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TRAVELER RESPONSE TO ELECTRONIC TOLLS BY DISTANCE TRAVELED AND TIME-OF-DAY

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Abstract: This paper examines potential travel behavioral changes of in response to the implementation of electronic tolls by distance traveled and time-of-day. An interactive computerized questionnaire with a stated preference experiment was designed to interview auto travelers using freeways for their daily commuting. The joint multinomial logit and nested logit models are employed to identify important factors influencing route and departure time choices. The preferred nested logit model implies a high correlation between unobserved utilities of two route alternatives (freeways and non-toll roads) in the earlier departure time nest and rejects the choice structure in which the choices of route and departure time are jointly determined. Elasticity analyses indicate that freeway travelers are more sensitive to total travel time than toll; existing short-distance toll-free travelers are more sensitive to the toll levels than other travelers and likely to alter their travel choices when implementing electronic tolls.

Key Words: Electronic tolls collection, Congestion pricing, Stated preference, Logit, Discrete choice

1. INTRODUCTION

Tolls on freeways in Taiwan are charged by vehicle types and collected manually at 22 mainline tollbooths. To help vehicles pass through more promptly, “no change” lanes are installed at toll stations in which drivers are encouraged to use coupons that can be purchased in advance to reduce paying time. However, significant traffic volumes during daily peak hours and special holidays create heavily traffic congestion and considerably delays at tollbooths. The mainline barrier toll collection is also unfair in that some travelers entering and exiting freeways do not need to pay toll, particularly in metropolitan areas. Toll stations on Taiwan freeways are located approximately every 30 km, and more than 50 percent of vehicles using freeways are toll-free.

With continuous growth of traffic and significant delays on tollbooths during peak hours, Taiwan Ministry of Transportation and Communications introduced the electronic toll collection (ETC) system such that travelers pay toll without stopping. The ETC, supervised by Taiwan Area National Freeway Bureau, is a BOT (Build-operate-transfer) project which was awarded by Far Eastern Electronic Toll Collection Company. Vehicles using the ETC must be equipped with an onboard unit (OBU) and an IC card which can be read by sensors installed at tollbooths. The ETC system will begin full implementation in 2006. Freeway users will still be charged at each mainline tollbooth in early stage. By July 2010, all users will pay tolls by distance traveled, with sensors installed between interchanges.

Another advantage of the ETC system is to facilitate the implementation of time-of-day toll pricing (also called congestion toll or value pricing) (DeCorla-Souza, 2000, 2002). Congestion pricing can shift peak period traffic to less congested periods and may relief peak period congestion (Frankena, 1979). Congestion pricing is decided by the degree of congestion, which collects extra tolls to reduce external costs that increase travel costs.

Recent studies have been investigated behavioral impacts of congestion pricing. Adler *et al.* (1999) evaluated traveler reactions to congestion pricing and determined how they would be likely to behave if the concepts were implemented. It was found that travelers will respond to congestion pricing by altering routes, departure time, modes, or giving up their trips; travellers with flexibility in their trip timing would react to congestion tolls by changing their travel behaviours. Yelds and Burris (2000) conducted a revealed preference survey to examine drivers' behavioural changes in response to the implementation of lower toll prices in the time periods on either side of traditional peaks. The results indicated that drivers having flexibility in their travel plans are likely to change their travel behaviour in order to take advantage of toll discounts. Lam and Small (2001) investigated actual behavior of commuters who choose between a free and a variably tolled route and developed discrete choice models of route choice both alone and combined with other choices, including time-of-day, car occupancy, and installation of transponders. Burris and Pendyala (2002) employed discrete choice models to investigate traveler participation in variable pricing programs. The results indicated that retired, lower income, and flexible schedule travelers tend to change their time of travel in response to variable tolls. Goh (2002) detailed the experience of Singapore and the effort made to reduce car increase on the roads using Electronic Road Pricing (ERP) scheme.

Although many countries and regions had begun to install the ETC system along with the implementation of congestion pricing, little examined travelers' potential reactions to electronic tolls by distance traveled as well as congestion pricing. The objective of this research is to evaluate changes of travel behaviors in response to distance-based and time-of-day toll pricing. The analysis approaches include a stated choice experiment and discrete choice modeling. The empirical study can provide an understanding of traveler behaviors and gain policy implications for road pricing.

The remainder of this paper is organized as follows. Section 2 describes a methodological framework for examining traveler response to electronic tolls by distance traveled and time-of-day. Section 3 presents the results of an empirical study, which describes data collection, the interpretation of model estimations, and draws policy implications from our analysis results. The research findings and future research directions are concluded in the final section.

2. METHODOLOGICAL FRAMEWORK

2.1 Stated Preference Experiment

Stated preference data are collected in experimental situations where respondents are presented with hypothetical choice alternatives and state their preferred choices. A stated preference experiment can be designed such that each attribute contains more variation than the data in the real world in order to identify impacts of key explanatory variables. An important advantage of stated preference data is to allow the assessment of market response to new products/services and to provide demand prediction for these new concepts. Stated choice models have been widely applied in various contexts such as route choice (Wardman, *et al*., 1997; Abdel-Aty, *et al*., 1995, 1997), departure time choice (Hunt and Patterson, 1996), and mode choice (Morikawa, *et al*., 1991; Norojono and Young, 2003; Shinghal and Fowkes, 2002). Louviere *et al*. (2000) provides an excellent review of choice experimental design and describes modeling approaches for examining stated preference data.

Though stated preference data we can identify how travelers evaluate trade-off attributes such as tolls and travel times while they use roads. With the implementation of electronic tolls by distance traveled and time-of-day, peak travelers will involve route and departure time decisions in which they make choices between toll and non-toll roads and their preferred departure time. Under this circumstance, travelers of toll roads will be charged by distance traveled; therefore, some existing short-distance travelers entering and exiting toll roads without paying tolls might shift to non-toll roads. In addition, peak-period tolls are higher than off-peak ones such that travelers often using toll roads during the peak periods are likely to change departure time from home to avoid higher tolls during the peak. In this research, the peak period of implementing congestion pricing was set to begin at 7:00 A.M. and end at 9:00 A.M., based on daily traffic flow data from the Taiwan Area National Freeway Bureau.

If an existing peak traveler decides to choose toll roads, he/she has to make a choice of three options: departing from home at the same time as now (higher tolls with distance-based and time-of-day pricing during peak periods), at an earlier time (regular tolls with distance-based pricing during off-peak periods), or at a later time (regular tolls with distance-based pricing during off-peak periods). Off-peak travelers only need to pay standard and regular tolls by distance traveled. If an existing peak traveler decides to choose non-toll roads, he/she has to make a choice of two options: departing from home at the same time as now or at an earlier time. Travelers using non-toll roads either at an earlier time or at the same time as now do not need to pay tolls.

A stated preference survey was designed to interview auto travelers who often use toll freeways during the peak for their daily commuting because peak users are most likely to be influenced by electronic tolls. Respondents presented with a set of choice experiments were asked to indicate their preferred one among five travel options. Total travel time and toll are two most important attributes for travelers to consider in choosing travel options. The levels of the total travel time and toll attributes for each alternative are shown in Table 1.

- Total Travel Time: Respondents answered the average total travel time spent on their daily commuting trips. Total travel time for toll alternatives -- driving on freeways at the same time as now, at an earlier time, and at a later time includes three levels: -5% of current total travel time, -10% of current, and -15% of current. We expect that the implementation of electronic tolls will reduce total travel time on freeways due to peak-hour traffic shifting to non-toll roads. Total travel time for non-toll alternatives – driving on non-toll roads at the same time as now and at an earlier time includes three levels: +30% of current total travel time, +50% of current, and +70% of current. A few O-D pairs which cover short, medium, and long-distance ranges were selected, and travel time differences between toll and non-toll roads were calculated. The average total travel time of toll freeways is approximate a half (50%) that of non-toll roads. +70% and +30% of current total travel time represent upper and lower bounds of travel time differences, respectively.

Table 1. Attributes and Levels of Stated Preference Experiment

Alternatives	Total travel time (Percentage of total travel time in current commuting trip)	Toll
Drive on freeways at the same time as now	-5% -10% -15%	NT$1.98 per km NT$3.96 per km
Drive on freeways at an earlier time	-5% -10% -15%	NT$1.32 per km
Drive on freeways at a later time	-5% -10% -15%	NT$1.32 per km
Drive on non-toll roads at an earlier time	+30% +50% +70%	0
Drive on non-toll roads at the same time as now	+30% +50% +70%	0

- Toll: In Taiwan, standard tolls charged by vehicle types and collected at mainline toll stations are NT$40 (1US$ = 33NT$ in 2004) for cars, NT$50 for buses and small trucks, and NT$65 for trailer trucks. According to the preliminary estimation by the Taiwan Institute of Transportation, the toll level by distance traveled for cars is NT$1.32 per km. Electronic tolls by distance traveled and time-of-day cars during the peak are NT$1.98 per km (1.5 times the standard distance-based toll) and NT$3.96 per km (2 times the standard distance-based toll), respectively.

The complete factorial involves $3^5 \times 2^1$ (=486) combinations in order to estimate all the possible effects. We used an orthogonal fractional design to reduce the number of combinations while also preserving the richness of the information in the design. We reduce 486 combinations to 18 choice sets. Each respondent was randomly assigned 9 of the 18 choice sets.

2.2 Route and Departure Time Choice Model

Discrete choice analysis is used to model the choice of one among a set of mutually exclusive alternatives based on principles of utility maximization. An individual is assumed to compare the alternatives in terms of a set of attributes and choose that alternative which yields the highest level of utility. With the implementation of electronic tolls by distance traveled and time-of-day, peak travelers select a combination of route and departure time alternatives with the highest utility. Joint route and departure time choices, two-dimensional choice situations, are formulated using the joint multinomial logit and nested logit model (McFadden, 1978; Ben-Akiva and Lerman, 1985). Figure 1 represents a nested structure with departure time choice (same as now, at an earlier time, or at a later time) at the upper level and route choice (toll freeways or non-toll roads) at the lower level. The probability of choosing a combination of route r and departure time d can be expressed as:

$$P_n(r,d) = P_n(r\,|\,d) \times P_n(d) = \frac{e^{\frac{V_{r/d}}{\mu_d}}}{\sum_{r' \in N_d} e^{\frac{V_{r'/d}}{\mu_d}}} \times \frac{e^{\left(V_d + \mu_d \ln \sum_{r' \in N_d} e^{\frac{V_{r'/d}}{\mu_d}}\right)}}{\sum_{d'} e^{\left(V_{d'} + \mu_{d'} \ln \sum_{r' \in N_{d'}} e^{\frac{V_{r'/d'}}{\mu_{d'}}}\right)}} \tag{1}$$

where $P_n(r\,|\,d)$ is the conditional probability of traveler n selecting route r among choice set N_d conditional on choosing departure time d; $P_n(d)$ is the marginal probability of traveler n choosing departure time d; the observable (systematic) utility of route r in departure time d is $V_{r/d}$ and the observable utility of departure time d is V_d; μ_d is the logsum parameter for departure time nest d. The nested logit model is consistent with utility maximization if the conditions, $0 < \mu_d \leq 1$, are satisfied for all μ_d. A logsum parameter associated with a nest is within zero and one range, indicating that route alternatives in that nest share a common unobserved (or error) component; any pair of utilities for route alternatives in that nest is correlated. If μ_d is equal to one for all d, the nested logit model collapses to the joint multinomial logit model, which implies that the choices of route and departure time are considered jointly.

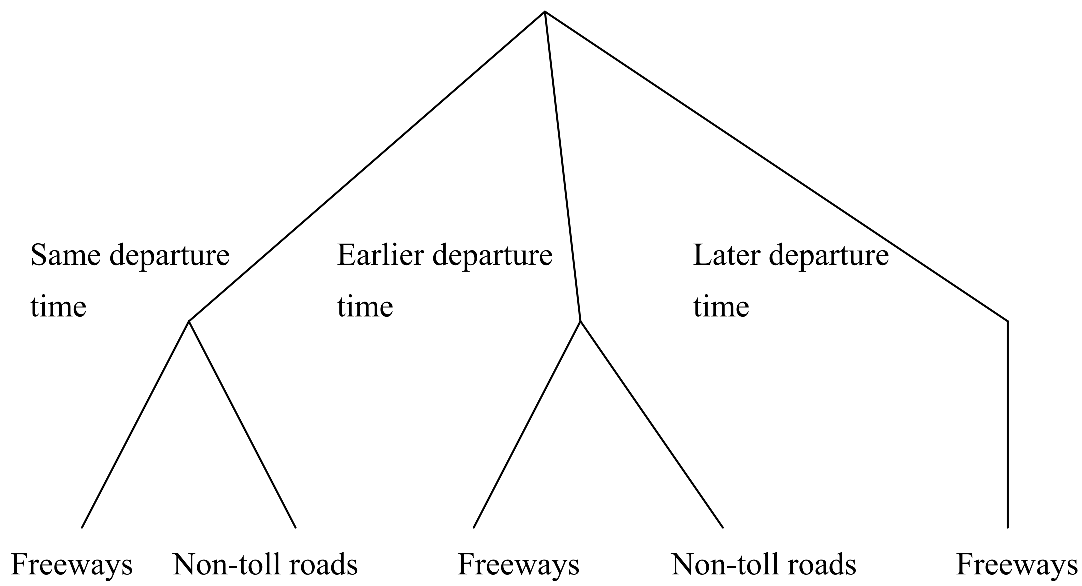

Figure 1. A Nested Structure with Departure Time Choice at the Upper Level and Route Choice at the Lower Level

In Figure 2, the departure time is the elemental alternative under route nests. The probability of choosing a combination of route r and departure time d for this nested structure can be written as:

$$P_n(r,d) = P_n(d \mid r) \times P_n(r) = \frac{e^{\frac{V_{d/r}}{\mu_r}}}{\sum_{d' \in N_r} e^{\frac{V_{d'/r}}{\mu_r}}} \times \frac{e^{\left(V_r + \mu_r \ln \sum_{d' \in N_r} e^{\frac{V_{d'/r}}{\mu_r}}\right)}}{\sum_{r'} e^{\left(V_{r'} + \mu_{r'} \ln \sum_{d' \in N_{r'}} e^{\frac{V_{d'/r'}}{\mu_{r'}}}\right)}} \quad (2)$$

where $P_n(d \mid r)$ is the conditional probability of traveler n choosing departure time d among choice set N_r conditional on selecting route r; $P_n(r)$ is the marginal probability of traveler n choosing route r; the systematic utility of departure time d in route r is $V_{d/r}$ and the systematic utility of route r is V_r; μ_r is the logsum parameter for route nest r.

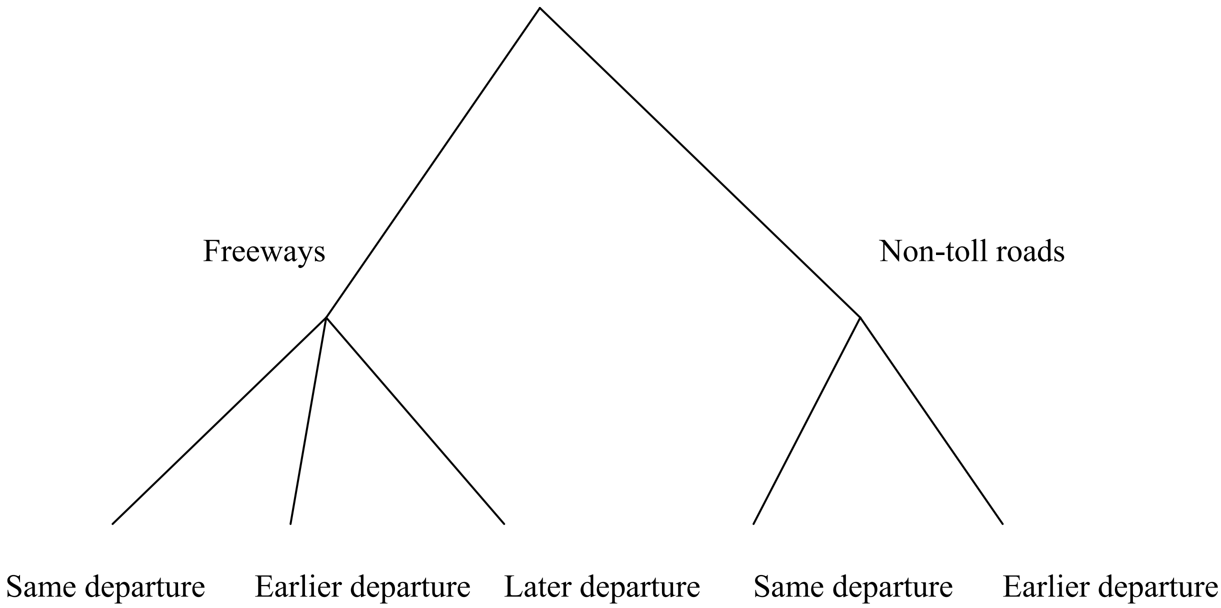

Figure 2. A Nested Structure with Route Choice at the Upper Level and Departure Time at the Lower Level

3. EMPIRICAL ANALYSIS

3.1 Data

An interactive computerized questionnaire with a stated preference survey was designed to collect the data on travelers' socio-demographic and trip characteristics and choice preferences. The data were collected by face-to-face interviews at service areas of Taiwan freeways during April to May in 2004. Respondents often using freeways for daily commuting between 7:00 A.M. to 9.00 A.M. were selected to fill out the questionnaires.

The survey consists of 280 respondents, and 254 samples were retained after eliminating invalid data. 90 percent of respondents are male, and 68 percent have monthly personal income between NT$30,000 and NT$60,000. The majority of respondents (47 percent) are between age 31 and 40. 60 percent of respondents using freeways are toll-free.

The distribution of five alternatives is shown in Table 2. The majority of respondents (35.4

percent) select alternative 2 – driving on freeways at an earlier time. Respondents still prefer to use freeways for daily commuting in order to save travel time, but they are likely to depart home earlier to avoid higher tolls during peak periods. Driving on non-toll roads at an earlier time is the second one. Some respondents tend to use toll-free routes to avoid toll charge and will alter their departure time to leave home earlier in order to avoid late arrival at work. Only 20.6 percent of respondents still choose freeways during peak hours and do not alter their departure time. Obviously, the implementation of electronic tolls will divert many vehicles to non-toll roads. In addition, congestion pricing encourages travelers to alter their departure time to either before or after peak periods. Electronic tolls by distance traveled and time-of-day will produce significant changes on travel behaviors.

Table 2. Distribution of Alternatives Chosen

Alternatives	Number of observations	Percentage
Freeways at the same time	471	20.6
Freeways at an earlier time	810	35.4
Freeways at a later time	280	12.3
Non-toll roads at an earlier time	592	25.9
Non-toll roads at the same time	133	5.8
Total	2286	100.0

3.2 Estimation Results

The utility function specifications in joint route and departure time choice models include socio-demographic and trip characteristics and attributes of route and departure time alternatives. The estimation result of the joint multinomial logit model, reported in Table 3, indicates that parameter estimates of the total travel time, toll, and schedule delay variables significantly differ from zero at a high level of significance, and estimates are all negative as expected. Increasing the value of these variables decreases utility of the alternative and reduces the probability of being chosen.

The toll variable specific to toll-free represents tolls paid by existing short-distance travelers without paying tolls. The toll variable specific to paying tolls represents tolls paid by existing travelers who have to pay tolls. The parameter estimate of the toll-free variable is larger than that of the paying toll variable provides evidence that existing short-distance and toll-free travelers are more sensitive to the toll level charged by distance and time-of-day.

The result shows that personal income, work schedule flexibility, driving distance, and proportion of commuting trips using freeways are important variables. High income travelers are more likely to choose driving on freeways at the same time as now than low income travelers because high income persons are less sensitive to higher tolls. The fixed work schedule variable is a 0-1 dummy variable. Travelers with a fixed work schedule tend to select either freeways to save total travel times or non-toll roads at an earlier time to avoid late arrival. Some prefer to choose freeways and depart home at an earlier or later time to avoid higher tolls during the peak hours.

Table 3. Estimation Result of the Joint Multinomial Logit Model

Variable	Parameter estimate (t-value)
Alternative specific constants	
Freeways and same departure time	-1.609 (-2.7)
Freeways and earlier departure time	-2.397 (-4.1)
Freeways and later departure time	1.274 (-1.7)
Non-toll roads and earlier departure time	0.433 (3.8)
Total travel time	-0.016 (-3.7)
Toll	
Toll-free	-0.053 (-15.4)
Paying tolls	-0.025 (-7.2)
Schedule delay	
Early	-0.021 (-10.0)
Late	-0.035 (-11.5)
Personal income	
Freeways and earlier departure time	-0.019 (-2.4)
Freeways and later departure time	-0.129 (-4.1)
Non-toll roads and earlier departure time	-0.030 (-3.2)
Non-toll roads and same departure time	-0.084 (-3.7)
Fixed work schedule (Yes = 1, No = 0)	
Freeways and same departure time	0.494 (2.3)
Freeways and earlier departure time	1.046 (5.0)
Freeways and later departure time	0.597 (2.5)
Non-toll roads and earlier departure time	1.048 (5.1)
Driving distances on freeways	
Freeways and same departure time	0.007 (2.1)
Freeways and earlier departure time	0.012 (6.2)
Non-toll roads and earlier departure time	-0.013 (-4.7)
Proportion of commuting trips using freeways	
Freeways and same departure time	1.482 (4.6)
Freeways and earlier departure time	1.076 (3.8)
Freeways and later departure time	1.531 (4.1)
Gender (male = 1, female = 0)	
Freeways and same departure time	0.668 (3.0)
Freeways and earlier departure time	1.073 (4.9)
Freeways and later departure time	1.640 (4.2)
Non-toll roads and same departure time	1.385 (3.8)
Age	
Freeways and same departure time	0.049 (5.0)
Freeways and earlier departure time	0.080 (9.1)
Freeways and later departure time	0.046 (3.9)
Log-likelihood value	
At convergence	-2615.484
At market share	-3322.499
At zero	-3650.205
Likelihood ratio index	
Vs. market share	0.213
Vs. zero	0.283

Long-distance travelers are more likely to use freeways at the same time as now or at an earlier time to avoid late penalty and less likely to choose non-toll roads due to longer travel times. Male, elder, and frequent freeway travelers prefer to use toll freeways than non-toll roads.

Estimation results of the nested logit models are reported in Table 4. Nested logit Model 1 includes two nests for freeways and non-toll roads, corresponding to the nested structure in Figure 2. The estimate of the logsum parameter for the freeway nest falls within zero to one range and significantly differs from one. However, the logsum estimate for the non-toll road nest is greater than one which falls outside the reasonable range. Therefore the logsum parameter for the non-toll road nest is fixed at 1.0. The corresponding model (nested logit Model 2) has a significant and reasonable logsum parameter and significantly rejects the joint multinomial logit model, using the likelihood ratio test.

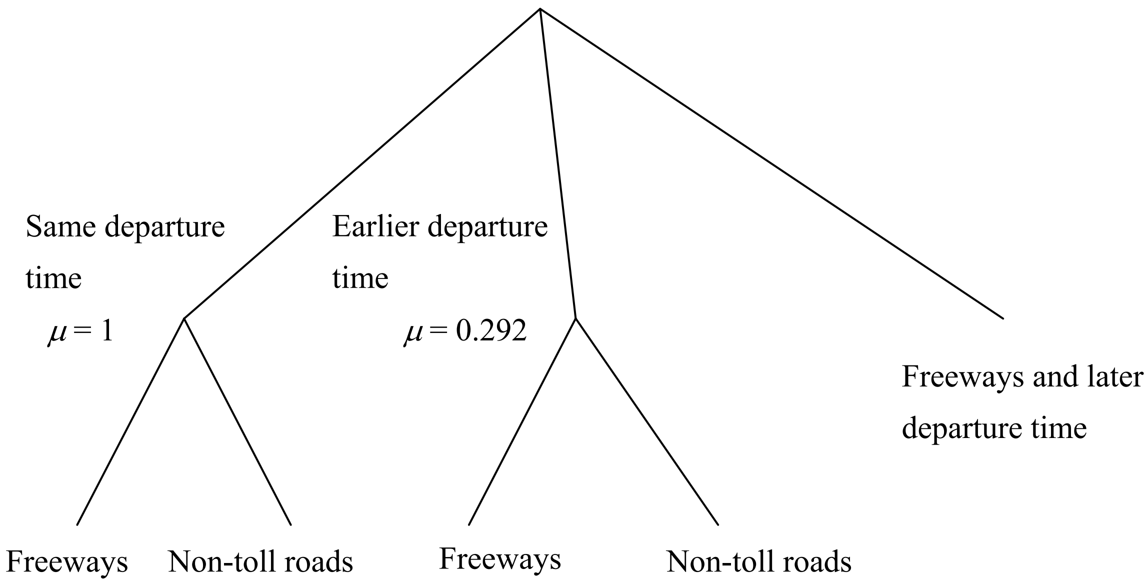

Figure 3. The Nested Structure for the Preferred Nested Logit Model (Model 4)

The nested logit Model 3 includes two multiple-alternative nests for the same and earlier departure time, corresponding to the nested structure in Figure 1. The estimate of the logsum parameter for the earlier departure time nest is within zero to one range and significantly differs from one. However, the logsum estimate for the later departure time nest falls outside the reasonable range. The logsum parameter for departure time nest is constrained to be 1.0, and the resultant model is the nested logit Model 4.

The nested logit Model 4 significantly rejects the joint multinomial logit model, using the likelihood ratio test, and the nested logit Model 2, using the non-nested hypothesis test (Horowitz, 1983) and is the preferred model. The preferred nested logit model implies a high correlation between unobserved utilities of two route alternatives, which share a common unobserved component in the earlier departure time nest, and rejects the choice structure in which the decisions of route and departure time choices are considered jointly.

Table 4. Estimation Results of Nested Logit Models

Variable	Parameter estimate (t-value)			
	Model 1	Model 2	Model 3	Model 4
Alternative specific constants				
Freeways and same departure time	11.294 (1.2)	-1.159 (-2.0)	-0.195 (-0.2)	-0.808 (-1.3)
Freeways and earlier departure time	10.489 (1.1)	-1.859 (-3.1)	1.084 (1.3)	0.199 (0.4)
Freeways and later departure time	11.711 (1.2)	-0.932 (-1.6)	1.063 (1.2)	-0.067 (-0.1)
Non-toll roads and earlier departure time	13.157 (1.4)	1.639 (4.3)	2.730 (3.7)	1.374 (3.5)
Total travel time	-0.014 (-3.0)	-0.012 (-2.7)	-0.013 (-3.8)	-0.009 (-3.7)
Toll				
Toll-free	-0.047 (-12.4)	-0.043 (-11.7)	-0.033 (-7.2)	-0.027 (-8.7)
Paying tolls	-0.014 (-6.7)	-0.011 (-7.0)	-0.028 (-7.2)	-0.019 (-11.6)
Schedule delay				
Early	-0.009 (-4.3)	-0.007 (-4.3)	-0.013 (-6.4)	-0.011 (-7.7)
Late	-0.031 (-6.9)	-0.022 (-6.9)	-0.044 (-9.7)	-0.039 (-9.4)
Personal income				
Freeways and earlier departure time	-0.009 (-2.2)	-0.008 (-2.4)	-0.022 (-2.7)	-0.014 (-1.8)
Freeways and later departure time	-0.068 (-3.2)	-0.050 (-3.1)	-0.151 (-4.0)	-0.127 (-3.4)
Non-toll roads and earlier departure time	-0.014 (-0.5)	-0.019 (-1.8)	-0.028 (-2.7)	-0.018 (-2.0)
Non-toll roads and same departure time	-0.092 (-0.7)	-0.073 (-2.5)	-0.152 (-2.8)	-0.079 (-2.8)
Fixed work schedule				
Freeways and same departure time	4.466 (1.6)	0.689 (3.2)	1.168 (2.3)	0.414 (1.9)
Freeways and earlier departure time	4.743 (1.7)	0.889 (4.2)	1.623 (3.9)	1.014 (4.8)
Freeways and later departure time	4.666 (1.7)	0.835 (3.7)	1.262 (2.8)	0.582 (2.2)
Non-toll roads and earlier departure time	5.830 (1.7)	1.080 (5.1)	1.675 (4.0)	1.069 (5.2)
Driving distances on freeways				
Freeways and same departure time	0.005 (3.2)	0.004 (3.2)	0.009 (2.3)	0.004 (1.4)
Freeways and earlier departure time	0.007 (4.8)	0.005 (4.8)	0.006 (2.9)	0.006 (2.9)
Non-toll roads and earlier departure time	-0.007 (-1.6)	-0.009 (-2.8)	-0.009 (-2.7)	-0.004 (-1.8)
Proportion of commuting trips using freeways				
Freeways and same departure time	1.343 (4.2)	1.230 (4.1)	1.339 (3.4)	1.039 (3.0)
Freeways and earlier departure time	1.221 (4.4)	1.147 (4.2)	0.385 (2.4)	0.266 (2.2)
Freeways and later departure time	1.212 (3.9)	1.046 (3.5)	1.311 (3.4)	1.126 (2.9)
Gender				
Freeways and same departure time	1.751 (2.5)	0.808 (4.1)	0.645 (2.7)	0.707 (3.5)
Freeways and earlier departure time	1.929 (2.4)	0.964 (4.3)	0.642 (3.9)	0.529 (4.3)
Freeways and later departure time	2.418 (2.9)	1.385 (5.9)	1.601 (4.4)	1.517 (4.1)
Non-toll roads and same departure time	8.095 (1.6)	1.443 (3.7)	1.670 (2.5)	1.180 (3.1)
Age				
Freeways and same departure time	0.055 (5.5)	0.057 (5.7)	0.022 (2.0)	0.017 (2.1)
Freeways and earlier departure time	0.075 (7.3)	0.073 (7.2)	0.036 (4.6)	0.028 (4.9)
Freeways and later departure time	0.059 (5.4)	0.060 (5.7)	0.020 (1.8)	0.016 (1.5)
Logsum (t-value vs. 1)				
Freeway nest	0.515 (7.0)	--	--	--
Non-toll road nest	6.790 (1.3)	0.390 (12.2)	--	--
Same departure time nest	--	1.0	2.142 (3.7)	1.0
Earlier departure time nest	--	--	0.371 (10.8)	0.292 (18.2)
Late departure time nest	--	--	1.0	1.0
Log-likelihood value				
At convergence	-2579.739	-2593.024	-2553.949	-2571.701
At market share	-3322.499	-3322.499	-3322.499	-3322.499
At zero	-3650.205	-3650.205	-3650.205	-3650.205
Likelihood ratio index				
Vs. market share	0.224	0.220	0.231	0.226
Vs. zero	0.293	0.290	0.300	0.295

3.3 Policy Implications

Based on the estimation result of the preferred model, we calculate aggregate elasticity which measures the responsiveness of aggregate group of individuals rather than that of any individual (Ben-Akiva and Lerman, 1985). Aggregate elasticity can be computed based on disaggegate elasticity representing the change of an individual's choice probability with respect to a change in the value of some attributes. Disaggregate direct and cross-elasticities with respect to a change in attribute *k* of route *r* and departure time *d* by traveler *n*, X_{rdkn}, for the nested logit model are shown in Table 5.

Table 5. Disaggregate Direct and Cross-elasticities for the Nested Logit Model

Disaggregate direct-elasticity, $E_{X_{rdkn}}^{P_n(r,d)}$	Disaggregate cross-elasticity, $E_{X_{rdkn}}^{P_n(r',d')}$
(*r*, *d*) not in nest $\left[1-P_n(r,d)\right]\beta_k X_{rdkn}$	Either (*r*, *d*) or (*r′*, *d′*) not in nest $-P_n(r,d)\beta_k X_{rdkn}$
(*r*, *d*) in nest m $\left\{\left[1-P_n(m)\right]P_n(r,d\mid m)+\left(\frac{1}{\mu_m}\right)\left[1-P_n(r,d\mid m)\right]\right\}\beta_k X_{rdkn}$	(*r*, *d*) and (*r′*, *d′*) in nest *m* $-\left[P_n(r,d)+\left(\frac{1-\mu_m}{\mu_m}\right)P_n(r,d\mid m)\right]\beta_k X_{rdkn}$

The expressions for aggregate direct and cross-elasticities, respectively, are

$$E_{X_{rdkn}}^{\bar{P}_n(r,d)} = \frac{\sum_{n=1}^{N} P_n(r,d) E_{X_{rdkn}}^{P_n(r,d)}}{\sum_{n=1}^{N} P_n(r,d)} \tag{3}$$

$$E_{X_{rdkn}}^{\bar{P}_n(r',d')} = \frac{\sum_{n=1}^{N} P_n(r',d') E_{X_{rdkn}}^{P_n(r',d')}}{\sum_{n=1}^{N} P_n(r',d')} \tag{4}$$

where $\bar{P}_n(r,d) = \sum_{n=1}^{N} P_n(r,d)$; N is the number of decision makers.

Tables 6-8 contain aggregate elasticities with respect to changes of the total travel time and toll variables. In Table 6, the first column represents a 1 percent increase in total travel time of the driving on freeways at the same time as now alternative leads to a 0.314 percent reduction in the proportion of trips by driving on freeways at the same time as now. This 1 percent increase in total travel time leads to a 0.085 percent increase in trips by driving on freeways at an earlier time.

Direct-elasticities of the total travel time variable are larger than those of the toll variables. The results demonstrate that travelers are more sensitive to total travel time than toll. Direct-elasticities of the toll variables by toll-free and paying tolls reveal that existing short-distance toll-free travelers are more sensitive to toll than other travelers and likely to alter their travel choices when toll levels are changed. Direct elasticities with respect to the toll variables, ranged between –0.135 and –0.328, are similar to the results obtained by Burris (2003a, 2003b).

Table 6. Aggregate Elasticities with Respect to Total Travel Time Variable

Alternatives	Freeways			Non-toll roads	
	same time	earlier time	later time	earlier time	same time
freeways at the same time	-0.304	0.149	0.046	0.138	0.031
freeways at an earlier time	0.085	-0.401	0.053	0.415	0.032
freeways at a later time	0.079	0.161	-0.333	0.136	0.042
Non-toll roads at an earlier time	0.064	0.341	0.037	-0.792	0.040
Non-toll roads at the same time	0.064	0.120	0.053	0.176	-0.562

Table 7. Aggregate Elasticities with Respect to Toll Variable Specific to Toll-free

Alternatives	Freeway		
	Same time	earlier time	later time
Freeways at the same time	-0.328	0.055	0.020
Freeways at an earlier time	0.049	-0.262	0.005
Freeways at a later time	0.053	0.015	-0.153
Non-toll roads at an earlier time	0.136	0.305	0.042
Non-toll roads at the same time	0.104	0.054	0.035

Table 8. Aggregate Elasticities with Respect to Toll Variable Specific to Paying Toll

Alternatives	Freeway		
	same time	earlier time	later time
Freeways at the same time	-0.264	0.030	0.007
Freeways at an earlier time	0.098	-0.142	0.033
Freeways at a later time	0.083	0.098	-0.135
Non-toll roads at an earlier time	0.020	0.115	0.007
Non-toll roads at the same time	0.038	0.062	0.021

Cross-elasticities show high substitutability between toll and non-toll roads at an earlier departure time, resulting from the two alternatives in the same nest. If tolls on freeway are increased, current toll-free travelers tend to use non-toll roads and depart home earlier to avoid late arrival at workplace (Table 7). For example, a 1 percent increase in tolls of the driving on freeways at the same time as now alternative leads to a larger effect in the driving on non-toll roads at an earlier time alternative (0.136 percent increase) than other alternatives.

The implementation of electronic tolls by distance traveled and time-of-day will divert many travelers to non-toll roads and encourages them to alter their departure time to either before or after the peak. The diversion of a large amount of toll road vehicles to non-toll roads will produce significant traffic impacts. Thus, before implementing this new tolling strategy, transportation agency should develop effective traffic management plans to avoid potentially serious congestion on non-toll roads. Apparently, time-of-day toll pricing is a powerful scheme to motivate peak-period travelers shifting to less congested periods. However, toll levels during the peak periods should be cautiously determined. Large differences between peak and off-peak tolls will lead to significant diversion of vehicles to non-toll roads. To enable time-of-day toll pricing more successful, the government could encourage public and private sectors to adopt flexible working hours to allow travelers changing their travel plans.

4. CONCLUSIONS

This paper examines auto travelers' potential response to electronic tolls by distance traveled and time-of-day by employing stated preference methods and discrete choice modeling. With the implementation of this new toll scheme, peak travelers will involve route and departure time decisions in which they make choices between toll and non-toll routes and their preferred departure time. Joint route and departure time choices are formulated using the joint multinomial logit and nested logit models.

The result of the joint multinomial logit model indicate that total travel time, toll, schedule delay, income, work schedule, driving distance, gender, age, and proportion of trips using freeways for commuting are significant variables affecting the route and departure time choices. The preferred nested logit model implies a high correlation between unobserved utilities of two route alternatives (freeways and non-toll roads) in the earlier departure time nest and rejects the choice structure in which decisions of route and departure time are jointly determined.

Aggregate elasticities with respect to changes of total travel time and tolls demonstrate that travelers are more sensitive to travel time than toll. Existing short-distance toll-free travelers are more sensitive to changes of toll levels than other travelers and likely to alter their travel choices. The implementation of electronic tolls by distance traveled and time-of-day will divert a substantial amount of travelers to non-toll roads and encourages them to alter their departure time to off-peak periods. Before implementing this new toll scheme, transportation agency should develop effective management plans to avoid potentially traffic congestion on non-toll roads. Time-of-day toll pricing can enable peak-period travelers shifting to less congested periods. However, toll levels during peak periods should be carefully determined to avoid over-diversion of vehicles to non-toll roads.

A number of extensions to this work could be considered. The empirical analyses only consider freeway commuters. Future research could include non-commuter samples. This study uses the multinomial logit and nested logit models to explore joint route and departure time choices. However, the ability of these models to represent substitutability between pairs of alternatives is limited. Using more flexible discrete choice models such as the generalized nested logit (Wen and Koppelman, 2001) models to examine these choices could be considered for future study.

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REFERENCES

Abdel-Aty, M.A., Kitamura, R. and Jovanis, P.P. (1995) Investigating the Effect of Travel Time Variability on Route Choice Using Repeated-measurement Stated Preference Data, **Transportation research record, No. 1493**, 39-45.

Abdel-Aty, M.A., Kitamura, R. and Jovanis, P.P. (1997) Using Stated Preference Data for Studying the Effect of Advanced Traffic Information on Drivers' Route Choice**, Transportation Research Part C, Vol. 5C, No. 1**, 39-50.

Adler, T., Ristau, W. and Falzarano, S. (1999) Traveler Reactions to Congestion Pricing Concepts for New York's Tappan Zee Bridge, **Transportation Research Record, No. 1659**, 87-96.

Ben-Akiva, M. and Lerman, S.R. (1985) **Discrete Choice Analysis: Theory and Application to Travel Demand,** MIT Press, Cambridge.

Burris, M.W. and Pendyala, R.M. (2002) Discrete Choice Models of Traveler Participation in Differential Time of Day Pricing Programs, **Transport Policy, Vol. 9, No. 3**, 241-251.

Burris, M.W. (2003a) Application of Variable Tolls on Congestion Toll Road, **Journal of Transportation Engineering, Vol. 129, No. 4**, 354-361.

Burris, M.W. (2003b) The Toll-Price Component of Travel Demand Elasticity, **International Journal of Transport Economics, Vol. XXX, No. 1**, 45-59.

DeCorla-Souza, P. (2000) Expanding the Market for Value Pricing, **ITE Journal, July**, 44-46.

DeCorla-Souza, P. (2002) The Long-Term Value of Value Pricing in Metropolitan Areas, **Transportation Quarterly, Vol. 56, No. 3**, 19-31.

Frankena, M.W. (1979) **Urban Transportation Economics.** Butterworth & Canada Ltd.

Goh, M. (2002) Congestion Management and Electronic Road Pricing in Singapore, **Journal of Transport Geography, Vol.10, No. 1**, 29-38.

Horowitz, J.H. (1983) Statistical Comparison of Non-Nested Probabilistic Discrete Choice Models, **Transportation Science, Vol. 17, No. 3**, 319-350.

Hunt, J.D. and Patterson D.M. (1996) A Stated Preference Examination of Time of Travel Choice for a Recreational Trip, **Journal of Advanced Transportation, Vol. 30, No. 3**, 17-44.

Lam, T.C. and Small, K.A. (2001) The Value of Time and Reliability: Measurement from a Value Pricing Experiment, **Transportation Research Part E, Vol. 37, No.2-3,** 231-251.

Louviere, J.J., Hensher, D.A. and Swait, J.D. (2000) **Stated Choice Methods: Analysis and Applications.** Cambridge, Cambridge University Press.

McFadden, D. (1978) Modeling the Choice of Residential Location, **Transportation Research Record, No. 672**, 72-77.

Morikawa, T., Ben-Akiva, M. and Yamada, K. (1991) Forecasting Intercity Rail Ridership Using Revealed Preference and Stated Preference Data, **Transportation Research Record, No. 1328**, 30-35.

Norojono, O. and Young, W. (2003) A Stated Preference Freight Mode Choice Model, **Transportation Planning and Technology, Vol. 26, No. 2**, 195-212.

Shinghal, N. and Fowkes, T. (2002) Freight Mode Choice and Adaptive Stated Preferences, **Transportation Research Part E, Vol. 38E, No. 5**, 367-378.

Wardman, M., Bonsall, P.W. and Shires, J.D. (1997) Driver Response to Variable Message Signs: A Stated Preference Investigation, **Transportation Research Part C, Vol.5C, No. 6**, 389-405.

Wen, C.H. and Koppelman, F.S. (2001) The Generalized Nested Logit Model, **Transportation Research Part B, Vol. 35, No.7**, 627-641.