VALUE OF TRAVEL TIME SENSITIVE TO INDIVIDUALS' SOCIOECONOMIC CHARACTERISTICS

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Abstract: This paper first showed the derived indirect utility functions based on the utility maximization problem. Then according to the indirect utility function, this paper divided the factors might affect the value of time (VOT) into three groups: (a) income and time budgets, (b) personal specific tastes caused by sex, age, trip purpose, etc., and (c) alternative modes' attributes. This paper then focused on the income and time budgets. We defined three types of direct utility function, and derived three models with different indirect utility function forms. These three models were estimated using the intercity passengers' mode choice data in Taiwan. The results showed that the performances of all three models were quite good. The results of one model, which introduced the impact of income, indicated that the VOT of high-income travelers was proportion to their income. The results of another model, which introduced the impact of expenditure rate, indicated that VOT was proportional to travelers' income but inversely proportional to their time budget.

Key Words: indirect utility function, income and time budgets, value of time, multinomial logit model, intercity travel

1. INTRODUCTION

Travel timesaving is frequently one of the most important sources of benefit in transportation projects. Generally, value of travel time (VOT) is measured by calculating the ratio of travel time and travel cost parameters from a predefined indirect utility function of mode choice model.

Factors might affect VOT can generally be summarized and divided into four categories. They are: (1) individuals' income and time budgets; (2) individuals' other characteristics, such as sex and age; (3) trip purposes; (4) types of travel time, such as in-vehicle and out-of-vehicle travel time or different modes' travel time. The empirical results of Bradley and Gunn (1990) may be a good example of analyzing the impact of these factors on VOT. In general, it is concluded that individuals with higher income and/or less time budgets, male, and business travelers tend to have higher VOT; and that out-of-vehicle VOT is higher than in-vehicle VOT. In some cases, the size of travel time savings was also considered having an effect on VOT (Hensher, 1976; Fowkes and Wardman, 1988)

Bradley and Gunn's conclusions are reasonable but not robust due to lack of theoretical proof. For example, any travel time savings are used by individuals to engage in activities. Therefore, to individuals, it should not make any difference whether the time savings are in-vehicle or out-of-vehicle travel time. In this case, it would be meaningless to estimate VOT with respect to in-vehicle and out-of-vehicle travel time. In other words, estimating in-vehicle and out-of-vehicle VOT will be useful only when we assume travel time provides individuals with disutility (see Jara-Diaz and Farah, 1987; Duann and Shiaw, 2000).

This paper will discuss the effect of the aforementioned factors on VOT based on microeconomic theory. First, it introduces the general VOT model, and then discusses the effect of income and time budgets, individuals' other socioeconomic characteristics, and attributes of alternative modes on VOT through the derivation of indirection utility functions. For empirical application, this paper assumes three different utiity functions, and then derives corresponding indirect utility functions under income and time budgets. These indirect utility functions are estimated and analyzed.

2. THEORETICAL MODELS OF VOT

2.1 General VOT Model

The most widely used model (for example, Truong and Hensher, 1985; Jara-Diaz and Farah, 1987), which describes individuals' decisions between composite goods (money) and time, can be expressed as follows:

$$\begin{aligned} \max_{\{G,L\}} \quad & U(G,L) \\ \text{s.t.} \quad & G + c_m = I \\ & L + t_m = T \\ & G, L \geq 0 \end{aligned} \qquad \text{(P1)}$$

where $U(\cdot)$ is the direct utility function; G and L denote the consumption of composite goods and time, respectively; I and T denote the fixed income budget and time budget, respectively; c_m and t_m denote the mode m's travel time and travel cost, respectively. Problem (P1) shows that under the circumstances that an individual chooses mode m (i.e., given c_m and t_m), he maximizes his utility by allocating money and time between G and L, subject to his income and time budgets.

From problem (P1), one can derive the value of travel time, *VOT*, as:

$$VOT = \left.\frac{\partial U / \partial L}{\partial U / \partial G}\right|_{U^*} = \frac{\mu}{\lambda} \qquad (1)$$

where μ and λ are the shadow prices with respect to the time constraint and income constraint.

μ/λ is often defined as the shadow price of time, which indicates the value of the increase in utility induced by using travel time savings to engage in activities.

2.2 VOT Models with Other Factors Included

Theoretically, we wish to have all the factors affecting the VOT defined in the utility maximization problem (e.g., (P1)), and then derive a VOT function that could reflect the effects of these factors. However, this will be too difficult to derive. In this paper, we will discuss the effects of these factors one by one. The factors include income and time budgets, individuals' other socioeconomic characteristics, and attributes of alternative modes.

2.2.1 Income and Time Budgets

Assuming problem (P1) is a true model to describes individuals' decisions between composite goods (money) and time under the circumstances the individual chooses mode m, we can derive the indirect utility function, V, as:

$$V((I-c_m),(T-t_m)) \tag{2}$$

Equation (2) shows that the indirect utility is a function, strictly a non-decreasing function, of individuals' disposable income, $I-c_m$, and disposable time, $T-t_m$, i.e.,

$$\frac{\partial V}{\partial I} \geq 0, \text{ and } \frac{\partial V}{\partial T} \geq 0 \tag{3}$$

Equation (3) shows that as individuals' income and time budgets increase, the levels of their indirect utility will never decrease.

On the other hand, it is also found that:

$$\frac{\partial V}{\partial c_m} \leq 0, \text{ and } \frac{\partial V}{\partial t_m} \leq 0 \tag{4}$$

Because as c_m increases, $I-c_m$ decreases, and as t_m increases, $T-t_m$ also decreases. Both cause the level of the indirect utility to decrease.

In most cases, the indirect utility is considered a non-decreasing concave function of $I-c_m$ and $T-t_m$. That means:

$$\frac{\partial^2 V}{\partial I^2} \leq 0, \text{ and } \frac{\partial^2 V}{\partial T^2} \leq 0 \tag{5}$$

For $\lambda=\partial V/\partial I$ and $\mu=\partial V/\partial T$, equation (5) actually means:

$$\frac{\partial \lambda}{\partial I} \leq 0, \text{ and } \frac{\partial \mu}{\partial T} \leq 0 \tag{6}$$

That implies the more money individuals have, the less they value money; the more time individuals have, the less they value time.

From equation (6), it is concluded that for individuals who choose the same mode, those with higher income budget (i.e., with smaller λ) and/or less time budget (i.e., with larger μ) will have higher VOT. Moreover, from equation (2), we find the income and time budget variables can be defined in the indirect utility functions; the only problem is how to define them.

2.2.2 Individuals' Other Socioeconomic Characteristics

Individuals' other socioeconomic characteristics; e.g., sex and age, and trip purposes, are closely tied to their tastes. In theory, these factors determine the specific forms of individuals' direct utility function and then the derived indirect utility function. Therefore, it would be perfect if we could define utility functions with respect to each individual or each group of individuals with similar characteristics or trip purposes. In practice, however, this is quite difficult.

One way of dealing with this problem is to define different direct utility functions for different groups, then derive the respective indirect utility functions and VOT (Jara-Diaz and Farah, 1987). The other way is to define a common indirect utility function, and then estimate it with respect to each group of individuals (i.e., segments). The common indirect utility function is generally defined as a linear form; e.g.:

$$V_m^j = \omega^j c_m + \pi^j t_m + \varepsilon_m^j \tag{7}$$

where j represents group j, ω^j and π^j denote the parameters of travel cost and travel time for group j; $\omega^j \leq 0$ and $\pi^j \leq 0$ because of equation (4), and ε_m^j is error term. From equation (7), each group's VOT can be estimated as π^j/ω^j. Groups can be segmented according to sex, age, trip purposes, or even income and time budgets. However, since income and time budgets can be defined in an indirect utility function, as shown in equation (2), their segmentation may not be needed.

2.2.3 Attributes of Alternative Modes

Based on equation (2), it is obvious that VOT is closely tied to the attributes of alternative modes. Take model (7) for example. If individuals have two modes (air and bus) to choose, and they could be segmented according to the mode they choose, then for those who choose air, it is obvious that:

$$\omega^a c_{air} + \pi^a t_{air} + \varepsilon_{air}^a \geq \omega^a c_{bus} + \pi^a t_{bus} + \varepsilon_{bus}^a \tag{8}$$

where a represents the group of individuals who choose air. From (8), we obtain:

$$VOT^a = \frac{\pi^a}{\omega^a} \geq \frac{c_{air} - c_{bus}}{t_{bus} - t_{air}} + \frac{1}{\omega^a} \cdot \frac{\varepsilon_{air}^a - \varepsilon_{bus}^a}{t_{bus} - t_{air}} \tag{9}$$

Likewise, for those who choose bus, it is obvious that:

$$\omega^b c_{bus} + \pi^b t_{bus} + \varepsilon^b_{bus} \geq \omega^b c_{air} + \pi^b t_{air} + \varepsilon^b_{air} \tag{10}$$

where b represents the group of individuals who choose bus. From (10), we obtain:

$$VOT^b = \frac{\pi^b}{\omega^b} \leq \frac{c_{air} - c_{bus}}{t_{bus} - t_{air}} + \frac{1}{\omega^b} \cdot \frac{\varepsilon^b_{air} - \varepsilon^b_{bus}}{t_{bus} - t_{air}} \tag{11}$$

If $\varepsilon^a_{air} = \varepsilon^a_{bus}$ and $\varepsilon^b_{air} = \varepsilon^b_{bus}$, we find from (9) and (11) that:

$$VOT^a \geq VOT^b \tag{12}$$

due to the fact that $c_{air} \geq c_{bus}$ and $t_{bus} \geq t_{air}$ in general. This means that individuals who choose air are bound to have higher, or at least equal, VOT than those who choose bus, no matter who have higher income or lower time budgets.

But alternative modes' other attributes may also affect individuals' mode choice, and it is reasonable to believe that $\varepsilon^a_{air} \neq \varepsilon^a_{bus}$ and $\varepsilon^b_{air} \neq \varepsilon^b_{bus}$. This means that individuals do not choose air or bus just because air is faster or bus is cheaper. In this case, (12) may not be true.

To sum up, what causes individuals to choose their favorite modes can be divided into three factors. They are: (a) income and time budgets, (b) personal specific tastes possibly caused by sex, age, trip purpose, etc., and (c) alternative modes' attributes which may provide utility or disutility, such as their safety, comfort, travel time, travel cost, etc. The VOT of an individual is decided through the complex interactions among these three factors. Since we can easily estimate equation (7) to get the indirect utility functions for different segments of travelers, the following discussion will be focused on the effects of income and time budgets.

3. SPECIFICATION OF UTILITY FUNCTIONS

To proceed the empirical study, we need to derive indirect utility functions that can be used in application. The derivation is based on problem (P1).

3.1 General Linearized Model

The first-order approximation at point $\Psi = (\overline{G}, \overline{L})$ of U in (P1) is:

$$U \approx U(\Psi) + \left.\frac{\partial U}{\partial G}\right|_{\Psi} (G - \overline{G}) + \left.\frac{\partial U}{\partial L}\right|_{\Psi} (L - \overline{L}) \tag{13}$$

The first-order conditions for the maximum is:

$$\left.\frac{\partial U}{\partial G}\right|_{\Psi} = \overline{\lambda}, \text{ and } \left.\frac{\partial U}{\partial L}\right|_{\Psi} = \overline{\mu} \tag{14}$$

The levels of $\overline{\lambda}$ and $\overline{\mu}$ are determined by the evaluation point Ψ; i.e., they depend on the levels of $I - c_m$ and $T - t_m$.

Substituting equation (14) into equation (13), we can get:

$$\begin{aligned} U &\approx \overline{U} + \overline{\lambda}(G - \overline{G}) + \overline{\mu}(L - \overline{L}) \\ &= (\overline{U} + \overline{\lambda}\overline{G} + \overline{\mu}\overline{L}) + \overline{\lambda}G + \overline{\mu}L \\ &= (\overline{U} + \overline{\lambda}\overline{G} + \overline{\mu}\overline{L}) + \overline{\lambda}(I - c_m) + \overline{\mu}(T - t_m) \\ &= \overline{\kappa} - \overline{\lambda}c_m - \overline{\mu}t_m \end{aligned} \tag{15}$$

$\overline{\kappa}$ has no impact on the mode choice of any individual. Equation (15) is a general linear model, so one needs to segment travelers to show the effects of I and T on VOT.

3.2 Additive Cobb-Douglas Form

Defining the utility function in problem (P1) as an additive Cobb-Douglas form:

$$U = K_1 G^{\alpha} + K_2 L^{\delta} \tag{16}$$

where $0<\alpha<1$, $0<\delta<1$, and K_1 and K_2 are constants. Accordingly, we can derived the shadow prices, λ and μ, as:

$$\lambda = \alpha K_1 (I - c_m)^{\alpha - 1} \tag{17}$$

$$\mu = \delta K_2 (T - t_m)^{\delta - 1} \tag{18}$$

In the case that λ and μ are evaluated at I and T; i.e., before individuals spend c_m and t_m. Equation (16) becomes:

$$\overline{\lambda} = \alpha K_1 I^{\alpha - 1}, \tag{19}$$

$$\overline{\mu} = \delta K_2 T^{\delta - 1} \tag{20}$$

Substituting $\overline{\lambda}$ and $\overline{\mu}$ for those in equation (15), we obtain:

$$U \approx \overline{v} - \tau \frac{c_m}{I^{1-\alpha}} - \upsilon \frac{t_m}{T^{1-\delta}} \tag{21}$$

where $\overline{v}$, τ, and υ are constants. Equation (21) is an approximately linear model, which includes the impact of I and T. However, one needs to segment travelers to show the effects of travelers' personal characteristics, e.g., sex, age, and trip purposes, on VOT.

3.3 Multiplicative Cobb-Douglas Form

Defining the utility function in problem (P1) as a multiplicative Cobb-Douglas form:

$$U \approx \overline{v} - \tau \frac{c_m}{I^{1-\alpha}} - \upsilon \frac{t_m}{T^{1-\delta}} \tag{22}$$

$$U = KG^{\alpha} L^{\delta} \tag{23}$$

where 0<α<1, 0<δ<1, and K is a constant. Accordingly, we can derived the shadow prices, λ and μ, as:

$$\lambda = \alpha K(I - c_m)^{\alpha-1}(T - t_m)^{\delta} \quad (24)$$
$$\mu = \delta K(I - c_m)^{\alpha}(T - t_m)^{\delta-1} \quad (25)$$

In the case that λ and μ are evaluated at I and T. Equation (24) and (25) become:

$$\overline{\lambda} = \alpha K I^{\alpha-1} T^{\delta} = \alpha K I^{\alpha+\delta-1} \eta^{\delta} \quad (26)$$

$$\overline{\mu} = \delta K I^{\alpha} T^{\delta-1} = \delta K I^{\alpha+\delta-1} \eta^{1-\delta} \quad (27)$$

where $\eta = I/T$, which Jara-Diaz and Farah (1987) referred to as expenditure rate.

Substituting $\overline{\lambda}$ and $\overline{\mu}$ for those in (15), we obtain:

$$U \approx \overline{\iota} + K I^{\alpha+\delta-1}(-\alpha\eta^{-\delta} c_m - \delta\eta^{1-\delta} t_m) \quad (28)$$

where $\overline{\iota}$ is a constant. Jara-Diaz (1991) used equation (28) to test the connection between income I and taste δ.

On the assumption of δ=1, equation (28) can be reformulated as (see Jara-Diaz and Ortuzar, 1989; Jara-Diaz, 1991):

$$U \approx \overline{\iota} + K I^{\alpha}(-\alpha \frac{c_m}{\eta} - t_m) \quad (29)$$

Equation (29) is an approximately linear model, which considers the impact of I and T, but it is necessary to segment travelers to show the effects of other factors on VOT.

3.4 Summary

To sum up, we have three indirect utility functions, (15), (21), and (29), in application. In order for these models to be easily applied, we reformulated these three models as:

$$V = \theta_1 c_m + \theta_2 t_m + \gamma \boldsymbol{X}_m + \varepsilon \quad (30)$$

$$V = \varphi_1 \frac{c_m}{I^{1-\alpha}} + \varphi_2 \frac{t_m}{T^{1-\delta}} + \gamma \boldsymbol{X}_m + \varepsilon \quad (31)$$

$$V = \zeta_1 \frac{c_m}{\eta} + \zeta_2 t_m + \gamma \boldsymbol{X}_m + \varepsilon \quad (32)$$

where $\boldsymbol{X}_m$ is mode m's attribute vector other than t_m and c_m, and α, δ, θ_i, φ_i, ζ_i, and γ the parameters. To estimate α and δ, trial and error method will be needed. These three models are referred to as Model I, Model II, and Model III, respectively. The major differences among these models are the way of dealing with the income and time budgets.

4. EMPIRICAL STUDY

4.1 Data

The travel related data of passengers between Taipei and Tainan, two major cities in Taiwan, was used for empirical validation. The distance between these two cities is about 300 km, and there are three main public transportation modes, i.e., train, bus, and air. The mode choice behavior of these passengers is the focus of this paper. We used choice-based sampling approach to acquire sufficient samples for each mode. A total of 543 effective samples were acquired including 205 for train, 117 for bus, and 221 for air. The interviews were conducted during from October 1996 to March 1997.

This choice data includes: (1) Alternative and Chosen modes' travel attributes, e.g., travel cost, in-vehicle travel time, and out-of-vehicle travel time. (2) Other factors that might affect individuals' mode choices behavior. For example, whether a traveler has to arrive the destination in time (named arrival time restriction), and whether he/she has made plans to engage in-vehicle activities (named in-vehicle activity); e.g., reading or working on the vehicles (see Marks et al, 1986). (3) Individuals' socioeconomic characteristics such as sex, age, income, weekly working hours and so on.

4.2 Estimation Results

We used multinomial logit model (MNL) (Ben-Akiva and Lerman, 1985) to estimate the parameters of equations (30), (31) and (32). The software used is ALOGIT software (Hague Consulting Group, 1992). These models' estimation results are shown in Table 1. $LL(\Omega)$ is the log-likelihood at convergence; ρ_c^2 is the rho square index relative to constants only model. The standard errors of VOT were calculated according to Fowkes and Wardman (1993).

We used personal income to represent travelers' income budget. If a traveler's personal income is zero (e.g., non-working spouse), we used the average household income (household income/the number of household members) instead. The expenditure rate was calculated by income budget/time budget. The time budget of a traveler was calculated by subtracting his/her weekly working hours and sleeping hours from the number of hours in a full week.

In the process of estimation, Model I and Model III run quite smoothly. For Model II, however, the travel cost variable has to be classified into low-income group and high-income group (specified as dummy variable). The travel cost divided by income was only specified for the high-income group to improve this model's performance. By trial and error method, we found that the best α estimate in the high-income group is zero. This means that the travel cost/income variable becomes a common type, c_m/I. The best δ estimate across sample is one, which means that the time budget variable is not influential at all in Model II.

4.3 Discussion

The ρ_c^2's of all three models in Table 1 are quite high (the value of ρ_c^2 between 0.2 and 0.4 is generally regarded as very good fit). Model I has as good fits as model II, and both of them are slightly better than model III. All the coefficients of travel related variables in these models are significant and have the correct sign. The sizes of travel time variable, in-vehicle activity variable, and arrival time restriction variable are very close in all three models. This results shows that the specification of travel cost variable does not affect them. In model III, however, the parameter of travel cost/expenditure rate variable is not as convincing as we expected, though it's still significant. This is probably due to the difficulties for respondents to accurately estimate their time budget. Such difficulties may also cause the δ estimate in Model II to approach 1 and lead the time budget variable to become trivial. The sign of in-vehicle activity variable means that when a traveler intends to engage activity while traveling, he/she will prefer to choose train, other things being equal. The signs and sizes of arrival time restriction variables show that when a traveler has to arrive destination in time, he/she will prefer to choose air, followed by train.

Table 1 Estimation Results of MNL models

Variables	Coefficients (t value) Model I	Model II	Model III
Bus Constant	0.276 (1.3)	0.260 (1.2)	0.724 (3.9)
Air Constant	-1.050 (-2.1)	-1.086 (-2.2)	-2.429 (-5.5)
Travel Time (in 100 minutes)	-1.593 (-7.0)	-1.622 (-7.2)	-1.696 (-7.5)
Travel Cost (in NT$[1]1,000)	-1.904 (-4.2)		
Travel Cost (in NT$1,000) -Low Income Group[2]		-2.044 (-4.5)	
Travel Cost/Income (in NT$1,000/NT$1,000) -High Income Group[2]		-113.1 (-3.5)	
Travel Cost/Expenditure Rate (in NT$1,000/(NT$1,000/hour))			-0.123 (-1.9)
In-Vehicle Activity-Train	1.534 (7.1)	1.542 (7.1)	1.518 (7.1)
Arrival Time Restriction-Train	1.666 (4.9)	1.681 (5.0)	1.653 (4.9)
Arrival Time Restriction-Air	2.088 (5.9)	2.096 (5.9)	2.139 (6.1)
Sample Size	543	543	543
$LL(\hat{\Omega})$	-379.46	-378.26	-386.79
ρ_c^2	0.182	0.185	0.166
VOT (in NT$/ hour) (Standard Error)	502(139)	low-income 476 (125) high-income 644 (207)	560(296)

Note: 1.1US$=30NT$.
2.The boundary of income group is NT$ 50,000 per month.

The VOT estimated from these models are also shown in Table 1. The travelers' average VOT for model I is 502NT$/hour. This level seems reasonable for long distance inter-city traveling in Taiwan. The average VOT is 476 for low-income travelers and 644NT$/hour for high-income travelers for model II which introduces the impact of income. The VOT difference between these two income groups seems acceptable. The results of model II also indicate that income does not play a major role in low-income travelers' mode choice behavior. However, for high-income travelers, the more income they have, the more VOT they value.

Finally, the average VOT is 560 NT$/hour for model III which introduces the impact of both income and time budget (i.e., expenditure rate). It also shows that the more income travelers have, the more VOT they value; the less time budgets travelers have, the more VOT they value. The results are reasonable and verify the theoretical conclusions in equation (6).

In summary, the estimation results of all three models are quite convincing. In theory, Model II and Model III are better since they consider the impact of travelers' income and time budget at the same time. However, collecting the time budget data can be a challenge in practice. We have already shown how this challenge may affect these two models' performances.

5. CONCLUSIONS

Many factors have long been considered affecting VOT, but the way they affect VOT is still a question. In theory, VOT is derived from individuals' utility maximization problem, which is formulated based on individuals' activity and mode choice. Actually, the utility maximization problem can be formulated as a money and time allocation problem.

This study first showed the derived indirect utility functions based on the utility maximization problem. Then according to the indirect utility function, this study divided the factors might affect VOT into three groups: (a) income and time budgets, (b) personal specific tastes caused by sex, age, trip purpose, etc., and (c) alternative modes' attributes. The ways these factors affecting VOT and some properties of VOT were discussed. We then focused on the income and time budgets. We defined three types of direct utility function, and derived three models with different indirect utility function forms.

These three models were estimated using the intercity passengers' mode choice data in Taiwan. The results showed that the performances of all three models were quite good. The results of model II, which introduced the impact of income, indicated that income did not play a major role in low-income travelers' mode choice behavior. However, for high-income travelers, the more income they had, the more they valued VOT. The results of model III, which introduced the impact of expenditure rate, indicated that the more income travelers had, the more they valued VOT; the less time budgets travelers had, the more they valued VOT. However, the difficulty in collecting the time budget data might have affected its performance.

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