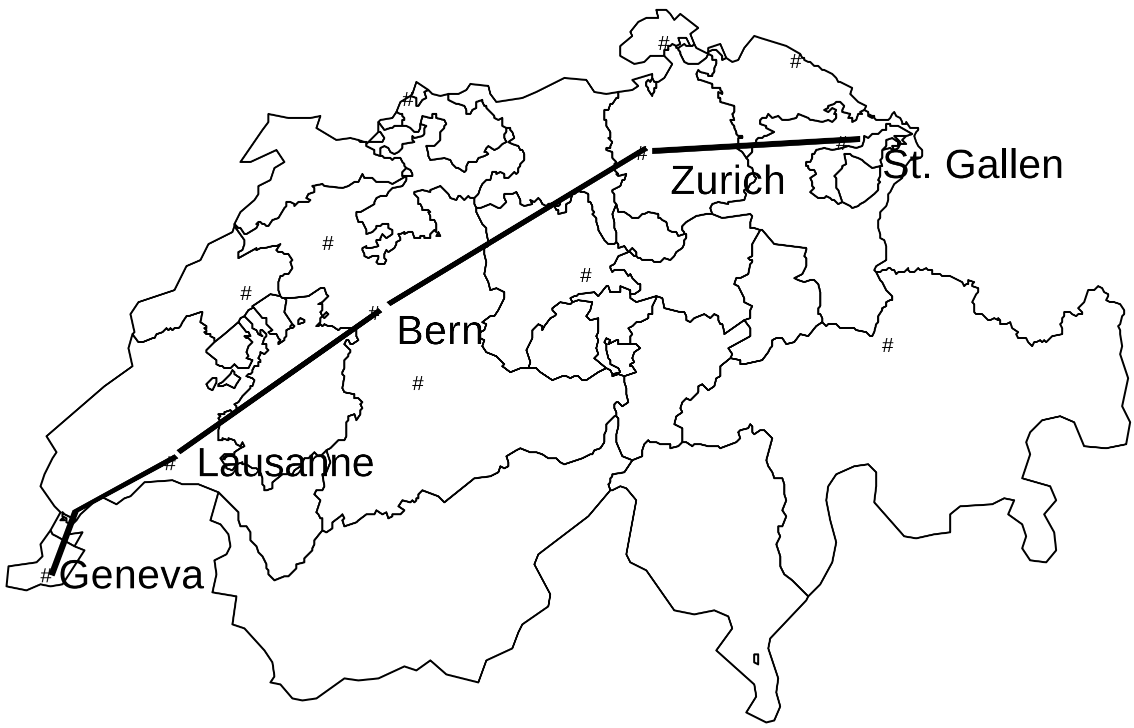
Keywords

Swissmetro – Logit model – Cross nested logit - SP surveys – Modal innovation – Swiss Transport Research Conference – STRC 2001 – Monte Verità

1. The case of Swissmetro

Innovation in the market for intercity passenger transportation is a difficult enterprise, as the existing modes: private car, coach, rail and regional and long-distance air services continue to innovate in their own right by offering new combinations of speeds, services, prices and technologies; consider for example high-speed rail links between the major centres or direct regional jet services between smaller centres. The Swissmetro SA, Geneva is promoting such an innovation: a mag-lev underground system operating at speeds up to 500 km/h in partial vacuum (For details see www.swissmetro.com) connecting the major Swiss conurbations, in particular along the Mittelland corridor: St. Gallen, Zurich, Bern, Lausanne and Geneva. Later extensions are planned in the direction of Basel and Lucerne/Ticino. There are even discussions of using the system as a Eurometro connecting Europe's major centres (See Figure 1).

Figure 1 Assumed Swissmetro network



This proposal has been subject to numerous studies assessing the technological feasibility, the network configuration (Pingoud, 1997), the impacts on land use (Gruber, Zbinden and Schmid, 1999; Katell, Schuler, Bassand and Rumley, 1999) and on the structure of interregional travel demand (Abay, 1999).

The purpose of this paper is to reanalyse the survey data collected by Abay (1999) using more complete descriptions of the structure and errors of the data. Models of increased complexity will be estimated from the same data set, and the results are compared in order to illustrate the importance of capturing the complex interactions in a choice process. The next section will discuss the methodological approach based on the generalised extreme value (GEV) class of random utility models employed for the analysis. This will be followed by a description of the data collection procedures and of their rationale. The main section will describe the results obtained using four model from the GEV family: (i) the Multinomial Logit with linear-in-parameters utility functions, (ii) the Multinomial Logit with nonlinear utility functions, (iii) the Nested Logit and (iv) the Cross-Nested Logit. The conclusions draw the lessons from the work with respect to the choice of complexity in the modelling of the structure of a data set and of the structure of the associated residuals.

2. Methodological approach

The Generalized Extreme Value (GEV) can be derived from the random utility model proposed by McFadden (see Ben-Akiva and Lerman, 1985 for details). This general model consists of a large family of models that include the Multinomial Logit and the Nested Logit models. The probability of choosing alternative i within C_n is

$$P(i \mid C_n) = \frac{e^{V_{in}} \frac{\partial G}{\partial e^{V_{in}}} \left(e^{V_{1n}},\ldots,e^{V_{J_n n}}\right)}{mG\left(e^{V_{1n}},\ldots,e^{V_{J_n n}}\right)}.$$

J_n is the number of alternatives in C_n and G is a non-negative differentiable function defined on $\mathrm{IR}_+^{J_n}$ with the following properties:

1. G is homogeneous of degree $m > 0$[1],

2. $\lim_{x_i \to \infty} G(x_1,\ldots,x_i,\ldots,x_{J_n}) = \infty, \forall i = 1,\ldots,J_n$

[1] McFadden's original formulation with m=1 was generalized to m>0 by Ben-Akiva.

3. the kth partial derivative with respect to k distinct x_i is non-negative if k is odd, and non-positive if k is even, that is, for any distinct $i_1,\ldots i_k \in \{1,\ldots J_n\}$ we have

$$(-1)^k \frac{\partial^k G}{\partial x_{i_1} \ldots \partial x_{i_k}}(x) \leq 0 \;\; \forall x \in \mathbb{R}_+^{J_n}.$$

The Multinomial Logit Model, the Nested Logit Model and the Cross-Nested Logit Model are GEV models, with

$$G(x) = \sum_{i=1}^{J_n} x_i^{\mu}$$

for the Logit model,

$$G(x) = \sum_{m=1}^{M} \left(\sum_{i \in C_{mn}} x_i^{\mu_m} \right)^{\frac{\mu}{\mu_m}}$$

for the Nested Logit model and

$$G(x) = \sum_{m=1}^{M} \left(\sum_{j \in C_n} \alpha_{jm} x_j^{\mu_m} \right)^{\frac{\mu}{\mu_m}}$$

for the Cross-nested Logit model. The Multinomial and Nested logit models are well known and widely used. The Cross-Nested Logit has recently received more attention, as it is able to capture more complex correlation structures then the Nested Logit (Small, 1987, Vovsha, 1997, Papola, 2000).The formulation of the cross-nested logit model mentioned above, and used in this paper, has been proposed by Ben-Akiva and Bierlaire (1999) and analysed in more detail by Bierlaire (2001).

Estimating a general GEV model is a difficult task because not all the model parameters can be estimated. The parameter dependence is well-known for Multinomial and Nested logit models (see Bierlaire, Lotan and Toint, 1997), but not for general GEV models. Therefore, the estimation process has been designed to handle overspecified models, where any number of parameters can be estimated. If some parameters are mutually dependent, the variance-covariance matrix of the estimates cannot be computed, but the values of the parameters are available. This enables to investigate the power of such models.

A new model estimation package called Biogeme (BIerlaire's Optimization routines for GEv Model Estimation) has been developed. It is designed to estimate a wide variety of discrete choice models. Actually, any model out of the GEV model family can be estimated. Moreover, nonlinear utility functions can be handled. In particular, a specific scale parameter can be associated with different groups in the sample.

3. Data collection

The Swissmetro is a true innovation. It is therefore not appropriate to base forecasts of its impact on observations of existing revealed preferences (RP). It is necessary to obtain data from surveys of hypothetical markets/situations, which include the innovation, to assess the impact. Such stated-preference surveys (SP) have been employed for this purpose for more than twenty years in transportation and market research more generally (see for example Louviere, Hensher and Swait, 2000; FGSV, 1996; Axhausen, 1995). Abay (1999) adopted this methodology to interview both current rail and road users, as the two main groups, which will be affected by a possible Swissmetro. Air travel within Switzerland is at this time mostly feeder traffic to the hubs at Zürich and Basel and is unlikely to be affected.

Given the novelty of the system it was felt that the SP experiments should reflect a particular trip in the corridor which the respondent was undertaking or had undertaken (See Polak, Jones, Vythoulkas, Meland and Tretvik, 1991 for an early example of this approach). A two stage procedure was therefore required: an initial interview about the trip or an observation of the trip, followed-up by the SP experiments based on that trip. In the case of rail travel it was possible to undertake the interview during the target trip, as respondents can be approached in a rail carriage. In the case of road travel a more complex approach to sample selection had to be implemented.

The 470 respondents for the rail-based sample were approached on the train between St. Gallen and Geneva during March 1998. Due to data problems only 435 of those interviews were suitable for analysis. The computer-based interview obtained a description of the current trip from the respondent including the first and last station. Based on this information and a suitable main effects fractional factorial experimental design the software generated nine stated-choice situations for each respondents offering as alternatives: rail, Swissmetro and car (only for car owners). Each alternative was described by their travel time, fare/cost and headway (rail-based alternatives only). For the Swissmetro the seating arrangements were additionally specified as “rail 1. Class” or “plane business class”. The travel times were door-to-door making certain assumptions about car-based distances (1.25 * crow-flight distance) and future Swissmetro speeds. Travel times on the feeder connections were assumed to be unchanged in the future. The fare of Swissmetro was calculated as the current relevant rail fare, including all reductions, multiplied with a fixed factor (1.2) to reflect the higher speeds. For the car alternative a fixed average costs per kilometre was assumed (1.20 sFr/km).

To search for relevant car trips with a household or telephone survey was deemed impractical. The sample was therefore constructed using licence plate observations on the motorways in the corridor. This data was also used to estimate road-based origin-destination matrices for the demand estimation. A total of 10'529 relevant licence plates were recorded during September 1997 at Zürich (West bound), Bern (East- and westbound) and Geneva (Eastbound) using video-recorders. The central Swiss car licence agency had agreed to sending up to 10'000 owners of these cars a survey-pack, which asked them about the trip and enquired about their willingness to participate in a second survey. Until April 1998 9'658 letters were mailed, of which 1'758 were returned. A total of 1'070 persons filled in the survey completely and was willing to participate in the second SP survey, which was generated using the same approach which had been used for the rail interviews. 770 usable SP surveys were returned.

The response rate of 18% to the first wave is impressive given its nature and the delay between the trip and the approach[3], although the official endorsement by the central registry must have helped. The 72% response rate for the SP is well within the range of such follow-up surveys.

4. Modelling results

All models presented below are based on the same utility functions. Our analysis aims at illustrating the impact of modelling assumptions on estimation results with real data. The models were estimated for the subset of business and commuting trips in the overall data set.

The model involves 5 alternatives:

- SBB/RP: train alternative in a RP context,

[3] The delay was due to the difficulties in processing the video tapes

- SBB/SP: train alternative in a SP context,
- SM/SP: Swissmetro alternative (of course in a SP context),
- Car/RP: car alternative in a RP context,
- Car/SP: car alternative in a SP context.

Note that not all alternatives are available together. For respondents of a RP survey, only SBB/RP and Car/RP are available. For respondents of a SP experiment, only SBB/SP, SM/SP and Car/SP are available. Therefore, we actually have two independent models from the viewpoint of the alternatives, but with common explanatory variables.

The explanatory variables are the following.

- Alternative specific constants for each alternative (ASC Car/RP, ASC Car/SP, ASC SM/SP). The Alternative Specific Constants for the train alternatives have been fixed as zero.
- B-Cost is the parameter associated with the transportation cost. Note that contrarily to Abay (1999) we do not consider alternative specific coefficients.
- B-Time is the parameter associated with travel time.
- B-Freq is the parameter associated with the frequency of public transportation.
- B-Age is the parameter associated with the choice maker's age.
- B-GA is the parameter capturing the effect of the "Generalabonnement" (GA), the Swiss annual season ticket for the rail system and most local public transport.
- B-Luggage is the parameter associated with presence of relevant amounts of luggage during the trip
- B-Seats is the parameter associated with the seat configuration in the Swissmetro.

The alternatives are defined as follows.

- Train-TT is the train travel time calculated as discussed above.
- SM-TT is the Swissmetro travel time calculated as discussed above.
- Car-TT is the car travel time calculated as discussed above.
- Train-Cost is the train cost calculated as discussed above if the respondent does not have a GA, and is zero otherwise. We adopt here another approach then Abay (1999), who computes a day-equivalent cost from the cost of the GA. We prefer to make the distinction between regular and occasional travellers, assuming that the cost impact is fundamentally different. A more detailed analysis of the impact of cost and of season-tickets on mode choice would be desirable (See for example Simma and Axhausen, 2001).

- SM-Cost is the Swissmetro cost calculated as discussed above if the respondent does not have a general season-ticket, and is zero otherwise.
- Car_Cost is the car cost calculated as discussed above.
- Train-Freq is the train frequency as reported in the sample file.
- SM-Freq is the Swissmetro frequency as reported in the sample file.
- GA is 1 if the individual owns a GA, zero otherwise.
- Age captures the age class of the individual. The coding is 1 if age <= 24, 2 if age <= 39, 3 if age <= 54, 4 if age <= 65 and 5 if age > 65.
- Luggage is zero if the traveller does not carry luggage, 1 if she is carrying one piece of luggage and 2 if she is carrying more than one.
- Seats is zero for 1. Class rail seating and zero otherwise.

The utility functions used are shown in Table 1.

Table 1 Utility functions used

Variable		Alternative				
		Car-RP	SBB-RP	SM-SP	Car-SP	SBB-SP
ASC	Constant	Car/RP		SM/SP	Car/SP	
TT	Travel time	B-Time	B-Time	B-Time	B-Time	B-Time
Cost	Travel cost	B-Cost	B-Cost	B-Cost	B-Cost	B-Cost
Freq	Frequency		B-Freq	B-Freq		B-Freq
GA	Annual season		B-GA	B-GA		B-GA
Age	Age in classes		B-Age			B-Age
Luggage	Pieces of luggage	B-Luggage			B-Luggage	
Seats	Airline seating			B-Seats		

The models presented below have been estimated using 7823 observations, corresponding to RP and SP data collected from long-distance business and commuting travellers.

4.1 Multinomial logit model

We have first estimated a simple multinomial logit model. All parameters appeared to be significant, except the parameter B-Luggage (see Table 2).

4.2 Multinomial Logit Model with nonlinear utility functions

Combining RP and SP data is known to be invalid if the model does not capture the scale between the two types of data. Bradley and Daly (1993) have proposed a methodology based on an artificial Nested Logit model to estimate this scale factor (See also Ben-Akiva and Morikawa, 1990). We prefer here to keep the multinomial model, and to explicitly include the scale parameter in the model. Therefore, each utility function corresponding to SP data is multiplied by a parameter λ. The utility functions are then nonlinear. Due to the small amount of RP data, the new model is not significantly different from the previous one (see Table 3). First, the value of the likelihood ratio test is 1.7918, while the threshold of 95% significance of the Chi-Square test with one degree of freedom is 3.841. Also, the t-test of the λ parameter shows that it is not significantly different from 1.

4.3 Nested Logit Model

We have estimated a Nested Logit model with two nests: one including existing modes, and one containing the Swissmetro alternative. Note that the nested logit model is also based on nonlinear utility functions, with the scale parameter. The improvement in the model quality is very significant. The likelihood ratio test between the Nested Logit and the MNL with nonlinear utility function is 231.7, far above the 99% threshold of the Chi-Square test. The μ parameter associated with the nest of existing modes is significantly different from one. Interestingly, the scale parameter for SP observations is now significantly different from one.

Table 2 MNL parameter estimates

Parameter	Estimate	t-test
ASC Car/RP	1.704E+00	1.084E+01
ASC Car/SP	1.108E+00	8.607E+00
ASC SM/SP	1.302E+00	1.074E+01
B-Age	2.199E-01	6.781E+00
B-Cost	-1.038E-02	-1.961E+01
B-Freq	-2.617E-03	-2.792E+00
B-GA	1.287E+00	7.709E+00
B-Luggage	*3.658E-02*	*7.353E-01*
B-Seats	-4.837E-01	-5.594E+00
B-Time	-1.259E-02	-2.266E+01
Final log-likelihood	-5682.87	
N	7823	

Table 3 MNL (with non-linear utility functions; scale parameter) parameter estimates

Parameter	Estimate	t-test
ASC Car/RP	1.72E+00	9.88E+00
ASC Car/SP	1.29E+00	6.23E+00
ASC SM/SP	1.53E+00	6.77E+00
B-Age	2.47E-01	5.82E+00
B-Cost	-1.22E-02	-8.04E+00
B-Freq	-2.62E-03	-2.39E+00
B-GA	1.43E+00	6.81E+00
B-Luggage	5.40E-02	9.15E-01
B-Seats	-5.64E-01	-4.74E+00
B-Time	-1.46E-02	-8.66E+00
Scale parameter λ	8.51E-01	-1.51E+00
Final log-likelihood	-5681.974	
N	7823	

Table 4 Nested Logit model parameter estimates

Parameter	Estimate	t-test
ASC Car/RP	8.653E-01	9.484E+00
ASC Car/SP	5.872E-01	6.036E+00
ASC SM/SP	6.881E-01	6.434E+00
B-Age	1.133E-01	5.638E+00
B-Cost	-5.531E-03	-7.380E+00
B-Freq	-1.333E-03	-2.778E+00
B-GA	6.379E-01	6.591E+00
B-Luggage	-2.412E-02	-9.450E-01
B-Seats	-2.258E-01	-3.385E+00
B-Time	-6.369E-03	-7.687E+00
Scale parameter μ	2.153E+00	9.738E+00
Scale parameter λ	1.352E+00	2.203E+00
Final log-likelihood	-5566.15	
N	7823	

4.4 Cross-Nested Logit model

The structure of the Cross-Nested logit is rather complex, and the exact role of the additional nesting parameter is still subject to discussion. A first analysis performed by Bierlaire (2001) shows the direct dependence among the ASCs and the cross-nested parameters. Also, it appeared from these results that the scale parameter is also related to the cross-nested parameters.

The difficulty was to estimate a model with the correct number of parameters. With too many parameters, the model is overspecified, and no variance-covariance matrix is available. With too few, we do not obtain the best model possible. We have first estimated a model with all parameters. It was definitely overspecified, but the algorithm was robust enough to find a solution. We obtained a final loglikelihood equal to –5489.55. It is an upper bound on the loglikelihood that can be produced with a Cross-Nested Logit model on this data set. We then constrained several parameters to a fixed value, in order to obtain an estimable model.

The model reported in Table 5 contains 14 estimated parameters. The final loglikelihood is sufficiently close to the upper bound to be accepted. Each parameter of the Cross-Nested

Logit corresponds to the combination of a nest and an alternative. Only three out of the 10 have been estimated. The scale parameter has been removed from the model, as its effect is captures by the cross nesting parameters α.

Table 5 Cross Nested Logit model parameter estimates

Parameter	Estimate	t-test (Scale parameters =1)
ASC Car/RP	*2.170E+00*	*7.028E+00*
ASC Car/SP	*-9.245E-01*	*-2.396E+00*
ASC SM/SP	*-4.976E-01*	*-1.548E+00*
B-Age	1.410E-01	8.002E+00
B-Cost	-7.673E-03	-1.770E+01
B-Freq	-1.755E-03	-3.630E+00
B-GA	6.613E-01	7.615E+00
B-Luggage	-5.654E-02	-2.268E+00
B-Seats	-2.785E-01	-3.397E+00
B-Time	-8.569E-03	-1.743E+01
Scale parameter μ	8.917E+00	4.585E+00
Car/SP EXIST	1.549E-01	-3.393E+00
SBB/SP FUTURE	4.288E-02	-5.733E+01
Car/RP FUTURE	2.288E-01	-8.957E+00
Car/SP FUTURE	5.000E-01	Fixed
SBB/RP EXIST	5.000E-01	Fixed
SBB/SP EXIST	1.000E-06	Fixed
SM/SP EXIST	0.000E+00	Fixed
Car/RP EXIST	1.000E-06	Fixed
SBB/RP FUTURE	5.000E-01	Fixed
SM/SP FUTURE	1.000E+00	Fixed
Final log-likelihood	-5490.68	
N	7823	

Note that the condition

$$\sum_m a_{im}^{m/m_m} = K, \ \forall i, \ K > 0$$

is not verified. Therefore, the value of the Alternative Specific Constants cannot be compared with those from other models (see Bierlaire, 2001). They have been written in italic to emphasize that. It is not clear yet why the B_Luggage suddenly becomes significantly different from zero in this model. It may reflect a reality in the data, or capture some effects due to the model structure.

In any case, the estimated cross-nested logit model significantly improves the Nested-Logit model. The likelihood ratio test is 150.94.

4.5 Parameters comparison

In Table 6, we have compared the value of the parameters across estimated models.. The table contains the ratio between the estimated value for a given model and the corresponding value for the simple MNL model. Clearly, these values drastically vary from one model to the other. However, their ratios seem to be more stable, even if the difference is still significant.

Table 6 Comparison of the model parameter estimates with the MNL estimates

Parameter	MNL	MNL (scale)	NL	CNL
ASC Car/RP	100.0%	101.0%	50.8%	
ASC Car/SP	100.0%	116.8%	53.0%	
ASC SM/SP	100.0%	117.4%	52.9%	
B-Age	100.0%	112.4%	51.5%	64.1%
B-Cost	100.0%	117.3%	53.3%	73.9%
B-Freq	100.0%	100.0%	50.9%	67.0%
B-GA	100.0%	111.0%	49.5%	51.4%
B-Luggage	100.0%	147.7%	-65.9%	-154.6%
B-Seats	100.0%	116.7%	46.7%	57.6%
B-Time	100.0%	116.2%	50.6%	68.0%
Value of time (VOT) [sFr/min]	1.21	1.20	1.15	1.12
Value of frequency (VOF) [sFr/min]	2.52	2.15	2.41	2.29
VOT relative to MNL	100.0%	99.1%	94.9%	92.0%
VOF relative to MNL	100.0%	85.3%	95.6%	90.7%
Final log-likelihood	-5682.9	-5682.0	-5566.2	-5490.7
Number of parameters	10	11	12	14

We have reported in the last two rows the Value of Time Savings (ratio of B-Time and B-Cost) and the Value of Frequency (ratio of B-Freq and B-Cost). The values are very substantial but not implausible for the long-distance trips for which the models were estimated, which are normally performed by wealthier travellers.

5. Conclusions and outlook

The comparisons of different models have shown that the use of more complex models, able to better capture correlation structures, significantly improves the quality of the estimated models (See substantial increases in the log-likelihoods). The known improvement from MNL to NL models has again been verified for this case study. But we have also demonstrated that a significant improvement can be achieved when preferring the Cross-Nested to the Nested. Note that the choice context we have analysed involves few possibilities of nest definition. We believe that applications involving route choice or departure time choice will benefit even more from the Cross-Nested model.

There are still several theoretical and empirical work to be done on the Cross-Nested logit model. This paper is a first step toward a better knowledge of the model structures. Also, now that an estimation package is available, other GEV models may be considered to capture other complexities of the choice process.

The results also encourage more detailed work on the values-of-time using a more detailed socio-demographic description of the travellers and a more detailed categorisation of the trips undertaken. The consistently positive age effect is an indication of that.

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