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INCORPORATING DIFFERENCES IN MARGINAL UTILITIES OF TIME ACROSS ACTIVITIES IN A TIME ALLOCATION MODEL

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Abstract: Most existing activity time allocation models assume that individuals allocate their time to different activities over a period in such a way that the marginal utilities of time across activities are equal. Their argument is that, if not equal, an individual is free to allocate more time to those activities whose marginal utilities of time are higher and, finally allocates the optimal time to each activity with equal marginal utility. However, such an ideal situation may not always prevail in reality, especially when an individual is under income constraint and/or under intense time pressure. In order to incorporate such differences in marginal utilities of time across activities, we enrich the traditional activity time allocation model by explicitly including income constraint and by adding marginal extension activity choice model. As an application, the developed integrated model is used to estimate the value of activity time during weekends in Tokyo. The results are encouraging in that they forecast the individual time allocation more accurately and estimate realistically the value of activity time for each activity in a set of different activities than do by existing traditional models.

Key Words: *activity time allocation, marginal utility of time, value of activity time*

1. INTRODUCTION

Many policy decisions in transportation infrastructure involve individuals' time use and value of time. Microeconomic models are the basis of most existing research for analyzing individual activity time allocation and valuation. They are based on the assumption that an individual allocates his or her scarce resources (e.g., time, money) to different activities and to various goods over a period of time (say a day or a week) to maximize his or her total utility. These microeconomic models of individual activity time allocation and valuation are very popular not only because of mathematical tractability, but also due to a wide range of applications such as, analyzing travel behavior, examining transport policy options and evaluating transportation projects from time saving benefits.

Becker (1965) laid down the foundation for considering both amounts of time allocated to different activities and quantities of various good consumed in an individual's direct utility

function, indirectly through 'final commodities', under both income and time constraints. This study has had significant impact on transportation researchers as well as on economists. Becker treated the total available time as a fixed time endowment or a constraint, and did not care about consumption time constraint for each particular activity. DeSerpa (1971) incorporated both amounts of time allocated to different activities and quantities of various goods consumed directly in an individual's direct utility function, and theoretically proposed three distinct terminologies related to value of time for lower-bounded consumption-time constrained activities as such travel: value of time as a resource (VOTR), value of saving time (VOST), and value of activity time (VOAT). Various transportation researches (Kraan, 1997; Jara-Diaz, 1998; Jara-Diaz, 2000) have built on both Becker (1965) and DeSerpa (1971) foundations. Jara-Díaz and Guevara (2003) developed a combined work trip mode choice model and activity demand model from a common microeconomic framework to estimate the components of subjective value of saving time (VOST) in travel. However, their model can only estimate value of activity time (VOAT) for work activity and travel activity. Jara-Díaz (2003) developed a theoretical framework for establishing all possible technical relationships between consumption of goods and assignment of time to each activity; however, the estimation of these models has not been explored. Prastyo *et al.* (2003a), Fukuda *et al.* (2003) have initiated the concept of marginal utility differences across activities but lack significantly to establish a generalized theoretical foundation, to consider a large set of activity types and to consider error variance heterogeneity in their models. Nepal *et al.* (2005) and Fukuda *et al.* (2005) have discussed the latent determinants of activity time allocation using both time and income constraints. However, they have not considered the marginal utility differences across activities.

Another stream of research on individual activity time allocation emerges in transportation research to analyze travel behavior (Kitamura, 1984; Kitamura *et al.*, 1996; Yamamoto and Kitamura, 1999; Bhat and Misra, 1999; Meloni *et al.*, 2004; Bhat, 2005). Kitamura (1984) introduced a random utility model, under a utility maximizing principle, to formulate estimable models of individual activity time allocation. Kitamura *et al.* (1996) formulated a discrete-continuous choice model of time allocations to two types of discretionary activities using doubly censored regression model. Yamamoto and Kitamura (1999) further extended these researches, incorporating interactions between working and non-working days. Bhat and Misra (1999) employed the same concept to model weekly discretionary activity time allocations between in-home and out-of-home and between weekdays and weekends. Meloni *et al.* (2004) analyzed the time allocations to discretionary in-home and out-of-home activities including trips using Nested-Tobit model. Bhat (2005) developed a multiple discrete-continuous extreme value model for discretionary time-use decisions using a flexible direct utility function proposed by Kim *et al.* (2002) and, a time constraint. These models are based on the principle of constrained utility maximization where an individual's direct utility is only a function of the amounts of time allocated to different activities over a period of study (usually a day or a week) and, a time constraint. They did not consider the quantities of various goods consumed in direct utility function and the income constraint (hence, cannot be used to estimate the value of activity time). As a result, the modeling equations are simple in the form of either a simple regression or a log-linear regression or a Tobit-censored regression model. However, such simplifications have suffered from an assumption that the marginal utilities of time across activities are equal. Their argument is that, if not equal, an individual is free to allocate more time to those activities whose marginal utilities of time are higher and, finally allocates the optimal time to each activity with equal marginal utility. However, such an ideal situation may not always prevail in reality, especially when an individual is under income constraint and/or under intense time pressure. We included a income constraint and

also conducted a stated preference survey to elicit such differences when the total time resource is marginally extended (for survey details, refer Section 3 of this paper).

In the carefully designed survey, we asked each individual two subsequent questions. First, we asked each individual whether he or she was satisfied with the existing time allocations to different activities for a particular day. Second, we added a subsequent question for those who were not satisfied with the existing time allocations to indicate a single activity from a set of activities that were participated on that specific day, which are, in fact, a subset of pre-specified six activities, on which they would prefer to allocate additional time obtained from reducing commute time by half an hour one way. This

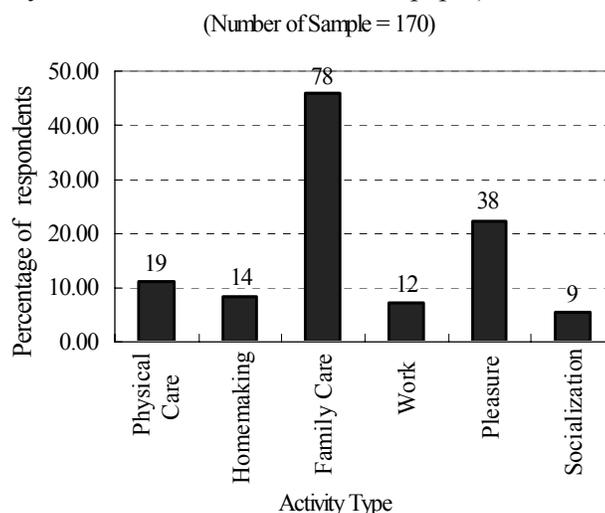


Figure 1 SP choice of each activity type

marginal extension activity choice helps us to understand the marginal utilities of time across activities. The individuals' choices are shown in Figure 1. It shows that the majority of respondents have had their higher preferences to allocate marginally extended time to 'family care', and 'pleasure' activities during weekends, given the chosen activity was participated on that day. This result gives a tentative idea that the marginal utilities of time for 'family care' and 'pleasure' activities were higher than other activities during weekends in Tokyo. The result is not unrealistic for the people in Tokyo because they had very limited time to spend with their families and participate in interesting activities during a short weekend time periods. For these individuals, the marginal utilities of time of these activities are, in fact, higher than other participated activities. It is important to include such differences in activity time allocation model.

In this study, we extend the works by Prasetyo *et al.* (2003a) and Fukuda *et al.* (2003) to model individual activity time allocation incorporating differences in marginal utilities of time across activities by including income constraint and using a marginal extension activity choice model, and to estimate value of activity time, different by activity type. We consider six types of activities as defined by motivational theory of psychological needs (Maslow, 1970), allow error variances to be different across activities (i.e. error variance heterogeneity), include indicators of psychological needs as observed determinants of time allocation decisions (latent indicators), and estimate the parameters of the model in detail. We treat the travel modes and activity locations as fixed, so the total travel time and travel cost over the study period are exogenous to the model system, and not included in an individual's direct utility function. Since six types of activities with different variances across activities are analyzed, a simulation method is used to estimate the model parameters. Simulation system is essential to estimate the parameters of marginal extension activity choice model where the probability of choosing an activity type is simulated using *GHK* simulator (e.g. Train, 2003). The underlying theories behind the developed model are microeconomic theory of utility maximization, motivational theory of psychological needs and discrete choice theory.

The rest of the paper is organized as follows. In Section 2, we present a schematic diagram of the models and reformulate a general microeconomic model of individual activity time allocation. We present econometric specifications of three models, namely, an activity time

allocation model, a marginal extension activity choice model and an integrated model. This section also includes the formulation to estimate the value of activity time, different by activity type. A small-scale empirical study, as a pilot investigation, is presented in Section 3 along with the estimated parameters and estimated value of activity time. Section 4 concludes the paper with some directions for further improvements.

2. MODEL DEVELOPMENT

We reformulate a general microeconomic model of individual activity time allocation based on the principle of utility maximization in which an individual's direct utility is the function of both amounts of time allocated to different activities and quantities of various goods consumed, under both time and income constraints. An individual's total utility over a study period is represented as multiplicative functional form of parameters and natural logarithm of utility arguments. The parameters are assumed to depend on a set of explanatory variables in an exponential functional form in order to ensure these parameters to be strictly positive. A marginal extension activity choice model, which incorporates the differences in marginal utilities across activities, is built using the same utility function and additional data of stated choice of activity type. An integrated model is proposed by combining the log-likelihood function of the both models. As the models developed in this study are based at the individual level, the subscript for the individual is omitted for the convenience of notation.

2.1 Diagrammatic Representation

The proposed integrated framework for modeling individual activity time allocation that explicitly incorporates differences in marginal utilities of time across activities consists of two model components: an individual activity time allocation model using revealed preference (RP) optimal time allocation data and a marginal extension activity choice model using stated preference (SP) time allocation data. Such a combination is useful for considering differences in marginal utilities of time across activities in traditional time allocation model. The path diagram is shown in Figure 2, where an ellipse represents the unobserved variable and rectangles represent the observed variables. An individual's direct utility is unobserved and optimal time allocations to various activities are assumed as the manifestations of maximizing direct utility.

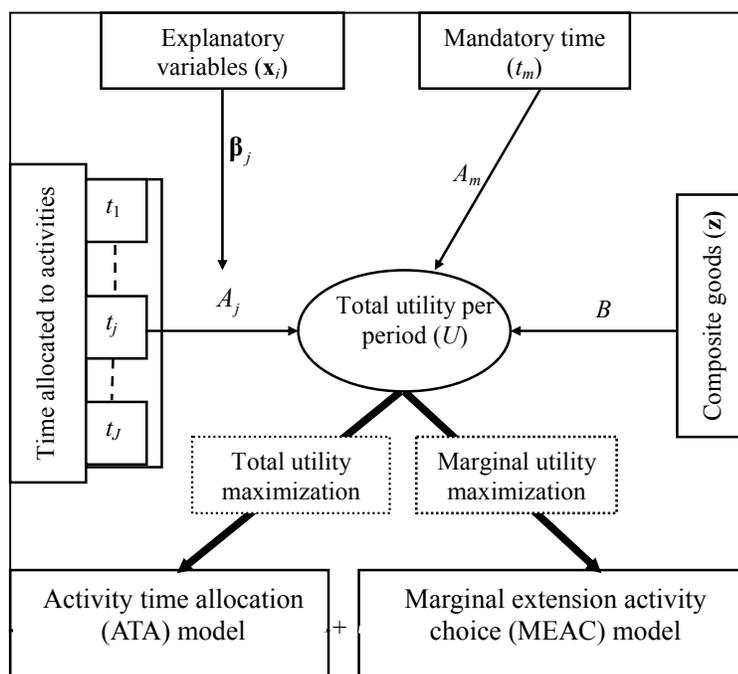


Figure 2 Theoretical modeling framework

2.2 Theoretical Background

The arguments of the direct utility function play a major role in the development of the activity time allocation and valuation models. We use DeSerpa (1971)'s functional form of utility that depends on both amounts of time allocated to different activities and quantities of various goods consumed over the study period:

$$U = U(\mathbf{t}, \mathbf{z}) = U(t_1, \dots, t_j, \dots, t_J, z_1, \dots, z_k, \dots, z_K) \quad (1)$$

where:

U = direct utility function of an individual;

\mathbf{t} = J -dimensional vector of consumption time;

\mathbf{z} = K -dimensional vector of various goods consumed;

t_j = time allocated to activity $j \in J$ during a study period;

z_k = consumption of good $k \in K$ during a study period.

However, since separate consumption of goods and related prices are not generally included in the activity time use surveys, all goods are usually represented as composite goods (Z) with composite price (P). Hence, Equation (1) can be re-written as:

$$U = U(\mathbf{t}, Z) = U(t_1, t_2, \dots, t_j, \dots, t_J, Z) \quad (2)$$

The individual maximizes utility (2) under time constraint (3) and budgetary constraint (4):

$$T - \sum_j t_j - T_t = 0 \quad (\mu) \quad (3)$$

$$y - \sum_j r_j t_j - PZ - T_c = 0 \quad (\lambda) \quad (4)$$

where:

r_j = unit cost of participation to activity j ;

T_t = total travel time during the study period;

T_c = total travel cost during the study period;

T = total time available during the study period;

y = fixed income apart from market labor;

μ = Lagrange multiplier of time resource constraint;

λ = Lagrange multiplier of money budget constraint.

Basically, there are two types of time use constraints: time resource, and consumption time. Time resource is the fixed time endowment for doing different activities, and, hence, a constraint. The ratio μ/λ is, then, seen as the value of extending time resource, and is known as the value of time as a resource (VOTR). Each activity can be performed only at the expense of time and the amount of time allocated to each activity is partly a matter of choice, and partly a matter of necessity. The consumption time constraint applies only when it is binding. For example, individuals have to spend a minimum necessary travel time, but they generally prefer to spend as little travel time as possible. Hence, there is a value in lowering the minimum necessary travel time; this is known as the value of saving time (VOST) in travel. However, since the proposed modeling framework assumes exogenous total daily travel time, only consumption times at the destinations are modeled. The consumption times at the destinations are, in general, non-binding because individuals are free to allocate their

time to different activities except for a few exceptions of opening hours of supermarkets, fixed working time, movie show times at a theater etc. So, we did not consider consumption time constraints in our model. However, an individual's utility changes with the variation in the consumption time duration. In this case, the valuation of time allocated to an activity due to direct variation in utility is the value as a commodity. It is sometimes useful to evaluate directly how important is the activity for an individual and is known as value of activity time (VOAT). The value of activity time is defined as the marginal rate of substitution of time allocated to the particular activity for money and is usually estimated by taking the ratio of the marginal utility of time allocated to each activity and marginal utility of total money budget:

$$VOAT_j = \frac{\partial U / \partial t_j}{\lambda} \quad \forall j \quad (5)$$

The constrained utility maximization formulations Equation (2), Equation (3) and Equation (4) can be solved by the Lagrange principle:

$$L = U(.) + \mu(T - \sum_j t_j - T_i) + \lambda(y - \sum_j r_j t_j - PZ - T_c) \quad (6)$$

From the first order conditions with respect to the decision variables t_j and Z , we can get:

$$\frac{\partial U}{\partial t_j} = \mu + \lambda r_j \quad \forall j \quad \text{and} \quad \frac{\partial U}{\partial Z} = \lambda P \quad (7)$$

$$\frac{\partial U}{\partial t_j} = \mu + \frac{1}{P} \times \frac{\partial U}{\partial Z} \times r_j \quad \forall j \quad (8)$$

Equation (8) shows that the marginal utilities of time across activities are not equal because of the presence of income constraint, so do other constraints like time pressure and time required for consuming various goods. Sometimes it is useful to classify the activities into mandatory activity and discretionary activities. It is not unrealistic to assume exogenous mandatory time (time required for mandatory activities such as sleeping, bathing etc.) because mandatory time for an individual is more or less constant. So, it is possible to model time allocated to discretionary activities assuming exogenous mandatory time. For mandatory activity labeled by "m", from Equation (8),

$$\frac{\partial U}{\partial t_m} = \mu + \frac{1}{P} \times \frac{\partial U}{\partial Z} \times r_m \quad (9)$$

Substituting the value of μ from Equation (9) in Equation (8), we obtain:

$$\frac{\partial U}{\partial t_j} = \frac{\partial U}{\partial t_m} + \frac{1}{P} \times \frac{\partial U}{\partial Z} (r_j - r_m) \quad \forall j \neq m \quad (10)$$

Equation (10) means that the marginal utilities of time across activities are not equal unless the unit costs of participation to the activities are the same.

2.3 Econometric Specifications

We need to make further assumptions about functional forms of utility and parameters to

arrive at an estimable activity time allocation model from Equation (10). We use the logarithmic Cobb-Douglas functional form of utility over its arguments. Kitamura (1984) discussed the suitability of such a functional form of utility.

$$U = \sum_j A_j \ln(t_j) + B \ln(Z) \quad (11)$$

The functional form of the utility in Equation (11) reveals that for positive utility parameters, the increase in the values of arguments in utility increases the total utility but the marginal utility decreases, as shown in Equation (12). Marginal utilities with respect to t_j and Z are:

$$\frac{\partial U}{\partial t_j} = \frac{A_j}{t_j} \quad \forall j \quad \text{and} \quad \frac{\partial U}{\partial Z} = \frac{B}{Z} \quad (12)$$

where A_j is the random parameter associated with the activity j , and B is the parameter associated with the quantity of composite goods consumed. The functional form of A_j determines the shape of the utility function and varies among individuals. We assume that it depends on the characteristics of the activities and on the individual's socioeconomic characteristics. To ensure that the parameter A_j is strictly positive, we used exponential functional forms of the parameters with deterministic and stochastic terms:

$$A_j = \exp(\mathbf{x}_j \boldsymbol{\beta}_j + \varepsilon_j) \quad (13)$$

where:

A_j = parameter vector associated with activity j ;

\mathbf{x}_j = explanatory variables of activity j ; and

ε_j = random error term associated with activity j .

We separately derive econometric models of both activity time allocation and marginal extension activity choice. The integrated model is obtained by combining the log-likelihood function of both models.

2.3.1 Activity Time Allocation (ATA) Model

We can derive econometric activity time allocation model by substituting the functional form of utility and parameters from Equation (12) and Equation (13) into Equation (10):

$$\frac{\exp(\mathbf{x}_j \boldsymbol{\beta}_j + \varepsilon_j)}{t_j} = \frac{A_m}{t_m} + \frac{B}{PZ} (r_j - r_m) \quad \forall j \neq m \quad (14)$$

We can take the natural logarithm to both sides and arrange the terms:

$$\ln(t_j) = \mathbf{x}_j \boldsymbol{\beta}_j - \ln\left(\frac{A_m}{t_m} + \frac{B}{PZ} (r_j - r_m)\right) + \varepsilon_j \quad \forall j \neq m \quad (15)$$

Equation (15) is the general expression of the activity time allocation model for activity j . However, it is sometimes more beneficial to model the systems of equations of all activities, except for m , jointly:

$$\left. \begin{aligned} \ln(t_1) &= \mathbf{x}_1 \boldsymbol{\beta}_1 - \ln\left(\frac{A_m}{t_m} + \frac{B}{PZ} \times (r_j - r_m)\right) + \varepsilon_1 \\ &\dots \\ \ln(t_j) &= \mathbf{x}_j \boldsymbol{\beta}_j - \ln\left(\frac{A_m}{t_m} + \frac{B}{PZ} \times (r_j - r_m)\right) + \varepsilon_j \\ &\dots \\ \ln(t_j) &= \mathbf{x}_j \boldsymbol{\beta}_j - \ln\left(\frac{A_m}{t_m} + \frac{B}{PZ} \times (r_j - r_m)\right) + \varepsilon_j \end{aligned} \right\} \quad (16)$$

Doing this requires more effort to specify the variance-covariance structures of the disturbances and constraints on the parameters across activities. The different model structures include covariance structures, random coefficient structures and unrestricted structures [See Greene (1997) for different model structures and estimation approaches]. For simplicity, we assume that the error terms are independently and normally distributed across activities (i.e. cross-sectional heteroscedasticity):

$$\begin{aligned} E(\varepsilon_j) &= 0 \\ \text{Cov}(\varepsilon_j, \varepsilon_{j'}) &= \begin{cases} \sigma_j^2 & \text{if } j = j' \\ 0 & \text{otherwise} \end{cases} \end{aligned} \quad (17)$$

Since we assume that the disturbances are independent across activities, we can derive the model for each activity and extend it to all activities when calculating the likelihood function. Extensions to other model structures are straightforward, but the complexity of estimation increases with the flexibility of model structures. Then, the density of time allocated to activity j from Equation (15) can be generally written as:

$$f(t_j | x_j, t_m; \boldsymbol{\beta}_j, A_m, B, \sigma_j) \quad (19)$$

Assuming the error density $\varepsilon_j \approx N(0, \sigma_j^2)$, in other words, independent normal distribution across activities with mean zero and standard deviation σ_j , we can estimate the activity time allocation model for each activity j from the following likelihood function:

$$(L_j)_{ATA} = \prod_{n_j} \frac{1}{\sigma_j} \phi\left(\frac{\varepsilon_j}{\sigma_j}\right) \quad \forall j \neq m \quad (20)$$

where ε_j is the error term of activity j and can be obtained from (15), n_j represents all respondents used to model activity j , and ϕ is the normal density function. However, with data from a limited period, we may not observe any of an individual's time allocations for some of the activities. We can overcome this problem by using a non-linear Tobit censored regression model for $t_j > 0$ and $t_j = 0$:

$$(L_j)_{ATA} = \prod_{n_{j1}} \frac{1}{\sigma_j} \phi\left(\frac{\varepsilon_j}{\sigma_j}\right) \times \prod_{n_{j0}} \Phi\left(\frac{\varepsilon_j}{\sigma_j}\right) \quad \forall j \neq m \quad (21)$$

where n_{j1} represents the respondents with non-zero time allocation for activity j , n_{j0} represents the respondents with zero time allocation for activity j , and Φ is the cumulative normal distribution. Since we assume the disturbances are independent across activities, we can estimate the joint model of all activities by multiplying all likelihood functions. The combined likelihood and log-likelihood of joint model are given in Equation (22) and Equation (23) respectively.

$$L_{ATA} = \prod_{j \neq m} (L_j)_{ATA} \quad (22)$$

$$LL_{ATA} = \sum_{j \neq m} \ln(L_j)_{ATA} \quad (23)$$

Note here that the variances of the error term are allowed to vary across activities unlike Prasetyo *et al.* (2003a) and Fukuda *et al.* (2003), where the variances are restricted to be the same for all activities.

2.3.2 Marginal Extension Activity Choice (MEAC) Model

The activity time allocation model presented in the previous section considers only income constraint for incorporating differences in marginal utilities of time across activities. Other constraints such as time pressures and time required for the consumption of various goods have not been incorporated. These constraints are difficult to model mathematically. In order to include these constraints indirectly, a marginal extension activity choice model in the form of multinomial Probit model, based on the maximization of marginal utility using stated preference survey, is proposed here. In this study, we assumed that the additional unit disposable time would be allocated to a single activity, not to the multiple activities.

The marginal utility of the time spent on activity j can be obtained by taking partial derivative of an individual's utility function in Equation (11) with respect to activity time t_j as:

$$\frac{\partial U}{\partial t_j} = \frac{A_j}{t_j} = \frac{\exp(\mathbf{x}_j \boldsymbol{\beta}_j + \varepsilon_j)}{t_j} \quad \forall j \neq m$$

Taking logarithm in both sides:

$$\ln(\partial U / \partial t_j) = x_j \beta_j - \ln(t_j) + \varepsilon_j \Rightarrow U_j \equiv V_j + \varepsilon_j, \quad \forall j \neq m \quad (24)$$

where, U_j and V_j are total and deterministic utilities of an individual respectively. In MEAC model, we assume that the individual will choose the activity of which marginal utility of time is the highest. Since the distribution of the ε_j is assumed as independent normal across activities as in activity time allocation model, Equation (24) can be modeled as marginal extension activity choice model analogous with heteroscedastic normal distribution model. This assumption may not be unrealistic in the case of stated choice data because unobserved factors of alternative preferences are less likely to be correlated in hypothetical choice scenarios. Since we assume that ε_j is distributed normal with mean vector zero and restricted

variance-covariance matrix $\mathbf{\Omega}$, the density of $\boldsymbol{\varepsilon}$ is given by:

$$\phi(\boldsymbol{\varepsilon}) = \frac{1}{(2\pi)^{J/2} |\mathbf{\Omega}|^{1/2}} \exp\left(-\frac{1}{2} \boldsymbol{\varepsilon}' \mathbf{\Omega}^{-1} \boldsymbol{\varepsilon}\right)$$

In this Probit type model, the choice probability (P_j) of marginal extension activity choice model is, then:

$$P_j = \Pr(V_j + \varepsilon_j > V_j' + \varepsilon_j') = \int I(V_j + \varepsilon_j > V_j' + \varepsilon_j', \forall j \neq j') \phi(\boldsymbol{\varepsilon}) d\boldsymbol{\varepsilon} \quad (25)$$

where $I(\cdot)$ is an indicator of whether the statement in the parenthesis holds and the integral is over all values of $\boldsymbol{\varepsilon}$. The log-likelihood function of the choice probability for all individuals and alternatives can be written as:

$$(LL)_{MEAC} = \sum_{j \neq m} \delta_j \ln(P_j) \quad (26)$$

where, δ_j is the dummy variable taking a value 1 when an activity j is chosen. Here, $\boldsymbol{\beta}_j$ and $\mathbf{\Omega}$ are the unknown parameters that maximize the log-likelihood function. It is not surprising that the econometric estimation of this model requires normalization and identification issues. Since the scales and levels of utilities of the alternatives are irrelevant to the choice behavior, the normalization should be done so as to fix the location of the model. Walker (2001) has presented clear and in-depth analysis for identification. One parameter in Equation (26) is to be fixed for identification. We fixed the variance of one activity obtained from activity time allocation model as the normalization parameter for integrated model.

2.3.3 Integrated (ATA+MEAC) model

Since the independent ATA model does not capture all the constraints that result the differences in marginal utilities of time across activities, the incorporating MEAC model into ATA model will be useful to incorporate the properties of both models. Since parameters $\boldsymbol{\beta}_j$ and $\mathbf{\Omega}$ are common to both activity time allocation model and marginal extension activity choice model, the integrated model will be more helpful to estimate common parameters simultaneously. This can be obtained by summing up of the log likelihood function of the both models with simultaneously estimating the parameters. We can write the log likelihood function of the integrated model as:

$$LL = (LL)_{ATA} + (LL)_{MEAC} \quad (27)$$

Note that we have not considered variance heterogeneity between RP and SP data to simply the estimation process, but could be extended easily. There are plenty of existing literatures that describe how to combine RP and SP data sources (e.g. Morikawa, 1989).

2.3.4 Value of Activity Time (VOAT)

After estimating parameters of both ATA and (ATA+MEAC) models from Equation (27), we can estimate the value of time allocated to discretionary activities using following relationship:

$$VOAT_j = \frac{\frac{\partial U}{\partial t_j}}{\lambda} = \frac{A_j}{t_j} \times \frac{1}{\lambda} = \frac{PZ}{t_j} \times \frac{A_j}{B} \quad \forall j \neq m \quad (28)$$

The value of activity time to a specific activity depends on the time allocated to the activity. According to Equation (28), the value of activity time for an activity is the decreasing function of time allocated to that activity and depends also on explanatory variables that are included in the parameters of the utility function.

3. EMPIRICAL STUDY

3.1 Activity Time-use Survey

For this study, we use our previous dataset (Prasetyo *et al.*, 2003a; 2003b). The survey included a small-scale weekend activity time use survey collaborated with Mitsubishi Research Institute Inc. among individuals living in Tokyo at the Aqua-line toll road, which connects Tokyo Metropolitan and Chiba prefecture on opposite side of the Tokyo Bay in November 2000. We distributed 7000 pre-prepared questionnaires, and requested that respondents mail them back. Of the 819 returned questionnaire (response rate 11.7%), 413 respondents lived in Tokyo, who used transportation system regularly, are our interested respondents. We used only 170 respondents for calibration, which are precise and consistent, and satisfied our criteria. We collected a complete activity diary survey for a day including total daily travel costs, travel time and socioeconomic characteristics for an individual. In the data we used for estimation, individuals were over 18 years of age; 15.3% were female and 84.7 % were male. We took age (*AGE*), number of household members (*NHM*), and income (*INCO*) as the major explanatory variables. We manually classified the activities into six types according to the motivational theory of psychological needs (Maslow, 1970), except mandatory activity and travel. For detailed characteristics of the activity time-use survey, refer to Prasetyo *et al.* (2003b).

We also collected two indicators to elicit psychological needs: existing level of need satisfaction (*EXNEED*) on a 5-point semantic scale (5: very satisfied, 4: satisfied, 3: no complain, 2: dissatisfied, 1: very dissatisfied) and long-term priority of need preference (*PRNEED*) on a 6-point priority rank for six types of activities. The distribution of existing level of need satisfaction across respondents is shown in Figure 3. It shows that 42.9% of the respondents were not satisfied (i.e., very dissatisfied and dissatisfied) with the existing time allocations to ‘physical care’. Similar figures for ‘pleasure’, ‘work’, ‘family care’, ‘homemaking’ and ‘socialization’ are, respectively, 27.6%, 21.2%, 19.4 %, 18.8% and 15.3%. Similarly, the distribution of long-term priority of need preference across respondents is plotted in Figure 4. It shows 38.8% of the respondents had the first priority to ‘family care’. Similar figures, respectively in the decreasing order, are 26.5%, 17%, 9.7%, 4.1% and 3.5% for ‘physical care’, ‘pleasure’, ‘work’, ‘homemaking’ and ‘socialization’.

Interestingly, existing level of need satisfaction and long-term priority of need preference are not perfectly consistent. For example, 42.9% of the respondents were dissatisfied with existing time allocation to ‘physical care’, but only 26.7% respondents were interested to invest their additional time to ‘physical care’ as the first priority. However, less than 20% of respondents were dissatisfied with existing time allocation to ‘family care’ but 38.8% of them chose ‘family care’ as their first priority. This characteristic suggests that long-term priority

of need preference and an individual's intention to use extra time is more consistent than existing level of needs satisfaction. Hence, the analysis of psychological need of an individual might solve the problem of forecasting psychometric data and sheds light to the more detail analysis of activity-need relationships to incorporate socio-psychometric factors in time allocation modeling.

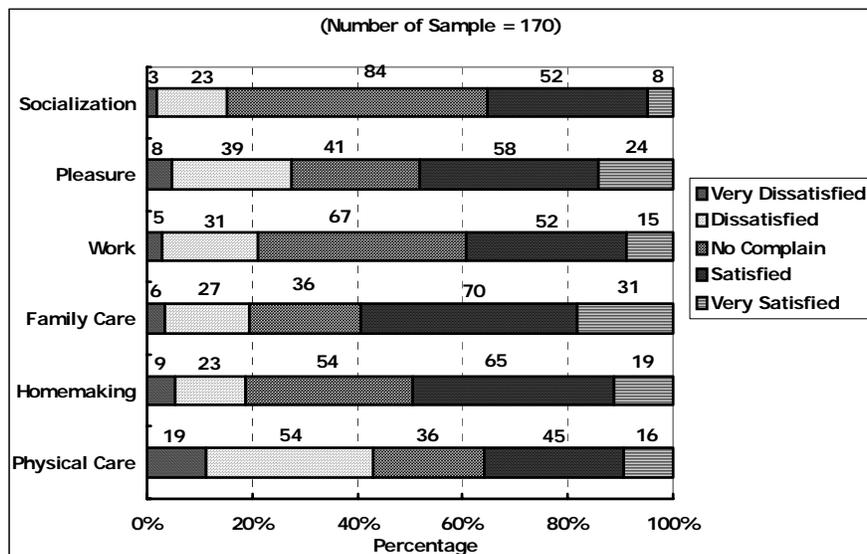


Figure 3 EXNEED distribution

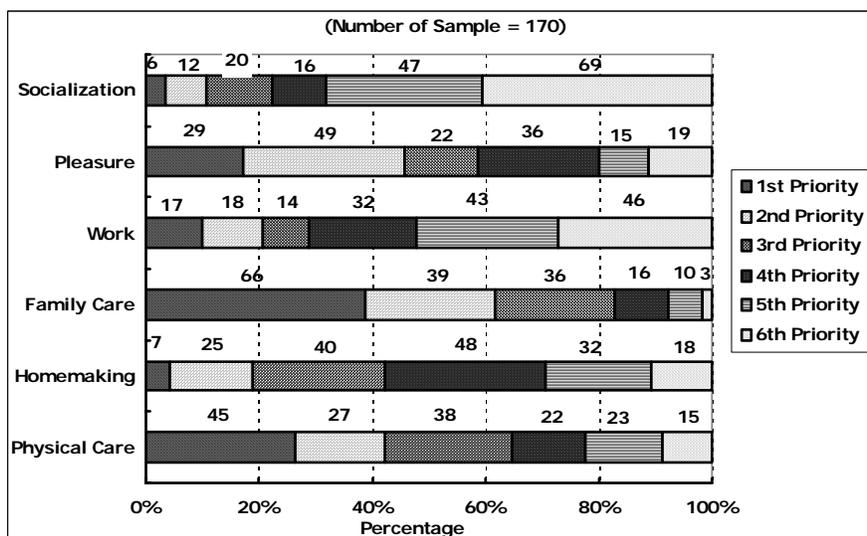


Figure 4 PRNEED distribution

3.2 Empirical Models Specification

Based on our limited data, we specified very simple structures of the marginal extension activity choice model and the activity time allocation model. We expressed the exponential functional forms for parameters A_m and B in Equation (11). In its simplest form, the activity time allocation model for the activity $j \neq m$ is specified below, where the parameters across activities are constrained to be equal, but error variances are allowed to vary across activities:

$$\ln(t_j) = \beta_1 \times EXNEED + \beta_2 \times PRNEED - \ln\left(\frac{e^{\beta_3 \times AGE}}{t_m} + \frac{(r_j - r_m)}{PZ} e^{\beta_4 \times INCO + \beta_5 \times NHM}\right) + \varepsilon_j \quad (29)$$

The marginal extension activity choice model reads:

$$\bar{U}_j = \beta_1 \times EXNEED + \beta_2 \times PRNEED - \ln(t_j) + \varepsilon_j \quad (30)$$

From these very restricted model specifications (few and constrained parameters), we estimated two separate models: an activity time allocation model and an integrated model. Since we did not collect the quantities of composite goods, market prices and participation costs for different activities, we conducted a separate analysis to fix the term $(r_j - r_m)/PZ$ equal to 0.03, 0.02, 0.05, 0.01, 0.06, 0.04 for ‘physical care’, ‘homemaking’, ‘family care’, ‘work’, ‘pleasure’ and ‘socialization’ respectively, as used in Prastyo *et al.* (2003b).

3.3 Parameter Estimations and Empirical Results

Using the data described above, two models were estimated using the program coded in GAUSS. The simulated maximum likelihood estimation method is used for integrated model using 100 standard uniform random draws and later converted to the normally distributed draws using inverse cumulative function in GHK Probit simulator as described in Train (2003). Estimated parameters and t-statistics (in the parentheses) for both an activity time allocation (ATA) model and an integrated (ATA + MEAC) model are summarized in Table 1.

Table 1 Estimated model parameters

Explanatory variables		ATA Model	ATA+MEAC Model
Psychometric indicators	EXNEED	-0.449 (-1.91)	-0.352 (-1.67)
	PRNEED	0.973 (5.64)	1.15 (7.66)
socioeconomic variables	AGE	0.181 (4.14)	0.193 (4.43)
	INCO	0.786 (3.87)	0.866 (4.37)
	NHM	1.42 (5.36)	1.58 (6.10)
Error parameters	St. deviation (physical care)	6.46 (10.7)	6.25 (11.8)
	St. deviation (homemaking)	4.98 (9.86)	4.93 (10.9)
	St. deviation (family care)	7.99 (12.2)	8.80 (12.1)
	St. deviation (work)	5.91 (10.1)	5.83 (11.3)
	St. deviation (pleasure)	9.03 (12.6)	8.75 (13.5)
	St. deviation (socialization)	5.73 (9.18)	5.53 (10.8)
Final log-likelihood		-1334.07	-1590.46
Sample size		170	

There are two broad categories of variables included in the models: indicators of psychological needs (*EXNEED* and *PRNEED*) and individual socioeconomic variables (*AGE*, *INCO*, and *NHM*). The signs and relative values of the parameters are as expected. Negative parameter for existing level of need satisfaction shows that the activity time allocation and preference of the activity choice decreases if an individual’s needs are satisfied in the existing time allocation conditions. The positive parameter for long-term priority of need preference shows that the activity time allocation and the preference for the activity choice increase when the activity is highly preferred in long run. Individual socioeconomic variables such as age, income and number of family members are all positive meaning that time allocations to the activities are low for aged high-income multi-member family households. The reason for high-income family for less time allocations to discretionary activities might be due to the

lack of time for those activities. Less time allocations to multi-member family may be due to the intra-member work distributions. The variance parameters for ‘family care’ and ‘pleasure’ are high compared with ‘homemaking’ and ‘work’. This may be due to the rather flexible activity participations to ‘family care’ and ‘pleasure’ activities. Use of t-tests for the estimated parameters reveals that they are statistically significant. Parameter estimates of the integrated model are more significant than independent models, which justify the combined estimations. Since we combined two different models, we can not compare the final log-likelihoods of these two models as a measure of fit.

3.4 Value of Activity Time

The relative values of activity time with respect to ‘family care’ and per unit of daily expenditures on good from Equation (28) and are summarized in Figure 5 using the parameters from both ATA and ATA+ MEAC models. It clearly shows that ‘family care’, ‘physical care’ and ‘pleasure’ activities have comparatively higher average value of time than ‘work’, ‘homemaking’ and ‘socialization’ during weekends. The comparison of VOAT calculated from both ATA model and ATA+MEAC model shows that the average relative values of activity time

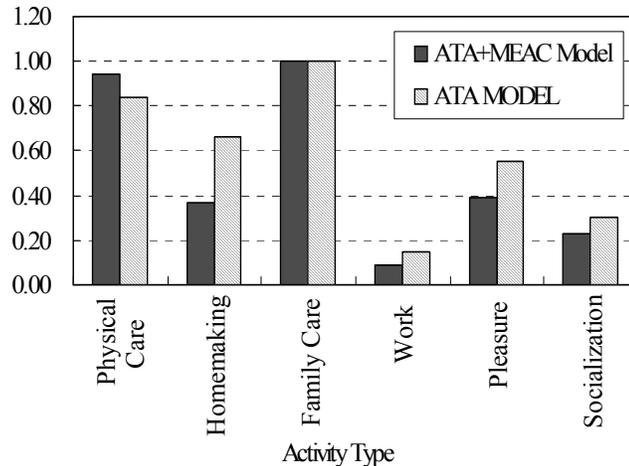


Figure 5 Comparison of relative average values of VOAT using ATA and ATA+MEAC Models

(VOAT) are slightly different between two model types. In the model which considers only income constraint as a factor of differences in marginal utilities of time across activities, relative average value of activity time (VOAT) for less preferred activities (on which individuals were not interested to allocate the marginally extended time such as ‘homemaking’, ‘work’ and ‘socialization’) are overestimated whereas for more preferred activities such as ‘family care’ and ‘physical care’ are underestimated (with an exception for ‘pleasure’ activities). It is a realistic result because ‘family care’ and ‘physical care’ activities are more likely to have higher marginal utilities under intense time pressure for the individual in Tokyo on weekends. Nonrealistic result for pleasure activity might be due to the similar nature of activities in ‘pleasure’ and ‘physical care’ types.

5. SYNTHESIS AND CONCLUSIONS

This study has reformulated a general and basic microeconomic random utility model of individual activity time allocation, and has extended it to incorporate differences in marginal utilities of time across activities using income constraint and from a marginal extension activity choice model. We also considered the indicators of psychological needs as the determinants of an individual’s activity time allocation decisions. We have derived estimable econometric models for activity time allocation model, marginal extension activity choice model and integrated model. Since independent ATA model does not capture all factors of differences in marginal utilities of time across activities, the ATA model is enriched by including MEAC model. Both integrated (ATA+MEAC) model and traditional ATA model

are used to estimate the value of activity time of different activity types and to compare the results. We used the data collected among individuals from Tokyo during weekends. The empirical results showed that psychological factors and individual socioeconomic characteristics influence his or her time allocation and activity participation decision. Majority of respondents have had greater needs for 'family care', 'physical care' and 'pleasure' on weekends. As these needs must be fulfilled within the limited time available on weekends, the time spent on these activities turned out to be valuable. The results also show that the value of time for non-productive activities such as 'family care', 'physical care' and 'pleasure' could be higher when they are highly demanded or needed. The comparison result shows that the average relative values of activity time (VOAT) are slightly different between two model types. In ATA model, relative average value of activity time (VOAT) for less preferred activities are overestimated whereas for more preferred activities such as 'family care' and 'physical care' are underestimated. These findings suggest that the integrated model, which incorporates the differences in marginal utilities of time across activities, is valuable not only for modeling activity time allocation, but also in calculating value of activity time, different by activity types. We drew these conclusions from the significant parameter estimates, and more realistic estimates of the value of activity time for different activities.

There are still many voids in the proposed model and, hence, requires further improvements. First, the analysis of the interactions between needs and activities is the major issue. More detailed studies of interactions, scheduling and timings of the activity participations are very important. Second, instead of using indicators of psychological needs directly as explanatory variables, a latent variable model could be used in order to elicit important latent determinants from indicators. Third, more detailed empirical studies, applied to real world projects, are essential to assess practical efficiency of the model. Fourth, incorporating variance heterogeneity across RP and SP data sources will further improve the model. Moreover, there are some limitations with respect to model specifications, such as uncorrelated disturbances and restricted model parameters across activities, which could be improved easily, provided the detailed data are available to estimate the parameters.

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