Las Condes – Centro Corridor Case Study

Logit Model Developments by Naomi Panjaitan for the TTP 289A course

Abstract

This study develops and compares the multinomial logit model, nested logit model, and cross-nested logit model using a case study of transport mode choice for commute trips in the Las Condes – Centro corridor of Santiago, Chile (Ortuzar and Donoso, 1983). Using the R package of Apollo, this study ran 10 logit models in total: 4 multinomial logit models, 5 nested logit models, and 1 cross-nested logit model (Bunch et al., 1993; Hess & Palma, 2019). Model improvements are done by introducing one-by-one the effect of income on the alternatives' attributes, the effect of decision-makers' characteristics, and both. The nested model and cross-nested logit model divide the alternatives into private use or public use of mode. The results show that the income holds a significant impact on the utility. The interaction between income and travel costs changes the utility's trajectory. Moreover, the nesting is based on the interaction between income and travel costs. It calls transit agencies and policy-makers to review the public transportation fare and its market target to be more sensitive to income level.

Introduction

This study aims to develop logit models from simple multinomial logit models to nested-form logit models using a case study in Santiago, Chile. The data set consists of revealed preferences for work trips for the Las Condes – Centro corridor in the morning peak (Ortuzar and Donoso, 1983). There are 9 alternatives with names and definitions as below.

1. Auto : Driving a car
2. Companion : Being dropped-off/picked-up by a family member of a friend
3. Taxi : Riding a shared taxi (i.e. there are several unrelated people in the taxi)
4. Metro : Riding a subway train
5. Bus : Riding a bus
6. Auto-metro : Driving a car then transfer to riding a subway train
7. Companion-metro : Being dropped-off/picked-up then transfer to riding a subway train
8. Taxi-metro : Riding a shared taxi then transfer to riding a subway train
9. Bus-metro : Riding a bus then transfer to riding a subway train

Train (2009) defines the multinomial logit model as the following, "the standard logit model exhibits independence from irrelevant alternative s(IIA), which implies proportional substitution across alternatives." Meanwhile, the nested logit model extends the standard logit modeling to account for the reliance across responses by categorizing alternatives into bigger categories or nests. The probability ratio of alternatives in the same nest is independent of the existence of alternatives in other nests (i.e. IIA holds within each nest), while the probability ratio of alternatives in different nests depends on the alternatives' attributes in the two nests (i.e. IIA does not hold for alternatives in other nest) (Train, 2009).

Tasks

In developing the logit models, I ran 10 models from 3 types of logit modeling: the Multinomial Logit Model (MNL), the Nested Logit Model (NL), and the Cross-Nested Logit Model (CNL) using the Apollo package of R and the BGW algorithm (Bunch et al., 1993; Hess & Palma, 2019). I started by looking at the effect of alternatives' attributes only, then I added either the effect of wage rate or the decision-makers characteristics (socio-demographic). Finally, I looked at the effect of the alternatives' attributes, the effect of wage rate, and the decision-makers' characteristics. This development is applied to the MNL and the NL models. For the NL model, I looked at two types of nesting: (1) whether the mode belongs to the decision-makers (private) or the mode is shared with others (public), and (2) whether the mode is used solely privately (private), shared (public), or required transfer (transfer). As for the CNL model, I only develop the cross-nesting between private or public definitions of using the mode. The model development is summarised in Table 1.

Table 1. Logit models summary

MNL	**NL**	**CNL**
MNL-1 Effect: Attributes only	NL-1 Effect: Attributes only Nests: Private / Public vehicle	--
MNL-2 Effect: Attributes + wage rate	NL-2 Effect: Attributes + wage rate Nests: Private / Public vehicle	--
MNL-3 Effect: Attributes + demographic	NL-3 Effect: Attributes + demographic Nests: Private / Public vehicle	--
MNL-4 Effect: Attributes + wage rate + demographic	NL-4 Effect: Attributes + wage rate + demographic Nests: Private / Public vehicle	CNL-4 Effect: Attributes + wage rate + demographic Nests: Private / Public vehicle
--	NL-4a Effect: Attributes + wage rate + demographic Nests: Private / Public / Transfer	--

Nested Logit

In the Nested Logit model (NL), I made 2 kinds of nesting with the utility function being the same as the utility function of MNL_4.

1. NL_4 (Private/Public): The decision-makers choose to use private transport modes (i.e. modes that they own) or public transport modes (i.e. modes that they shared with non-household-members). This approach is based on the assumption that the decision-makers would think about whether they want to use their household car they own or take public transportation. This decision may depend on the willingness of the decision-makers to share the mode with non-household members or not.
2. NL_4a (Private/Public/Transfer): The decision-makers choose to use private transport modes (i.e. modes that they own), public transport modes (i.e. modes that they shared with non-household-members), or having a transfer from one mode to another regardless of the private/public nature. In this case, we assume that the decision-makers want to choose between using a single mode to their destination or using a combination of modes by transferring from one mode to another. The single mode is divided between private vehicle or public transportation as using these two kinds of modes imposes different travel behaviors.

I tried at least three other nesting models – such as a division between a single mode or a combination of modes; a division between a single private mode, a single public mode, a combination with private modes, and a combination with public modes; and a division between private modes, shared taxi, and public transportation. However, the modeling results gave a nesting parameter of more than 1 which means that these nestings did not work.

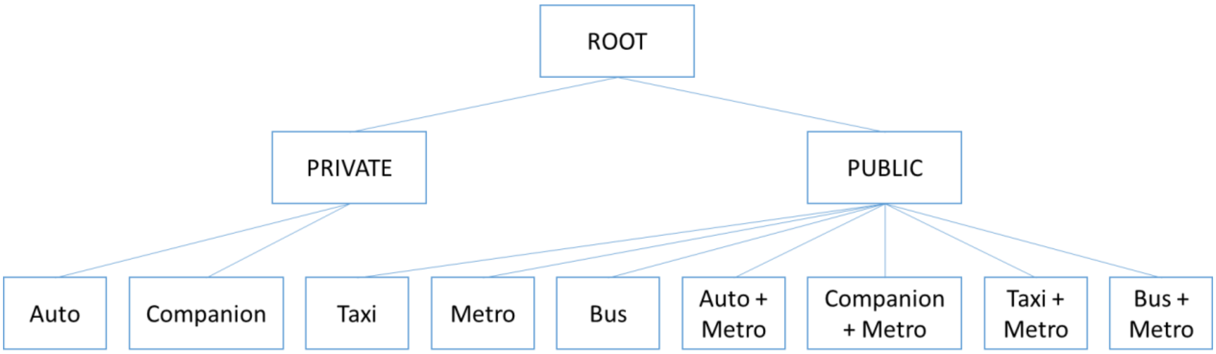

Figure 1. Nested Model NL_4

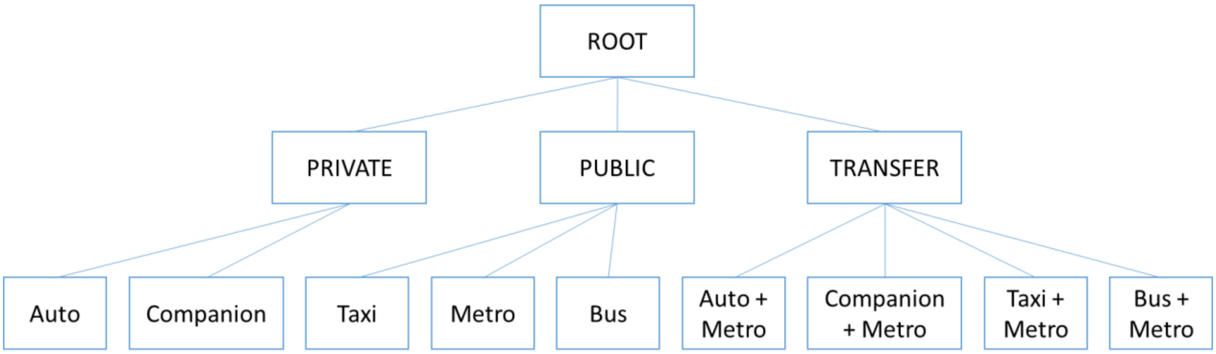

Figure 2. Nested Model NL_4a

Cross-Nested Logit

For the Cross-Nested Logit model (CNL), I developed the first NL model (NL_4) in which the categories are Private modes and Public modes of transportation. The utility function for the Cross-Nested Logit model CNL_4 is the same as the utility function of MNL_4.

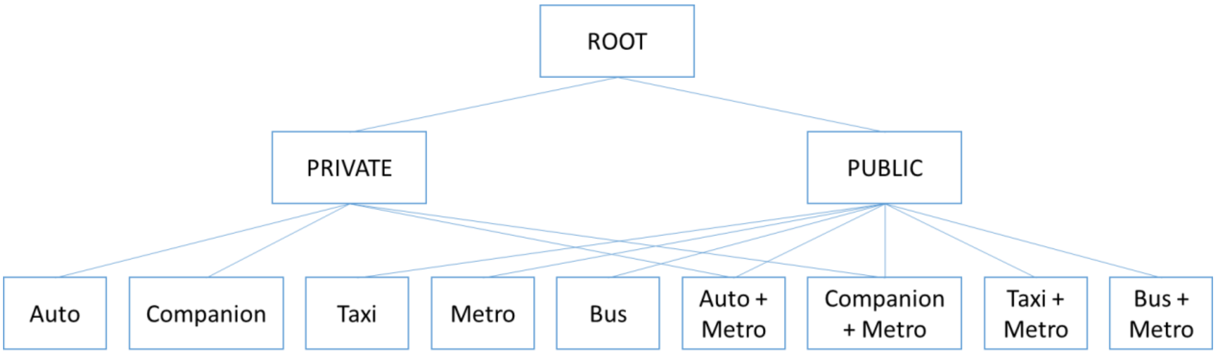

Figure 3. Cross-Nested Model CNL_4

In the Cross-Nested Logit model, there is a nest allocation parameter of α for alternatives included in multiple nests that represents the degree of correlation of each alternative to the respective nest.. Therefore, in this case, the "Auto + Metro" choice and the "Companion + Metro" choice have the nest allocation parameters of α in which the value is smaller than 1. This parameter The table below illustrates the position of the nest allocation parameters.

Table 2. Nest allocation parameters

	Auto	Companion	Taxi	Metro	Bus	Auto + Metro	Companion + Metro	Taxi + Metro	Bus + Metro
Private	1	1	0	0	0	$\alpha_{AutoMetro\_private}$	$\alpha_{CompMetro\_private}$	0	0
Public	0	0	1	1	1	$\alpha_{AutoMetro\_public}$	$\alpha_{CompMetro\_public}$	1	1

Discussion

From the modeling results summarised in Table 3, Table 4, and Table 5, the models generally show a slight improvement based on the goodness of fit (i.e. the value of final log-likelihood, the adjusted Rho-square, the AIC, and the BIC) for both the multinomial logit model (MNL) and the nested logit model (NL) as the wage rate and the socio-demographic are considered in the estimation models. The likelihood-ratio test results in Table 6, Table 7, and Table 8 show that as the models are improved, the latter model is significantly different from the preceding model (p-value < 0.05). However, the p-value of CNL_4 model is greater than 0.05 (p-value=0.1653) when being compared to the NL_4 model. This means that the simple two-level nesting and the cross-nesting are not significantly different from each other.

In the comparison between each multinomial logit model (Table 3) and between each nested logit model (Table 4), a remarkable difference is found when the wage rate is included in the model. When the wage rate is included, some change from negative to positive, and others change from positive to negative. Although the significance levels are not that great, this means that the interaction between income and alternatives' attributes has a significant impact on the utility of choosing a commute mode of transportation. The same thing applies to men in their utility on choosing the bus, the combination of auto + metro, and the combination of companion + metro. Without considering the effect of income interacting with alternatives' attributes, the utilities on these alternatives for men are negative. However, when income is taken into account in the form of the wage rate, the utilities become positive. The parameter of the trade-off between travel cost and time (a) for MNL_2 (without the socio-demographic effect) and MNL_4 (with the socio-demographic effect) are 0.23 and 0.24 respectively. Having a value closer to 0 than 1, both indicate that income affects travel cost more than travel time.

When the Multinomial Logit Model of MNL_4, the Nested Logit Model of NL_4, and the Cross-Nested Logit Model of CNL_4 are compared, both the Nested Logit Model of NL_4 and the Cross-Nested Logit Model of CNL_4 show better fit than the Multinomial Logit Model of MNL_4. Meanwhile, the goodness of fit of the Nested Logit Model of NL_4 and the Cross-Nested Logit Model of CNL_4 are only slightly different from each other.

In terms of the coefficient estimates, the only differences between the nested model and the non-nested model are in the effect of travel cost in being dropped-off/picked-up (companion) and in the effect of alighting time when riding the metro. In the case of the travel cost of being dropped-off/picked-up (companion), nesting makes the utility trajectory change from negative to positive like the effect of the travel cost on the utility of driving a car (auto). This reflects the mental map of the decision-makers when considering the travel cost of being dropped-off/picked-up (companion) and of driving a car (auto) are indifferent as they see these two alternatives under one nest of using a private vehicle. As for the change in the effect of the alighting time in riding the metro, nesting makes the utility trajectory change from negative to positive like the effect of the alighting time in riding the bus. This means that nesting highlights the effect of alighting time in riding the metro and riding the bus being indifferent as the decision-makers perceive both as public transportation.

A significant difference is found in the parameters of the trade-off between travel cost and time of MNL_4, NL_4, and CNL_4. As nesting gets introduced, the trade-off parameter is closer to 0. Moreover, the more complex the nesting (CNL compared to NL), the closer the trade-off parameter is to 0. This indicates that the basis of nesting is related to the travel cost more than to the travel time. The decision-makers perceive the division between private and public transport modes based on the travel cost of using the mode.

Conclusions

The estimation modeling shows that nested models are better than the standard multinomial logit models. However, this example shows no improvement when the nested model becomes a cross-nested model. On the other hand, the interaction between income and travel cost holds a significant impact on the utility. It does not only change the utility trajectory from being positive to negative (and vice versa) but also it defines the nesting division. This finding calls the attention of public transit agencies and policy-makers to review the public transit's fare and its target market based on income level.

References

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Ortúzar, J.de D. and Donoso, P. (1983), "Survey design, implementation, data coding and evaluation for the estimation of disaggregate choice models in Santiago de Chile", Second International Conference on New Survey Methods in Transport. Hungerford Hill Village, 12-16 Septiembre de 1983, Sidney.

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Appendix A. Model specification

MNL_1

```
V[["auto"     ]] = asc_auto      + b_tt_auto      * TDV1 + b_tc_auto      * CTOT1 + b_acs_auto      * TCAM1
V[["companion"]] = asc_comp      + b_tt_comp      * TDV2 + b_tc_comp      * CTOT2 + b_acs_comp      * TCAM2
V[["taxi"     ]] = asc_taxi      + b_tt_taxi      * TDV3 + b_tc_taxi      * CTOT3 + b_acs_taxi      * TCAM3 + b_alt_taxi  * TESP3
V[["metro"    ]] = asc_metro     + b_tt_metro     * TDV4 + b_tc_metro     * CTOT4 + b_acs_metro     * TCAM4 + b_alt_metro * TESP4
V[["bus"      ]] = asc_bus       + b_tt_bus       * TDV5 + b_tc_bus       * CTOT5 + b_acs_bus       * TCAM5 + b_alt_bus   * TESP5
V[["autometro"]] = asc_autometro + b_tt_autometro * TDV6 + b_tc_autometro * CTOT6 + b_acs_autometro * TCAM6 + b_alt_metro * TESP4
V[["compmetro"]] = asc_compmetro + b_tt_compmetro * TDV7 + b_tc_compmetro * CTOT7 + b_acs_compmetro * TCAM7 + b_alt_metro * TESP4
V[["taximetro"]] = asc_taximetro + b_tt_taximetro * TDV8 + b_tc_taximetro * CTOT8 + b_acs_taximetro * TCAM8 + b_alt_metro * TESP4
V[["busmetro" ]] = asc_busmetro  + b_tt_busmetro  * TDV9 + b_tc_busmetro  * CTOT9 + b_acs_busmetro  * TCAM9 + b_alt_metro * TESP4
```

MNL_2

```
V[["auto"     ]] = asc_auto      + b_tt_auto      * TDV1 * (-w^a) + b_tc_auto      * CTOT1 * (-w^(a-1)) + b_acs_auto      * TCAM1
V[["companion"]] = asc_comp      + b_tt_comp      * TDV2 * (-w^a) + b_tc_comp      * CTOT2 * (-w^(a-1)) + b_acs_comp      * TCAM2
V[["taxi"     ]] = asc_taxi      + b_tt_taxi      * TDV3 * (-w^a) + b_tc_taxi      * CTOT3 * (-w^(a-1)) + b_acs_taxi      * TCAM3 + b_alt_taxi  * TESP3
V[["metro"    ]] = asc_metro     + b_tt_metro     * TDV4 * (-w^a) + b_tc_metro     * CTOT4 * (-w^(a-1)) + b_acs_metro     * TCAM4 + b_alt_metro * TESP4
V[["bus"      ]] = asc_bus       + b_tt_bus       * TDV5 * (-w^a) + b_tc_bus       * CTOT5 * (-w^(a-1)) + b_acs_bus       * TCAM5 + b_alt_bus   * TESP5
V[["autometro"]] = asc_autometro + b_tt_autometro * TDV6 * (-w^a) + b_tc_autometro * CTOT6 * (-w^(a-1)) + b_acs_autometro * TCAM6 + b_alt_metro * TESP4
V[["compmetro"]] = asc_compmetro + b_tt_compmetro * TDV7 * (-w^a) + b_tc_compmetro * CTOT7 * (-w^(a-1)) + b_acs_compmetro * TCAM7 + b_alt_metro * TESP4
V[["taximetro"]] = asc_taximetro + b_tt_taximetro * TDV8 * (-w^a) + b_tc_taximetro * CTOT8 * (-w^(a-1)) + b_acs_taximetro * TCAM8 + b_alt_metro * TESP4
V[["busmetro" ]] = asc_busmetro  + b_tt_busmetro  * TDV9 * (-w^a) + b_tc_busmetro  * CTOT9 * (-w^(a-1)) + b_acs_busmetro  * TCAM9 + b_alt_metro * TESP4
```

MNL_3

```
V[["auto"     ]] = asc_auto            + b_tt_auto      * TDV1 + b_tc_auto      * CTOT1 + b_acs_auto      * TCAM1
V[["companion"]] = asc_comp_value      + b_tt_comp      * TDV2 + b_tc_comp      * CTOT2 + b_acs_comp      * TCAM2
V[["taxi"     ]] = asc_taxi_value      + b_tt_taxi      * TDV3 + b_tc_taxi      * CTOT3 + b_acs_taxi      * TCAM3 + b_alt_taxi  * TESP3
V[["metro"    ]] = asc_metro_value     + b_tt_metro     * TDV4 + b_tc_metro     * CTOT4 + b_acs_metro     * TCAM4 + b_alt_metro * TESP4
V[["bus"      ]] = asc_bus_value       + b_tt_bus       * TDV5 + b_tc_bus       * CTOT5 + b_acs_bus       * TCAM5 + b_alt_bus   * TESP5
V[["autometro"]] = asc_autometro_value + b_tt_autometro * TDV6 + b_tc_autometro * CTOT6 + b_acs_autometro * TCAM6 + b_alt_metro * TESP4
V[["compmetro"]] = asc_compmetro_value + b_tt_compmetro * TDV7 + b_tc_compmetro * CTOT7 + b_acs_compmetro * TCAM7 + b_alt_metro * TESP4
V[["taximetro"]] = asc_taximetro_value + b_tt_taximetro * TDV8 + b_tc_taximetro * CTOT8 + b_acs_taximetro * TCAM8 + b_alt_metro * TESP4
V[["busmetro" ]] = asc_busmetro_value  + b_tt_busmetro  * TDV9 + b_tc_busmetro  * CTOT9 + b_acs_busmetro  * TCAM9 + b_alt_metro * TESP4

  asc_comp_value      = asc_comp      + asc_comp_shift_male      * SEXO + asc_comp_shift_auto * AUTLIC
  asc_taxi_value      = asc_taxi      + asc_taxi_shift_male      * SEXO
  asc_metro_value     = asc_metro     + asc_metro_shift_male     * SEXO
  asc_bus_value       = asc_bus       + asc_bus_shift_male       * SEXO
  asc_autometro_value = asc_autometro + asc_autometro_shift_male * SEXO + asc_autometro_shift_auto * AUTLIC
  asc_compmetro_value = asc_compmetro + asc_compmetro_shift_male * SEXO + asc_compmetro_shift_auto * AUTLIC
  asc_taximetro_value = asc_taximetro + asc_taximetro_shift_male * SEXO
  asc_busmetro_value  = asc_busmetro  + asc_busmetro_shift_male  * SEXO
```

MNL_4

```
V[["auto"     ]] = asc_auto            + b_tt_auto      * TDV1 * (-w^a) + b_tc_auto      * CTOT1 * (-w^(a-1)) + b_acs_auto      * TCAM1
V[["companion"]] = asc_comp_value      + b_tt_comp      * TDV2 * (-w^a) + b_tc_comp      * CTOT2 * (-w^(a-1)) + b_acs_comp      * TCAM2
V[["taxi"     ]] = asc_taxi_value      + b_tt_taxi      * TDV3 * (-w^a) + b_tc_taxi      * CTOT3 * (-w^(a-1)) + b_acs_taxi      * TCAM3 + b_alt_taxi  * TESP3
V[["metro"    ]] = asc_metro_value     + b_tt_metro     * TDV4 * (-w^a) + b_tc_metro     * CTOT4 * (-w^(a-1)) + b_acs_metro     * TCAM4 + b_alt_metro * TESP4
V[["bus"      ]] = asc_bus_value       + b_tt_bus       * TDV5 * (-w^a) + b_tc_bus       * CTOT5 * (-w^(a-1)) + b_acs_bus       * TCAM5 + b_alt_bus   * TESP5
V[["autometro"]] = asc_autometro_value + b_tt_autometro * TDV6 * (-w^a) + b_tc_autometro * CTOT6 * (-w^(a-1)) + b_acs_autometro * TCAM6 + b_alt_metro * TESP4
V[["compmetro"]] = asc_compmetro_value + b_tt_compmetro * TDV7 * (-w^a) + b_tc_compmetro * CTOT7 * (-w^(a-1)) + b_acs_compmetro * TCAM7 + b_alt_metro * TESP4
V[["taximetro"]] = asc_taximetro_value + b_tt_taximetro * TDV8 * (-w^a) + b_tc_taximetro * CTOT8 * (-w^(a-1)) + b_acs_taximetro * TCAM8 + b_alt_metro * TESP4
V[["busmetro" ]] = asc_busmetro_value  + b_tt_busmetro  * TDV9 * (-w^a) + b_tc_busmetro  * CTOT9 * (-w^(a-1)) + b_acs_busmetro  * TCAM9 + b_alt_metro * TESP4

  asc_comp_value       = asc_comp       + asc_comp_shift_male      * SEXO + asc_comp_shift_auto * AUTLIC
  asc_taxi_value       = asc_taxi       + asc_taxi_shift_male      * SEXO
  asc_metro_value      = asc_metro      + asc_metro_shift_male     * SEXO
  asc_bus_value        = asc_bus        + asc_bus_shift_male       * SEXO
  asc_autometro_value  = asc_autometro  + asc_autometro_shift_male * SEXO + asc_autometro_shift_auto * AUTLIC
  asc_compmetro_value  = asc_compmetro  + asc_compmetro_shift_male * SEXO + asc_compmetro_shift_auto * AUTLIC
  asc_taximetro_value  = asc_taximetro  + asc_taximetro_shift_male * SEXO
  asc_busmetro_value   = asc_busmetro   + asc_busmetro_shift_male  * SEXO
```

Note:

`V` = observed utility

`asc` = alternate specific constant, the average effect of choosing the respective mode on the utility which captures all unobserved effect

`b_tt` = beta travel time, the effect of the travel time on the utility

`b_tc` = beta travel cost, the effect of the travel cost on the utility

`b_acs` = beta access time, the effect of time taken to access the mode on the utility

`b_alt` = beta alighting time, the effect of time taken to alight from the mode on the utility

`TDV` = travel time (minutes)

`CTOT` = travel cost (1981 Chilean dollars)

`TCAM` = access time (minutes)

`TESP` = alighting time (minutes)

`w` = wage rate, given $w = \frac{ILM}{WS \times 4 \times 60}$

`ILM` = the respondent’s monthly income (1981 Chilean dollars)

`WS` = weekly working hours (hours)

`a` = alpha, the trade-off parameter between travel time and cost

`SEXO` = the respondent’s sex

`AUTLIC` = the ratio of drivers and vehicles owned in the respondent’s household

Appendix B. Modeling Results

Table 3. Multinomial Logit Modeling results

Model name	MNL_1		MNL_2		MNL_3		MNL_4	
Number of observations	697		697		697		697	
Estimated parameters	38		39		49		50	
LL(final)	-912.67		-912.04		-900.35		-897.02	
Adj.Rho-square (0)	0.2341		0.2338		0.2352		0.2371	
Adj.Rho-square (C)	0.083		0.0826		0.0842		0.0865	
AIC	1901.33		1902.07		1898.7		1894.03	
BIC	2074.11		2079.4		2121.49		2121.37	
	estimate	Rob.t-ratio(0)	estimate	Rob.t-ratio(0)	estimate	Rob.t-ratio(0)	estimate	Rob.t-ratio(0)
asc_auto	0	NA	0	NA	0	NA	0	NA
asc_comp	-1.12510	-1.67	-0.74650	-1.14	-0.59290	-0.73	-0.33430	-0.43
asc_taxi	-2.90040	-1.87	-4.75240	-4.03	-2.86290	-1.83	-4.63350	-3.78
asc_metro	9.29850	1.30	-0.70010	-0.54	9.16920	1.31	-1.67390	-1.30
asc_bus	-1.46460	-0.63	-0.51940	-0.70	-1.41710	-0.62	-1.14650	-1.44
asc_autometro	-2.85530	-3.85	-2.78450	-3.11	-3.85320	-4.32	-3.79390	-3.61
asc_compmetro	-9.08270	-2.06	-3.47720	-3.59	-9.42120	-2.07	-3.90710	-3.75
asc_taximetro	-3.14300	-1.61	-4.32120	-2.77	-3.53270	-1.83	-5.04740	-3.24
asc_busmetro	-8.84900	-2.00	-2.97450	-3.35	-9.07330	-2.04	-3.45570	-3.73
b_tt_auto	-0.09680	-2.56	0.05210	1.17	-0.09890	-2.57	0.05160	1.13
b_tt_comp	-0.09520	-1.69	0.07200	1.75	-0.08860	-1.53	0.05880	1.50
b_tt_taxi	0.07500	1.66	-0.04340	-1.05	0.07380	1.61	-0.04230	-1.04
b_tt_metro	0.04690	0.60	-0.03930	-0.71	0.04850	0.60	-0.03930	-0.67
b_tt_bus	-0.11350	-5.29	0.07600	2.37	-0.11440	-5.29	0.07780	2.37
b_tt_autometro	-0.06820	-1.56	0.00790	0.23	-0.07850	-1.80	0.01290	0.35
b_tt_compmetro	-0.02790	-1.20	0.01020	0.63	-0.02900	-1.23	0.01210	0.74
b_tt_taximetro	0.01490	0.25	-0.02180	-0.47	0.00740	0.13	-0.01130	-0.26
b_tt_busmetro	-0.01180	-0.40	0.00470	0.24	-0.01180	-0.39	0.00500	0.26
b_tc_auto	-0.00670	-2.01	0.01930	1.70	-0.00700	-2.05	0.02040	1.72
b_tc_comp	0.00190	0.05	-0.06070	-1.10	0.00630	0.15	-0.04310	-0.77
b_tc_taxi	-0.04520	-1.90	-0.01750	-0.73	-0.04550	-1.86	-0.01340	-0.52
b_tc_metro	-0.73120	-1.35	-0.17740	-1.58	-0.74320	-1.41	-0.27530	-2.25
b_tc_bus	0.07110	0.63	-0.09680	-1.28	0.06590	0.58	-0.13400	-1.59

b_tc_autometro	0.01860	3.44	-0.02780	-1.65	0.02070	3.93	-0.03220	-1.98
b_tc_compmetro	0.44290	1.35	-0.17180	-2.09	0.47130	1.37	-0.21430	-2.35
b_tc_taximetro	-0.01470	-0.41	-0.04900	-1.43	-0.01200	-0.35	-0.06860	-2.10
b_tc_busmetro	0.18830	1.41	-0.06060	-1.79	0.19270	1.43	-0.07860	-2.19
b_acs_auto	-0.20570	-5.44	-0.20520	-5.13	-0.20580	-5.42	-0.20190	-4.99
b_acs_comp	-0.49370	-5.55	-0.49100	-5.47	-0.51370	-5.44	-0.50360	-5.31
b_acs_taxi	-0.09620	-1.82	-0.10130	-1.96	-0.09270	-1.74	-0.09330	-1.80
b_acs_metro	-0.07040	-1.76	-0.07420	-1.76	-0.09360	-2.21	-0.09370	-2.14
b_acs_bus	-0.10760	-2.81	-0.10460	-2.59	-0.10590	-2.75	-0.11370	-2.76
b_acs_autometro	-0.02930	-0.60	-0.04990	-1.01	-0.03720	-0.75	-0.05890	-1.17
b_acs_compmetro	-0.20500	-2.65	-0.21870	-2.78	-0.20220	-2.58	-0.21490	-2.73
b_acs_taximetro	-0.24420	-3.86	-0.23870	-3.72	-0.25450	-3.99	-0.25060	-3.74
b_acs_busmetro	-0.15900	-3.70	-0.15310	-3.64	-0.16020	-3.65	-0.15140	-3.53
b_alt_taxi	-0.10960	-0.13	-0.29950	-0.36	-0.10780	-0.13	-0.28050	-0.37
b_alt_metro	0.01730	0.03	-0.04580	-0.08	-0.00170	0.00	-0.05940	-0.11
b_alt_bus	0.00190	0.01	0.04970	0.32	0.01770	0.13	0.10760	0.68
alpha	NA	NA	1.21460	1.14	NA	NA	1.17060	1.06
a (The trade-off parameter)			0.22889				0.23675	
asc_auto_shift_male	NA	NA	NA	NA	0	NA	0	NA
asc_comp_shift_male	NA	NA	NA	NA	-0.76820	-1.93	-0.55280	-1.29
asc_taxi_shift_male	NA	NA	NA	NA	-0.17140	-0.43	-0.27600	-0.67
asc_metro_shift_male	NA	NA	NA	NA	0.89180	1.70	1.27050	2.28
asc_bus_shift_male	NA	NA	NA	NA	-0.02970	-0.10	0.73550	1.87
asc_autometro_shift_male	NA	NA	NA	NA	-0.21550	-0.68	0.05170	0.15
asc_compmetro_shift_male	NA	NA	NA	NA	-0.05580	-0.13	0.45840	0.92
asc_taximetro_shift_male	NA	NA	NA	NA	0.60150	1.17	1.08690	1.89
asc_busmetro_shift_male	NA	NA	NA	NA	0.03510	0.10	0.39970	1.05
asc_comp_shift_auto	NA	NA	NA	NA	-0.54620	-0.97	-0.57080	-1.04
asc_autometro_shift_auto	NA	NA	NA	NA	1.57790	3.19	1.41840	2.88
asc_compmetro_shift_auto	NA	NA	NA	NA	-0.13950	-0.27	-0.05550	-0.11

Table 4. Nested Logit Modeling results

Model name	NL_1		NL_2		NL_3		NL_4		NL_4a	
Number of observations	697		697		697		697		697	
Estimated parameters	40		41		51		52		53	
LL(final)	-907.06		-901.43		-891.66		-882.07		-891.98	
Adj.Rho-square (0)	0.237		0.2408		0.2406		0.2475		0.2387	
Adj.Rho-square (C)	0.0865		0.091		0.0907		0.0991		0.0885	
AIC	1894.11		1884.85		1885.33		1868.14		1889.96	
BIC	2075.98		2071.27		2117.21		2104.58		2130.94	
	estimate	Rob.t-ratio(0)	estimate	Rob.t-ratio(0)	estimate	Rob.t-ratio(0)	estimate	Rob.t-ratio(0)	estimate	Rob.t-ratio(0)
asc_auto	0	NA	0	NA	0	NA	0	NA	0	NA
asc_comp	-0.84650	-2.11	-0.55600	-1.91	-0.37300	-0.68	-0.15380	-0.38	-0.14420	-0.34
asc_taxi	-1.75040	-1.78	-2.23300	-2.59	-1.37780	-1.72	-1.84510	-2.44	-4.03790	-3.11
asc_metro	5.25230	1.18	-1.01590	-1.56	4.57440	1.29	-1.20710	-1.98	-1.30520	-1.09
asc_bus	-0.72680	-0.55	-0.67490	-1.58	-0.53290	-0.52	-0.88040	-1.83	-1.07710	-1.63
asc_autometro	-1.82330	-2.68	-1.27500	-2.17	-2.06400	-2.82	-1.51150	-2.32	-3.12190	-3.58
asc_compmetro	-4.80270	-1.70	-1.81780	-2.56	-3.76020	-1.70	-1.74400	-2.49	-2.95490	-3.17
asc_taximetro	-1.96610	-1.72	-2.04030	-2.37	-1.78590	-1.90	-1.98470	-2.45	-3.45350	-2.87
asc_busmetro	-4.74700	-1.73	-1.63740	-2.56	-3.70390	-1.74	-1.59720	-2.46	-2.88440	-3.67
b_tt_auto	-0.06930	-2.01	0.04470	1.40	-0.05510	-1.63	0.03580	1.12	0.06030	1.57
b_tt_comp	-0.06440	-1.55	0.03650	1.18	-0.04390	-1.08	0.01640	0.51	0.04660	1.33
b_tt_taxi	0.03130	1.13	-0.01680	-0.91	0.02160	1.03	-0.01340	-0.90	-0.04150	-0.96
b_tt_metro	0.06980	1.33	-0.07160	-1.73	0.07120	1.60	-0.07050	-1.77	-0.06020	-0.95
b_tt_bus	-0.06710	-2.90	0.04230	2.21	-0.05280	-2.57	0.03560	2.08	0.08240	2.97
b_tt_autometro	-0.04470	-1.52	0.02250	1.03	-0.03890	-1.52	0.02180	1.06	0.01180	0.43
b_tt_compmetro	-0.02060	-1.52	0.01060	1.20	-0.01710	-1.56	0.00960	1.27	0.01130	1.02
b_tt_taximetro	-0.00170	-0.05	-0.00200	-0.09	-0.00610	-0.25	-0.00040	-0.03	-0.00510	-0.20
b_tt_busmetro	-0.01310	-0.77	0.00830	0.74	-0.01100	-0.81	0.00630	0.68	0.00290	0.20
b_tc_auto	-0.00380	-1.25	0.00840	0.83	-0.00430	-1.38	0.00900	0.67	0.00910	0.64
b_tc_comp	0.00450	0.20	0.01210	0.47	0.00760	0.32	0.03320	1.08	0.02540	0.91
b_tc_taxi	-0.02520	-1.66	-0.01340	-1.34	-0.02010	-1.63	-0.01270	-1.44	-0.01290	-0.63
b_tc_metro	-0.45920	-1.37	-0.10730	-1.95	-0.41460	-1.53	-0.13180	-2.18	-0.27200	-2.45
b_tc_bus	0.02550	0.39	-0.09010	-2.27	0.01270	0.26	-0.09870	-2.27	-0.15710	-2.03
b_tc_autometro	0.00980	2.11	-0.01790	-2.05	0.00840	2.16	-0.01770	-1.99	-0.02780	-2.14

b_tc_compmetro	0.20920	1.09	-0.11510	-2.44	0.15450	1.03	-0.12180	-2.35	-0.16960	-2.20
b_tc_taximetro	-0.00770	-0.42	-0.02890	-2.08	-0.00460	-0.35	-0.03280	-2.32	-0.04960	-2.09
b_tc_busmetro	0.09150	1.20	-0.04400	-2.39	0.06720	1.16	-0.04790	-2.38	-0.07150	-2.60
b_acs_auto	-0.22570	-5.92	-0.23090	-6.18	-0.21710	-5.64	-0.22560	-5.34	-0.23820	-5.12
b_acs_comp	-0.37270	-5.06	-0.31010	-4.64	-0.38070	-4.60	-0.30060	-3.26	-0.32190	-3.07
b_acs_taxi	-0.06130	-1.91	-0.04870	-1.87	-0.04660	-1.79	-0.03750	-1.78	-0.07400	-1.59
b_acs_metro	-0.05710	-2.21	-0.05370	-2.36	-0.06730	-2.76	-0.05950	-2.53	-0.09550	-2.39
b_acs_bus	-0.07170	-2.67	-0.05390	-2.27	-0.05480	-2.31	-0.04330	-2.05	-0.09000	-2.18
b_acs_autometro	-0.03620	-1.29	-0.03360	-1.49	-0.03450	-1.46	-0.03070	-1.57	-0.07300	-2.15
b_acs_compmetro	-0.12270	-2.24	-0.09180	-2.04	-0.09360	-2.10	-0.07070	-1.97	-0.14710	-2.18
b_acs_taximetro	-0.14050	-2.68	-0.09960	-2.31	-0.11140	-2.44	-0.08110	-2.17	-0.14970	-2.03
b_acs_busmetro	-0.09590	-2.71	-0.06740	-2.32	-0.07380	-2.41	-0.05190	-2.15	-0.10500	-2.34
b_alt_taxi	-0.11420	-0.24	-0.19630	-0.60	-0.09530	-0.27	-0.16410	-0.64	-0.40160	-0.55
b_alt_metro	0.20630	0.62	0.13400	0.51	0.17630	0.71	0.08600	0.46	-0.22370	-0.40
b_alt_bus	-0.03260	-0.46	-0.01200	-0.22	-0.02420	-0.44	0.00680	0.15	0.05080	0.30
alpha	NA	NA	2.52200	1.27	NA	NA	3.11350	0.93	1.77100	1.35
a (The trade-off parameter)			0.07433				0.04255		0.14542	
asc_auto_shift_male	NA	NA	NA	NA	0	NA	0	NA	0	NA
asc_comp_shift_male	NA	NA	NA	NA	-0.47840	-1.76	-0.31550	-1.57	-0.33630	-1.60
asc_taxi_shift_male	NA	NA	NA	NA	-0.09340	-0.36	0.05280	0.19	-0.35580	-0.91
asc_metro_shift_male	NA	NA	NA	NA	0.50790	1.43	0.63180	1.82	1.05810	2.05
asc_bus_shift_male	NA	NA	NA	NA	-0.05150	-0.22	0.31560	1.14	0.49070	1.27
asc_autometro_shift_male	NA	NA	NA	NA	-0.12090	-0.50	0.08790	0.33	0.04980	0.17
asc_compmetro_shift_male	NA	NA	NA	NA	-0.03840	-0.14	0.24700	0.87	0.27510	0.78
asc_taximetro_shift_male	NA	NA	NA	NA	0.22660	0.77	0.42840	1.43	0.57240	1.29
asc_busmetro_shift_male	NA	NA	NA	NA	-0.00140	-0.01	0.25200	0.94	0.33470	1.07
asc_comp_shift_auto	NA	NA	NA	NA	-0.52550	-1.37	-0.45060	-1.69	-0.46870	-1.63
asc_autometro_shift_auto	NA	NA	NA	NA	0.86450	2.76	0.63570	2.55	1.17540	2.81
asc_compmetro_shift_auto	NA	NA	NA	NA	0.05630	0.26	0.07760	0.52	0.14120	0.48
lambda_private	0.46310	2.54	0.29560	1.83	0.46390	2.25	0.27100	1.14	0.29720	1.09
lambda_public	0.52800	3.16	0.36730	2.67	0.39650	2.88	0.28320	2.54	0.83460	4.70
lambda_transfer	NA	NA	NA	NA	NA	NA	NA	NA	0.45770	1.58

Table 5. Comparison between MNL, NL, and CNL modeling results

Model name	MNL_4		NL_4		CNL_4	
Number of observations	697		697		697	
Estimated parameters	50		52		54	
LL(final)	-897.02		-882.07		-880.27	
Adj.Rho-square (0)	0.2371		0.2475		0.2473	
Adj.Rho-square (C)	0.0865		0.0991		0.0989	
AIC	1894.03		1868.14		1868.53	
BIC	2121.37		2104.58		2114.06	
	estimate	Rob.t-ratio(0)	estimate	Rob.t-ratio(0)	estimate	Rob.t-ratio(0)
asc_auto	0	NA	0	NA	0	NA
asc_comp	-0.33430	-0.43	-0.15380	-0.38	-0.09460	-0.37
asc_taxi	-4.63350	-3.78	-1.84510	-2.44	-1.36030	-0.99
asc_metro	-1.67390	-1.30	-1.20710	-1.98	-0.93170	-1.16
asc_bus	-1.14650	-1.44	-0.88040	-1.83	-0.64590	-0.85
asc_autometro	-3.79390	-3.61	-1.51150	-2.32	-1.02420	-0.96
asc_compmetro	-3.90710	-3.75	-1.74400	-2.49	-1.20770	-1.07
asc_taximetro	-5.04740	-3.24	-1.98470	-2.45	-1.46720	-1.13
asc_busmetro	-3.45570	-3.73	-1.59720	-2.46	-1.16880	-1.04
b_tt_auto	0.05160	1.13	0.03580	1.12	0.02620	0.57
b_tt_comp	0.05880	1.50	0.01640	0.51	0.00870	0.22
b_tt_taxi	-0.04230	-1.04	-0.01340	-0.90	-0.01130	-0.84
b_tt_metro	-0.03930	-0.67	-0.07050	-1.77	-0.08040	-2.10
b_tt_bus	0.07780	2.37	0.03560	2.08	0.02860	1.34
b_tt_autometro	0.01290	0.35	0.02180	1.06	0.01870	0.94
b_tt_compmetro	0.01210	0.74	0.00960	1.27	0.00850	0.81
b_tt_taximetro	-0.01130	-0.26	-0.00040	-0.03	-0.00040	-0.07
b_tt_busmetro	0.00500	0.26	0.00630	0.68	0.00550	0.61
b_tc_auto	0.02040	1.72	0.00900	0.67	0.00500	0.78
b_tc_comp	-0.04310	-0.77	0.03320	1.08	0.02480	0.91
b_tc_taxi	-0.01340	-0.52	-0.01270	-1.44	-0.01030	-1.14
b_tc_metro	-0.27530	-2.25	-0.13180	-2.18	-0.11330	-1.50
b_tc_bus	-0.13400	-1.59	-0.09870	-2.27	-0.08410	-1.77
b_tc_autometro	-0.03220	-1.98	-0.01770	-1.99	-0.01440	-1.43

b_tc_compmetro	-0.21430	-2.35	-0.12180	-2.35	-0.09720	-1.60
b_tc_taximetro	-0.06860	-2.10	-0.03280	-2.32	-0.02650	-1.45
b_tc_busmetro	-0.07860	-2.19	-0.04790	-2.38	-0.03950	-1.53
b_acs_auto	-0.20190	-4.99	-0.22560	-5.34	-0.21870	-6.37
b_acs_comp	-0.50360	-5.31	-0.30060	-3.26	-0.26630	-4.20
b_acs_taxi	-0.09330	-1.80	-0.03750	-1.78	-0.02930	-0.99
b_acs_metro	-0.09370	-2.14	-0.05950	-2.53	-0.05050	-1.32
b_acs_bus	-0.11370	-2.76	-0.04330	-2.05	-0.03380	-1.09
b_acs_autometro	-0.05890	-1.17	-0.03070	-1.57	-0.02400	-0.88
b_acs_compmetro	-0.21490	-2.73	-0.07070	-1.97	-0.05700	-1.08
b_acs_taximetro	-0.25060	-3.74	-0.08110	-2.17	-0.06270	-1.08
b_acs_busmetro	-0.15140	-3.53	-0.05190	-2.15	-0.04010	-1.07
b_alt_taxi	-0.28050	-0.37	-0.16410	-0.64	-0.13360	-0.48
b_alt_metro	-0.05940	-0.11	0.08600	0.46	0.01500	0.19
b_alt_bus	0.10760	0.68	0.00680	0.15	0.00430	0.11
alpha	1.17060	1.06	3.11350	0.93	5.06540	0.20
a (The trade-off parameter)	0.23675		0.04255		0.00627	
asc_auto_shift_male	0	NA	0	NA	0	NA
asc_comp_shift_male	-0.55280	-1.29	-0.31550	-1.57	-0.26140	-1.71
asc_taxi_shift_male	-0.27600	-0.67	0.05280	0.19	0.02300	0.07
asc_metro_shift_male	1.27050	2.28	0.63180	1.82	0.46320	0.94
asc_bus_shift_male	0.73550	1.87	0.31560	1.14	0.22220	0.76
asc_autometro_shift_male	0.05170	0.15	0.08790	0.33	0.03700	0.19
asc_compmetro_shift_male	0.45840	0.92	0.24700	0.87	0.17300	0.60
asc_taximetro_shift_male	1.08690	1.89	0.42840	1.43	0.31060	0.98
asc_busmetro_shift_male	0.39970	1.05	0.25200	0.94	0.17620	0.60
asc_comp_shift_auto	-0.57080	-1.04	-0.45060	-1.69	-0.40490	-1.90
asc_autometro_shift_auto	1.41840	2.88	0.63570	2.55	0.49670	1.29
asc_compmetro_shift_auto	-0.05550	-0.11	0.07760	0.52	0.09200	0.49
lambda_private	NA	NA	0.27100	1.14	0.20430	1.39
lambda_public	NA	NA	0.28320	2.54	0.21730	1.23
a_AM_pb	NA	NA	NA	NA	0.93550	17.14
a_CM_pb	NA	NA	NA	NA	0.92920	18.73

Notes:
Green cells show a positive value, while red cells show a negative value.
The description of each coefficient is as below.

asc = alternate-specific value – it captures all unobserved effect on the utility
tc = travel cost – the cost needed to take use mode
tt = travel time – time spent from the origin to the destination using the mode
acs = access time – time taken to access the mode by walking
alt = alighting time – time taken to alight from the bus or metro
a = the parameter of the trade-off between travel time and travel cost
lambda = the nesting parameter – the degree of independence in unobserved utility among the alternatives in the same nest
a_XX_yy= the nest allocation parameter – the degree of correlation of each alternative to the respective nest (XX represents the alternative, yy represents the nest)

Appendix C. Likelihood Ratio Test

Multinomial Logit Model

Table 6. Likelihood-ratio test of Multinomial Logit models

	LL	par		
MNL_2	-912.04	39	Likelihood ratio test-value:	30.04
MNL_4	-897.02	50	Degrees of freedom:	11
Difference	15.02	11	Likelihood ratio test p-value:	0.001562
	LL	par		
MNL_3	-900.35	49	Likelihood ratio test-value:	6.66
MNL_4	-897.02	50	Degrees of freedom:	1
Difference	3.33	1	Likelihood ratio test p-value:	0.00986

Nested Logit Model

Table 7. Likelihood-ratio test of Nested Logit models

	LL	par		
NL_2	-901.43	41	Likelihood ratio test-value:	38.72
NL_4	-882.07	52	Degrees of freedom:	11
Difference	19.36	11	Likelihood ratio test p-value:	5.91e-05
	LL	par		
NL_3	-891.66	51	Likelihood ratio test-value:	19.18
NL_4	-882.07	52	Degrees of freedom:	1
Difference	9.59	1	Likelihood ratio test p-value:	1.19e-05

Cross-Nested Logit Model

Table 8. Likelihood-ratio test of Cross-Nested Logit models

	LL	par		
MNL_4	-897.02	50	Likelihood ratio test-value:	33.5
CNL_4	-880.27	54	Degrees of freedom:	4
Difference	16.75	4	Likelihood ratio test p-value:	9.436e-07
	LL	par		
NL_4	-882.07	52	Likelihood ratio test-value:	3.6
CNL_4	-880.27	54	Degrees of freedom:	2
Difference	1.80	2	Likelihood ratio test p-value:	0.1653