An Investigation of Whether the Value of Travel Time Increases as Individuals Travel Longer: A Case Study of Modal Choice of Inter-urban Travelers in Japan

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Abstract. This paper analyzes the variation in the value of travel time saving (VTTS) over travel time applying the method of empirical discrete-choice analysis with non-linear utility functions. First, it formulates the time allocation model and derives the VTTS from the model. The theoretical consideration shows that it is impossible to identify the conditions determining the monotonic change in the VTTS over travel time. The paper then examines the variation in VTTS over travel time using empirical data on choices of inter-urban travel modes in Japan. The empirical analysis assumes constant marginal utility with respect to income for the first case using the model with a non-linear utility function and non-constant marginal utility for the second case using the model with a non-linear utility function. The first case analysis shows that the VTTS decreases as travel time increases. The second case shows that the variations in the estimated VTTS over travel time appear to be neutral in the case of rail and airplane users, whereas the estimated VTTS appears to decrease as travel time increases in the case of automobile users. If it is acknowledged that the VTTS decreases as travel time increases—the marginal benefit arising from the marginal travel time saving would increase as travel time reduces. This implies that society will require additional travel time saving as travel time decreases.

INTRODUCTION

The willingness to pay (WTP) for travel time saving is termed as the value of travel time saving (VTTS). The concept is widely used in the economic evaluation of transport investments. Although a constant VTTS is often used in practical transport planning, the constancy of VTTS is derived simply from the assumption of a linear utility function. When using a non-linear utility function, we can derive a non-constant VTTS with respect to travel time. Several researches have been conducted on the variation in the value of time over travel time or distance. For the British context, Wardman (*1*, *2*, *3*) has reviewed existing evidence regarding the value of travel time and indicated that it is expected to increase as the travel distance increases. De Lapparent *et al.* (*4*) formulated the Box-Cox Logit model and estimated the value of travel time using empirical data for Paris. They concluded that the WTP is effectively neutral to travel time variation. Axhausen et al. (*5*) examined the variation in the VTTS over travel distance by using stated preference (SP) data for Switzerland. They have demonstrated that the VTTS increases as travel distance increases. Hultkrantz and Mortazavi (*6*) and Hensher (*7*) have shown that the VTTS may decrease as travel time increases. Kato (*8*), by means of empirical studies on urban transportation, has shown that the VTTS decreases if the travel time is less than a specific threshold but that it increases if the travel time surpasses the threshold. The present paper will contribute to the existing analyses of the VTTS with respect to travel time. This paper examines the VTTS with respect to travel time for inter-urban leisure travel.

The remainder of the paper is organized as follows. The next section formulates a time allocation model and derives the VTTS from the model. Thereafter, it examines the variation in the VTTS over travel time from a theoretical perspective. Subsequently, the VTTS is derived from a discrete choice model with a non-linear utility function. The empirical analysis using inter-urban travel data for Japan is then presented. Finally, the paper indicates directions for further research.

MODEL

Derivation of VTTS from the time allocation model

Let us consider an individual who derives utility from the consumption of a composite good as well as travel service, leisure time, and travel time. We also assume that the individual maximizes her/his utility with respect to time and expenditure under the constraints of time, a monetary budget, and minimum travel time. Since we expect inter-urban leisure travel to take place on nonworking days, the individual's income is assumed to be fixed and given. Let the individual's utility be U. Following DeSerpa (*9*, *10*) and Evans (*11*), the time allocation model can be formulated as

$$\underset{X,T,\mathbf{x},\mathbf{t}}{Maximize} U = U(X, T, \mathbf{x}, \mathbf{t}) \tag{1a}$$

$$\text{subject to } PX + \sum_i c_i x_i = I \ [\lambda] \tag{1b}$$

$$T + \sum_i t_i x_i = T^0 \ [\mu] \tag{1c}$$

$$t_i \geq \hat{t}_i \text{ for } \forall i \ [\kappa_i^t], \tag{1d}$$

where $U(\cdot)$ is the utility function, X is the composite good, T is time available for leisure, $\mathbf{x}$ is a vector of travel frequency, $\mathbf{t}$ is a vector of travel time, P is the price of the composite good, c_i is the travel cost of transport service i, x_i is the travel frequency of transport service i, I is the monetary budget, T^o is the available time, t_i is the travel time of transport service i, and $\hat{t}_i$ is the minimum travel time of transport service i. λ, μ, and κ_i^t are the Lagrange multipliers corresponding to Equations (1b), (1c), and (1d), respectively. It is assumed that the marginal utility (MU) with respect to composite good consumption is positive, whereas the MU with respect to travel time is negative.

The Lagrange function corresponding to this time allocation model is described as follows:

$$L = U(X, T, \mathbf{x}, \mathbf{t}) + \lambda\left(I - PX - \sum_i c_i x_i\right) + \mu\left(T^o - T - \sum_i t_i x_i\right) + \sum_i \kappa_i^t (t_i - \hat{t}_i). \tag{3}$$

The first-order conditions of optimality are derived as follows:

$$\frac{\partial U}{\partial X} = \lambda P \,, \; \frac{\partial U}{\partial T} = \mu \tag{4a, b}$$

$$\frac{\partial U}{\partial x_i} = \lambda c_i + \mu t_i \text{ for } \forall i \,, \; \frac{\partial U}{\partial t_i} = \mu x_i - \kappa_i^t \text{ for } \forall i \tag{4c, d}$$

$$\kappa_i^t \left(t_i - \hat{t}_i \right) = 0 \text{ and } \kappa_i^t \geq 0 \text{ for } \forall i \tag{4e, f}$$

and Equations (2a) to (2c).

Next, let the indirect utility function of the individual be $v\left(\mathbf{c}, \hat{\mathbf{t}}, I, T^o\right)$. By applying the envelope theorem (Varian, *12*) to the above utility maximization problem, we obtain the following results:

$$\frac{\partial v}{\partial \hat{t}_i} = \frac{\partial U}{\partial \hat{t}_i} + \kappa_i^{t*} \frac{\partial \left(t_i - \hat{t}_i \right)}{\partial \hat{t}_i} = -\kappa_i^{t*} \tag{5}$$

$$\frac{\partial v}{\partial I} = \frac{\partial U}{\partial I} + \lambda^* \frac{\partial \left(I - PX - \sum c_i x_i \right)}{\partial I} = \lambda^* . \tag{6}$$

As the VTTS is defined as the WTP for savings in travel time, it is derived from Equations (5) and (6) as follows:

$$VTTS_i = - \frac{\partial v / \partial \hat{t}_i}{\partial v / \partial I} = \frac{\kappa_i^{t*}}{\lambda^*} . \tag{7}$$

On the other hand, from the first-order optimality conditions, we obtain the VTTS:

$$\frac{\kappa_i^{t*}}{\lambda^*} = x_i^* \frac{\mu^*}{\lambda^*} - \frac{\partial U / \partial t_i \big|_{U^*}}{\lambda^*} . \tag{8}$$

De Serpa (*9*) demonstrates the VTTS in the case wherein $x_i^* = 1$. He terms the first term on the right-hand side of Equation (8) as the value of time as a resource and the second as the value of time as a commodity.

Variation in the VTTS over travel time

In order to study the variation in the VTTS over travel time, it is important to understand the relationship between each component of the VTTS and travel time. In this section, this relationship is examined on the basis of Equation (8), for the case wherein the MU with respect to income is constant and wherein it is non-constant.

If the MU with respect to income λ^* is constant, the impacts of changes in travel time on the MU with respect to time as a resource μ^* and $\partial U / \partial t \big|_{U^*}$ need to be examined. First, with regard to the impact of changes in travel time on μ^*, the utility level changes in response to the changes in leisure time that occur as a result of changes in travel time. This change depends on the form of the utility function. In the case of a decreasing MU with respect to leisure time, μ^* increases as travel time increases. However, in the case of an increasing MU with respect to leisure time, μ^* decreases as travel time increases. Second, the impact of change in travel time on $\partial U / \partial t \big|_{U^*}$ depends on whether the MU with respect to travel time is increasing or decreasing. An increasing MU with respect to travel time implies that a traveler derives greater disutility such as fatigue and boredom as travel time increases, whereas a decreasing MU with respect to travel time implies that travelers gradually begin to feel indifferent to disutility as travel time increases. Although we expect the MU with respect to travel time to be negative, we cannot specify whether it is increasing or decreasing *a priori*. Hence, it may be impossible to judge *a priori* the clear tendency on the variation in the VTTS over travel time even under the assumption of a constant MU with respect to income.

If the MU with respect to income is non-constant, the change in the MU with respect to income should be considered in addition to the case wherein λ^* is constant. The travel cost is expected to increase as travel time increases. The increase in travel cost results in a decrease in the monetary budget available for composite good consumption. However, we cannot predict *a priori* whether the MU with respect to income λ^* is increasing or decreasing. In most cases, λ^* is considered to be constant or decreasing. If λ^* is decreasing, λ^* increases as travel time increases. If λ^* is constant, λ^* is neutral with respect to travel time. This unpredictability renders the results more complicated. Consequently, from a theoretical perspective, we find several patterns of variation in the VTTS with respect to travel time. There is no simple condition that explains the monotonic change in the VTTS over travel time. This implies that the characteristics of VTTS variation over travel time are highly dependent on the form of the utility function. In order to specify the pattern of the variation, we may be required to examine it using empirical data. Therefore, in the following section, we empirically analyze the variation in the VTTS over travel time by using an approximated utility function. Although the approximation may relax the precision of the analysis, it yields richer and more useful implications.

EMPIRICAL ANALYSIS

Derivation of VTTS in a discrete choice model system

Let us consider a situation wherein a traveler selects only one transport service i by excluding the other services. Moreover, the traveler consumes a single unit of service i in the time allocation model shown earlier. This means that both $x_i = 1$ and $x_j \neq 1 (\forall j \neq i)$ are satisfied in Equation (1). Consequently, as Train and McFadden (*13*) demonstrate, the utility maximization under the condition that an individual discretely chooses the transport service i is described as follows:

$$\underset{X,T,t_i}{Max}\, U_i = U_i(X,T,t_i) \tag{9a}$$

$$\text{subject to } PX + c_i = I \quad [\lambda] \tag{9b}$$

$$T + t_i = T^0 \quad [\mu] \tag{9c}$$

$$t_i \geq \hat{t}_i \quad [\kappa_i^t], \tag{9d}$$

where U_i denotes the conditional utility function for transport service i. The following first-order optimality conditions are derived from the Kuhn-Tucker theorem:

$$\frac{\partial U_i}{\partial X} = \lambda P,\ \frac{\partial U_i}{\partial T} = \mu,\ \frac{\partial U_i}{\partial t_i} = \mu - \kappa_i^t \tag{10a}$$

$$\kappa_i^t \left(t_i - \hat{t}_i\right) = 0 \text{ and } \kappa_i^t \geq 0 \tag{10b}$$

$$PX + c_i = I,\ T + t_i = T^0. \tag{10c}$$

Let the conditional indirect utility function be $v_i = v_i\left(c_i, \hat{t}_i, I, T^o\right)$. The following equations are derived from the envelope theorem:

$$\frac{\partial v_i}{\partial c_i} = \frac{\partial U_i}{\partial c_i} + \lambda^* \frac{\partial (I - PX - c_i)}{\partial c_i} = -\lambda^* \tag{11a}$$

$$\frac{\partial v_i}{\partial \hat{t}_i} = \frac{\partial U_i}{\partial \hat{t}_i} + \kappa_i^{t*} \frac{\partial \left(t_i - \hat{t}_i\right)}{\partial \hat{t}_i} = -\kappa_i^{t*}. \tag{11b}$$

Consequently, we obtain the VTTS in the discrete choice model system as follows:

$$\frac{\kappa_i^{t*}}{\lambda^*} = \frac{\partial v_i / \partial \hat{t}_i}{\partial v_i / \partial c_i}. \tag{12}$$

Approximation of the utility function

The utility function is approximated using the method demonstrated by Blayac and Causse (*14*). In the analysis, we use the following four approximations: the first-order approximation, the second-order approximation, the second-order approximation with a constant MU with respect to income, and the third-order approximation with a constant MU with respect to income. First, we apply the Taylor expansion to the conditional direct utility function at $(X,T,t_i) = (0,0,0)$. We obtain the following first-order approximation:

$$U_i(X,T,t_i) = \frac{\partial U_i}{\partial X} X + \frac{\partial U_i}{\partial T} T + \frac{\partial U_i}{\partial t_i} t_i + Z_{1\_i} \tag{13}$$

By substituting the first-order optimality conditions shown in Equation (10) into Equation (13), the first-order approximated conditional indirect utility function is derived:

$$v_i\left(c_i, \hat{t}_i, I, T^o\right) = \lambda^* (I - c_i) + \mu^* \left(T^o - \hat{t}_i\right) + \left(\mu^* - \kappa_i^{t*}\right) \hat{t}_i + Z_{1\_i}$$

$$= \lambda^*\left(I - c_i\right) + \mu^* T^o - \kappa_i^{t*}\hat{t}_i + Z_{1\_i} \cdot \tag{14}$$

This is the same result as that in the study conducted by Bates (*15*). In the subsequent empirical analysis, the multinomial logit (MNL) model is applied to travel mode choice. In the MNL model, as Ben-Akiva and Lerman (*16*) have shown, the probability of choosing a specific mode is described as the function of the difference between the indirect utility functions of the modes. Thus, generic variables such as $\lambda^* I$ and $\mu^* T^o$ in Equation (14) cannot be identified in our analysis. Consequently, we rewrite the conditional indirect utility function without the generic variables:

$$v_{1\_i} = -\lambda^* c_i - \kappa_i^{t*}\hat{t}_i + z_{1\_i} = \theta_{1\_c} c_i + \theta_{1\_t,i}\hat{t}_i + \theta_{1\_i} \cdot \tag{15}$$

This is the linear indirect utility function that is widely used in practical transport planning. Next, we obtain the second-order direct utility function in the same way as the first-order approximation:

$$U_i\left(X, T, t_i\right) = \frac{\partial U_i}{\partial X} X + \frac{\partial U_i}{\partial T} T + \frac{\partial U_i}{\partial t_i} t_i + \frac{1}{2}\left(\frac{\partial^2 U_i}{\partial X^2} X^2 + \frac{\partial^2 U_i}{\partial T^2} T^2 + \frac{\partial^2 U_i}{\partial t_i^2} t_i^2 \right)$$

$$+ \left(\frac{\partial^2 U_i}{\partial X \partial T} XT + \frac{\partial^2 U_i}{\partial X \partial t_i} X t_i + \frac{\partial^2 U_i}{\partial T \partial t_i} T t_i \right) + Z_{2\_i} \cdot \tag{16}$$

By substituting the first-order optimality conditions into Equation (16), we derive the following second-order approximated conditional indirect utility function:

$$v_i\left(c_i, \hat{t}_i, I, T^o\right) = \left(\frac{\alpha_T}{2} + \frac{\alpha_t}{2} - \alpha_{Tt} \right) \hat{t}_i^2 + \left(\frac{\alpha_X}{2P^2} \right) c_i^2$$

$$+ \left(\frac{\alpha_{XT} - \alpha_{Xt}}{P} \right) \hat{t}_i c_i + \left\{ \left(\alpha_{Tt} - \alpha_T\right) T^o + \left(\alpha_{Xt} - \alpha_{XT}\right) \frac{I}{P} - \kappa_i^{t*} \right\} \hat{t}_i$$

$$+ \left(-\lambda - \frac{\alpha_X I}{P^2} - \frac{\alpha_{XT} T^o}{P} \right) c_i + Z'_{2\_i} , \tag{17}$$

where the parameters are defined as follows:

$$\frac{\partial^2 U_i}{\partial X^2} = \alpha_X , \; \frac{\partial^2 U_i}{\partial T^2} = \alpha_T , \; \frac{\partial^2 U_i}{\partial t_i^2} = \alpha_t , \; \frac{\partial^2 U_i}{\partial X \partial T} = \alpha_{XT} , \; \frac{\partial^2 U_i}{\partial X \partial t_i} = \alpha_{Xt} , \; \frac{\partial^2 U_i}{\partial T \partial t_i} = \alpha_{Tt} \; . \tag{18}$$

As was the case for the first-order approximation, we obtained the following indirect utility function without the generic variables:

$$v_{2\_i} = \theta_{2\_c}\left(I, T^o\right) \cdot c_i + \theta_{2\_t}\left(I, T^o\right) \cdot \hat{t}_i + \theta_{2\_c2} c_i^2 + \theta_{2\_t2} \hat{t}_i^2 + \theta_{2\_ct} c_i \hat{t}_i + \theta_{2\_i} \cdot \tag{19}$$

The parameters associated with travel cost and (minimum) travel time follow the functions of income and available time, respectively. Since it is assumed that both the income and available time are given and constant, these parameters can be estimated in the same way as the other parameters.

With regard to the case of a constant MU with respect to income under the second-order approximation of the utility function, the utility function satisfies the following equations:

$$\frac{\partial^2 U_i}{\partial X^2} = 0 , \; \frac{\partial^2 U_i}{\partial X \partial T} = 0 , \; \frac{\partial^2 U_i}{\partial X \partial t_i} = 0 \cdot \tag{20}$$

By substituting Equation (20) into Equation (19), we derive the indirect utility function in the case of a constant MU with respect to income as follows:

$$v_{2c\_i} = \theta_{2c\_c} \hat{c}_i + \theta_{2c\_t} \hat{t}_i + \theta_{2c\_t2} \hat{t}_i^2 + \theta_{2c\_i} \cdot \tag{21}$$

Finally, we can derive the third-order approximation in the same way as the first- and the second-order approximations as follows:

$$v_{3c\_i} = \theta_{3c\_c} c_i + \theta_{3c\_t} \hat{t}_i + \theta_{3c\_t2} \hat{t}_i^2 + \theta_{3c\_t3} \hat{t}_i^3 + \theta_{3c\_i} \cdot \tag{22}$$

VTTS Estimation

The data used for parameter estimation is derived from the Third Inter-regional Transport Survey conducted in Japan in 2000 by the Ministry of Land, Infrastructure and Transport. The data includes information such as the traveler's origin zone, destination zone, chosen travel mode and route, and socio-demographic information. The zone is defined as a daily transport area within which most of the population commute, shop, and travel to school,

TABLE 1 Parameter Estimation Results of Four Models

	First-order approx.		Second-order approx.		Second-order approx.		Third-order approx.	
MU w.r.t. income	constant		constant		nonconstant		constant	
Variables	Coefficients	t-statistics	Coefficients	t-statistics	Coefficients	t-statistics	Coefficients	t-statistics
Travel cost*10^{-2}	−0.00528	(−5.75)	−0.00576	(−6.18)	−0.0164	(−6.08)	−0.00527	(−5.67)
Travel time	−0.00876	(−26.4)	−0.0111	(−27.4)	−0.0119	(−26.6)	−0.0164	(−18.2)
(Travel cost)^2*10^{-6}					0.00768	(12.8)		
(Travel time)*(Travel cost)*10^{-4}					−0.00566	(−12.7)		
(Travel time)^2*10^{-4}			0.0215	(20.7)	0.0914	(16.7)	0.130	(9.13)
(Travel time)^3*10^{-6}							−0.00294	(−5.53)
Initial log-likelihood	−3394.3		−3394.3		−3394.3		−3394.3	
Final log-likelihood	−2259.8		−2218.8		−2059.3		−2164.1	
Adjusted likelihood ratio	0.334		0.346		0.393		0.362	
Number of observations	3 000		3 000		3 000		3 000	

in the course of a day. There are 207 such zones demarcated in Japan. The survey covers inter-zonal journeys for business, leisure, and other purposes.

In the analysis only leisure travel is studied. For the preparation of the data of the level of transportation service, we follow the method used in the formal travel demand analysis for the long-term transport plan of Japan, conducted in 2000 (*17*, *18*). Three thousand samples were randomly selected from the master data set.

The MNL model is used for the parameter estimation with respect to the choice of travel modes. The following four models are estimated: the first-order approximation model, the second-order approximation model, the second-order approximation model with a constant MU with respect to income, and the third-order approximation model with a constant MU with respect to income. The same data set is used for all the models. Although the parameter corresponding to minimum travel time should depend on the travel mode as per Equation (15), it is assumed that the parameter is generic across travel modes. The estimation results are shown in Table 1. This shows that all the parameters of the models pass the statistical test at the significance level of 99%. The signs of the parameters also appear to be reasonable. Next, each VTTS is evaluated with respect to the above four models. These are derived from the approximated utility functions of Equations (15), (19), (21), and (22), respectively, as follows:

- First-order approximated VTTS:

$$VTTS_{1\_i} = \frac{\theta_{1\_t}}{\theta_{1\_c}} \qquad (23)$$

- Second-order approximated VTTS:

$$VTTS_{2\_i} = \frac{\theta_{2\_t} + 2\theta_{2\_t2}\hat{t}_i + \theta_{2\_ct}c_i}{\theta_{2\_c} + 2\theta_{2\_c2}c_i + \theta_{2\_ct}\hat{t}_i} \qquad (24)$$

- Second-order approximated VTTS with a constant MU w.r.t. income:

$$VTTS_{2c\_i} = \frac{\theta_{2c\_t} + 2\theta_{2c\_t2}\hat{t}_i}{\theta_{2c\_c}} \qquad (25)$$

- Third-order approximated VTTS with a constant MU w.r.t. income:

$$VTTS_{3c\_i} = \frac{\theta_{3c\_t} + 2\theta_{3c\_t2}\hat{t}_i + 3\theta_{3c\_t3}\hat{t}_i^2}{\theta_{3c\_c}} \qquad (26).$$

First, using Equation (23), the first-order approximated VTTS is estimated to be 165.9 yen/minute. Note that 1 US dollar was equal to 111.3 yen in November 2000. Second, as shown in FIGURE 1, by using Equation (25) and (26) respectively, the second- and third-order approximated VTTS with a constant MU with respect to income are estimated. They indicate that the VTTS decreases as travel time increases. Third, the VTTS from the second-order approximated model with a non-constant MU with respect to income is estimated. As Equation (24) shows, both travel time and travel cost are used to calculate the VTTS. The relation between travel time and travel cost may depend on the travel mode. The relationships between travel time and travel cost of sample travelers choosing the travel modes of rail, airplane, and automobile are shown in FIGURE 2. These figures indicate that travel cost increases with travel time, albeit not always proportionally. Even in the case of

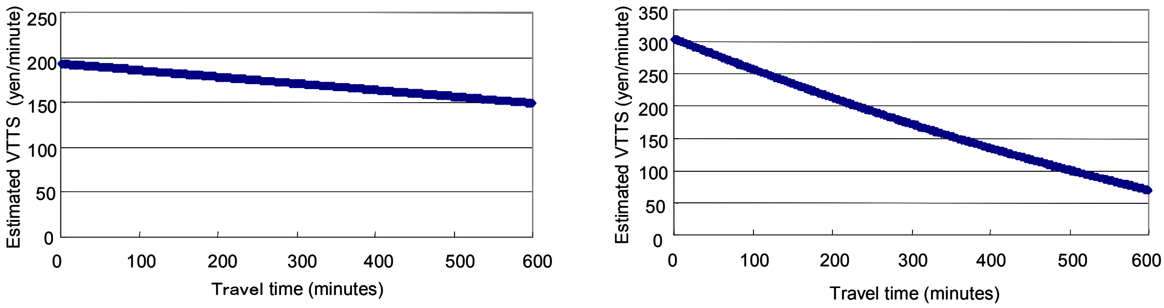

FIGURE 1 Estimated VTTS vs. travel time from the second-order approximated model with a constant MU w.r.t income (left) and the third-order approximated model with a constant MU w.r.t. income (right).

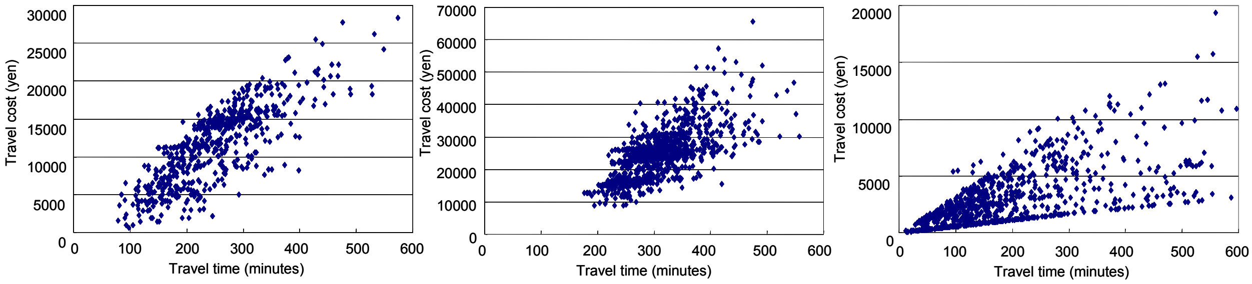

FIGURE2 Travel time vs. travel cost of sample data by travel mode (left: rail; middle: air; and right: automobile).

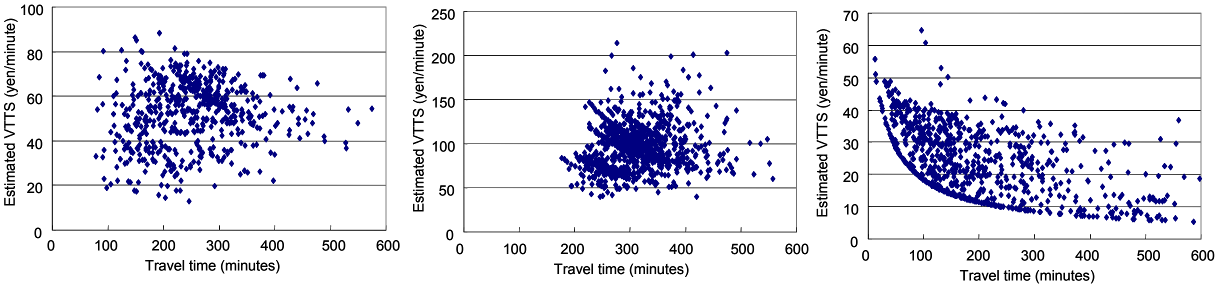

FIGURE 3 Estimated VTTS vs. travel time from the second-order approximated model with a non-constant MU w.r.t income by travel mode (left: rail; middle: air; and right: automobile).

automobile users, the travel cost corresponding to a specific duration of travel varies considerably because it is influenced by whether or not drivers use tolled expressways. The estimated VTTS for the rail, airplane, and automobile users are shown in FIGURE 3. To estimate the values of the VTTS, we apply the reported data of travel time and cost of the selected travel mode to the VTTS formula Equation (24). FIGURE 3 shows that the variations in the estimated VTTS over travel time appear neutral in the case of rail and airplane users; on the other hand, in the case of automobile users, the estimated VTTS appears to decrease as travel time increases.

Discussions

First, we will discuss the magnitude of the estimated VTTS for each model. In 2000, the average wage rate in Japan was 37.6 yen/minute. The estimated VTTS for the first-order approximation, the second-order approximation with a constant MU with respect to income, and the third-order approximation with a constant MU with respect to income exceeds 150 yen/minute for travelers with average travel time (248.9 minutes). On the other hand, the VTTS of the average travel time of rail and automobile users estimated using the second-order approximation are less than 80 yen/minute. Since long-distance travelers may earn higher income, their VTTS may be higher. However, a VTTS above 150 yen/minute appears to be rather high. From the perspective of the size of the VTTS, the assumption of a constant MU with respect to income may be inappropriate.

Second, the VTTS for different travel modes are compared. In general, travelers who use higher-speed travel modes have higher WTP for saving travel time. The empirical analysis with the second-order approximation shows that airplane users have the highest VTTS, followed by rail users and automobile users. Therefore, the estimated results appear to be quite reasonable.

Third, the variation in the VTTS over travel time is considered. In order to render the discussion more practicable, various factors should be considered, in addition to the theoretical considerations outlined in the earlier analysis. For example, in the theoretical analysis, the available time and monetary budget are assumed to be given and fixed. However, in reality, travelers may control such constraints by adjusting the time available to them and their budgets. The destination choice was not explicitly considered in the theoretical analysis; however, in reality, travelers may choose their destinations. Further, although long-distance travel offers various services for reducing the disutility derived from travel, this feature was not considered in the theoretical analysis. However, it will be explored in the cases of a constant MU and a non-constant MU with respect to income.

The results of the empirical analysis indicate that the VTTS decreases as travel time increases under the assumption that the MU is constant with respect to income. The reason for such results may be explored from the following two perspectives: the changes in the MU with respect to time as a resource μ^* and the change in the MU with respect to time as a commodity $\partial U/\partial t_i$. As regards the change in the MU with respect to time as a resource μ^* , there are three hypothetical situations that should be considered. The first is that the individual's available time and her/his destination are both fixed. Consequently, the increase in travel time reduces the time available for leisure activity. If it is assumed that the MU with respect to leisure time is decreasing, then the MU with respect to leisure time increases as travel time increases. This has been already pointed out by Jiang and Morikawa (*19*). However, we cannot assume *a priori* that the MU with respect to leisure time is decreasing. If it is increasing, the results will be quite the opposite. The second situation is one wherein the individual's available time is fixed but she/he can select the destination. The destination for leisure activity will be selected such that it maximizes the traveler's utility. A journey involving lengthy travel time implies that the destination is sufficiently attractive to spend leisure time therein, accounting for the travel duration. Consequently, the longer the travel time, the higher is the MU with respect to time as a resource. The third situation is one wherein the time available can be adjusted. We sometimes observe that people often stay longer for leisure activities at destinations farther from their home. For example, it is not uncommon for people to undertake day trips to nearer destination, but stay overnight at farther ones. This implies that they relax their constraints with respect to time devoted to leisure travels, as travel time increases. If this holds true, then the MU with respect to time as a resource may decrease as travel time increases. Next, with regard to the MU with respect to time as a commodity $\partial U/\partial t_i$, the following two factors are noticeable: the influence of disutility arising from travel time and of the choices made by a traveler in order to reduce travel disutility. For example, automobile drivers may rest more as they travel longer. If the duration of the period of rest is included in the travel time, then the MU with respect to travel time may decrease as travel time increases. Consequently, we can posit the following two hypothetical reasons that explain why the VTTS decreases as travel time increases. First, μ^* decreases as travel time increases due to the decrease in the MU with respect to leisure time or due to the relaxation of the constraint of available time. Second, $\partial U/\partial t_i$ decreases as travel time increases due to the decrease in the MU with respect to travel time or the change in the traveler's behavior in order to reduce travel disutility. Although, the hypothetical reasons for the decrease in VTTS can be indicated, it is not possible to determine the one that is the most appropriate given the data set. In order to do so, we need to collect data on individuals' leisure behavior.

Next, the results of the empirical analysis, under the assumption of a non-constant MU with respect to income, show that the VTTS of automobile users decreases as travel time increases, whereas the variations in the VTTS of rail and airplane users are neutral over travel time. We discuss this difference with regard to a constant MU with respect to income, as demonstrated earlier.

In accordance with classical microeconomic theory, it is assumed that the MU with respect to income is decreasing. Then, the results of the empirical analysis require that the income constraint become more rigid as the travel time increases for automobile users while the income constraint become more relaxed as travel time increases for rail and airplane users. The following three hypothetical reasons can be posited in regard to the above stipulations. The first is that the marginal expenditure for leisure activity with respect to leisure time is lower than the marginal travel cost with respect to travel time, for automobile users. The second is that automobile users do not adjust their budgetary constraints as travel time increases, unlike rail and airplane users. The third hypothetical reason is that there is no relation between travel time and the income of automobile users, whereas rail and airplane users with higher income tend to travel for longer durations. However, the reasons provided above are hypothetical; verifying them necessitates further analysis with other empirical data that address the relation between income and travel time.

CONCLUSIONS

In this study, we examined the variation in the VTTS over travel time. The theoretical consideration demonstrates that it is impossible to identify the conditions that determine the monotonic change in the VTTS over travel time. It is then examined using empirical data on the choice of travel modes for inter-urban travel in Japan. The results of the empirical analysis show that the VTTS decreases as travel time increases. We posited certain hypothetical reasons for such results. However, since the reasons are only hypothetical, verifying them necessitates further examination with more empirical data.

The results of our analysis may yield certain policy implications. First, it is shown that the VTTS changes with the travel time. Although a constant VTTS has often been used for benefit evaluation in practical transport planning, it may not be appropriate with respect to the economic evaluation of inter-urban transport investment in Japan. We need to take into account the variation in the VTTS even for practical benefit calculation. Second, our empirical analysis results show that the variation in the VTTS over travel time may differ across travel modes. We should consider the difference in the VTTS across travel modes with respect to a cost-benefit analysis. Third, the variation in the VTTS over travel time may influence the transport investment policy. If we acknowledge that the VTTS decreases as travel time increases, the marginal benefit caused by marginal travel time saving would increase as travel time reduces. This implies that society will require additional travel time saving as travel time decreases.

Finally, we point out certain research areas relating to the present analysis. First, we analyzed the VTTS with data used in the formal long-term transport planning in Japan. However, the VTTS estimation is highly influenced by the data definition, particularly by the level of service data including the travel time and travel cost of the alternative travel mode. We should examine the sensitivity of such data to the estimation. Second, we used only two variables—travel time and travel cost—in the model estimation for analytical simplification. However, in reality, there are other variables that may influence the choice of travel modes, such as the number of transfers and the congestion and comfort of the vehicle. As Hess *et al.* (*20*) indicate, the inappropriate incorporation of variables may bias the VTTS estimation results. We should verify the appropriateness of using two variables. Finally, we used the MNL model in the examination of the choice of travel mode. This model cannot consider the heterogeneity of individual preference. As Hess *et al.* (*20*) and Sillano and Ortuzar (*21*) show, the mixed logit model may be applicable to the VTTS estimation.

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