MODELING HOUSEHOLD TIME ALLOCATION BEHAVIOR: COMPARATIVE ANALYSIS USING A LARGE-SCALE DATA FROM SURVEY ON TIME USE AND LEISURE ACTIVITIES IN JAPAN

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ABSTRACT
Members in a household interact with each other when allocating their limited time resources to various activities, reflecting role specification and power structure within the household. For each member, some of activities are competitive in time allocation. In addition, each member might show different interest in or attach different importance to different activities. To reflect such complicated behavioral mechanisms, we developed two types of household time allocation models by integrating group decision-making theory and Becker's time allocation theory. One assumes a multi-linear household utility function and another adopts an iso-elastic function. These two types of utilities explicitly reflect relative influence of each member in household decision and inter-member (or intra-household) interaction. In representing intra-household interaction, these two types of utility functions overlap functionally. Each member's utility is further defined to incorporate relative importance of each activity and inter-activity interaction based on the multi-linear function. Using a large-scale national time use data collected in Japan, the effectiveness of the two models was first empirically confirmed. It is found that there is no significant difference in model accuracy between the two models on one hand, but different intra-household interactions are estimated on the other. This might suggest that to reach the same decision outcomes (refer to the allocated time patterns, here), several types of household decision-making rules might be applicable. In addition, to examine the applicability of the models to policy analysis, some scenarios related to infrastructure improvement were assumed and their impacts on quality of life from the perspective of time use were quantitatively evaluated.

1. INTRODUCTION

Due to limitation of available time, a household member has to trade off time allocation among different activities and different members might show different interest in or attach different importance to different activities. In case of multi-member households, members might further interact with each other when allocating their limited time to various activities, reflecting role specification and power structure within the household. It is known that time use research started at the beginning of the 20 century in the field of social science (e.g., Bevans, 1913; Pember-Reeves, 1913). Up to now, almost one century has elapsed. However, careful reviews suggest that there are many studies, which empirically analyze intra-household interaction, but only a few studies have been conducted to model such intra-household interaction (see review by Zhang *et al*, 2002, 2005a and 2005b; Zhang and Fujiwara, 2006). Under such circumstances, we developed two types of household time allocation models, which explicitly incorporate intra-household interaction based on utility theory. One model assumes a multi-linear type of household utility function, while another model adopts an iso-elastic class of welfare functions as household utility function (see review by Zhang *et al*, 2002, 2005a and 2005b; Zhang and Fujiwara, 2006). These two types of household utility functions overlap functionally. We have confirmed the effectiveness of these two types of models using two sets of activity diary data. One was collected in the Netherlands in 1997, and the sample sizes used for analysis were 257 households on weekday and 123 households on weekend. Another was collected at a depopulated region in Japan in 2002 and it included 150 households' one-week activity diary data. The household members analyzed were husband and wife. Using the data from the Netherlands, it is found that, 1) on weekday, dominant decision-makers are husbands within half of households, wives at 20% of households, while the remaining households do not show significantly different influence between husband and wife; 2) intra-household and inter-activity interactions are almost invariant between weekday and weekend; 3) households make decisions by giving higher priority to in-home activity and out-of-home independent, discretionary activities, with sufficient consideration of members' preferences; 4) shared (joint) activity are given higher priority on weekend than on weekday; 5) car ownership surely influences on household time allocation on weekday, but not on weekend. Using the data from a depopulated region in Japan, it is confirmed that, 1) even though husband has extremely relative influence than wife, husband gives priority to wife's preference when deciding household activities; 2) husband attaches the most importance to in-home activity, while wife does to out-of-home shared activity; 3) wife clearly takes inter-activity interaction into account, but husband does not; 4) car ownership significantly influences husband's time allocation, but not wife's time allocation. The aforementioned findings were obtained based on small sample sizes. To get more general conclusions about the proposed model and household decision-making mechanisms in the context of time allocation, it's better to use some large-scale time use data.

Therefore, this paper attempts to apply a large-scale time use data to examine the performance of the proposed household time allocation model. The data is obtained from the *Survey on Time Use and Leisure Activities* collected by the Ministry of General Affairs in 2001. In Japan, the first time use survey was conducted by Osaka City Hall, in 1923 (Tanaka, 1978). After that, the NHK (Japan Broadcasting Association) has conducted the same type of time use survey (called National Time Use Survey) every 5 years since 1960. After 16 years, the Ministry of General Affairs conducted its first national time use survey. Since then, the survey has been conducted every 5 years. The data used for this study come from the 6th survey.

In the remaining part of this paper, some conceptual issues are discussed and the developed models are briefly described in Section 2. Reviews about existing studies refer to our previous studies. Data is explained in Section 3, and model estimations are shown and discussed in Section 4. Simulation analyses are conducted in Section 5. The paper is concluded in Section 6 along with discussion about some future research issues.

2. MODELS

2.1 Conceptual Issues

Modeling household time allocation behavior is not an easy task. It is necessary to first make clear, for example, who are decision makers within a household, how they are involved in and affect household decision. Intuitively, it seems simple to identify them, but in fact it is not the case. Thinking about the case that a husband goes shopping in a day, it seems natural to assume that he made decision to go shopping by himself. However, he might be asked by his wife, simply because his wife did not have time, even though she usually goes shopping for the household. Such argument might hold for other household-serving activities. For the activities jointly performed by several members, one assumption might be that all the involved members in the party are decision makers. However, the involved children might just follow their parents without any opinion, for example. Specification of decision makers is also related to discussion about involvement of household members, especially in case that the members involved in joint decision cannot be clearly identified, or they are unknown to analysts at all. Decisions made by different members within a household may not be independent, suggesting the existence of intra-household interaction. This is clearly true for joint activity. Even for some independent activities performed by each member, for example, in the above-mentioned shopping activity, husband's decision to perform shopping activity is due to that his wife did not have time to do the shopping activity that is usually done by his wife, because she had to do other activities. In addition, since each member has to perform different activities within his/her available time (e.g., 24 hours), the occurrence of one activity leads to the decrease of the probability of performing other activities. Such inter-activity interaction cannot be ignored. Constraint of such available time should also be incorporated into modeling process.

Concerning household decision-making rules, it is obvious that there is no single rule that is applicable to any decision situations. Household decision could be rational or irrational depending on decision situations. Decision based on trade-off among different factors is an example of rational decision. Impulse shopping due to excessive persuasion by shop owner is a good example of irrational decision. Utility maximization rule and "if-then" heuristic rule could be applicable to represent rational decision. Irrational decision is beyond the scope of this paper.

Since one of the purposes to develop household time allocation model in this study is to evaluate public policies based on cost/benefit analysis and welfare economic analysis, the household model has to be consistent with microeconomic theory. Therefore, this paper adopts the principle of random utility maximization as household decision making rule. Next, two types of household utility functions are briefly described and the resulting household time allocation models are summarized based on our previous studies.

2.2 Household Utility Functions

(1) Multi-linear household utility function

The multi-linear household utility function is defined as follows:

$$HUF = H\left(u_1, u_2, \ldots, u_n\right) = \sum_{i=1}^{n} w_i u_i + \lambda \sum_{i=1}^{n} \sum_{i'>i} \left(w_i w_{i'} u_i u_{i'}\right) \tag{1}$$

$$w_i \geq 0 \text{ and } \sum_i w_i = 1 \tag{2}$$

where,

HUF denotes "*Household Utility Function*",

u_i is household member i's utility,

λ is parameter of intra-household interaction,

w_i is household member i's weight parameter, reflecting the relative influence of each member, and

n is the number of household members.

One can see that the first term in the right side of equation (1) is the weighted average value of members' utilities. The weight w_i can be interpreted as a measure of a member's power or relative influence within the household. It also reflects the influence of the degree of involvement and/or the types of strategies adopted in the household decision-making process.

The second term in the right side of equation (1) represents the influence of intra-household interaction. It is obvious that intra-household interaction is expressed in the form of Nash-type utility function without a reference point. The Nash-type utility function assumes that each household member identifies his/her most preferred outcome and the household then compromises by averaging along the resulting negotiation frontier (Curry *et al.,* 1991). Accordingly, the interaction parameter λ reflects household members' concern for achieving equality of utilities. A positive value of the interaction parameter λ means that the existence of intra-household interaction brings about an increase in household utility. The larger the value of λ, the higher the household's collective desire to choose a time allocation such that the utilities of all household members are approximately equal. On the other hand, a negative value of λ means that the existence of intra-household interaction reduces household utility and consequently suggests that the household does not prefer equality of members' utilities. The multi-linear household utility function finds its theoretical roots in "group decision theory" (e.g., Harsanyi, 1955). The multi-linear household utility function can include several special cases such as additive-type, autocratic type, compromise-type, and capitulation-type utility functions.

(2) Iso-Elastic household utility function
The iso-elastic household utility function is defined as follows:

$$HUF = H\left(u_1, u_2, ..., u_n\right) = \frac{1}{1-\alpha}\sum_i w_i u_i^{1-\alpha}, \quad w_i \geq 0 \; and \; \sum_i w_i = 1 \tag{3}$$

where, α is a parameter indicating intra-household interaction and other notions are the same as in equation (1).

The iso-elastic function is drawn from the research on social welfare function (Atkinson, 1970, 1983). The intra-household interaction parameter α describes how and to what extent the household positions its members (or considers the existence of its members) in the decision-making process and consequently makes its final decision-making. Therefore, different values of α and w_i, and the sign of α represent different household decision-making mechanisms. Equation (3) can also include some types of household utility functions as special cases such as minimum-type, maximum-type, Nash-type utility functions as well as additive-type, autocratic type, compromise-type, and capitulation-type functions

As seen above, in representing intra-household interaction, the multi-linear and iso-elastic utility functions adopt different modeling strategies and overlay functionally. If $\lambda = 0$ and $\alpha = 0$, both household utility functions become additive types. In this case, the household utility is determined only by each member's relative influence (or power) within the household. Considering that power relationships within a household may be difficult to change , the additive type utility function suggests that even if decision situations change, the household might choose the same decision outcomes. The interaction term (the second term in the right side of equation (1)) for the multi-linear utility function represents the similar Nash-type function, which is a special case of iso-elastic utility function. If $\lambda > 0$ and $\alpha < 1$, both types of functions suggest that household prefer the existence of intra-household interaction. In other words, the existence of intra-household interaction will lead to an increase in the household utility function. In this case, the relative influence parameter w_i will also work in the same way to bring about the change in household utility. On the other hand, the two types of household utility functions integrate the above-mentioned common governing behavioral elements about household decision-making in a different manner. The multi-linear utility function is composed of an additive-type utility function and a Nash-type interaction term. In this sense, the multi-linear utility function uses the Nash-type interaction term to represent the households' consideration of equality during the joint decision-making process. In contrast, the iso-elastic function introduces the parameter α, which is also called Atkinson's (1970) measure of aversion to inequality, to incorporate the influence of intra-household interaction. Because parameter α is the inverse of the elasticity of substitution along social indifference curves, it reflects households' preferences for trading off utility between their members. Due to the introduction of parameter α, the iso-elastic utility function can also represent minimum-type and maximum-type of household decision-making mechanisms, which cannot be represented by the multi-linear utility function. Accordingly, the iso-elastic utility function seems more general and flexible in representing household decision-making mechanisms.

2.3 Household Time Allocation Models

The household time allocation model can be derived by maximizing the following Lagrange function, where T_i is household member *i*'s available time and t_{ij} indicates the time of activity *j*. The second part of the following equation indicates constraints of members' available time T_i.

$$L = H(u_1, u_2, \ldots, u_n) + \sum_i \mu_i (T_i - \sum_j t_{ij}) \qquad (4)$$

Before deriving the household time allocation models, one needs to specify each member's utility function. To incorporate the influence of inter-activity interaction, which is usually ignored in conventional time allocation models, the multi-linear utility function is adopted to define each member's utility function as follows:

$$u_i = \sum_j r_{ij} u_{ij} + \sum_{j=1}^{J} \sum_{j'>j} \delta_i \, r_{ij} r_{ij'} u_{ij} u_{ij'} \qquad (5)$$

where,

u_{ij} is household member *i*'s utility for activity *j*,

δ_i is parameter of inter-activity interaction for member *i*,

r_{ij} is household member *i*'s weight (or relative interest) parameter for activity *j*, reflecting the relative importance of each activity for each member's utility, and

J is the number of activities for each member.

One can interpret the meanings of relative importance parameter r_{ij} and parameter δ_i of activity dependency, in the same way as for the relative influence parameter w_i and parameter λ of intra-household interaction. That is, r_{ij} refers to the importance of performing an activity for each member. The parameter δ_i reflects member *i*'s concern for achieving equality of utilities across different activities. Of course, δ_i can take any value along the real axis. A positive (or negative) value of δ_i means that the existence of activity dependency leads to an increase (or decrease) in each member's utility. Concerning the utility of each activity, the following logarithm function is adopted in order to derive an operational model.

$$u_{ij} = \rho_{ij} \, ln(t_{ij} + 1) \qquad (6)$$

where,

t_{ij} is the time of individual *i* performing activity *j*, and

ρ_{ij} reflects member *i*'s heterogeneous evaluation of the allocated time for non-shared activity *j*.

Here, $t_{ij}+1$ is introduced to guarantee computable logarithm function. To simplify equation description, henceforth, it is assumed that t_{ij} refers to $t_{ij}+1$.

$$u_{ij} = \rho_{ij} \ln\left(t_{ij}\right) \tag{7}$$

One can see that, the utility (u_{ij}) for each activity is assumed to be non-negative and its marginal utility is monotonically decreasing. Kitamura (1984) examined the rationality for this function in representing the utility of activity time. The resulting two types of household time allocation models have the same model structure, but elements included in the model are different, as summarized below. Details refer to our previous studies (Zhang *et al*, 2002, 2005a and 2005b; Zhang and Fujiwara, 2006).

(1) Time allocated to in-home activity

$$t_{iH} = T_i \cdot P(ns) \cdot P_i(H \mid ns) \tag{8}$$

(2) Time allocated to out-of-home independent activity

$$t_{iD_j} = T_i \cdot P(ns) \cdot P_i(D_j \mid ns) \tag{9}$$

(3) Time allocated to out-of-home allocated activity

$$t_{iA_k} = T_i \cdot P(ns) \cdot P_i(A_k \mid ns) \tag{10}$$

(4) Time allocated to out-of-home shared activity

$$t_{S_m} = T_i \cdot P(S_m) \tag{11}$$

where,

$$P(ns) = \frac{\sum_i (\psi_{iH} + \sum_j \psi_{iD_j} + \sum_k \psi_{iA_k})}{\sum_i (\psi_{iH} + \sum_j \psi_{iD_j} + \sum_k \psi_{iA_k} + \sum_m \psi_{iS_m})} \tag{12}$$

$$P(S_m) = \frac{\sum_i \psi_{iS_m}}{\sum_i (\psi_{iH} + \sum_j \psi_{iD_j} + \sum_k \psi_{iA_k} + \sum_m \psi_{iS_m})} \tag{13}$$

$$P_i(H \mid ns) = \frac{\psi_{iH}}{\psi_{iH} + \sum_j \psi_{iD_j} + \sum_k \psi_{iA_k}} \tag{14}$$

$$P_i(D_j \mid ns) = \frac{\psi_{iD_j}}{\psi_{iH} + \sum_j \psi_{iD_j} + \sum_k \psi_{iA_k}} \tag{15}$$

$$P_i(A_k \mid ns) = \frac{\psi_{iA_k}}{\psi_{iH} + \sum_j \psi_{iD_j} + \sum_k \psi_{iA_k}} \tag{16}$$

Here, '*ns*' stands for the non-shared activity and the argument for each relevant function is given as follows:

(i) Arguments of the multi-linear type household time allocation model

$$\psi_{iH} = mu_i mu_{iH} \rho_{iH}$$

$$\psi_{iD_j} = mu_i mu_{iD_j} \rho_{iD_j}$$

$$\psi_{iA_k} = mu_i mu_{iA_k} \rho_{iA_k}$$

$$\psi_{iS_m} = mu_i mu_{is} \rho_{is} + \sum_{i'} \left(\lambda w_i w_{i'} u_i mu_{i's} \rho_{i's} \right)$$

$$mu_i = w_i + \sum_{i'} \lambda w_i w_{i'} u_{i'}$$

$$mu_{ij} = r_{ij} + \sum_{j'} \delta \, r_{ij} r_{ij'} u_{ij'}$$

$$mu_{is} = r_{is} + \sum_{q \neq s} \delta \, r_{is} r_{iq} u_{iq}$$

(ii) Arguments of the iso-elastic type household time allocation model

$$\psi_{iH} = w_i u_i^{-\alpha} \Delta_{iH} \rho_{iH}$$

$$\psi_{iD_j} = w_i u_i^{-\alpha} \Delta_{iD_j} \rho_{iD_j}$$

$$\psi_{iA_k} = w_i u_i^{-\alpha} \Delta_{iA_k} \rho_{iA_k}$$

$$\psi_{iS_m} = w_i u_i^{-\alpha} \Delta_{iS_m} \rho_{iS_m}$$

$$\Delta_{ij} = r_{ij} + \delta_i \sum_{j'>j} r_{ij} r_{ij'} u_{ij'} \, , \; j \in (H, D_j, A_k, S_m)$$

One can observe that both the derived models include a nested model structure for time allocation, in that the upper level treats the choice between non-shared activities and out-of-home shared activities, and the lower level treats the choice among non-shared activities. Furthermore, $P(S_m)$, $P(ns)$, $P_i(H \mid ns)$, $P_i(D_j \mid ns)$ and $P_i(A_k \mid ns)$ can be interpreted as both probabilities and proportional time shares that members perform the corresponding activities over a specified time, a zero-share meaning that no time is allocated to that activity, or the probability of performing that activity is zero. Accordingly, $P(S_m)$, $P(ns)$, $P_i(H \mid ns)$, $P_i(D_j \mid ns)$ and $P_i(A_k \mid ns)$ can also be used as task allocation probabilities. This means that the derived models can represent task and time allocation behavior within a household in a flexible way.

Next, it is explained how to introduce explanatory variables into the models. Decision makers and analysts alike do not know for sure the utility function of each activity. In addition, utility may change with the attributes of households and their members, as well as their mode choice behavior, etc. To incorporate this kind of uncertainty and heterogeneity, ρ_{ij} in equation (7) is re-written as follows.

$$\rho_{ij} = exp\left(\delta_j + \sum_k \beta_{jk} x_{ijk} + \varepsilon_{ij} \right) ln\left(t_{ij} \right) \tag{17}$$

where,

x_{ijk}, β_{jk}	indicate the *k*th explanatory variable for activity *j,* and its parameter,
δ_j	is constant term, and
ε_{ij}	is error term.

Equations (17) and (18) are adopted to reflect the heterogeneous household time allocation behavior. Because utility functions shown in equations (17) and (18) includes error terms, the estimations of household time allocation models should reflect the influences of these error terms. As shown in our previous studies, equations (8) ~ (11) can be first log-transformed and then estimated simultaneously using a seemingly unrelated regression (SUR) estimation procedure (Zeller, 1962).

3. DATA

As discussed above, multi-linear and iso-elastic household utility functions play an overlapping role in household decision. They cannot replace each other completely. In this sense, theoretically, it is difficult to conclude which is better. Such conclusion is required to be examined through empirical analysis, especially based on large-scale time use data. The time use data used in this study come from the *Survey on Time Use and Leisure Activities* conducted by the Ministry of General Affairs in 2001. The survey period was October 5 to 13 (9 days in total, but each member was asked to report their time use at a weekday and a weekend). The survey was conducted to the households recruited in all the 47 prefectures in Japan. For each household, all the members over 10 years old were asked to report their time use. In total, 4,000 households were investigated and 19,398 members*days were obtained. Survey contents are briefly shown in Table 1.

Table 1. Contents of Time Use Survey

All household members	Birth date, relation with household head, situation of school or nursery school etc.
Household members over 10 years old	Gender, marital status, nursing-care situation, weather conditions of the date reported, ownership and usage of mobile phone and personal computer, two-day time use (one on weekday and another on weekend)
Household members over 15 years old	Employment, type of job, weekly working hours etc.
Household	Type of residence, number of rooms, car ownership, household income, use of nursing-care etc.

For the sake of simplifying the discussion about household time allocation models, we only deal with male and female household heads, i.e., husband and wife. The following households were excluded: single-member households, and the households whose husband and wife did not perform any out-of-home activity. As a result, number of valid household samples is 1,804 households, whose time use data on both weekday and weekend are adopted. In total, 2,780 households*days (the sample size) are finally used for the analysis. Here, segmentation based on weekday and weekend is ignored. Concerning the types of activities, originally, there are 62 types. Since there are many "zero" activities under original activity classification, to make model application meaningful, we need to regroup the activities under study. Here, five major types are distinguished: in-home activity, out-of-home compulsory, discretionary, shopping and shared activities (see Table 2). Table 3 shows time allocation patterns by region. Activity time in this study includes travel time for the activity. It is obvious that out-of-home compulsory activity time for husband is about twice than that of wife. In case of husband, compulsory activity time is the longest (282 minutes) in Tokai region, and the shortest (214 minutes) in Hokuetsu region. For out-of-home discretionary activity, activity time of husband is about 1.5 times longer than that of wife. In contrast, wife's shopping time is twice longer than husband's. For joint activity, the activity time in Shikoku region is the longest and that in Kinki region is the shortest.

Table 2. Activity Classification

In-home activity	All the activities conducted at home
Out-of-home compulsory activity	Mainly, job, side job, staying at school, study at cram school or preparatory school, use of public service, ceremonial occasions, seeing doctor, job-hunting etc.
Out-of-home discretionary activity	Private affairs, break with snacks and beverages, learning and research (not schoolwork), educational and recreational activities, original work, hobby, driving, sports, voluntary activities, and social activities etc.
Out-of-home shopping activity	Daily shopping outside home
Out-of-home shared (joint) activity	Activities jointly performed by 2 or more members outside home

Table 3. Time Allocation Patterns by Member and Region

Member	Region \ Activity	In-home Activity	Out-of-home Activity: Compulsory Activity	Discretionary Activity	Shopping Activity	Shared Activity
Husband	Hokkaido, Tohoku	957.5	271.5	174.0	22.4	14.6
	Kanto	982.2	239.2	171.4	29.5	17.6
	Hokuetsu	983.5	214.2	208.7	18.3	15.4
	Tokai	937.5	282.1	184.4	19.7	16.3
	Kinki	959.0	279.0	165.7	22.9	13.4
	Chugoku	985.1	226.9	183.9	25.2	18.9
	Shikoku	952.0	256.4	187.3	21.2	23.2
	Kyusyu, Okinawa	964.6	261.5	174.1	23.4	16.4
Wife	Hokkaido, Tohoku	1098.7	152.3	124.5	50.0	Same as above
	Kanto	1126.3	109.2	129.8	57.1	
	Hokuetsu	1095.5	157.4	132.5	39.2	
	Tokai	1091.3	166.3	121.7	44.4	
	Kinki	1136.1	117.8	119.8	52.9	
	Chugoku	1075.9	136.4	157.5	51.3	
	Shikoku	1091.5	139.2	131.1	55.0	
	Kyusyu, Okinawa	1104.8	146.6	119.5	52.7	

4. MODEL ESTIMATION

There are many factors that affect time allocation. Considering data availability, this paper selects individual and household attributes (x_{ik}), infrastructure-related variables by prefecture that household belongs (Ω_q), travel time for activity participation (τ_{ij}) as explanatory variables to describe ρ_{ij} in equation (7). Note that Ω_q is an objective indicator showing the convenience of daily life. Since Ω_q by region is different according to population, it is calculated as the value divided by population.

$$\rho_{ij} = exp\left(\sum_k \beta_{ik} x_{ik} + \theta_j \sum_q \beta_{iq} \Omega_q + \kappa_i \tau_{ij}\right) \tag{18}$$

where, $\beta_{ik}, \beta_{iq}, \theta_j, \kappa_i$ are unknown parameters.

To estimate activity time functions shown in equations (8) ~ (11), logarithm transformations are conducted, by taking in-home activity for each member as a reference activity. As a result, log-transformed compulsory, discretionary, shopping, and shared activity time functions are obtained. To incorporate the influence of inter-correlated error terms, a SUR (seemingly unrelated regression) estimation method is applied. Model estimation results are shown in Tables 4 and 5, and correlations between estimated and observed activity times (CEOAT) are shown in Table 6.

Model accuracy

Looking at multiple correlation coefficients (MCC) in Tables 4 and 5, compulsory activity time function shows the highest MCC, which is about twice higher than other time functions. Focusing on the CEOAT, it is still the highest for compulsory activity (0.485~0.691), but for other activities, the CEOAT values are 0.417~0.600. Except for in-home activity and shared activity, multi-linear model shows higher model accuracy than iso-elastic model. In contrast, the CEOAT value for shared activity is about 30% higher in iso-elastic model than that in multi-linear model (from 0.466 to 0.600). For the CEOAT values by member, little difference is observed. As a whole, model accuracy of iso-elastic model is a little bit higher than that of multi-linear model, but the two models do not have significant difference.

Group Decision-Making Mechanisms

It is assumed that utility of activity time is positive. As a result, sign of each member's utility is determined by sign of inter-activity interaction (δ_i). From Tables 4 and 5, it is found that inter-activity interaction parameters are all positive. In other words, all members' utilities are positive. The estimated utility values are shown in Table 7. Note that Table 7 is not used to compare utility levels across regions, but it is used to show relative influences of husband and wife in household decision. Observing the unweighed utility values, in multi-linear model, husband utility is smaller than wife utility, while iso-elastic model shows contrary results. However, after weighing the utilities, in both models, husband's weighed utility is clearly larger in multi-linear model than that in iso-elastic model. This means that husband is dominating household decisions. Such finding is further supported by statistical significance of member's weight parameter, and intra-household interaction parameter. Husband's weight parameter is very high: 0.832 in multi-linear model and 0.995 in iso-elastic model. These results support the development of multi-linear and iso-elastic models.

In multi-linear model, with respect to intra-household interaction parameter α, it is positive, meaning that intra-household interaction plays a role to increase total household utility. Ignoring intra-household interaction, household utilities range over 255.6~589.3, introducing intra-household interaction results in that household utility is valued at 309.9~907.0. Existence of intra-household interaction could increase household utility by 21% (Kanto region) to 54% (Chugoku region). In case of iso-elastic model, its intra-household interaction parameter is 1.573, and as also seen in Table 7, all household utilities are negative. If there was no intra-household interaction, all household utilities should be positive. Thus, in this case study about iso-elastic model, intra-household interaction results in the reduction of household utility.

In summary, these two models do not have statistically significant differences. This might be interpreted as, different household decision-making mechanisms could lead to the same decision outcomes (here, the allocated time to each activity).

Weight (Relative importance) of activity and inter-activity interaction

Two models estimate that members attach the most importance to in-home activity. Inter-activity interaction parameters are positive, quite similar in values and statistically significant. This implies that competition of using time resources by different activities does not necessarily reduce member's utility. In this case study, the increase of utility is observed.

Table 4. Model Estimation Results: Multi-linear Household Time Allocation Model

Explanatory variables and parameters of decision-making mechanisms	Husband (i=1) Parameter	t-score		Wife (i=2) Parameter	t-score	
Member's weight (relative influence)	0.823	11.688	**	0.177	-	
Intra-household interaction	0.004	2.593	**	Same as the left		
Weight of activity (relative importance)						
In-home activity	0.886	-		0.894	-	
Out-of-home compulsory activity	0.007	7.694	**	0.004	5.182	**
Out-of-home discretionary activity	0.099	4.879	**	0.078	4.362	**
Out-of-home shopping activity	0.009	3.503	**	0.157	3.780	**
Out-of-home shared activity	0.008	3.033	**	0.024	2.778	**
Inter-activity interaction	0.021	2.879	**	0.012	2.989	**
Individual and household attributes						
Age	0.002	0.852		0.000	0.264	
Employment (Employed: 1, Unemployed: 0)	0.621	12.271	**	0.699	21.932	**
Car ownership (Yes: 1, No: 0)	0.343	5.808	**	-0.103	-2.128	*
Weekend dummy (Weekend: 1, weekday: 0)	-0.451	-12.194	**	-0.299	-9.741	**
Number of household members	0.002	0.135		0.035	2.625	**
Living with children under 15 years old (Yes: 1, No: 0)	-0.212	-4.140	**	-0.324	-7.078	**
Living with elderly people over 65 years old (Yes: 1, No: 0)	0.231	5.088	**	-0.134	-3.491	**
Influence of infrastructure improvement on time allocation						
In-home activity		1.000		-		
Out-of-home compulsory activity		0.759		14.501	**	
Out-of-home discretionary activity		0.341		13.283	**	
Out-of-home shopping activity		0.064		2.291	*	
Out-of-home shared activity		-0.054		-1.257		
Infrastructure variables (original value divided by 1000 persons)						
Expressways (km)	-3.316	-2.561	*	-1.623	-1.253	
National and prefectural roads (km)	-0.679	-5.581	**	-0.422	-3.630	**
Municipal roads (km)	0.095	6.222	**	0.086	5.451	**
Railways (km)	3.480	5.605	**	1.934	3.049	**
Number of day-care service facilities	10.185	3.346	**	11.990	3.930	**
Number of home helpers	-0.091	-0.747		-0.219	-1.647	
Number of hospitals	0.682	1.936	+	1.848	4.773	**
Nuober of restaurants	0.060	3.472	*	0.070	3.569	**
Number of libraries	-7.753	-1.463		-33.489	-5.237	**
Number of supermarkets	-1.997	-1.451		4.149	2.900	**
Areas of urban parks (m^2)	0.058	4.230	**	0.034	2.374	**
Number of companies	-0.001	-0.162		0.008	0.799	
Travel time	0.042	104.683	**	0.045	98.273	**
Multiple correlation coefficients						
Out-of-home compulsory activity	0.708			0.639		
Out-of-home discretionary activity	0.321			0.329		
Out-of-home shopping activity	0.288			0.296		
Out-of-home shared activity	0.372					
Sample size (households*days)	2,780					

+: 10% significant; *: 5% significant; **: 1% significant

Table 5. Model Estimation Results: Iso-elastic Household Time Allocation Model

Explanatory variables and parameters of decision-making mechanisms	Husband (i=1) Parameter	t-score		Wife (i=2) Parameter	t-score	
Member's weight (relative influence)	0.995	108.014	**	0.005	-	
Intra-household interaction	1.573	8.773	**	Same as the left		
Weight of activity (relative importance)						
In-home activity	0.792	-		0.932	-	
Out-of-home compulsory activity	0.007	5.052	**	0.007	6.331	**
Out-of-home discretionary activity	0.133	5.168	**	0.051	4.801	**
Out-of-home shopping activity	0.053	3.648	**	0.055	2.678	**
Out-of-home shared activity	0.148	3.913	**	0.006	2.813	**
Inter-activity interaction	0.016	3.499	**	0.020	2.795	*
Individual and household attributes						
Age	-0.001	-0.448		0.003	1.921	+
Employment (Employed: 1, Unemployed: 0)	0.202	5.971	**	0.788	23.602	**
Car ownership (Yes: 1, No: 0)	0.189	5.003	**	0.006	0.118	
Weekend dummy (Weekend: 1, weekday: 0)	-0.195	-7.501	**	-0.415	-12.897	**
Number of household members	-0.024	-2.267	*	0.071	5.145	**
Living with children under 15 years old (Yes: 1, No: 0)	-0.308	-8.583	**	-0.223	-4.686	**
Living with elderly people over 65 years old (Yes: 1, No: 0)	0.141	4.460	**	-0.171	-4.255	**
Influence of infrastructure improvement on time allocation						
In-home activity		1.000		-		
Out-of-home compulsory activity		0.670		13.108	**	
Out-of-home discretionary activity		0.433		12.306	**	
Out-of-home shopping activity		-0.162		-3.935	**	
Out-of-home shared activity		0.010		0.235		
Infrastructure variables (original value divided by 1000 persons)						
Expressways (km)	-2.929	-2.614	**	-2.012	-1.635	
National and prefectural roads (km)	-0.995	-8.222	**	-0.464	-3.961	**
Municipal roads (km)	0.083	6.212	**	0.083	5.412	**
Railways (km)	3.444	6.250	**	2.542	4.142	**
Number of day-care service facilities	17.620	6.010	**	13.865	4.606	**
Number of home helpers	-0.307	-2.855	**	-0.108	-0.875	
Number of hospitals	1.622	5.088	**	0.347	0.999	
Nuober of restaurants	0.081	5.209	**	0.028	1.575	
Number of libraries	-4.089	-0.874		-16.555	-2.995	**
Number of supermarkets	2.343	1.921	+	-0.397	-0.290	
Areas of urban parks (m^2)	0.080	6.314	**	0.040	2.958	**
Number of companies	-0.003	-0.445		0.006	0.692	
Travel time	0.041	111.233	**	0.044	95.152	**
Multiple correlation coefficients						
Out-of-home compulsory activity	0.690			0.650		
Out-of-home discretionary activity	0.325			0.319		
Out-of-home shopping activity	0.296			0.309		
Out-of-home shared activity	0.234					
Sample size (households*days)	2780					

+: 10% significant; *: 5% significant; **: 1% significant

Table 6. Correlation between Estimated and Actual Activity Times

Activities \ Correlation	Multi-linear Model		Iso-elastic Model	
	Husband	Wife	Husband	Wife
In-home activity	0.530	0.425	0.443	0.502
Out-of-home compulsory activity	0.691	0.521	0.629	0.485
Out-of-home discretionary activity	0.482	0.485	0.479	0.459
Out-of-home shopping activity	0.479	0.476	0.417	0.444
Out-of-home shared activity	0.466		0.600	
All activities by household member	0.859	0.951	0.907	0.949
All activities of the whole household	0.909		0.930	

Table 7. Estimated Utilities by Multi-Linear Household Time Allocation Model

Region \ Model	Household Utility	Weighed Utilities			Unweighed Utilities	
		Husband	Wife	Intra-household Interaction	Husband	Wife
Hokkaido, Tohoku	675.7	347.1	143.8	184.7	422.0	811.1
Kanto	309.9	168.7	86.9	54.3	205.0	490.3
Hokuetsu	482.9	264.0	110.7	108.2	320.9	624.6
Tokai	455.3	234.1	118.6	102.7	284.5	668.7
Kinki	358.6	187.8	100.8	70.0	228.3	568.5
Chugoku	907.0	264.1	325.1	317.7	321.1	1833.7
Shikoku	507.9	182.1	194.6	131.2	221.4	1097.7
Kyusyu, Okinawa	459.8	222.9	129.8	107.1	270.9	732.3

Table 8. Estimated Utilities by Iso-Elastic Household Time Allocation Model

Region \ Model	Household Utility	Weighed Utilities		Unweighed Utilities	
		Husband	Wife	Husband	Wife
Hokkaido, Tohoku	-73431.3	869.0	1.2	873.2	250.4
Kanto	-27780.7	468.4	0.7	470.7	133.8
Hokuetsu	-59651.1	761.4	1.1	765.1	217.5
Tokai	-38070.0	572.2	0.9	575.0	187.9
Kinki	-34539.1	538.0	0.7	540.6	140.4
Chugoku	-92807.0	1008.4	1.6	1013.3	336.7
Shikoku	-34414.3	536.5	1.1	539.1	229.1
Kyusyu, Okinawa	-44318.1	630.3	0.9	633.4	178.0

Wife's weights show similar trend between the two models: attaches the most importance to in-home activity and gives the second highest priority to shopping. On the other hand, multi-linear model estimates that wife attaches more importance to shared (joint) activity than to compulsory activity. For husband, multi-linear model shows that husband gives the highest priority to in-home activity, followed by discretionary activity; in contrast, iso-elastic model shows that wife attaches relatively higher importance to joint activity. Thus, priorities of different activities in decision-making process are estimated differently. Note that, only based on weight parameter, it is not sufficient to judge the influences of different activity times. In this case, partial utility (the product of weight parameter and its variable value) is applicable. The relevant results are shown in Table 9 and reveal that influences can be ranked as, in-home activity, discretionary activity, compulsory activity, shopping and joint activity. Both models estimate that inter-activity interaction shows the second largest influence on each member's time allocation.

Table 9. Decompositions of Members' Utilities: Weighed Utilities

Region	Husband utility					
	Compulsory Activity	Discretionary Activity	Shopping Activity	In-home Activity	Shared Activity	Intra-household Interaction
Hokkaido, Tohoku	2.35	4.42	0.23	361.98	0.02	52.92
	2.57	7.55	0.05	736.31	0.55	126.17
Kanto	1.25	2.71	0.16	184.97	0.02	15.92
	1.70	4.65	0.07	416.95	0.59	46.71
Hokuetsu	0.77	4.09	0.21	285.55	0.02	30.24
	0.96	7.26	0.06	662.58	0.59	93.68
Tokai	1.81	3.77	0.19	248.76	0.03	29.97
	2.10	6.08	0.06	495.86	0.62	70.29
Kinki	2.17	3.36	0.16	198.85	0.02	23.71
	2.92	5.91	0.06	461.64	0.52	69.54
Chugoku	0.93	3.21	0.19	290.43	0.02	26.26
	1.53	6.67	0.06	880.40	0.58	124.06
Shikoku	1.43	4.88	0.15	189.30	0.03	25.58
	2.03	8.40	0.06	448.07	0.66	79.90
Kyusyu, Okinawa	1.38	3.41	0.18	240.88	0.02	25.02
	1.81	5.99	0.06	550.55	0.60	74.41
Region	Wife utility					
	Compulsory Activity	Discretionary Activity	Shopping Activity	In-home Activity	Shared Activity	Intra-household Interaction
Hokkaido, Tohoku	0.65	1.97	1.18	772.85	0.03	34.42
	0.39	1.36	0.24	238.54	0.03	9.82
Kanto	0.21	1.67	0.97	471.54	0.04	15.88
	0.13	0.98	0.26	128.73	0.03	3.70
Hokuetsu	0.39	1.98	0.88	598.45	0.04	22.83
	0.27	1.43	0.19	207.42	0.03	8.12
Tokai	0.39	1.99	1.01	639.75	0.05	25.52
	0.24	1.24	0.25	179.64	0.04	6.49
Kinki	0.28	1.63	1.00	546.84	0.04	18.68
	0.16	0.93	0.26	135.20	0.03	3.79
Chugoku	0.68	3.28	1.00	1728.47	0.03	100.18
	0.26	1.74	0.21	319.90	0.03	14.58
Shikoku	0.42	1.78	1.00	1054.67	0.05	39.80
	0.20	1.00	0.26	220.98	0.04	6.68
Kyusyu, Okinawa	0.41	1.71	1.03	703.09	0.04	25.98
	0.21	1.01	0.24	171.26	0.03	5.23

Upper level: Multi-linear model; Lower level: Iso-elastic model

Heterogeneity of household time allocation behavior

Most of the parameters of individual and household attributes, infrastructure-related variables are statistically significant. Note that all these parameters are estimated by taking in-home activity as a reference. Interpretation about model estimation results needs to be discussed reflecting the influence of such reference. Looking at employment status and car ownership, they all have positive parameters, implying that workers and household with car ownership prefer to perform longer activity time. Negative parameter of weekend dummy variable means that household members prefer to stay at home as much as possible, and do not prefer longer stay outside home.

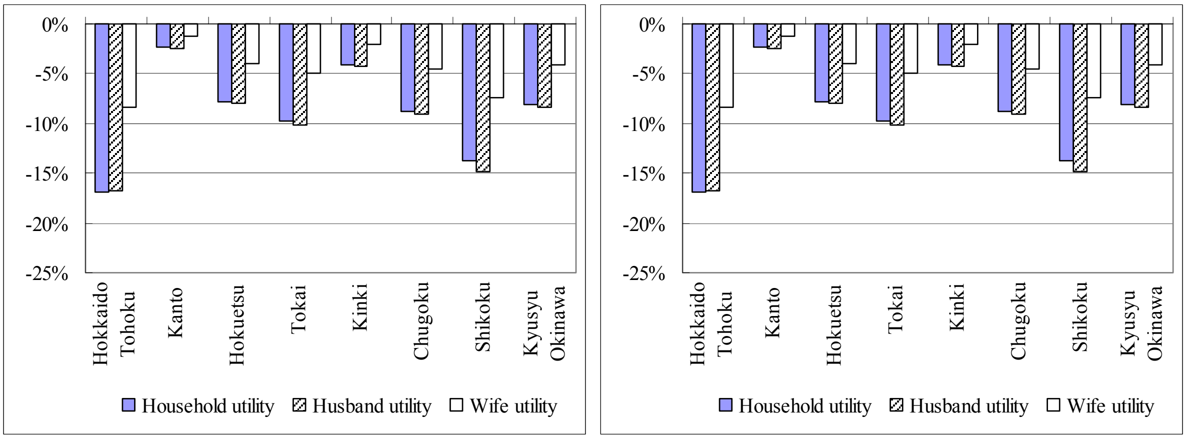
Influence of infrastructure improvement
Looking at the influence parameter (θ_j) of composite variable on each activity, impact on in-home activity is the highest, followed by out-of-home compulsory, discretionary, shopping and joint activities. In other words, improvement of infrastructure could easily influence participation in the activity with longer time. For the activity with shorter duration, improvement of infrastructure does not have significant influence. Focusing on the parameter β_{iq} in equation (18), if it is positive (or negative), it means that in the prefecture with poor infrastructure, activity duration is longer (or shorter), compared to other prefectures. Concerning travel time, its parameters are all positive for both husband and wife, implying that longer activity usually involves longer travel time.

5. Simulation: Impact of Infrastructure Improvement on QOL and Time Allocation

Time use pattern can be used to measure the level of quality of life (QOL). Here, household utility, its members' utilities are used to measure QOL. We have to admit that such measurement ignores some important aspects of QOL. For example, we ignore members' subjective evaluations about life satisfaction. Further refinement of modeling framework to cover such subjective evaluation is left as a future research issue. Here, construction of expressways and urban parks is dealt with to evaluate the effects of infrastructure improvement on mitigating inter-regional differences in QOL. Scenarios are set as follows:

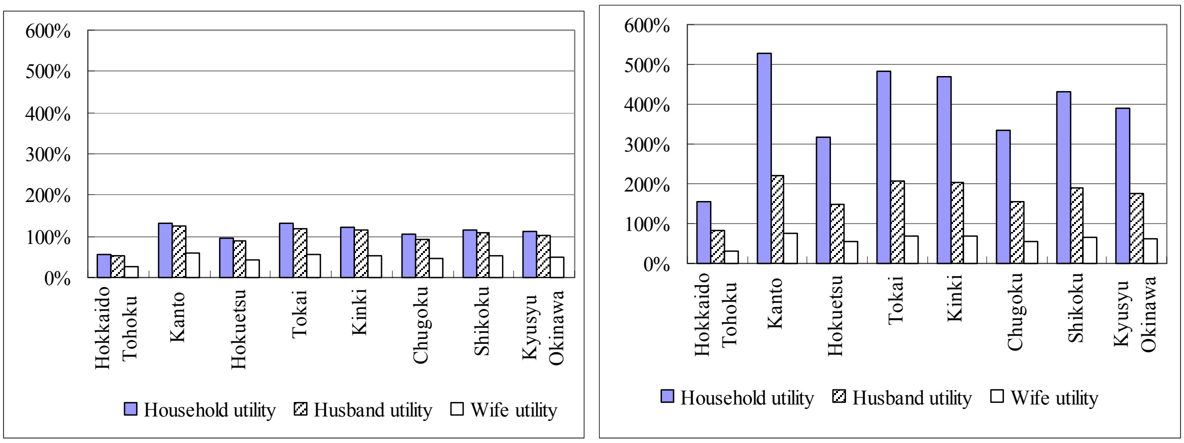
- Expressway construction: all the planned expressways across the whole country are completely constructed.
- Urban park construction: Currently, national average of park areas per capita is about 8.5 m^2. Compared with the long-term planning goal (20 m^2 per capita) set in 1995, 29.3 m^2 in New York, and 27.4 m^2 in Berlin, it is obvious that park areas need to be further constructed in the future. Scenario analysis is conducted by assuming that the long-term planning goals will be realized.

Since utility values cannot be directly compared across prefectures, here change ratio of utility due to infrastructure improvement is adopted to evaluate the impact on QOL (see Figures 1 and 2). After that, impact on time allocation is also simulated (Table 10). It is found that construction of expressways results in the decrease of QOL for all the regions, but construction of urban parks largely increase the QOL. Changes of QOL due to construction of expressways calculated by two models are not so large. However, for urban park, iso-elastic model shows quite sensitive impacts. In multi-linear model, it is estimated that construction of expressways and urban parks especially affect husband's activity participation. Construction of expressways could reduce husband's in-home activity by 14~40 minutes. Except for Hokkaido and Tohoku regions, husband's discretionary and shopping activities would increase by 12~19 minutes. Construction of urban parks could reduce husband's in-home activity time by 89~146 minutes, compulsory activity time by 41~89 minutes, discretionary activity time by 24~60 minutes, shopping time by 6~12 minutes. For wife's activity time, the large decrease is observed with respect to wife's in-home activity time (14~27 minutes) and less than 10 minutes increase is observed for other activities. In iso-elastic model, the most remarkable influence is observed with respect to husband's activity participation due to construction of urban parks. His in-home activity decrease by 41~76 minutes, while such reduced activity time shifts to compulsory and discretionary activities. On the other hand, change of wife's activity time is within 10 minutes. For construction of expressways, change of husband's activity time is very small, many activities remain unchanged at some regions.



(a) Multi-linear Model (b) Iso-elastic Model

Figure 1. Change of Utility due to Construction of Expressways



(a) Multi-linear Model (b) Iso-elastic Model

Figure 2. Change of Utility due to Construction of Urban Parks

In summary, multi-linear model predicts large changes in activity time due to infrastructure improvement, while iso-elastic model estimates small changes. For urban park construction, the estimated increase of QOL (change of utility) in iso-elastic model is several times larger than multi-linear model. Thus, both models have relatively good model performance, but simulation analyses show that predictions by two models are quite different. At this stage, it is still difficult to conclude which model is superior to another, even though intuitively, prediction of change of QOL by iso-elastic model might be too large.

6. CONCLUSIONS

Time use patterns reflect important aspects of people's quality of life. This paper attempts to develop some household time allocation models in order to support public policy making. Focusing on group decision-making mechanisms in household time allocation behavior, we developed two types of household models (i.e., multi-linear and iso-elastic models) in our

Table 10. Change of Activity Time due to Infrastructure Improvement

(a) Multi-linear Household Time Allocation Model: Construction of Expressways

Change of Activity Time / Region	Husband's Activity Time				Wife's Activity Time				Shared Activity
	Compulsory Activity	Discretionary Activity	Shopping Activity	In-home Activity	Compulsory Activity	Discretionary Activity	Shopping Activity	In-home Activity	
Hokkaido, Tohoku	-4	-1	16	-14	1	-4	7	-7	2
Kanto	2	19	13	-37	1	2	6	-11	3
Hokuetsu	4	15	16	-37	0	-3	5	-5	3
Tokai	-5	10	14	-23	0	-2	6	-6	3
Kinki	6	19	12	-40	1	0	6	-10	3
Chugoku	5	17	14	-38	4	1	6	-13	2
Shikoku	-8	16	12	-23	2	1	5	-11	3
Kyusyu, Okinawa	3	17	14	-36	1	-1	6	-9	3

(b) Multi-linear Household Time Allocation Model: Construction of Urban Parks

Change of Activity Time / Region	Husband's Activity Time				Wife's Activity Time				Shared Activity
	Compulsory Activity	Discretionary Activity	Shopping Activity	In-home Activity	Compulsory Activity	Discretionary Activity	Shopping Activity	In-home Activity	
Hokkaido, Tohoku	52	24	10	-89	6	0	6	-14	2
Kanto	66	52	9	-129	4	7	4	-17	2
Hokuetsu	41	55	12	-110	5	1	4	-13	2
Tokai	72	47	8	-129	6	4	5	-16	2
Kinki	89	49	6	-146	5	5	5	-17	2
Chugoku	47	52	11	-111	11	9	6	-27	2
Shikoku	53	60	7	-122	8	7	4	-22	2
Kyusyu, Okinawa	63	52	9	-126	6	4	5	-18	2

(c) Iso-elastic Household Time Allocation Model: Construction of Expressways

Change of Activity Time / Region	Husband's Activity Time				Wife's Activity Time				Shared Activity
	Compulsory Activity	Discretionary Activity	Shopping Activity	In-home Activity	Compulsory Activity	Discretionary Activity	Shopping Activity	In-home Activity	
Hokkaido, Tohoku	-5	-5	0	9	-1	-2	1	1	1
Kanto	0	0	0	0	0	0	0	0	0
Hokuetsu	-1	-3	0	3	0	-1	0	0	1
Tokai	-2	-3	0	4	-1	-1	0	0	1
Kinki	-1	-1	0	2	0	0	0	0	0
Chugoku	-2	-3	0	4	-1	-1	0	0	1
Shikoku	-3	-5	0	6	-1	-1	1	-1	2
Kyusyu, Okinawa	-2	-2	0	3	0	-1	0	0	0

(d) Iso-elastic Household Time Allocation Model: Construction of Urban Parks

Change of Activity Time / Region	Husband's Activity Time				Wife's Activity Time				Shared Activity
	Compulsory Activity	Discretionary Activity	Shopping Activity	In-home Activity	Compulsory Activity	Discretionary Activity	Shopping Activity	In-home Activity	
Hokkaido, Tohoku	21	23	-1	-41	4	5	-2	-5	-2
Kanto	39	38	-2	-70	3	7	-4	-1	-5
Hokuetsu	18	42	-1	-56	4	8	-2	-7	-3
Tokai	39	40	-2	-73	5	8	-3	-5	-5
Kinki	48	34	-2	-76	4	6	-4	-1	-5
Chugoku	26	40	-1	-63	5	10	-2	-10	-3
Shikoku	32	42	-2	-68	4	7	-3	-5	-4
Kyusyu, Okinawa	32	38	-1	-64	4	6	-3	-3	-4

previous studies. Different from our previous studies, this paper examined the effectiveness of the models using a large-scale national time use data in Japan, and the applicability of the models to evaluate the impacts of infrastructure improvement based on simulation analysis. Conclusions are summarized below.

1) Both multi-linear and iso-elastic models are effective to represent group decision-making mechanisms in household time allocation model from statistical significance

and model accuracy, and no significant difference of the two models is observed in estimating activity time.

2) The two models estimate different intra-household interaction parameters. Multi-linear model estimates that intra-household interaction increases household utility, while contrary trend is observed in iso-elastic model. Since difference of the two models in estimating activity time is small, this might be interpreted that different group decision-making strategies could lead to similar decision outcomes.
3) Concerning activity time by household member, the conclusions from two models are similar. In member's time allocation decision, in-home activity shows the largest influence, followed by inter-activity interaction, discretionary, compulsory, shopping, and shared activities.
4) This paper also proposed to use change of utility as an indicator to measure the level of QOL, especially emphasize the importance of intra-household interaction.
5) Simulation analysis confirms that in this case study, construction of expressways results in the decrease of QOL, in contrast, urban park construction increases the QOL level. Prediction by multi-linear model seems relatively realistic, even though theoretically, iso-elastic model seems more general. In this sense, the performance of two models might be different from context to context.

One of unsatisfactory results is that goodness-of-fit index is not high enough with respect to out-of-home discretionary, shopping and shared (joint) activity. Thinking about the reasons, the individual and household attributes are adopted, but infrastructure-related variables are the values measured at prefecture level. The Ministry of General Affairs did not provide us with more detailed spatial information for the sake of privacy protection. Since multi-linear and iso-elastic models do not show significant difference, it might be worth exploring how to combine these two models together in the future. It is also important to further figure out how to make effective use of household time allocation to cover other aspect of QOL. It is also expected that the developed model can be applied to evaluate other types of public policies.

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