A COVARIANCE HETEROGENEITY GENERALIZED NESTED LOGIT MODEL OF NEW BUS SERVICES

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Abstract: This research attempts to investigate long distance travelers' preferences for new bus services in which buses are equipped with seats or sleepers on the lower deck. The stated preference survey instrument includes alternative scenarios of bus fares and service frequency for two hypothetical bus classes. This paper adopts the generalized nested logit (GNL) model with covariance heterogeneity (COVGNL) to take account of flexible substitution patterns among alternatives and to allow heterogeneity across individuals in the covariance among nested alternatives. The estimation results indicate that travel cost, individual and trip characteristics, and quality-of-service are important factors affecting the choices of travel modes and bus service classes. The preferred GNL model includes two multiple alternative nests – the lower deck sleeper and seat in a nest and the lower deck sleeper and upper deck seat in a nest. The COVGNL model statistically rejects the multinomial logit, nested logit, and GNL models and indicates a significant difference in the correlation between the utilities of nested alternatives across individuals with different income earnings and gender. The empirical findings provide valuable insights for the proposed new bus services.

Key Words: Bus, Discrete choice, Logit, Stated preference

1. INTRODUCTION

Due to the rise in domestic airfares, the insufficiency of rail seats, and the improvement of intercity bus services, long distance travelers have shifted to bus in the west corridor of Taiwan. Plenty of passengers can be found waiting for well-equipped, high-quality service buses on weekends or holidays. Thus, increasing the bus capacity to serve more intercity travelers becomes an important issue.

In Taiwan, a regular long distance bus has 19 to 34 seats on the upper deck. The lower deck space includes a driver's seat, storage and washing rooms. Buses equipped with the lower deck sleeper are not yet available in the market. However, sleeper services on rail are available or under developed in many countries (Hensher, 1998; Sethi, 2000). Bus equipped with sleepers is a new concept. A bus with sleepers or seats on the lower deck can take two to five more passengers than a regular intercity bus. The primary objective of the research is to investigate long distance travelers' preferences for the lower deck seat or sleeper on buses and develop a stated choice model to understand the factors influencing the potential demand for new bus services.

Revealed preference (RP) data are widely used to observed behavior in an actual market and describe only those alternatives that exist. RP data are inadequate to model or forecast non-existing alternatives. On the other hand, stated preference (SP) data, based on hypothetical choice, can be used to model existing markets, but also consider markets that are different from existing ones. Because the new long distance bus service classes are unavailable in the market, the SP data were collected. The SP instrument includes alternative scenarios of bus fares and service frequency for two hypothetical bus classes on the lower deck. The travelers can choose from two new bus classes or their current use of travel modes.

Discrete choice analysis, widely used to model the selection of one among a set of mutually exclusive alternatives, is appropriate to model the choice of travel modes and new bus services. The multinomial logit (MNL) model (McFadden, 1973) is the most used discrete choice model due to simple model structure and ease of estimation. However, the MNL model has undesirable independence of irrelevant alternatives property that can lead to biased estimates and incorrect predictions in cases that violate the assumptions imposed by the MNL model. The most widely used relaxation of the MNL model is the nested logit (NL) model (Williams, 1977; McFadden, 1978). The NL model allows the error terms of alternatives in a group to be correlated. However, the restrictions on the equality of cross-elasticities between pairs of alternatives in a nest may be unrealistic.

The restrictive assumptions imposed by the MNL and NL models have been relaxed by the developments of advanced discrete choice models which include the multinomial probit (MNP) model (Daganzo, 1979), the heteroscedastic extreme value (HEV) model (Bhat, 1995), the mixed logit (ML) model (McFadden and Train, 2000; Hensher and Greene, 2003 for an overview), and the generalized extreme value (GEV) family of models such as the cross-nested logit (CNL) (Vovsha, 1997), the pair combinatorial logit (PCL) (Koppelman and Wen, 2000), and the generalized nested logit (GNL) models (Wen and Koppelman, 2001). The MNP model relaxes both the independent and identical assumptions of random error components. However, the flexibility of error structure increases computational complexity and practical problems (Horowitz, 1991). The use of the MNP model is very limited in research and industry. Bhat (1995) proposed the HEV model that allows non-identical error terms. However, the HEV model has an open form and requires numerical integration in estimation. The ML model allows a very flexible correlation structure among error terms and also requires the use of simulation techniques in estimation due to an open form model structure.

Other relaxations of the restrictive assumptions of the MNL model are derived from the GEV model. The advantage of the GEV family of models is that the model has a closed form for choice probabilities. Among recent developments of the GEV models, the GNL model has the most flexible error structure. The GNL model provides a unifying model structure for previously developed GEV models, with exception of the NL models (Wen and Koppelman, 2001). It includes the two-level NL model as a special case and can approximate closely multi-level NL models. The GNL model accommodates differential cross-elasticity among pairs of alternatives through the allocation of each alternative to a set of nests and allow different logsum parameters for nests.

The majority of developed choice models impose the restriction of equal correlation among nested alternatives across individuals. Bhat (1997) proposed the COVNL model that extends the NL model to allow heterogeneity across individuals in the covariance among nested alternatives. In the empirical analysis, Bhat demonstrated that the COVNL model is statistically superior to the MNL and NL models, and not accounting for covariance heterogeneity in the NL model may lead to biased model estimates and produce inaccurate prediction. Sethi (2000) formulated and estimated a GNL model with incorporating variance and covariance heterogeneity across individuals. This extension includes the GNL and COVNL as special cases. In the context of long distance travel choice with multiple modes and rail service classes, Sethi illustrated the theoretical and empirical superiority of the GNL with variance and covariance heterogeneity over the standard GNL model.

This paper develops a model formulation that extends the GNL model by allowing covariance heterogeneity across individuals and has a more general structure than the COVGNL model (covariance heterogeneity but no variance heterogeneity) developed by Sethi (2000). The COVGNL model can be estimated by employing a constrained full-information maximum likelihood method. The use of the COVGNL model can accommodate a higher degree of substitution patterns among alternatives, identify possible covariance heterogeneity across individuals, and provide valuable behavioral insights on travelers' choice.

The remainder of this paper is organized as follows. Section 2 presents the formulation and estimation approach for the COVGNL model. Section 3 describes the data and estimation results for the MNL, NL, GNL and COVGNL models. Section 4 provides a summary of research findings.

2. The COVGNL MODEL

The GNL model is a special case of the COVGNL model. The GNL model is a member of the GEV family of models and derived from the following function:

$$G(Y_1, Y_2, ..., Y_n) = \sum_m \left(\sum_{i' \in N_m} \left(\alpha_{i'm} Y_{i'} \right)^{1/\mu_m} \right)^{\mu_m} \tag{1}$$

where

N_m = set of all alternatives included in nest m,
α_{im} = portion of alternative i assigned to nest m,
μ_m = logsum (dissimilarity) parameter for nest m,

The allocation parameter α_{im} must satisfy the conditions $\alpha_{im} \geq 0$ and $\sum_m \alpha_{im} = 1, \forall i$. G is function of Y_i, $i = 1,2,...,n$, and satisfies the conditions required in the GEV model. The probability of individual q choosing alternative i for the GNL model is:

$$P_{qi} = \sum_m \left\{ \frac{(\alpha_{im} e^{V_{qi}})^{1/\mu_m}}{\sum_{i' \in N_m} (\alpha_{i'm} e^{V_{qi'}})^{1/\mu_m}} \times \frac{\left[\sum_{i' \in N_m} (\alpha_{i'm} e^{V_{qi'}})^{1/\mu_m} \right]^{\mu_m}}{\sum_m \left[\sum_{i' \in N_m} (\alpha_{i'm} e^{V_{qi'}})^{1/\mu_m} \right]^{\mu_m}} \right\} \tag{2}$$

where V_{qi} is the systematic utility of alternative *i* for individual *q*. The GNL model is consistent with random utility maximization if the conditions, $0 < \mu_m \le 1$ for all *m*, are satisfied.

An important property of the GNL model is the correlation structure between utilities of alternatives. The distribution function of the random error components for alternatives in the GNL model is the Gumbel distribution, $F(\varepsilon_i) = \exp[-\exp(-\varepsilon_i)]$. Using equation (1), the bivariate cumulative distribution function for any pair of random error components is obtained as follows (Small, 1987; Daganzo and Kusnic, 1993; Koppelman and Wen, 2000):

$$F_{GNL}(\varepsilon_i, \varepsilon_j) = \exp\left\{-\sum_m \left[(\alpha_{im} e^{-\varepsilon_i})^{1/\mu_m} + (\alpha_{jm} e^{-\varepsilon_j})^{1/\mu_m}\right]^{\mu_m}\right\} \times \exp\left[-(1-\sum_m \alpha_{im})e^{-\varepsilon_i} - (1-\sum_m \alpha_{jm})e^{-\varepsilon_j}\right] \tag{3}$$

The covariance (or correlation) of utilities in the GNL model cannot be written in a closed form but can be calculated numerically using equation (3) (see Wen and Koppelman, 2001 for a numerical example). The correlations between the random errors of alternatives are function of the logsum and allocation parameters.

The COVGNL model specifies the logsum and allocation parameters to vary with individuals. The probability function for the COVGNL model is:

$$P_{qi} = \sum_m \left\{ \frac{(\alpha_{qim} e^{V_{qi}})^{1/\mu_{qm}}}{\sum_{i' \in N_m} (\alpha_{qi'm} e^{V_{qi'}})^{1/\mu_{qm}}} \times \frac{\left[\sum_{i' \in N_m} (\alpha_{qi'm} e^{V_{qi'}})^{1/\mu_{qm}}\right]^{\mu_{qm}}}{\sum_m \left[\sum_{i' \in N_m} (\alpha_{qi'm} e^{V_{qi'}})^{1/\mu_{qm}}\right]^{\mu_{qm}}} \right\} \tag{4}$$

where

α_{qim} = portion of alternative *i* assigned to nest *m* for individual *q*,
μ_{qm} = logsum parameter of nest *m* for individual *q*.

The logsum and allocation parameters in the COVGNL model can be parameterized as functions of individual characteristics such as income, gender, and trip distance, similar to testing for heteroscedasticity. The logsum parameters are parameterized as follows:

$$\mu_{qm} = f(\lambda_m + \gamma'_m S_q)\ ,\ \forall m \tag{5}$$

where

S_q = vector of individual characteristics,
γ'_m = vector of unknown parameters for S_q variables,

λ_m = vector of unknown parameters which represent the constants when covariance heterogeneity is absent,

f = a transformation function for the logsum parameters.

If *f* is specified as the logistic function, the same distribution used by Bhat (1997) and Sethi (2000), it can ensure that the logsum parameters are within zero-one range. We write (5) as

$$\mu_{qm} = \frac{1}{1+\exp[-(\lambda_m + \gamma'_m S_q)]}\ ,\ \forall m \tag{6}$$

If $\gamma_m = 0$ for all *m*, the COVGNL model collapses to the standard GNL model.

The allocation parameters can also be parameterized as the follows:

$$\alpha_{qim} = \frac{1}{1+\exp[-(\kappa_{im} + w'_{im} S_q)]},\ \forall i, m \tag{7}$$

where

κ_{im} = vector of unknown parameters which represent the constants when covariance heterogeneity is absent,

w_{im} = vector of unknown parameters for S_q.

The parameterization of the allocation parameters recognizes the important role of this parameter in determining the degree of substitution among alternatives in the corresponding nest. However, this parameterization is very complex and computationally difficult in that the conditions $\sum_m \alpha_{qim} = 1, \forall i, q$ must be satisfied. Therefore, this paper preserves individual homogeneity in allocation parameters for the COVGNL model. The inclusion of equation (7) in the COVGNL model will be explored in future research.

This paper employs a constrained maximum likelihood (Aptech Systems, 1995) to estimate all sets of parameters, simultaneously, taking account of the restrictions that the logsum and allocation parameters are bounded by zero and one and that the allocation parameters for each alternative sum to one. The log-likelihood function of the choice model is:

$$L = \sum_q \sum_i d_{qi} \log P_{qi} \tag{8}$$

where d_{qi} is 1 if individual *q* chooses alternative *i* and 0 otherwise; P_{qi} is the estimated probability that individual *q* chooses alternative *i*. The estimates of the MNL model provide starting values for the NL models. We search for numerous nested structures to obtain the preferred NL model. The estimation results of the NL models are used as a basis to search for the best GNL model. Finally, the estimations of the COVGNL model are based on the preferred GNL specification.

Because the log-likelihood function for the GNL and COVGNL model is not negative semi-definite, repeated optimization with different starting values may be required. If the sample is choice-based with known population shares, the weighted exogenous sample maximum likelihood method is used.

3. ESTIMATION RESULTS

The empirical analysis attempts to understand long distance travelers' preferences for buses equipped with seats or sleepers on the lower deck. This study interviewed the passengers traveling in the Taipei-Kaohsiung (about 400km) and Taipei-Taichung (about 200km) corridors in 2001. The pictures of new long distance bus services were shown to respondents who were required to answer their current use of travel modes, including bus with seats on the upper deck, air, car and train. The SP survey instrument includes alternative scenarios of combining bus fare and frequency attributes for two hypothetical bus classes, the lower deck sleeper and seat. The lower deck sleeper includes a private cabin with a single bed, a liquid crystal television and a reading light. The lower deck seat does not have a private cabin but includes a reclining 90-degree seat, a liquid crystal television, a reading light, and a roomy space than seats on the upper deck. The fare of two bus classes on the lower deck is higher than that of seats on the upper deck. The lower deck sleeper is more expensive than the lower deck seat. Service frequency is the same for new bus service classes, but is few than a regular long distance bus with seats on the upper deck. It is hypothesized that each long distance bus has seats on the upper deck but not every bus includes the lower deck seat or sleeper.

The SP survey asked each respondent to choose from two new bus service classes or their current use of travel modes and included 3 replications for each respondent. A sample of 1,174 individuals was collected. The distribution of the sample which was collected from current intercity modes includes bus (671, 57%), train (191, 16%), air (220, 18%), and car (92, 9%). 56 percent travelers are male. 70 percent travelers are under age 30. 54 percent respondents have monthly income under NT$30,000.

The utility function specifications include level of service, individual and trip characteristics, and quality-of-service variables. The quality-of-service variables, such as privacy, safety, and convenience, are 0-1 dummy variables that have the value 1 if an individual places importance on the items. Each respondent was asked to select at most three important service quality factors. Trip purpose variable has the value 1 if a traveler engages in a business trip and 0 otherwise.

Table 1 reports the estimation results of the MNL, NL, GNL, and COVGNL models. The estimation result of the MNL model (column 1) indicates that high-income travelers prefer to select car, while travelers for business trip are more likely to choose air. Travelers who consider privacy to be important are more likely to select the lower deck sleeper. Travelers who consider safety as an important quality-of-service factor are less likely to choose the lower deck sleeper and seat. In case of a traffic incident occurred, some people might concern that passengers in the lower deck cannot escape easily. The parameters of the MNL models have expected signs and are significantly different from zero at the 0.10 level of significance.

Two NL models (columns 2 and 3) have the logsum parameters within the zero-one range and significantly different from one. These are the NL models with the logsum parameters for the lower deck sleeper and seat in a nest and the lower deck sleeper and upper deck seat in a nest.

The two NL models significantly reject the MNL model. The implied utility function correlations of the two NL models are very high (0.99 for the lower deck sleeper and seat in a nest and 0.68 for the lower deck sleeper and upper deck seat in a nest). The NL model with the logsum parameter for the lower deck sleeper and seat in a nest rejects another NL model at a high level of significance using the non-nested test (Horowitz, 1983) and is the preferred NL model. This implies a higher degree of substitution between the lower deck sleeper and seat.

Estimation results for the GNL and COVGNL models are reported in columns 4, 5 and 6. The nested structure of the preferred GNL model (column 4) includes air alone, train alone, car alone, the lower deck sleeper and seat nest, and the lower deck sleeper and upper deck seat nest (Figure 1). This model rejects the preferred NL models with the likelihood ratio test $\chi^2 = 12.2$, given a χ^2 statistic 7.8 with 3 degrees of freedom at the 0.05 level of significance. The preferred GNL model obtains the logsum parameters that are significantly different from one.

The GNL model 2 (column 5) is the corresponding GNL model 1 (column 4) with the parameterized logusm parameter but no covariance heterogeneity. The t-values for the constants in the GNL model 2 are not showed because the test of the constant parameters is against positive infinity. The estimations of the COVGNL model are based on the preferred GNL specification. The final COVGNL model (column 6) rejects the preferred GNL models with the likelihood ratio test $\chi^2 = 10.4$, given a χ^2 statistic 9.5 with 4 degrees of freedom at the 0.05 level of significance. The preferred COVGNL model indicates that the parameters representing covariance heterogeneity for both nests are significant. There are significant differences in the correlations between the utilities of nested alternative across individuals with different income earnings and gender.

A positive coefficient of income parameter for lower deck sleeper and seat in a nest indicates that the unobserved perception (such as comfort and convenience) of the lower deck sleeper and seat may vary substantially more among high-income travelers than those low-income travelers. High-income travelers are more likely to use air and car and able to perceive the difference between two new bus service classes. The larger perceived variability among high-income travelers reduces the correlation (similarity) between the two new bus classes. It implies that a higher degree of substitution between the lower deck sleeper and seat for low-income travelers relative to high-income travelers.

A negative coefficient of income parameter for the lower deck sleeper and upper deck seat in a nest indicates a lower degree of substitution for low-income travelers than for high-income travelers. Currently, the upper deck seat is a regular service class. Low-income persons are more likely to use bus for long distance traveling than high-income persons and perceive the difference between the lower deck sleeper and upper deck seat in comfort and convenient levels. Further, the lower deck sleeper is more expensive than the other two bus service classes. As a result, low-income travelers are less likely to substitute between the lower deck sleeper and a regular bus seat on the upper deck. The parameters of the gender variable (1 for female and 0 for male) in the COVGNL model are negative, implying that female is more sensitive to unobserved perception than male. Therefore, male travelers had a higher degree of substitution between nested alternatives than female travelers.

The differences in the estimated models may lead to different in forecasts of passengers' ridership. The empirical findings provide valuable behavioral insights and serve a basis for evaluating the ridership potential for the proposed new bus services.

4. CONCLUSIONS

This paper investigates long distance travelers' preferences for new bus services in which buses are equipped with sleepers or seats on the lower deck. The SP survey was designed to collect travelers' choice preferences. This paper adopts the COVGNL model to take account of flexible substitution patterns among alternatives and to allow heterogeneity across individuals in the covariance among nested alternatives. The COVGNL model is estimated by employing a constrained maximum likelihood method.

This study interviewed passengers traveling in the Taipei-Kaohsiung and Taipei-Taichung corridors in Taiwan. The empirical analysis includes the estimations of the MNL, NL, GNL and CONGNL models. The estimation results of the MNL model indicate that high-income travelers prefer to choose car. Travelers who place important on privacy tend to prefer the choice of the lower deck sleeper. Travelers considering safety to be important are less likely to choose the lower deck sleeper and seat.

Two NL models have the logsum parameters within the zero-one range and significantly different from one. The NL models with the logsum parameters for the lower deck sleeper and seat in a nest and the lower deck sleeper and upper deck seat in a nest significantly rejected the MNL model. The preferred NL model implies a higher degree of substitution between the lower deck sleeper and seat. The preferred COVGNL model rejects the MNL, NL and GNL models at a high level of significance. The COVGNL model indicates that the parameters representing covariance heterogeneity for the logsum parameters are significant, which implies a significant difference in the correlation between the utilities of nested alternative across individuals with different income earnings and gender. The empirical findings provide valuable behavioral insights on long distance travelers' preferences and serve a basis for evaluating the ridership potential for the proposed new bus services.

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REFERENCES

Aptech Systems (1995) **Gauss applications: constrained maximum likelihood**, Aptech Systems. Inc., Maple Valley, WA.

Bhat, C.R. (1995) A heteroscedastic extreme value model of intercity mode choice, **Transportation Research Part B, Vol. 29,** 471-483.

Bhat, C.R. (1997) Covariance heterogeneity in nested logit models: econometric structure and application to intercity travel, **Transportation Research Part B, Vol. 31,** 11-21.

Daganzo, C. (1979) **Multinomial probit: the theory and its application to demand forecasting**. Academic Press, New York.

Daganzo, C. and Kusnic, M. (1993) Two properties of nested logit model, **Transportation Science, Vol. 27,** 395-400.

Hensher, D.A. (1998) Intercity rail services: a nested logit stated choice analysis of pricing options, **Journal of Advanced Transportation, Vol. 32,** 130-151.

Hensher, D.A. and Greene, W.H. (2003) The mixed logit model: the state of practice, **Transportation, Vol. 30**, 133-176.

Horowitz, J.H. (1983) Statistical comparison of non-nested probabilistic discrete choice models, **Transportation Science, Vol. 17**, 319-350.

Horowitz, J.H. (1991) Reconsidering the multinomial probit model, **Transportation Research Part B, Vol. 25,** 433-438.

Koppelman, F.S. and Wen, C.-H. (2000) The paired combinatorial logit model: properties, estimation and application, **Transportation Research Part B, Vol. 34**, 75-89.

McFadden, D. (1973) Conditional logit analysis of qualitative choice behavior, In Zaremmbka, P. (ed.), **Frontiers in Econometrics**, Academic Press, New York.

McFadden, D. (1978) Modeling the choice of residential location, **Transportation Research Record, 672**, TRB, National Research Council, Washington, D.C., 72-77.

McFadden, D. and Train, K. (2000) Mixed MNL models for discrete response, **Journal of Applied Econometrics, Vol. 15**, 447-470.

Sethi, V. (2000) **Modeling complex substitution patterns with variance and covariance heterogeneity in long distance travel choice models**, Ph.D. Dissertation, Civil Engineering, Northwestern University.

Small, K. (1987) A discrete choice model for ordered alternatives, **Econometrica, Vol.55,** 409-424.

Vovsha, P. (1997) Application of cross-nested logit model to mode choice in the Tel Aviv, Israel, metropolitan area, **Transportation Research Record, 1607**, TRB, National Research Council, Washington, D.C., 6-15.

Wen, C.-H. and Koppelman, F.S. (2001) The generalized nested logit model, **Transportation Research Part B**, **Vol. 35,** 627-641.

Williams, H.C.W.L. (1977) On the formation of travel demand models and economic evaluation measures of user benefit, **Environment and Planning**, **Vol. 9A**, 285-344.

Table 1. Estimation results of the MNL, NL, GNL and COVGNL models

Variables	MNL Model	NL Model 1	NL Model 2	GNL Model 1	GNL Model 2	COVGNL Model
Alternative specific constants						
Train	1.3187 (5.0)	1.3306 (5.1)	1.3903 (5.3)	1.3855 (5.3)	1.3855 (5.3)	0.9399 (4.0)
Air	1.0668 (1.8)	1.0664 (1.8)	0.5147 (0.9)	0.5800 (1.0)	0.5800 (1.0)	0.2100 (0.4)
Upper deck seat	0.5908 (2.2)	0.4655 (1.7)	0.7640 (2.8)	0.6038 (2.2)	0.6038 (2.2)	-0.2068 (-1.2)
Lower deck sleeper	-0.6786 (-2.8)	-0.4928 (-2.1)	0.7271 (3.1)	0.7399 (3.3)	0.7399 (3.3)	-0.1617 (-0.8)
Lower deck seat	0.3761 (1.6)	0.3213 (1.4)	0.7131 (3.0)	0.5685 (2.4)	0.5685 (2.4)	-0.2431 (-1.5)
Car (base)						
Total travel cost	-0.0013 (-2.6)	-0.0013 (-2.6)	-0.0007 (-1.4)	-0.0008 (-1.6)	-0.0008 (-1.6)	-0.0014 (-7.0)
Income (specific to car)	0.7164 (2.2)	0.7234 (2.2)	0.7373 (2.3)	0.7361 (2.3)	0.7361 (2.3)	1.5666 (3.3)
Trip purpose (specific to air)	0.5025 (1.9)	0.4047 (1.8)	0.0407 (1.1)	0.0441 (1.2)	0.0441 (1.2)	-0.1882 (-0.6)
Privacy dummy (specific to lower deck sleeper)	0.6826 (2.5)	0.6331 (2.8)	0.0386 (1.1)	0.0453 (1.2)	0.0453 (1.2)	0.2453 (3.0)
Comfort dummy (specific to air)	0.7407 (3.1)	0.7374 (3.1)	0.7272 (3.1)	0.7264 (3.1)	0.7264 (3.1)	1.2241 (4.7)
Safety dummy (specific to lower deck sleeper and seat)	-0.1589 (-1.8)	-0.1529 (-1.8)	-0.1460 (-1.6)	-0.1445 (-1.7)	-0.1445 (-1.7)	-0.3156 (-2.8)
Frequency dummy (specific to air)	-0.5962 (-2.4)	-0.5270 (-2.5)	-0.0335 (-1.0)	-0.0419 (-1.1)	-0.0419 (-1.1)	-0.1373 (-0.9)
Convenience dummy (specific to car)	1.2537 (4.3)	1.2534 (4.3)	1.2312 (4.3)	1.2348 (4.3)	1.2348 (4.3)	1.8383 (4.8)
Travel time dummy (specific to air)	1.0348 (3.9)	1.0398 (3.9)	0.9541 (3.6)	0.9634 (3.6)	0.9634 (3.6)	1.2162 (4.4)
Logsum parameter (t-value versus 1)						
Upper deck seat – Lower deck sleeper nest		0.5693 (4.7)		0.0605 (32.4)		
Lower deck seat – Lower deck sleeper nest			0.0730 (17.4)	0.0540 (25.7)		
Allocation parameter						
Upper deck seat – Lower deck sleeper nest						
Upper deck seat				1.0000	1.0000	1.0000
Lower deck sleeper				0.1494 (3.7)	0.1494 (3.7)	0.1646 (5.1)
Lower deck seat – Lower deck sleeper nest						
Lower deck seat				1.0000	1.0000	1.0000
Lower deck sleeper				0.8506 (21.0)	0.8506 (21.0)	0.8354 (25.9)
Train nest				1.0000	1.0000	1.0000
Car nest				1.0000	1.0000	1.0000
Air nest				1.0000	1.0000	1.0000
Covariance heterogeneity parameter						
Upper deck seat – Lower deck sleeper nest						
Constant					2.4106 (*)	2.8717 (*)
Income						-0.0613 (-4.4)
Gender						-1.3249 (-4.2)
Lower deck seat – Lower deck sleeper nest						
Constant					2.8635 (*)	-2.5536 (*)
Income						0.0258 (4.8)
Gender						-1.0117 (-2.5)
Log-likelihood at zero	-1091.8	-1091.8	-1091.8	-1091.8	-1091.8	-1091.8
Log-likelihood at convergence	-894.7	-887.8	-882.8	-876.7	-876.7	-871.5
Likelihood ratio index	0.1805	0.1868	0.1914	0.1970	0.1970	0.2018
Likelihood ratio test versus MNL		13.8 > 3.8	23.8 > 3.8	36.0 > 3.8	36.0 > 3.8	46.4 > 3.8

Note: Values in parentheses are t-statistics.

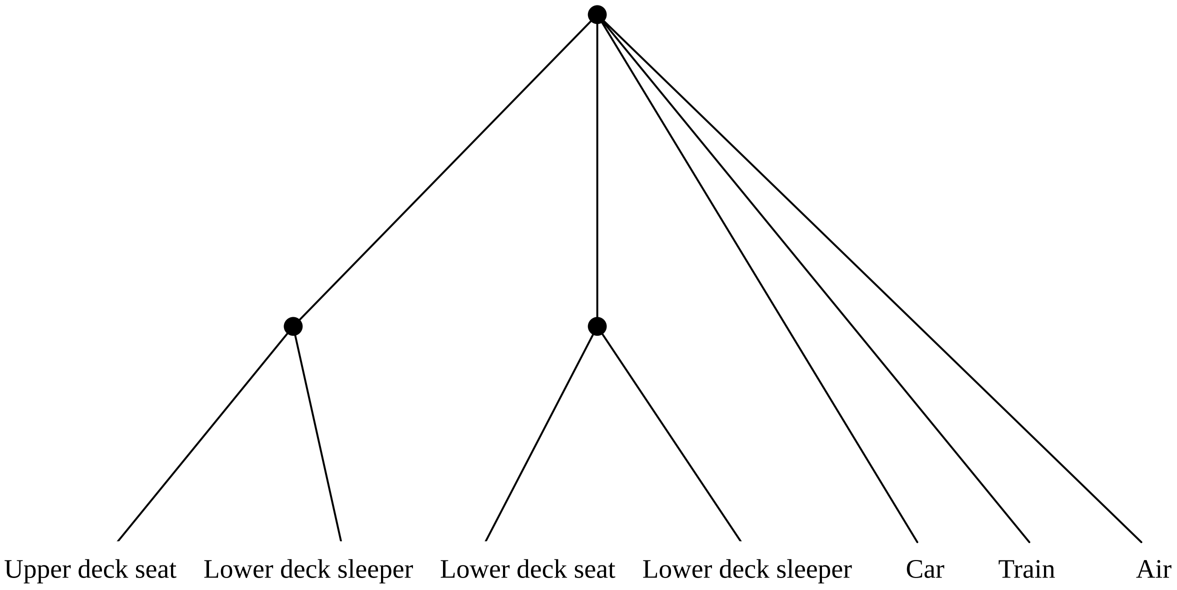

Figure 1. The nested structure of the preferred GNL model