Investigating Preference Heterogeneity in Value of Time (VOT) and Value of Reliability (VOR) Estimation for Managed Lanes

Md Sakoat Hossan

FIU | FLORIDA INTERNATIONAL UNIVERSITY

Background

- Roadway pricing: A popular active transportation and demand management (ATDM) tool
  - Congestion levels, environmental issues, fiscal constraints
- Managed lanes: A set of lanes where operational strategies are proactively implemented and managed in response to changing conditions
- Challenges of Managed lanes facility
  - Pricing structure, revenue generation, transit operations, social equity concerns, access control, vehicle eligibility, design flexibility, enforcement etc.
- Understanding travel behavior of managed lane users is essential for prescribing solutions

Research Hypothesis

- VOT and VOR Estimation: Substantial variations
  - VOT Estimation Range: $3.88/hour ~ $47.50/hour
  - VOR Estimation Range: $2.31/hour ~ $57.45/hour
  - Estimation variation range: VOT = 0.55 to 3.22 VOR
- Treatment of user heterogeneity: current practice
  - User heterogeneity aspect of choice behavior is seldom incorporated to the full extent
  - Assume single estimate to represent the entire population
- Addressing User Heterogeneity
  - Identify what attributes lead to higher or lower VOT and VOR
  - Quantify the extent of influence on VOT and VOR estimation

Data Collection – Stated Preference

- Data Source
  - South Florida Expressway Stated Preference Survey
- Survey Period
  - 11/16/2011 – 12/15/2011
- Observations
  - 2,041respondents
  - 16,327 SP observations (8 different scenarios)
- Study Corridors and Respondent Share
  - I-95 between Golden Glades & SR 112
  - I-75 between I-595 and SR 826
  - SR 826 between SR 836 and I-95

Corridor	Number	Percentage
I-95	1060	52%
I-75	521	25.5%
SR 826	460	22.5%
Total	2041	100%

Data Processing - Revealed Preference

- Source
  - Regional Integrated Transportation Information Systems (RITIS)
- Survey Period
  - 01/01/2012 – 12/31/2012
- Study Corridors
  - I-95 between Golden Glades & SR 112
- Travel Time Distribution
  - 24 by 365 for each facility type by direction

Figure: a) I-95 NB GP b) I-95 NB ML c) I-95 SB GP d) I-95 SB ML

Reliability Measure Estimation

- Semi-standard deviation
- Expected to capture unique benefits offered by the MLs
- A temporal variation is also expected by TOD, as peak periods may have higher variation of travel time compared with off-peak

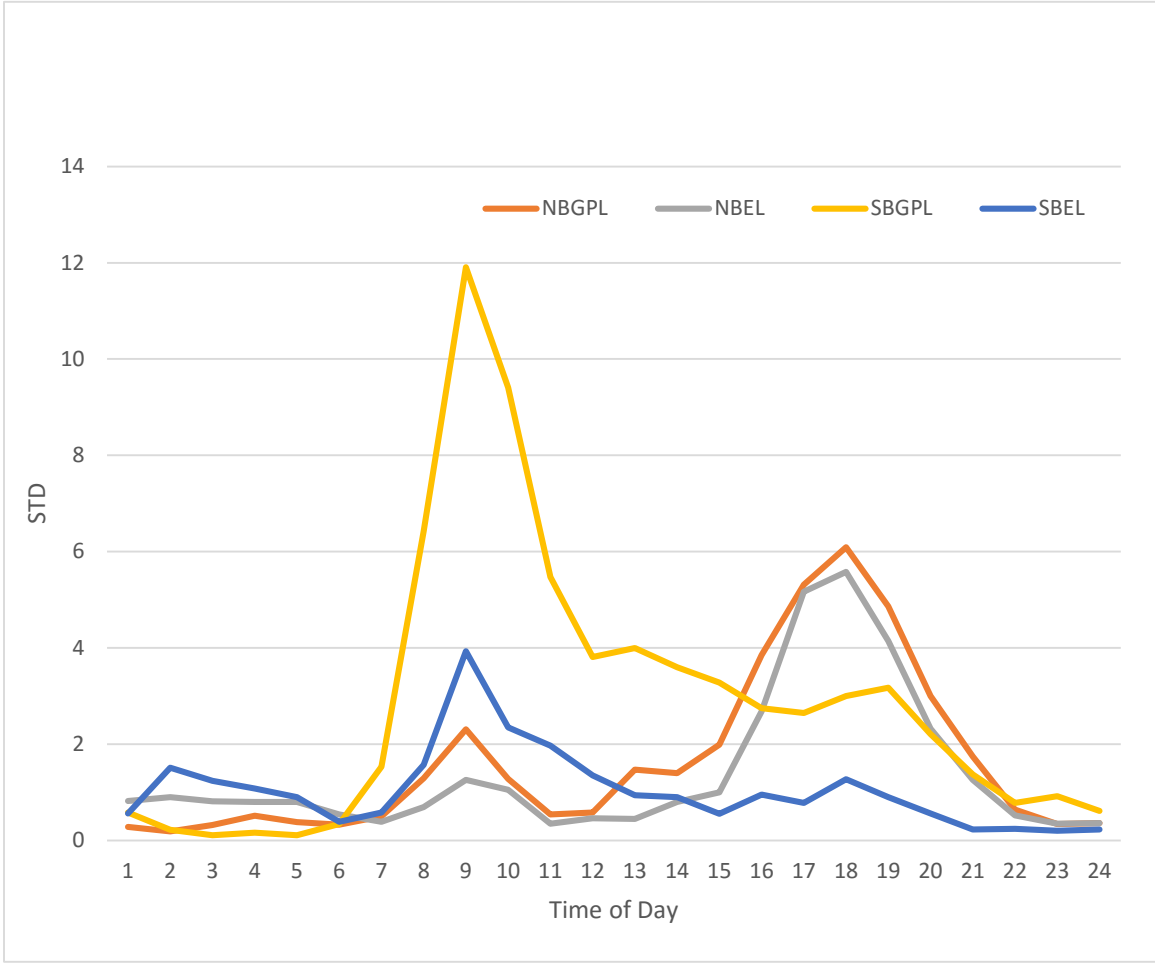


Figure: Standard deviation comparison by time of day

Descriptive Statistics – Combined RPSP Data

- SP data
  - Generally respondents selected GP alternative ove ML alternatives, except for high income responden
- RP data
  - Respondents who were male, employed, young or medium age people, from medium and high incom households selected MLs mostly
  - Mandatory trips, medium and very frequent trips, weekday trips, drive alone trips, medium and long distance trips were conducted mainly in MLs

		Category	RP Alternatives (%)		SP Alternatives (%)				
			GP	ML	GP	ML	ML Before Peak	ML After Peak	ML Additional Passenger
Personal Attributes	Age	16-34	40%	60%	51%	24%	3%	6%	16%
		35-54	48%	52%	60%	22%	4%	4%	11%
		55 -75+	51%	49%	60%	21%	2%	4%	13%
	Gender	Male	45%	55%	57%	23%	3%	4%	13%
		Female	51%	49%	59%	21%	3%	4%	13%
	Household Income	Low (<50k)	54%	46%	62%	16%	3%	4%	15%
		Med (50k~150k)	48%	52%	59%	23%	3%	4%	11%
		High (>150k)	29%	71%	45%	37%	2%	5%	11%
	Employment	Employed	45%	55%	56%	24%	3%	4%	12%
		Unemployed	63%	37%	64%	14%	2%	4%	16%
	Arrival Flexibility	With Flexibility	44%	56%	59%	21%	4%	4%	12%
		No Flexibility	56%	44%	57%	22%	3%	4%	13%
	Sun Pass	User	45%	55%	57%	23%	3%	4%	12%
		Not User	76%	24%	65%	10%	5%	5%	15%
Trip Attributes	Trip Urgency	Urgent	46%	54%	53%	24%	5%	5%	14%
		Not Urgent	48%	52%	60%	21%	2%	4%	12%
	Trip Purpose	Mandatory	39%	61%	55%	26%	4%	5%	10%
		Non Mandatory	59%	41%	60%	18%	3%	4%	15%
	Trip Frequency (per month)	Less Freq.(<4)	51%	49%	58%	22%	3%	4%	14%
		Med Freq.(4~12)	39%	61%	53%	25%	5%	5%	12%
		Very Freq. (>12)	37%	63%	60%	22%	3%	5%	9%
	Day of Week	Week Day	42%	58%	57%	24%	3%	5%	12%
		Weekend	64%	36%	61%	18%	3%	3%	14%
	Trip Occupancy	Drive Alone	42%	58%	58%	25%	3%	4%	9%
		Drive Another	56%	44%	50%	14%	2%	3%	31%
		HOV3	55%	45%	66%	23%	4%	7%	0%
	Trip Length (miles)	Short (<20)	57%	43%	62%	18%	3%	4%	13%
		Med (20~40)	44%	56%	55%	26%	3%	4%	12%
		Long (>40)	44%	56%	53%	22%	4%	6%	15%
	Delay Experience	Have Experience	53%	47%	55%	23%	4%	5%	12%
		No Experience	43%	57%	60%	22%	2%	4%	13%
Total Sample N			47%	53%	58%	22%	3%	4%	13%
			513		16327				

Summary

- GP alternative was selected more in SP and ML alternatives were more chosen in RP
  - Experience of RP respondents on managed lanes
  - Benefits of managed lanes were not well represented in the SP survey design
- Interestingly, ML alternatives were less chosen by the respondents when traveling with additional passengers
  - I-95 express lane requires pre-registration in order to receive a toll charge waiver

Model Structure (1)

- Multinomial Logit (MNL)
  - Utility Function: $U_{i,n} = \beta_i' \, X_{i,n} + \epsilon_{i,n}$
  - Probability Equation: $P(i) = \frac{e^{U_i}}{\sum e^{U_j}}$

Where, P (i) is the probability that any particular alternative (i) will be chosen and U_i is the utility of that alternative

- Limitations of MNL
  - Identical and Independently Distributed (IID)
  - Independence from Irrelevant alternatives (IIA)

Model Structure (2)

- Mixed Logit (ML)
  - Utility Function: $U_{itn} = \beta'_n X_{itn} + [\eta_{itn} + \varepsilon_{itn}]$
  - Probability Equation:

$$P_{iq} = \int_{\eta_{in}} L_{in}(\beta_n|\phi) f(\beta_n|\phi) \eta_{in}$$

Where f $(\beta_n|\phi)$represents the density function of the coefficient vector$\boldsymbol{\beta}$

- Advantages of ML
  - Coefficients are randomly distributed with a mean and a standard deviation across individuals and scenarios
  - Include inter-alternative correlation error term

Treatment of User Heterogeneity

- Interaction Effects of random parameters

$$\boldsymbol{U}_{in} = \beta X_{in} + \beta_{TT} TT_{in} + \beta_{TTR} TTR_{in} + \beta_{TC} TC_{in} + \gamma_{TT} (S_{in} * TT_{in}) + \gamma_{TTR} (S_{in} * TTR_{in}) + \gamma_{TC} (S_{in} * TC_{in}) + \varepsilon_{in} + \eta_{in}$$

Where, β	Coefficient vector of non-random parameters
X_{in}	Vector of non-random explanatory variables
β_{TT}	Coefficient of Travel Time
$TT_{,in}$	Vector of Travel Time
β_{TTR}	Coefficient of Travel Time Unreliability
TTR_{in}	Vector of Travel Time Unreliability
β_{TC}	Coefficient of Travel Cost
$TC_{,in}$	Vector of Travel Cost
S_{in}	Segmentation dummy variable
γ_{TT}	Interaction coefficient for travel time
γ_{TTR}	Interaction coefficient for travel time unreliability
γ_{TT}	Interaction coefficient for travel cost

Base Model – Multinomial Logit

- ## Dependent Variables
  - SP Alternatives (5): GP, ML Peak, ML Before Peak, ML After Peak, and ML Additional Passengers
  - RP Alternatives (2) : GP and ML

- ## Independent Variables
  - Generic Attributes: time, reliability, and cost
  - Alternative Specific Attributes: age, gender, household income, employment status, arrival flexibility, sunpass user, previous delay experience, trip purpose, trip length, trip frequency, trip urgency, day of the week, vehicle occupancy

Generic Attributes in utility functions

Independent Variables	Parameter
Time	-0.085 (-24.20)
Reliability	-0.158 (-14.97)
Cost	-0.588 (-41.16)

Alternative Specific Attributes in utility functions

Independent Variables	SP – ML Peak	SP – ML Before Peak	SP – ML After Peak	SP-ML Ad. Passenger	RP-ML
ASC	-3.23 (-23.5)	-2.37 (-11.1)	-2.91 (-19.1)	-2.43 (-26.8)	-2.42 (-5.13)
Male	-0.11 (-2.63)	-	-	-	-
Young People (16-34)	0.67 (12.85)	0.30 (2.70)	0.94 (10.18)	0.54 (9.35)	0.56 (2.20)
Med Income (50 ~ 150K)	0.30 (5.35)	-	-	-0.19 (-3.69)	-
High Income (>150k)	1.23 (18.25)	-	0.52 (4.85)	-	0.96 (3.71)
Employed	0.42 (6.30)	-	-	-	-
Sunpass User	0.72 (7.96)	-0.60 (-4.54)	-	-	1.21 (2.77)
Delay Experienced	-	-	-0.32 (-3.76)	-	-
Mandatory	0.50 (10.06)	-	-	-	-
Flexible Trip	-	-0.20 (-1.99)	-	0.10 (1.85)	-
Less Freq. (<4/month)	0.38 (6.49)	0.63 (5.14)	0.49 (4.78)	0.62 (8.90)	-
Med. Freq. (<12/month)	0.47 (6.06)	1.11 (7.41)	0.55 (3.88)	0.42 (4.24)	-
Weekday Trip	0.34 (8.90)	-0.38 (-3.32)	0.28 (2.60)	-	0.88 (3.72)
Urgent Trip	0.21 (4.40)	0.41 (4.19)	-	0.21 (3.71)	-
Short Trip (<20 miles)	-0.40 (-9.19)	-	-0.35 (-4.13)	-	-
Drive Another	0.57 (13.76)	-	-	-	-
VOT	$8.67				
VOR	$16.12				

All variables shown are significant at 5% significance level

Base Model – Mixed Logit

- Model Specifications
  - Time, reliability, and cost
  - Normally distributed random parameters
  - 1000 Halton draws
  - $\frac{\sigma}{\mu} < 0.33$ constraints imposed
- Model Results
  - Average VOT $10.68 per hour
  - Average VOR $13.91 per hour

Independent Variables	Parameter	Standard Deviation
Random parameters in utility functions		
Time	-0.20 (-109.31)	0.07 (109.31)
Reliability	-0.26 (-26.22)	0.09 (26.22)
Cost	-1.13 (-65.63)	0.37 (65.63)

Non-Random parameters in utility functions					
Independent Variables	SP – ML Peak	SP – ML Before Peak	SP – ML After Peak	SP-ML Additional Passenger	RP-ML
ASC	-3.7 (-36.20)	-3.6 (-27.17)	-3.9 (-39.09)	-2.8 (-47.82)	-2.82 (-4.52)
Male	-0.13 (-4.20)	-	-	-	-
Young People (16-34)	0.83 (19.65)	0.43 (5.59)	1.06 (17.02)	0.62 (15.91)	0.56 (1.91)
Med Income (50~150K)	0.34 (8.13)	-	-	-0.21 (-6.47)	-
High Income (>150k)	1.45 (28.54)	-	0.57 (8.54)	-	1.03 (3.41)
Employed	0.47 (8.59)	-	-	-	-
Sunpass User	0.76 (11.19)	-0.55 (-7.06)	-	-	1.17 (2.01)
Delay Experienced	-	-	-0.50 (-9.10)	-	-
Mandatory Trip	0.41 (10.74)	-	-	-	-
Arrival Flexibility	-	-0.17 (-2.75)	-	0.07 (2.00)	-
Less Freq. (<4/month)	0.60 (12.62)	0.83 (9.82)	0.73 (10.62)	0.84 (18.43)	-
Med. Freq. (<12/month)	0.61 (9.99)	1.44 (14.02)	0.87 (9.07)	0.57 (8.61)	-
Weekday Trip	0.25 (5.94)	-0.36 (-4.49)	0.23 (3.45)	-	1.28 (4.49)
Urgent Trip	0.14 (3.82)	0.39 (6.09)	-	0.11 (3.24)	-
Short Trip (<20 miles)	-0.30 (-9.16)	-	-0.21 (-4.06)	-	-
Drive Another	-0.78 (-19.3)	-	-	-	-
VOT	$10.68				
VOR	$13.91				

Model Performance: Log Likelihood Function = -16270.68, McFadden Pseudo R-squared = 0.546
All variables shown are significant at 5% significance level; t-statistics are shown in parentheses.

Mixed Logit Interaction Effects Model

Independent Variables	Parameter	Standard Deviation
Random parameters in utility functions		
Time	-0.38 (-79.34)	0.13 (79.34)
Reliability	-1.94 (-36.94)	0.64 (36.94)
Cost	-2.74 (-70.42)	0.90 (70.42)

Non-Random parameters in utility functions

Independent Variables	SP – ML Peak	SP – ML Before Peak	SP – ML After Peak	SP-ML Additional Passenger	RP-ML
ASC	-3.32 (-16.7)	-2.93 (-10.8)	-3.45 (-15.4)	-2.63 (-21.7)	-2.91 (-4.20)
Male	-0.18 (-2.46)	-	-	-	-
Young People (16-34)	-	-0.38 (-2.8)	0.29 (2.43)	0.22 (3.15)	-
Med Income (50~150K)	0.28 (3.00)	-	-	-0.17 (-2.65)	-
High Income (>150k)	1.09 (8.93)	-	0.45 (3.17)	-	-
Employed	0.56 (5.17)	-	-	-	-
Sunpass User	0.92 (6.89)	-0.39 (-2.43)	-	-	1.55 (2.35)
Mandatory Trip	0.59 (7.08)	-	-	-	-
Less Freq. (<4/month)	-	0.87 (4.36)	0.62 (3.32)	0.56 (5.11)	-
Med. Freq. (<12/month)	0.66 (3.03)	1.82 (6.59)	1.09 (4.05)	0.65 (4.08)	-
Weekday Trip	0.24 (2.32)	-0.48 (-2.97)	0.34 (2.23)	-	1.27 (3.84)
Urgent Trip	0.33 (3.62)	0.77 (6.15)	-	0.48 (6.49)	-
Short Trip (<20 miles)	-0.40 (-5.27)	-	-0.37 (-3.47)	-	-
Drive Alone	-	-	0.24 (2.24)	-	-
Drive Another	1.65 (19.80)	-	-	-	-

Cost Coefficient= -2.74 + 0.47(High income) + 0.13(Med income) +0.23 (Urgent trip) +0.26 (Employed) +0.30 (Age<34) + 0.28(Age>54) + 0.22(Drive alone) – 0.18(Drive another) + 0.28(Freq. <4/month) + 0.19 (Freq. 4~12/month) + 0.21(Sunpass user) +0.23 (Weekday) + 0.22 (Delay experienced)

Time Coefficient = -0.38 + 0.02(Urgent trip) + 0.04(Employed) - 0.05(Age<34) + 0.02(Age>54) + 0.07(Drive alone) + 0.14(Drive another) +0.03(Freq<4/month) +0.06(Sunpass user) + 0.03(Delay experienced)

Reliability Coefficient = -1.94 - 0.19 (High Income) + 0.25(Urgent trip) + 0.80(Distance<20 miles) + 0.70(Distance<20~40 miles) + 0.24(Age<34) + 0.18(Age>54) + 0.18(male) -0.27(Drive another) + 0.59(Freq. <4/month) + 0.33(Freq. 4~12/month) + 0.24(Delay experienced) - 0.16(Arrival Flexibility)

Heterogeneity	Time	Reliability	Cost
High Income (>150K)	-	-0.19 (-1.66)	0.47 (5.70)
Med Income (50~150K)	-	-	0.13 (2.09)
Urgent Trip	0.02 (2.21)	0.25 (3.07)	0.23 (4.16)
Employed	0.04 (3.01)	-	0.26 (3.42)
Short Trip (<20 miles)	-	0.80 (7.26)	-
Med. Trip (20~40 miles)	-	0.70 (6.52)	-
Young People (<34)	-0.05 (-4.46)	0.24 (2.57)	0.30 (4.78)
Old People (>54)	0.02 (2.31)	0.18 (2.27)	0.28 (5.00)
Male	-	0.18 (2.25)	-
Drive Alone	0.07 (6.06)	-	0.22 (3.08)
Drive Another	0.14 (9.95)	-0.27 (-2.25)	-0.18 (-2.27)
Mandatory Trip	-	-	-
Less Freq. (<4/month)	0.03 (2.19)	0.59 (6.40)	0.28 (4.65)
Med. Freq. (<12/month)	-	0.33 (2.18)	0.19 (2.26)
Sunpass User	0.06 (4.75)	-	0.21 (2.35)
Weekday Trip	-	-	0.23 (3.47)
Delay Experienced	0.03 (3.74)	0.24 (2.98)	0.22 (4.27)
Arrival Flexibility	-	-0.16 (-1.96)	-

Model Performance: Log Likelihood Function = -14021.82, McFadden Pseudo R-squared = 0.572
All variables shown are significant at 5% significance level; t-statistics are shown in parentheses.

Heterogeneity in VOT and VOR

$$\frac{\delta VOT}{\delta s} = \frac{\left(\frac{\partial TT}{\partial s}\right) \times TC - \left(\frac{\partial TC}{\partial s}\right) \times TT}{TC^2} = \frac{\gamma_{TT} \times TC - \gamma_{TC} \times TT}{TC^2}$$

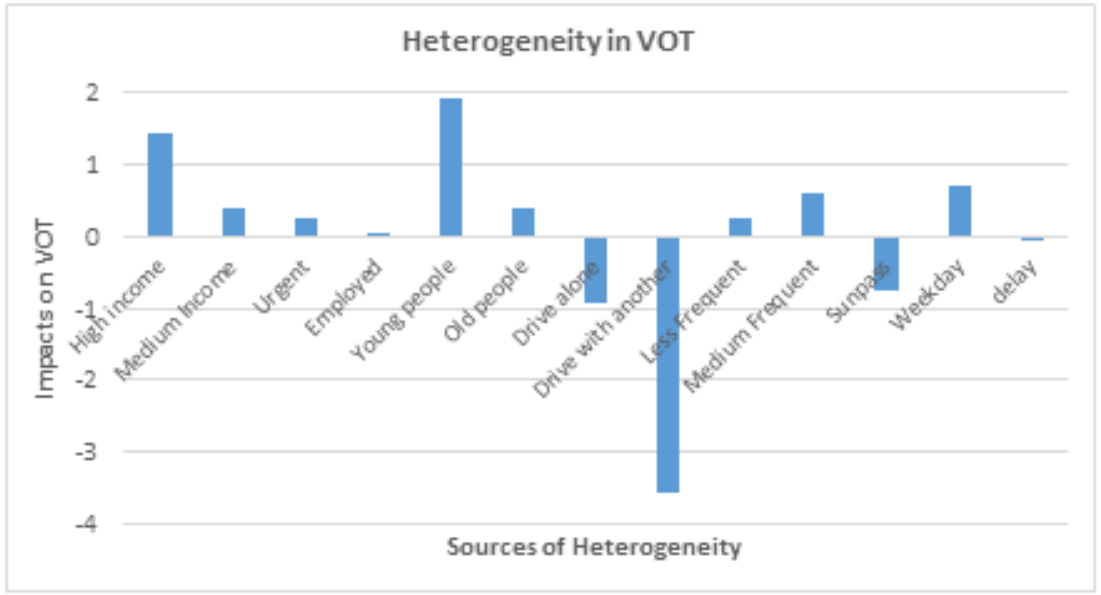
$$\frac{\delta VOR}{\delta s} = \frac{\left(\frac{\partial TR}{\partial s}\right) \times TC - \left(\frac{\partial TC}{\partial s}\right) \times TR}{TC^2} = \frac{\gamma_{TR} \times TC - \gamma_{TC} \times TR}{TC^2}$$

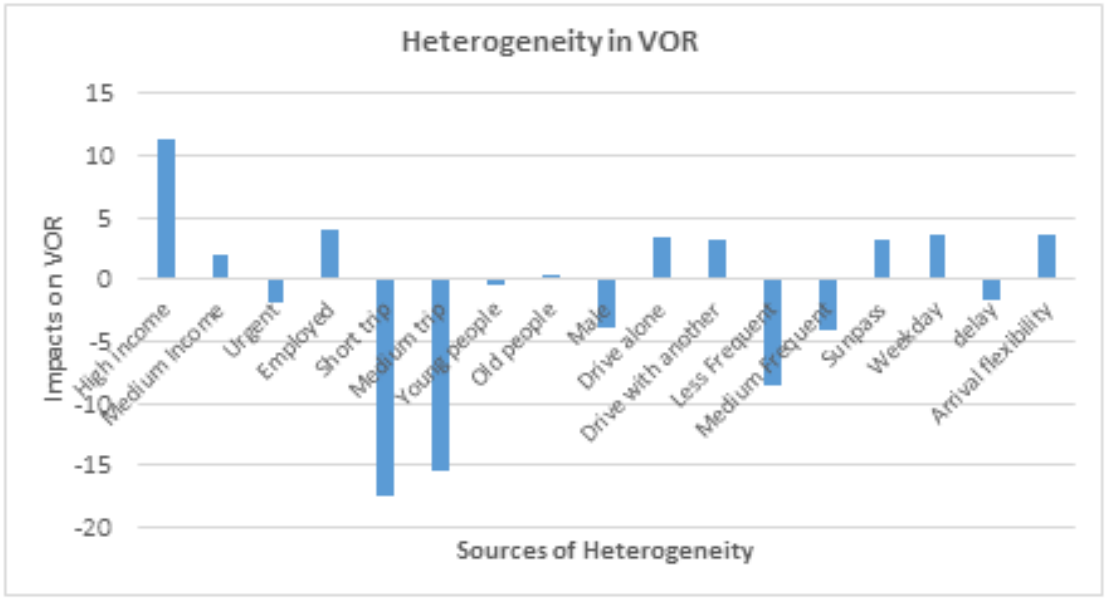
$$\frac{\delta VOT}{\delta(High\ income)} = \left(\frac{0.00 \times (-2.74) + 0.47 \times 0.38}{(-2.74)^2}\right) \times 60 = 1.42\ \$/hour$$

$$\frac{\delta VOR}{\delta(High\ income)} = \left(\frac{(-0.19) \times (-2.74) + 0.47 \times 1.94}{(-2.74)^2}\right) \times 60 = 11.34\ \$/hour$$

Heterogeneity Sources	ΔVOT	ΔVOR
High Income (>150K)	1.42	11.34
Med Income (50~150K)	0.40	2.05
Urgent Trip	0.25	-1.96
Employed	0.03	4.09
Short Trip (<20 miles)	0.00	-17.43
Med. Trip (20~40 miles)	0.00	-15.40
Young People (<34)	1.93	-0.54
Old People (>54)	0.38	0.34
Male	0.00	-3.86
Drive Alone	-0.92	3.47
Drive Another	-3.58	3.16
Less Freq. (<4/month)	0.26	-8.58
Med. Freq. (<12/month)	0.59	-4.19
Sunpass User	-0.75	3.24
Weekday Trip	0.71	3.60
Delay Experienced	-0.06	-1.76
Flexible Trip	0.00	3.50

Heterogeneity in VOT and VOR





Summary

- Mixed logit model results indicated an average value of $10.68 per hour for VOT and $13.91 per hour for VOR, with significant heterogeneity among the travelers

- In view of sensitivity to time, reliability, and cost
  - High and medium income groups, older individuals, and weekday trips lead to higher values for both VOT and VOR.
  - Urgent trips, less frequent trips, young individuals, and delay experienced travelers perceived higher VOT and lower VOR
  - Female travelers showed considerably higher VOR than males
  - Both driving alone and driving with one passenger reflected lower VOT
  - Short and medium trips only affected VOR, both of which had significantly lower VOR values compared to long trips
  - Less frequent and medium frequent trips resulted in lower VOR values compared with very frequent trips

Study Limitations

- Lack of reliability data
- Reliability Measure
- Simple market segmentation

Future Research

- Modal shifts for transit on managed lanes facility
- Impacts on automated/connected vehicle on VOT and VOR
- Robust market segmentation of managed lane users by latent class model (LCM)
- Joint impacts of heterogeneity and attitudes on choice behavior by hybrid choice model (HCM)

THANK YOU

QUESTIONS ?