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Freeway drivers' willingness-to-pay for a distance-based toll rate

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ABSTRACT

This paper applies the contingent valuation method to investigate and estimate the toll rate that freeway drivers are willing-to-pay (WTP) for each unit of distance they travel, after switching from per-entry based to distance-based tolling system. Due to a large portion of respondents who are unwilling to pay a toll at all, we adopt the spike model to avoid estimation errors. The estimation results show that average willingness to pay toll is TWD[1] 0.86/km, which can be refined further to TWD 0.81/km for short distance travelers, TWD 0.93/km for medium distance travelers, and TWD 0.97/km for long distance travelers. Additionally, the WTP toll rate of short distance travelers is significantly different on public holidays but not during peak hours. In contrast, the WTP toll rates of medium and long distance travelers significantly different during peak hours but not on public holidays.

1. Introduction

Due to the high construction and maintenance cost, more and more freeway networks are tolled instead of free charged worldwide. In addition, to increase the fairness in toll payment and prevent the overuse of short free trips, a distance-based scheme is adopted at the very beginning or to replace an original per-entry toll scheme. Taking Taiwan for instance, the original per-entry toll scheme is currently being converted into a distance-based toll scheme. Since the geometric of the freeway networks is designed for mainline-barrier per-entry toll system, very limited space is left for converting into a ramp-closed manual toll collection system. To smoothly convert the current per-entry toll system into a distance-based one, a two-phase conversion method is adopted: the first phase (the current phase as of this paper) to promote the adoption of electronic toll collection (ETC) under a per-entry toll scheme until the utilization rate reaching 65% and the second phase is to transform the current scheme into a distance-based toll one.

Additionally, the distance-based toll scheme can better manage traffic than the per-entry toll one through tolling. Taking Taiwan Freeway No. 1, a 373.3 km-long freeway with 10 mainline toll stations as an example, the daily traffic reaches 2.5–2.6 millions trips of which 68.09% and 58.25% are not tolled as shown in Table 1. During peak hours, serious recurrent traffic congestion causing by the overuse of short-distance trips occurs almost everyday, especially at those sections in metropolitan areas (29% non-tolled trips in Taipei metropolitan, 12% in Taichung metropolitan, and 13% in Kaohsiung metropolitan). Obviously, to mitigate traffic congestion during peak hours is to discourage the freeway usage of short-distance trips by tolling; however, it cannot be done under the current per-entry toll scheme. Therefore, one of main reasons to switch the toll scheme is to effectively manage traffic congestion by avoiding the short-distance trips to use freeways during peak periods.

However, because of the fundamental differences between distance-based and per-entry based toll schemes, undoubtedly, the toll formulas and rate for distance-based tolling should be advised in advance. As opposed to other approaches

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[1] *Note*: 30.04 Taiwanese Dollars (TWD) was equivalent to $1 USD (October, 2011).

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Table 1
Trip distributions by the number of toll stations passed. *Source*: Taiwan Area National Freeway Bureau (2010).

Number of toll stations passed	Weekday			Weekend		
	Trips	Percentage	Cumulative percentage	Trips	Percentage	Cumulative percentage
0	1828,055	68.09	68.09	1465,245	58.25	58.25
1	656,626	24.46	92.55	765,450	30.43	88.67
2	112,038	4.17	96.73	149,680	5.95	94.62
3	37,810	1.41	98.14	58,903	2.34	96.96
4	24,850	0.93	99.06	38,019	1.51	98.48
5	11,826	0.44	99.50	19,127	0.76	99.24
6	4675	0.17	99.68	7210	0.29	99.52
7	2944	0.11	99.79	4165	0.17	99.69
8	2986	0.11	99.90	3536	0.14	99.83
9	2011	0.07	99.97	2933	0.12	99.95
10	751	0.03	100.00	1364	0.05	100.00
Total	2684,572	100.00	–	2515,632	100.00	–

focusing on the supply side, this study attempts to use a contingent valuation method to estimate the toll rate that freeway drivers are willing to pay (WTP) under a distance-based ETC system. Furthermore, due to a large portion of our survey freeway users being unwilling to pay any toll at all, a spike model is adopted in order to avoid estimation errors.

Previous studies have examined various components of ETC, including: the hardware requirements, the merits of new technologies and regulations (Lee et al., 2008), and privacy disclosure and ETC promotion (Riley, 2008). Methods which have been used to examine these components include statistical analysis, stated preferences, and individual choice models. Olszewski and Xie (2005) adopted a discrete choice model to examine the different central business districts and freeways, which charge different rates between peak and off-peak hours. The authors discuss the different vehicle types which are prevalent on each freeway, the condition of the freeways, and the impact that tolls have individual departure times and travel routes.

Some studies use structural equations to modify new models (e.g., the theory of planned behavior, the technology acceptance model) to investigate the low ratio of drivers installing ETC equipment and using the ETC service (Chen et al., 2007). Other studies discuss the impact of the media and point to anecdotal evidence of the effectiveness of ETC equipment (Jou et al., 2011a). Nevertheless, there is a lack of research on the toll rate that drivers are WTP. The majority of research employs the contingent valuation method to estimate the toll rate that drivers are WTP, however our model differs from these studies. For instance, Hanemann (1984) and Salvador (2001) both adopted logit or probit models to estimate the price that users are WTP, but these models were prone to estimation errors when a large number of survey respondents reported as the WTP price is zero (i.e. they are not willing to pay at all). In light of this, many studies employ a spike model to avoid the estimation errors, which considers the respondents with zero WTP price (Kristroöm, 1997; Saz-Salazar and Garcia-Menendez, 2001; Yoo and Kwak, 2002; Yoo et al., 2006; Bengochea-Morancho et al., 2005; Hu, 2006; Jou et al., 2011b, in press). Following the same vein, this study utilizes a spike model to estimate the distance-based toll rate which freeway users are WTP.

The rest of this paper is organized as follows. Firstly, a brief introduction to the spike model is given in Section 2. Section 3 presents the questionnaire design and survey along with some descriptive statistics. Model estimation results along with some policy implications are given in Section 4. Finally, concluding remarks and suggestions for future studies are presented.

2. The spike model

Kristroöm (1997) proposed the use of a spike model to resolve the issues that arise when the reported price users are WTP is zero or negative, which has been proven to be superior to other traditional models, such as logit and probit models. It is better for a number of reasons. Firstly, also the major advantage, it can recognize the respondent's response equals to zero. In this study, many respondents (above 10%) are not willing to pay any money to use freeways. Secondly, the results in traditional models always under-estimate compared to the results of the spike model, as the former one does not account for zero willingness to pay (see Jou et al. (in press) for more methodological details).

The spike model assumes that the individual's utility function can be written as:

$$U(Y,X,Q) = V(Y,X,Q) + \varepsilon \quad (1)$$

where Y is income, X is a vector of socio-economic characteristics, Q is a vector of the asset value and ε is a random disturbance term with zero expected value. When users are WTP for a distance-based toll, it means that they prefer the new state (V_1) over the current state (V_0) (meanwhile their asset value will alter from the current asset (Q_0) to the new asset (Q_1). Thus, the individual's utility can be rewritten as:

$$V_1(Y - A_1, X, Q_1) + \varepsilon_1 \geqslant V_0(Y, X, Q_0) + \varepsilon_0 \quad (2)$$

When the user is WTP for a distance-based toll, their income will be reduced by A_1, though they still prefer the new utility V_1. We assume an income equal to Y in the initial stage, V_0 ($Y_0 = Y$), and ε_0 and ε_1 are random terms with an independent and identical (*iid*) Gumbel distribution. Thus, the probability function that a given user pays the amount A_1 in the new state can be derived as:

$$\begin{aligned} &V(Y-A_1,X,Q_1)-V(Y,X,Q_0) \geqslant \varepsilon_0-\varepsilon_1 \\ &\Pr(Yes)=\Pr(\Delta V(*) \geqslant \varepsilon)=F_\varepsilon(\Delta V(*)) \end{aligned} \tag{3}$$

where $\Delta V(.)$ indicates the difference between the utilities of the new state and the current state. Moreover, if the bid A_1 offered in the questionnaire is smaller than the *willingness to pay* value (*willingness to pay* $\geqslant A_1$), it means that the traveler will pay that amount A_1 to use the freeway. The probability of individual paying the amount A_1 in the new state can be derived as:

$$\Pr(Yes)=\Pr\ (\textit{willingness to pay} \geqslant A_1)=1-G(A_1)=F_\varepsilon(\Delta V(*)) \tag{4}$$

where $G(A_1)$ is the cumulative distribution function (c.d.f.) of the respondent who is not willing to pay the amount A_1. The domain of the cumulative distribution function can then be expressed as:

$$G(A_1)=\begin{cases} 0, & A_1<0 \\ P, & A_1=0 \\ F(A_1), & A_1>0 \end{cases} \tag{5}$$

We can further derive the expected *willingness to pay* as:

$$E\ (\textit{willingness to pay})=\int_0^{\infty}(1-G(A_1))dA-\int_0^{-\infty}(G(A_1))dA=\int_0^{\infty}(F_\varepsilon(\Delta V(*)))dA-\int_0^{-\infty}(1-F_\varepsilon(\Delta V(*)))dA \tag{6}$$

where p belongs to $(0,1)$ and $F(A_1)$ is a continuous and increasing function such that $F(A_1 = 0) = p$ and $\lim_{A_1\to\infty}F(A_1)=1$. The maximum likelihood function for the sample is then given as:

$$L=\sum_i^N M_iW_i\ln(1-G(A_1))+\sum_i^N M_i(1-W_i)\ln(G(A_1)-G(0))+\sum_i^N(1-M_i)\ln(G(0)) \tag{7}$$

where M indicates whether the *willingness to pay* is greater than 0 or not. If the user rejects a series of bids it will generate a *willingness to pay* smaller than 0. Another W is defined by whether the *willingness to pay* is greater than the bid A_1 or not, as Eqs. (8) and (9) calculate respectively:

$$M=\begin{cases} 1, & \textit{willingness to pay}>0 \\ 0, & \textit{otherwise} \end{cases} \tag{8}$$

$$W=\begin{cases} 1, & \textit{willingness to pay}>A_1 \\ 0, & \textit{otherwise} \end{cases} \tag{9}$$

Without a loss of generality, we assume that the utility function is a linear utility function, and consider only the effect of income Y.[2] The utility function (Eq. (1)) can thus be rewritten as:

$$V(A,X,Q)=\alpha_j+\beta A_1, j=0,1 \tag{10}$$

The difference between the utilities of the new state and the current state can therefore be expressed as:

$$\Delta V(*)=\alpha_1-\alpha_0-\beta A_1=\alpha-\beta A_1 \tag{11}$$

We then assume $G(A_1)$ has the form of a logistical function, meaning that $F_\varepsilon(\Delta V(*))$ can be shown as:

$$F_\varepsilon(\Delta V(*))=\frac{1}{1+\exp(-\alpha+\beta A_1)} \tag{12}$$

Eq. (5) can be further expressed as:

$$G(A_1)=\begin{cases} 0, & A_1<0 \\ [1+\exp(\alpha)]^{-1}, & A_1=0 \\ [1+\exp(\alpha-\beta A_1)]^{-1}, & A_1>0 \end{cases} \tag{13}$$

where α is the marginal utility of improving travel conditions after adopting a distance-based toll system. β is the marginal utility of paying the toll. We can derive the expected toll rate that users are WTP as:

[2] For simplicity, we only derive the toll rate the user is WTP with the income variable. It is straightforward to derive the WTP with other variables included, such as Q and X; however, it is noted that these two kinds of variables shall be specified as alternative specific variables, instead of generic variables for estimation purposes.

$$E\ (willingness\ to\ pay) = \int_0^{\infty}(1 - G(A_1))dA_1 - \int_0^{-\infty}(G(A_1))dA_1 = \int_0^{\infty}\left(\frac{\exp(\alpha - \beta A_1)}{1 + \exp(\alpha - \beta A_1)}\right)dA_1$$
$$= \frac{1}{\beta}\left\{\lim_{A_1 \to \infty}(-\ln[1 + \exp(\alpha - \beta A_1)] + \ln[1 + \exp(\alpha)])\right\} \tag{14}$$

The expected price users are WTP can be derived as $A_1 \to \infty$ and shown as:

$$E\ (willingness\ to\ pay) = \frac{1}{\beta}\ln[1 + \exp(\alpha)] \tag{15}$$

Spike value can be defined as following the equation by setting $A_1 = 0$.

$$Spike = \frac{1}{1 + \exp(\alpha)} \tag{16}$$

3. Data collection

This study designed a questionnaire to survey the WTP toll rate of freeway users. The questionnaire design and survey along with descriptive statistics are detailed below, respectively.

3.1. Questionnaire design

The questionnaire contains four categories of questions: (1) frequency of freeway use, (2) presence of and willingness to use ETC, (3) demographics of the principle drivers, and (4) The rate which the user is WTP for under a distance-based toll scheme. Each of these categories will be explained in more details below.

(1) Frequency of freeway use.

This section enquiries drivers the origin and destination of their most frequently used freeway sections, their most common purpose for travel, the weekday they most frequently travel, the hour(s) they most frequently travel, whether they travel during peak hours, monthly average usage of the freeway, average freeway travel time and costs, average travel time and costs for traveling on local roads, average number of accompany persons when traveling.

(2) The presence of and willingness to use ETC.

This section enquiries drivers whether an e-pass has been installed, how long has an e-pass been installed, the frequency of use of the e-pass after installation, the average deposit amount, the average amount of ETC transactions each month, the frequency of ETC transaction failure, and if they have any reasons for not installing an e-pass.

(3) Details of the principle drivers.

This section enquiries drivers about their demographic background, including age, gender, marital status, occupation, position, working hours, education, individual monthly income, number of vehicles (including cars and motorcycles) owned per household, and the number of vehicles with an e-pass installed per household.

(4) The distance-based toll rate that the user is WTP.

The contingent valuation method scenario design of this study adopts a dichotomous choice method, which presents an initial distance-based toll rate, then queries whether drivers are WTP for that amount. Following the initial offer, we alter the rate in subsequent phases, based on if they were WTP for the initial phase. Utilizing this method, three scenario prices can be offered (see Fig. 1). By converting the current toll rate of TWD 40 (for passenger cars) per entry under average spacing of 37 km of mainline barrier toll stations, the initial toll rate is set as TWD 1/km.

To illustrate further, the initial price (toll rate) offered by the questionnaire is TWD 1/km. If the respondent is WTP for this price, the next price offered will be TWD 1.25/km; if not, the next price offered will be TWD 0.75/km. In the third phase, the price offered is TWD 1.375 and 1.125/km for those who are and are not WTP TWD 1.25/km, respectively. At the last phase, for those who are WTP TWD 1.375/km, they are further asked to state the maximum price they are WTP. If drivers are not WTP any price offered, then they are asked to state the least price they are WTP. In conclusion, our questionnaire is designed to investigate the price that respondents are WTP the toll rates ranging from TWD 0.625/km, to TWD 1.25/km at an increment

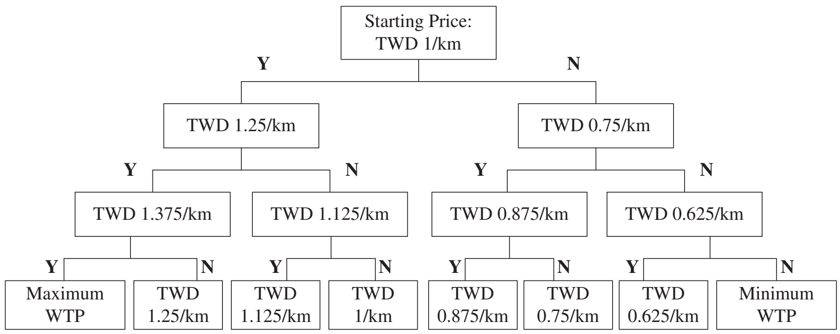

Fig. 1. Flow diagram of prices offered and willingness to pay for each phase (Y = WTP; N = not WTP).

of TWD 0.125/km. For those who accept or decline all prices offered, the maximum and minimum prices they are WTP are further asked.

3.2. Data analysis

The questionnaires were mailed by post to owners of cars nationwide, with 25,000 samples being randomly drawn from Taiwan's Vehicle Registration (VR) Database, which is maintained by the Directorate General of Highways (DGH), Ministry of Transportation and Communications (MOTC). The VR Database contains information that includes vehicle license plate numbers, names, addresses, and telephone numbers of vehicle owners, as well as some vehicle characteristics, and while the information is confidential, it can be used for designated purposes with the permission of the DGH. A proportional stratified random sampling method is adopted, and the questionnaires are independently disseminated to car owners in 22 cities/counties in Taiwan proportionally to the numbers of cars registered in those jurisdictions during November 15–December 15, 2010. A total of 1143 valid questionnaires were returned.

To examine the differences in the WTP toll rates of drivers with different trip length, three categories of drivers are compared: short distance travelers with trip length less than 50 km, medium distance travelers with trip length between 51 and 150 km, and long distance travelers with trip length longer than 151 km. The demographic breakdown of respondents is presented in Table 2. For each of the travel distance categories, more than 80% of the drivers are male (86% for short, 87% for medium, and 84% for long distance). The age range of 50–59 accounts for the biggest proportion in all three travel distance categories (31%, 35% and 32% respectively). The average age is 48 years old. The largest portion of the occupation of respondents in the short and medium travel distance categories is the third degree industry (39% and 37%, respectively). However, that of respondents in long travel distance category is the second degree industry (43%). However, most of them hold a position of a clerk/operator (47%, 44% and 45%, respectively). Most of respondents are of a university education level (more than 50% for all travel distance categories). The majority of respondents work at a fixed working hours schedule (71%, 71% and 68%, respectively). The average monthly income of respondents is TWD 50,000. The majority of sampled households have one or two vehicles (approximately 82%). Additionally, for all three travel distance categories, more than 70% of sampled households have not installed an ETC e-pass yet.

Table 3 analyzes the trip characteristics of sampled car drivers. As shown in Table 2, the most common trip purpose of three travel distance categories is families/friends visit (36%, 44% and 56%, respectively), followed by leisure tour (28%, 31% and 29%, respectively). However, for the short travel distance category, approximately 21% of trips are for work or school, which is noticeably higher than other less frequent travel types, indicating that freeway users undergoing short trips have more diversified travel purposes than other two travel distance categories, and therefore we need to conduct further analysis and investigation into their decision-making and the toll rate they are WTP.

Of the three travel distance categories, most trips occur on the weekend only, (45%, 55% and 62%, respectively), followed by weekdays only (26%, 20% and 18%, respectively). Short distance trips occur 21% more often than the other two travel distance categories. Therefore, attention should be paid to any changes in the frequency of short trips after the full implementation of distance-based ETC. For all three travel distance categories, the most frequent time for a trip to take place is in off-peak hours (43%, 45% and 55%, respectively). In addition, the longer the trip is, more drivers prefer to use freeway during off-peak hours. This is especially true when the travel distance is more than 151 km, in which case nearly 60% of drives choose to travel in off-peak hours. The motivation for this may be that longer trips require more travel time, and therefore drivers choose to travel during periods with lighter traffic, in order to significantly reduce travel time and driving stress. Furthermore, regarding the difference between outbound and inbound trips during peak hours, we found that, regardless of the travel distance, the most frequent situation is to have both inbound and outbound trips occurring in peak hours (34%, 31% and 33%, respectively); and the second most common situation was to have only the inbound trips in off-peak hours (32%, 34% and 36%, respectively). Regarding the freeway usage frequency per month of respondents, the category with the most frequent use is short distance trips (an average of 11 times per month), followed by medium distance trips (an average of 7

Table 2
Demographic breakdown of sampled car drivers.

Items	Travel distance		
	Short	Medium	Long
Gender			
Male	633 (85.54)	263 (86.80)	140 (84.43)
Female	107 (14.46)	40 (13.20)	26 (15.57)
Age			
<20	5 (0.68)	4 (1.32)	1 (0.6)
20–29	43 (5.81)	18 (5.94)	8 (4.82)
30–39	150 (20.27)	59 (19.47)	30 (18.07)
40–49	210 (28.38)	59 (19.47)	39 (23.49)
50–59	230 (31.08)	107 (35.31)	53 (31.93)
>60	102 (13.78)	56 (18.48)	35 (21.08)
Average age	47	48	48
Education			
Primary or below	29 (3.92)	14 (4.62)	7 (4.22)
Junior high school	47 (6.35)	17 (5.61)	6 (3.61)
Senior high school	190 (25.68)	67 (22.11)	46 (27.71)
University	376 (50.81)	162 (53.47)	89 (53.61)
Master	91 (12.3)	36 (11.88)	18 (10.84)
Ph.D.	7 (0.95)	7 (2.31)	0 (0)
Occupation			
Military, public service, education	148 (21.45)	64 (22.3)	28 (18.06)
Second degree industry	167 (24.2)	75 (26.13)	33 (21.29)
Third degree industry	272 (39.42)	105 (36.59)	66 (42.58)
First degree industry	25 (3.62)	7 (2.44)	6 (3.87)
Student	3 (0.43)	1 (0.35)	0 (0)
N/A	65 (9.42)	29 (10.1)	16 (10.32)
Other	10 (1.45)	6 (2.09)	6 (3.87)
Position			
Director	131 (17.7)	68 (22.44)	35 (21.08)
Manager	193 (26.08)	80 (26.4)	41 (24.7)
Clerk/operator	345 (46.62)	134 (44.22)	75 (45.18)
Student	5 (0.68)	1 (0.33)	0 (0)
Unemployed	66 (8.92)	20 (6.6)	15 (9.04)
Working hours			
Fixed	527 (71.22)	214 (70.63)	113 (68.07)
Flexible	213 (28.78)	89 (29.37)	53 (31.93)
Monthly income (TWD)			
<20,000	112 (15.41)	43 (14.48)	27 (16.67)
20,000–40,000	204 (28.06)	73 (24.58)	42 (25.93)
40,000–60,000	207 (28.47)	103 (34.68)	49 (30.25)
60,000–80,000	131 (18.02)	39 (13.13)	26 (16.05)
80,000–100,000	39 (5.36)	20 (6.73)	11 (6.79)
100,000–120,000	26 (3.58)	14 (4.71)	5 (3.09)
>120,000	8 (1.1)	5 (1.68)	2 (1.23)
Average monthly income (TWD 10,000)	4.9	5.1	5.1
Number of vehicles per household			
0	11 (1.49)	2 (0.66)	3 (1.81)
1	354 (47.84)	123 (40.59)	81 (48.8)
2	252 (34.05)	125 (41.25)	55 (33.13)
3 or more	93 (16.62)	53 (17.49)	27 (16.27)
Number of e-passes per household			
0	590 (79.84)	223 (73.84)	126 (76.36)
1	117 (15.83)	63 (20.86)	32 (19.39)
2 or more	32 (4.33)	16 (5.29)	7 (4.24)
Number of samples	740	303	166

Note: The percentages of respondents in each category are given in parentheses.

times per month), and finally long distance trips (an average of 6 times per month). These results are consistent with our expectations. Additionally, the majority of drivers do not avoid toll stations (86%, 75% and 78%, respectively) by detouring to local roads. For those who try to avoid toll stations, most of them only avoid 1–2 toll stations. For medium travel distance category, there is around 25% of drivers attempt to avoid 1–2 toll stations. A possible reason for this is that for this particular travel distance, avoiding toll stations will not have a significant impact on total travel time, and may even reduce the travel time when freeway is congested.

Table 3
Trip characteristics of sampled car drivers.

Items	Travel distance		
	Short	Medium	Long
Trip purpose			
Work or school	219 (21.3)	40 (9.3)	14 (6.01)
Families/friends visit	373 (36.28)	191 (44.42)	130 (55.79)
Leisure	291 (28.31)	135 (31.4)	67 (28.76)
Business	120 (11.67)	55 (12.79)	18 (7.73)
Others	25 (2.43)	9 (2.09)	4 (1.72)
Days of travel			
Everyday	166 (21.5)	46 (14.38)	20 (11.43)
Weekdays	201 (26.04)	64 (20)	31 (17.71)
Partially weekdays	54 (6.99)	33 (10.31)	16 (9.14)
Weekdays	351 (45.47)	177 (55.31)	108 (61.71)
Travel periods			
Morning peak	281 (31.22)	113 (31.48)	55 (28.35)
Afternoon peak	229 (25.44)	83 (23.12)	33 (17.01)
Off-peak	390 (43.33)	163 (45.4)	106 (54.64)
Outbound and inbound trips in peak hours			
Neither in peak hours	239 (32.3)	104 (34.32)	59 (35.54)
Outbound in peak hours; Inbound in off-peak hours	130 (17.57)	48 (15.84)	22 (13.25)
Outbound in off-peak hours; Inbound in peak hours	119 (16.08)	56 (18.48)	31 (18.67)
Both in peak hours	252 (34.05)	95 (31.35)	54 (32.53)
Freeway usage frequency per month			
More than 30	40 (5.41)	7 (2.31)	4 (2.41)
20–29	111 (15)	16 (5.28)	3 (1.81)
8–19	129 (17.43)	47 (15.51)	18 (10.84)
4–7	210 (28.38)	92 (30.36)	50 (30.12)
Less than 3	246 (33.24)	138 (45.54)	90 (54.22)
Never	4 (0.54)	3 (0.99)	1 (0.6)
Average usage frequency per month	11	7	6
Number of toll stations passed			
None	334 (45.14)	0 (0)	0 (0)
1–2	406 (54.86)	187 (61.72)	0 (0)
3–4	0 (0)	107 (35.31)	47 (28.31)
5–6	0 (0)	9 (2.97)	84 (50.6)
7–8	0 (0)	0 (0)	24 (14.46)
More than 8	0 (0)	0 (0)	11 (6.63)
Number of toll stations avoided			
None	636 (85.95)	226 (74.59)	129 (77.71)
1–2	104 (14.05)	75 (24.75)	35 (21.08)
More than 3	0 (0)	2 (0.66)	2 (1.2)

Note: The percentages of respondents in each travel distance category are given in parentheses.

Table 4 presents analysis results regarding e-passes installation and usage of car drivers. The majority of drivers in each travel distance category have not installed an e-pass (15%, 20%, and 19%, respectively). Of the drivers who have installed an e-pass, most of them did so 3 years ago (34%, 47% and 45%, respectively). Of the drivers with an e-pass, most of them have used it for more than 300 times (27%, 37% and 35%, respectively). The drivers who have used their e-pass less than 50 times predominantly take short distance trips. A possible reason for this is that although these drivers use freeways, they usually do not pass through any toll station. For e-pass owners, most have a current balance below TWD 1000 (47%, 48% and 43%, respectively), followed by above TWD 3000 (39%, 39% and 30%, respectively). A possible reason for this large range is the impact of an e-pass installation promotion, in which if an individual credits their account with more than TWD 4000, they will receive a 5% toll reduction, thus drivers are drawn to larger top-up amounts to take advantage of the savings. However, approximately 77% of drivers have monthly transactions less than TWD 1000. The majority of drivers have not experienced an ETC transaction failure (71%, 66%, and 61%, respectively). For those who have experienced transactions failures, most of them have fewer than five failures (29%, 24%, and 35%, respectively). For those who have not installed an e-pass, our analysis shows that the key reason is they do not use a freeway often enough (41%, 45% and 43% respectively); followed by the costs involved in installing an e-pass (36%, 33% and 35%, respectively).

Table 5 shows the analysis results of the toll rates that car drivers are WTP by travel distance category. For each of the three travel distance categories, the largest portion of WTP toll rate answered by freeway users is TWD 0.625/km (35%, 39% and 37%, respectively). It is worth noting that the average WTP toll rate that drivers with short travel distance is TWD 0.59/km which is lower than those of the drivers of medium and long travel distance categories (both are TWD

Table 4
E-pass installation characteristics of sampled cars drivers.

Items	Travel distance		
	Short	Medium	Long
E-pass installation			
Installed	112 (15.14)	62 (20.46)	31 (18.67)
Not installed	628 (84.86)	241 (79.54)	135 (81.33)
Years e-pass has been installed			
Less than 1 year	16 (14.28)	8 (12.91)	4 (9.91)
1 year	23 (20.53)	9 (14.52)	7 (22.58)
2 years	35 (31.25)	16 (25.80)	6 (19.36)
More than 3 years	38 (33.93)	29 (46.77)	14 (45.16)
Frequency of e-pass use			
Less than 50	26 (23.21)	10 (16.13)	4 (12.9)
50–100	16 (14.29)	8 (12.9)	6 (19.35)
101–200	29(25.89)	12 (19.35)	6 (19.35)
200–300	11 (9.82)	9 (14.52)	4 (12.9)
More than 300	30 (26.79)	23 (37.1)	11 (35.48)
Average amount of ETC deposit			
TWD 0	2 (1.8)	0 (0)	0 (0)
TWD 1000	52 (46.85)	29 (47.54)	13 (43.33)
TWD 1001–3000	14 (12.61)	8 (13.11)	8 (26.67)
Above TWD 3001	43 (38.73)	24 (39.34)	9 (30)
Average per travel distance category	2433	2264	2083
Average monthly transactions with ETC			
0	3 (2.7)	0 (0)	1 (3.33)
Less than TWD 1000	86 (77.48)	51 (83.61)	23 (76.67)
Above TWD 1001	22 (19.82)	10 (15.39)	6 (20)
Average per travel distance category	760	760	646
Number of ETC transactions failures			
Never	80 (71.43)	41 (66.13)	19 (61.29)
1–5	32 (28.57)	15 (24.19)	11(35.48)
5–10	0 (0)	4 (6.45)	1 (3.23)
10–15	0(0)	0 (0)	0 (0)
More than 15	0 (0)	2 (3.23)	0 (0)
Reasons for not installing an e-pass			
Cost too high	292 (36.45)	100 (32.68)	63 (35)
Inconvenient to install	75 (9.36)	31 (10.13)	15 (8.33)
Inconvenient to deposit	59 (7.37)	22 (7.19)	14 (7.78)
Do not use freeway often	326 (40.7)	137 (44.77)	77 (42.78)
Other	49 (6.12)	16 (5.23)	11 (6.11)

Note: The percentages of respondents in each travel distance category are given in parenthesis.

Table 5
WTP toll rates of sampled car drivers under the distance-based toll scheme.

WTP toll rate (TWD)	Travel distance					
	Short		Medium		Long	
	Samples	Percentage	Samples	Percentage	Samples	Percentage
0	85	11.82	31	10.51	18	11.25
0.001–0.624	177	24.62	55	18.64	34	21.25
0.625	251	34.91	114	38.64	59	36.88
0.750	43	5.98	20	6.78	7	4.38
0.875	67	9.32	30	10.17	19	11.88
1.000	41	5.70	15	5.08	6	3.75
1.125	40	5.56	17	5.76	12	7.50
1.250	10	1.39	9	3.05	4	2.50
1.375	4	0.56	1	0.34	0	0.00
1.376	1	0.14	3	1.02	1	0.63
Total	719	100.00	295	100.00	160	100.00
Average	0.59		0.63		0.63	

0.63/km). Possible explanations are that short travel distance drivers are less likely to pass through toll stations under current per-entry toll scheme. Based on this, to further capture the toll rates that drivers with different travel distances are WTP,

Table 6
WTP toll rates of car drivers estimated by the spike models.

Variables	Total	Travel distance		
		Short	Medium	Long
Constant	1.703 (18.49)	1.642 (14.13)	1.815 (9.70)	1.799 (6.99)
Bid of scenario toll rate	−217.33 (−20.07)	−224.94 (−16.20)	−210.618 (−9.79)	−200.56 (−6.81)
Spike	0.154 (12.83)	0.162 (10.27)	0.140 (6.21)	0.142 (4.53)
WTP toll rate under distance-based toll scheme	0.86 (33.05)	0.81 (26.46)	0.93 (16.16)	0.97 (11.31)
Wald statistic (*p*-value)	1092.019 (<0.00)	700.058 (<0.00)	261.078 (<0.00)	127.904 (<0.00)
Number of samples	1143	700	228	155

Note: *t*-values are given in parentheses.

Table 7
Estimated spike models by travel distance.

Variables	Total	Travel distance		
		Short	Medium	Long
Constant	2.050 (15.01)	1.727 (4.40)	2.116 (7.50)	2.455 (8.02)
Bid of scenario toll rate	−220.760 (−20.20)	−232.420 (−16.36)	−226.283 (−9.28)	−215.825 (−6.58)
Age		0.015 (2.19)		
University or above			0.600 (2.41)	
Travel for work or meetings on daily basis	−0.425 (−2.33)			
Travel on weekdays	−0.336 (−2.67)	−0.557 (−3.31)		
Travel every day		−0.546 (−2.83)		
Travel on weekdays with return trips in off-peak hours	−0.220 (−1.79)			−0.879 (−2.56)
Most frequently travel in off-peak hours			−0.747 (−3.17)	
Short distance trip	−0.201 (−1.71)			
Travel less than 30 min		−0.441 (−2.27)		
Less than three times travel per month		−0.369 (−2.28)		
Frequency after e-pass installation	0.143 (1.86)			
Number of cars with e-pass		0.238 (1.78)		
Ratio of toll stations avoided			−1.176 (−3.33)	−3.403 (−3.13)
Spike	0.138 (8.12)	0.168 (7.36)	0.062 (3.57)	0.171 (3.05)
WTP distance toll rate	0.90 (17.40)	0.77 (14.04)	1.23 (12.79)	0.82 (7.79)
Wald statistic (*p*-value)	302.855 (<0.00)	197.124 (<0.00)	163.629 (<0.00)	60.746 (<0.00)
Number of samples	1143	700	228	155

Note: *t*-values are given in parentheses.

three spike models of each travel distance category are respectively developed with detailed discussions of influential variables.

4. Results

Table 6 presents the distance-based toll rate estimated by the spike models. As shown in Table 6, as anticipated, the higher the toll rate offered, the fewer drivers are WTP. The average toll rate that drivers are WTP is TWD 0.86/km. Furthermore, for the freeway drivers in the short distance category, the average WTP toll rate is TWD 0.81/km. However, the toll rates that medium and long trip drivers are WTP are TWD 0.93/km and 0.97/km, respectively, which are fairly close. It is interesting to note that the current toll rate surely has a strong effect on the estimated WTP toll. The current toll rate is TWD 40 per-entry for a passenger car and the average distance between two consecutive toll stations is 37.3 km. Thus, the distance-based toll rate is approximately TWD 1.07/km, which is very close to the estimated WTP toll rates. As abovementioned, drivers with short travel distance have a relatively low WTP toll rate because currently they often do not have to pay tolls (about 58–68% drivers do not pass any toll station in using freeway), and the distance-based toll scheme will surely increase their travel cost.

Table 7 further presents the estimated spike models by travel distance category.[3] Results show that all three models are significantly tested. As anticipated, the higher the toll rate offered, the fewer drivers are WTP. In addition, most of estimated parameters based on total samples are negative, suggesting that drivers prefer to pay lower distance-based tolls. Moreover, since short trips are most likely to be occurred on a daily basis, during weekdays, and with a trip purpose for work and using freeway on a daily basis may significantly increase travel cost, drivers with short travel distance prefer not to pay any toll at all.

[3] We started with large number of possible explanatory variables and then chose the model with variables whose coefficients were both with corrected signs and significant *t* values.

Table 8
Percentage changes of the average WTP toll rates.

Models	Total	Travel distance		
		Short	Medium	Long
Simple spike	1.0 (0)	94.2 (−5.8)	108.1 (+8.1)	112.8 (+12.8)
Influential variable	1.0 (0)	85.6 (−14.4)	136.7 (+36.7)	91.1 (−8.9)

Note: Percentage changes are given in parentheses.

For drivers working at a flexible work hours, they can flexibly make their inbound and outbound trips in off-peak hours on a weekday; therefore this group of drivers may not benefit from the reductions in traffic congestion at toll stations brought by distance-based ETC. However, it is possible that those individuals who use their e-pass more often may prefer new technology, and thus prefer the distance-based ETC.

In the short travel distance category, we found that older drivers show a preference for distance-based ETC. A possible explanation for this is that they are more likely to be financially stable. Additionally, if they travel on the freeway daily, or on each weekday, their travel costs are likely to increase, which may lead to a preference for this group to not pay tolls. On the other hand, those who use the freeway less than three times per month are also reluctant to pay for distance-based ETC. This would indicate that the implementation of distance-based ETC would encourage freeway users to re-evaluate whether it is necessary to travel on freeways. This also indicates that the full implementation of the distance-based ETC may cause a shift in popular travel routes for short trips. This would indicate that there is a need for further study into the impact that this may have. Drivers with less than 30 min of travel time on the freeway are unwilling to pay for distance-based ETC, because they can detour to other local non-tolled roads. For short trips, drivers who frequently use an e-pass may be more supportive of new traffic control technology. As a result, they may prefer paying for distance-based ETC.

For the medium and long distance travel categories, we found that drivers with a university education level or above are more likely to accept paying tolls; hence they are more supportive for distance-based ETC. Those responders who travel in off-peak hours for both inbound and outbound trips, or at least for the majority of their trips, may be reluctant to pay tolls because of their longer travel times, and because there is less traffic in off-peak hours. Also they are unlikely to experience the benefits of less congestion and improved traffic flow that distance-based ETC will bring. Finally, we found that drivers who often avoid toll stations are reluctant to pay distance-based tolls. This may be because this type of driver is focused on reducing travel costs, and therefore they dislike anything that is likely to increase their travel costs.

In summary, some policy implications can be drawn based on the model estimation results. Firstly, since the toll rates drivers willing to pay are different in both travel periods and distances, it is possible to introduce differential pricing for different travel periods (such as peaks and off-peaks) and distances (such as discount for a longer trip). We suggest varied toll rates for short trips occurring on weekdays, weekends, and public holidays, because short trips are often undertaken when traveling to work or school, and distanced-based toll scheme may divert traffic from the freeways to other non-tolled roads. For medium and long trips, we suggest varied toll rates for peak and off-peak hours, which may help to maintain freeway service quality. Secondly, the toll rate can be set to be higher than the price the short distance travelers are willing to pay. As a result, those travelers might switch to different modes (such as bus or carpool) or routes (such as non-tolled local roads). Thirdly, the guidance systems on alternative local roads should be well established so as not to raise strong opposition of short distance travelers.

We further modified the proposed models to estimate the toll rate that freeway users are WTP for distance-based ETC, the results are shown in Table 8. The weighted average toll rates that drivers are WTP, derived from the simple spike model and influential variables model, are TWD 0.86/km and 0.87/km, respectively. The results are fairly close to the estimated results for each travel distance category, which proves that the estimated models by travel distance, are relatively reliable. Additionally, when analyzing the percentage change across the samples for the different travel distance categories trips, we found that without the influence from other variables, the price that drivers are WTP for a short trip is the lowest (5.8% lower than the average value); however the longer the travel distance, the higher the price that drivers are WTP. This may be due to the small price difference for drivers who usually take long distance trips (when compared with the cost for the previous per-entry based tolling), and the expectation that the new system will reduce the amount of drivers using the freeways for short trips, thus reducing traffic congestion. In the influential variable model, we found that drivers who usually take medium distance trips are WTP a higher toll rate, which may be because most of these drivers travel through 2–4 toll stations. Considering the toll cost, and travel time required, distance-based ETC is able to reduce traffic congestion, and maintain freeway service quality. Medium distance travelers are the category that is most likely to experience this difference.

5. Concluding remarks

The toll scheme of Taiwan freeways is planning to be switched from per-entry toll to distance-based toll by December 22, 2012. Due to the differences between two tolling schemes, toll formulas and rates have to be adjusted accordingly. Previous studies mostly focused on compensation plans and traffic management to investigate toll pricing. However, this study is conducted from drivers' point of view, and employed a contingent valuation method along with a large-scale car owners questionnaire survey to estimate the toll rate that drivers are WTP for distance-based ETC. Additionally, due to a great portion of respondents reporting they are not WTP at all, this study applies a spike model in order to avoid estimation errors. The results of this model indicate that the average toll rate that drivers are WTP for short trips is lower than that for medium and long trips (TWD 0.81/km, TWD 0.93/km and TWD 0.97/km, respectively). Furthermore, according to the estimated parameters, the WTP toll rate that drivers in the short travel distance category is affected by the presence of weekdays or weekends, rather than peak or off-peak hours. However, medium and long travel distance travelers are the opposite, implying that future distance-based ETC may consider introducing varied toll rates for the drivers in different travel distance categories so as to avoid the overuse of short distance trips and mitigate recurrent traffic congestion.

Additionally, due to the different toll rates that the drivers in travel distance categories are WTP, three spike models (short, medium and long travel distance) are developed to estimate the toll rates they are WTP. In reality, we believe that different social backgrounds and travel purposes will also have an impact on the WTP toll rate. Future studies may continue to use a latent class model to segment drivers, in order to build models with stronger explanatory power. Furthermore, the WTP toll rate and the WTP price for purchasing an e-pass are mutually related, so future studies could further investigate the correlation, so as to provide more insights for government decision making.

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References

Bengochea-Morancho, A., Fuertes-Eugenio, A.M., Saz-Salazar, S.D., 2005. A comparison of empirical models used to infer the willingness to pay in contingent valuation. Empirical Economics 30, 235–244.
Chen, C.D., Fan, Y.W., Farn, C.K., 2007. Predicting electronic toll collection service adoption: an integration of the technology acceptance model and the theory of planned behavior. Transportation Research Part C 15, 300–311.
Hanemann, W.H., 1984. Welfare evaluations in contingent valuation experiments with discrete responses. American Journal of Agricultural Economics 66, 332–341.
Hu, W., 2006. Use of spike models in measuring consumers' willingness to pay for non-GM oil. Journal of Agricultural Economics 38, 525–538.
Jou, R.C., Chiou, Y.C., Ke, J.C., 2011a. Impacts of impression changes on freeway driver intention to adopt electronic toll collection service. Transportation Research Part C 19, 945–956.
Jou, R.C., Wu, Y.C., Chen, K.H., 2011b. Analysis of environmental benefits of a motorcycle idling stop policy at urban intersections. Transportation 38, 1017–1033.
Jou, R.C., Wu, Y.C., Jian, R.Y., in press. A study of passengers' willingness to pay for business class seats of high speed rail in Taiwan, Transportmetrica.
Kristroöm, B., 1997. Spike models in contingent valuation models. American Journal of Agricultural Economics 79, 1013–1023.
Lee, W.H., Tseng, S.S., Wang, C.H., 2008. Design and implementation of electronic toll collection system based on vehicle positioning system techniques. Computer Communications 31, 2925–2933.
Olszewski, P., Xie, L., 2005. Modelling the effects of road pricing on traffic in Singapore. Transportation Research Part C 39, 755–772.
Riley, P.F., 2008. The tolls of privacy: an underestimated roadblock for electronic toll collection usage. Computer Law & Security Report 24, 521–528.
Salvador, L., 2001. Restoring Dockland Areas for Recreation Purposes: A Contingent Valuation Study. European Real Estate Society Conference.
Saz-Salazar, S.D., Garcia-Menendez, L., 2001. Willingness to pay for environmental improvements in a large city. Environmental and Resource Economics 20, 103–112.
Taiwan Area National Freeway Bureau, 2010. A Study on the Distance-based Electronic Toll Rate. Research Report. Taiwan Area National Freeway Bureau, Ministry of Transportation and Communications, Taiwan.
Yoo, S.H., Kwak, S.J., 2002. Using a spike model to deal with zero response data from double bounded dichotomous choice contingent valuation surveys. Applied Economics Letters 9, 929–932.
Yoo, S.H., Shin, C.O., Kwak, S.J., 2006. Inconvenience cost of spam mail: a contingent valuation study. Applied Economics Letters 13, 933–936.