Intra-household Interaction Analysis among a Husband, a Wife, and a Child using the Joint Time-Allocation Model

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Abstract. This paper describes research on intra-household interactions, based on results of an activity-based time allocation model. The paper describes a joint time-allocation model that explicitly considers a child in addition to its parents. It analyzes both activity duration as well as the activity type. This model was formulated as a non-linear Tobit model for econometric analysis. The model parameters were estimated using data from a household time allocation survey completed during 2003 in Toyama, Japan. Two models were estimated with the sample datasets: one for weekdays and one for weekend days. The results show that the social or cultural backgrounds relating to the husband's preference on child gender, the household child-care role sharing between the husband and wife and the husband's immersion in work influence the household interactions significantly. The paper presents a summary of model results, conclusions and recommendations for further research.

INTRODUCTION

Importance of Intra-household Interaction Analysis

Most activity-based travel demand models assume that individuals make decisions regarding their own activities. While this assumption is reasonable in some cases, it may be unsuitable for the activities that involve the participation of more than one individual. A household is perhaps the most fundamental group that exemplifies such joint decision-making behavior. The joint decision-making of household members is important from the perspective of transportation planning: A transportation policy will impact an individual's behavior not only directly but also indirectly through a change in household behavior.

This paper describes research on intra-household interactions completed by developing a household resource-allocation model using the empirical activity diary data. The research focuses on non-obligatory activities because such activities impose fewer constraints on resource allocation than obligatory activities.

The model proposed in this paper has the similar approach to Zhang and Fujiwara (*1*). It has three main refinements over their research. First, a child is explicitly considered in the time-allocation model. This is because we expect that the existence of a child has a significant influence on the allocation of household resources. Therefore, this paper considers a household with three members: a husband, a wife and a child. Second, the model considers both the household's time allocation and monetary budget, while most of previous similar research has considered only the time allocation. Finally, the intra-household interactions between a weekday and a weekend day are compared.

This paper is organized as follows: the remaining part of this section briefly summarizes past research on intra-household interaction. Next, a microeconomic model framework is used to describe a household joint resource-allocation model. Then, the empirical research—including an activity diary survey conducted in Toyama city, Japan—and the model estimation is presented. The final section briefly summarizes the study and suggests topics for further research.

Past Research on Intra-household Interaction Analysis

Although the importance of interpersonal dependencies is widely recognized in transportation planning, most of the research efforts to date have accommodated household interaction effects, at best, by using household-level characteristics as explanatory variables in individual-level models (Srinivasan and Bhat, *2*). The simultaneous equation models including Golob (*3*), Golob and McNally (*4*), Lu and Pas (*5*), Fujii *et al.* (*6*), Meka *et al.* (*7*), and Simma and Axhausen (*8*) have studied the activity and travel behavior of household members. However, most of them do not consider the household decision-making process explicitly. Recently, several types of research have explored the household activity analysis with an explicit consideration of intra-household interactions. They include micro-simulation models, rule-based models, and utility-maximizing models (Timmermans, *9*). An example of micro-simulation models is Pribyl and Goulias (*10*). They suggest an approach to simulate activity patterns that take interactions within the family into account. The micro-simulation models have a potential problem in that they lack the behavioral mechanisms of how individuals and household adjust their preferred schedules in time and space to cope with the various types of constraints they face. Rule-based models including Albatross (Arentze and Timmermans, *11*, *12*) and Tasha (Miller and Roorda, *13*) have successfully modeled household interactions to some extent. However, as Timmermans (*9*) points out, household characteristics have been incorporated only as explanatory variables in individual-level models in most of the rule-based models. To understand the mechanisms of the household decision-making process, the amount of analytical research especially with the utility-maximizing concept has increased rapidly over the last couple of years. These studies can be categorized into two types of approaches from a methodological viewpoint. The first approach is based on the discrete choice model system. The studies by Vovsha *et al.* (*14*), Bradley and Vovsha (*15*), Scott and Kanaroglou (*16*), Wen and Koppelman (*17*), Srinivasan and Bhat (*18*), and Srinivasan and Athuru (*19*) are included in this approach. Gliebe and Koppelman (*20*) who used the proportional share model of time allocation may also be included in this approach. The second approach is based on the time-allocation model system, and it includes Zhang *et al.* (*21*), Zhang and Fujiwara (*1*), and Zhang *et al.* (*22*).

While many studies have analyzed joint decision-making in households, there are several issues that need to be examined further. First, most of the approaches were limited solely to household heads and did not explicitly consider other household members as active agents in the intra-household decision-making process. Some research took other household members into consideration, but they were limited to couples, although research shows that the presence of a child significantly affects the household joint activity (Jones *et al.*, *23*; Chandrasekharan and Goulias, *24*). Second, as Meister *et al.* (*25*) point out, the intra-household interactions and group dynamics in activity-travel scheduling and the utility derived from such interactions are inextricably linked to monetary expenditures, an aspect of activity-travel engagement that is often overlooked due to the absence of both data and a fundamental theory that links monetary expenditures to activity-travel expenditures by household members. Third, as Zhang *et al.* (*22*) pointed out, although the decision-making process may differ between weekdays and weekends, it is rarely examined.

On the other hand, there has been much economic research on the household time-allocation model. The analysis of household time-allocation originated from a study conducted by Becker (*26*). He extended a traditional individual behavioral model to the household time-allocation model by introducing the concept of time into both the utility function and the household production function. This type of model is referred to as a unitary model. The unitary model treats a household as if it were an individual. A household has a utility function that consists of the aggregated amounts of time and goods of the household, whereas it has a pooled time budget and a monetary budget. The model assumes a constrained maximization of the household utility function with respect to time and goods consumption.

Although the unitary model is simple and clear, it has been criticized by researchers interested in intra-household interaction. First, they claim that the unitary model is unacceptable from the viewpoint of individualism, which is at the core of microeconomics (Chiappori, *27*). Second, they criticize the unitary model for ignoring the interaction between household members and dealing with the joint decision-making process as a black box. Third, the unitary model only considers allocations between households and disregards questions concerning intra-household inequalities, which may lead to incorrect welfare implications (Haddad and Kanbur, *28*). For example, a tax reform may increase the welfare of a household, but it may not improve the inequality among household members (Apps and Rees, *29*). Fourth, although the demand functions in the unitary model must satisfy homogeneity, the Walras law, and the Slutsky equations (or revealed preferences restriction) in the same manner as an ordinary individual consumer model, they are not often supported by empirical analyses (e.g., Kooreman and Kapteyn, *30*).

In order to overcome these problems with a unitary model, a model that requires only Pareto efficiency has found acceptance in recent microeconomic theory (Vermeulen, *31*). This model is named the collective model (Chiappori, *27*, *32*; Bourguignon and Chiappori, *33*). The collective model was proposed as a criticism against the unitary model and with the aim of generalizing the cooperative game model (Manser and Brown, *34*; McElroy and Horney, *35*). In the collective model, no additional assumption to the Pareto efficiency is made about the decision-making process. This implies that no restriction is imposed *a priori* on which point on the Pareto frontier will be chosen. Recently, there have been some empirical studies based on the collective model, including Chiappori (*36*), Fortin and Lacroix (*37*), and Aronsson *et al.* (*38*).

In terms of transportation research, the model proposed in this paper is classified as a time-allocation model. On the other hand, in terms of economic research, it is considered as Samuelson's model (*39*), because the household utility function is defined as the Bergson-Samuelson-type social welfare function. As Chiappori *(27)* points out, this type of household utility function is also considered as one of the special forms of the collective model. Thus, unlike the unitary model, the model used in this research explicitly considers the fact that multi-person households consist of several members who have different preferences. In addition, our model holds the Pareto efficiency in the time allocation among household members.

MODEL

Basic Structure of the Household Time-Allocation Model

Consider a household consisting of two or more members with a household utility function that includes the sub-utility functions of its members. Assume that an individual has a selfish sub-utility function of her/his time and expenditure for activities. It is assumed that the household members allocate their time and expenditure by maximizing the household utility function under the constraints of time and monetary budgets. The resource allocation of a household can then be formulated as

$$\max_{\mathbf{t},\mathbf{c}} W_n = U_n\left(U_{n1}(\mathbf{t}_{n1}, \mathbf{c}_{n1}), U_{n2}(\mathbf{t}_{n2}, \mathbf{c}_{n2}), \cdots\right) \tag{1}$$

$$\text{subject to} \qquad \mathbf{T}_n(\mathbf{t}) \le 0\,,\ \mathbf{C}_n(\mathbf{c}) \le 0 \tag{2}$$

where $U_n(\cdot)$ is a group utility function of a household n; $U_{ni}(\cdot)$ is a sub-utility function of a household member i in the household n; $\mathbf{t}_{ni}$ is a vector of time consumption of the household member i in the household n; $\mathbf{c}_{ni}$ is a vector of expenditure of the household member i in the household n; $\mathbf{T}_n(\mathbf{t})$ is a vector of constraint associated with the vector of time consumption $\mathbf{t}$ of the household n; and $\mathbf{C}_n(\mathbf{c})$ is a vector of constraint associated with the vector of expenditure $\mathbf{c}$ of the household n.

In order to analyze the model, a functional form of the utility function must be specified. There has been much discussion on the types of group utility functions or the social welfare functions (e.g., Atkinson, *40*; Eliashberg and Lilien, *41*; Zhang *et al.*, *42*). As Zhang *et al.* (*42*) point out, there has been no clear theory for selecting a specific group utility function. However, there is a theoretical minimum requirement for the group utility function. A group utility function must be selected with which a unique solution can be obtained. This means that the group utility function should be a concave function (Dorfman, *43*; Panzar and Willig, *44*). Additionally, in order to select a specific functional form of the group utility function, the decision-making process of the group members should be assumed. This paper assumes that a household has the weighted linear group utility function based on the Utilitarian social welfare function. The theoretical background for this type of social welfare function is shown by Harsanyi (*45*, *46*). He reveals that the social welfare function should be the weighted linear function of the individual utility functions, if the individual and social decision-making satisfy both the von Neumann-Morgenstern axioms and the Pareto efficiency under an assumption of cardinal utility. This can be interpreted as follows. Suppose that all members in a group consider their group welfare from an ethical viewpoint. Then, any member in the group will consider other member's welfare in addition to his or her own welfare by being hypothetically their standpoints with specific probabilities. The probability may reflect how significantly the member's welfare is considered by other group members. Although the hypothetical probabilities may vary among group members, it is assumed that they will make a consensus on the unique probabilities. Under this assumption, the weight parameters of the weighted linear group utility function are regarded as the hypothetical relative significance of group member's welfare. Since a household is one of the most fundamental human-being's groups, we expect that the household members consider the household welfare in the ethical manner and have the consensus on the significance of each member's welfare. Thus, we conclude that it is quite reasonable to use the weighted linear group utility function as the household utility function. Although it is sure that more complicated group utility functions shown by such as Zhang *et al.* (*42*) and Zhang and Fujiwara (*1*) can reflect the interactions among members more explicitly, we do not use them simply because we can not find the clear theoretical background for them. Recent studies in labor economics have often used the weighted linear group utility function (e.g., Browning and Chiappori, *47*) for the empirical analysis of household decision-making.

Model Formulation

This study assumes a household with a husband, a wife, and a child. Each household member chooses one of the activities discretely while she/he continuously allocates time and expenditure for the chosen activity.

In general, activities can be classified into two types: an obligatory activity and a non-obligatory activity (Yamamoto and Kitamura, *48*). The obligatory activity is defined as an activity which an individual must engage in within a given period, while the non-obligatory activity is defined as an activity which an individual can choose to engage in or not. In this study these two activity types were further classified into:

(a) Obligatory activities:

- Required activity: a productive or learning activity, such as working at one's workplace or at home and learning at school.
- Fundamental activity: basic activities of necessity for human beings, such as sleeping, bathing and having a meal at home.
- Maintenance activities: activities for maintaining daily life, such as grocery shopping and going to banks.

(b) Non-obligatory activities:

- Out-of-home leisure: an activity that involves traveling, such as going shopping for leisure or to the theater.
- In-home leisure: an activity that does not involve traveling, such as watching television or reading at home.

This study assumes both time and expenditure allocated to obligatory activities as given and fixed, although the time and the expenditure in the required activity may be adjusted in the long term, for example, through a change in occupation. In this sense, it can be stated that the model is a short-term model. With regard to out-of-home leisure activities, they are further classified into two categories: an independent activity and a joint activity. The independent activity is engaged in by an individual alone, while the joint activity is engaged in together with other household members. It is assumed that an individual will choose an out-of-home joint leisure activity by selecting the members with whom she/he will want to engage in the activity. Although the in-home joint activity may influence the out-of-home joint activity, we do not take them into an account. This is simply because it is difficult to identify the joint activity at home with a simple activity diary data.

Next, three basic assumptions are made regarding the choice of activities for household members:

Assumption 1: All household members participate in the household joint decision-making process.

The model assumes that all members do not have the altruistic utility function, but have their own selfish utility function. This means that every household member including even a child can contribute to the joint decision-making. This is based on the assumption that the child may contribute through a discussion with her/his parents, provided she or he is old enough to communicate with her/his parents. It may be true that a very young child does not have the ability to choose an activity. However, this assumption can be satisfied, because the empirical analysis in this study focuses on children who are attending primary school and range between the ages of six to twelve years old.

Assumption 2: An individual never engages in two or more activities simultaneously (monochronic time use, Kaufman *et al.*, *49*). This is due to the independency of defined activities.

Assumption 3: The income of all household members is pooled into a single household monetary budget. In reality, the household income is allocated to each household member as, for example, an individual allowance. However, it may be difficult to observe the mechanism of income allocation. As Chiappori (*22*) theoretically demonstrates, if the "collective model" is used, the non-labor income allocation among members need not be of any concern. As mentioned earlier, the model in this study is classified as a collective model. Therefore, this assumption does not bias the model structure.

The household joint decision-making is then formulated as

$$\max U(U_h, U_w, U_c) = w_h \cdot U_h + w_w \cdot U_w + w_c \cdot U_c \quad (3a)$$

subject to

$$t_i^{ind} + t_i^{hwc} + t_i^{hc} + t_i^{wc} + t_i^{hw} + t_i^{\mathrm{hom}\,e} = T_i,\ \ i = h, w, c \quad (3b)$$

$$\sum_i c_i^{ind} + c^{hwc} + c^{hc} + c^{wc} + c^{hw} = Y \quad (3c)$$

$$t^{hwc} = t_h^{hwc} = t_w^{hwc} = t_c^{hwc} \quad (3d)$$

$$t^{hc} = t_h^{hc} = t_c^{hc},\ t^{wc} = t_w^{wc} = t_c^{wc},\ t^{hw} = t_h^{hw} = t_w^{hw} \quad (3e)$$

$$t_i^{ind} \ge 0,\ t^{hwc} \ge 0,\ t^{hw} \ge 0,\ t^{hc} \ge 0,\ t^{wc} \ge 0,\ t_i^{\mathrm{hom}\,e} \ge 0,\ i = h, w, c \quad (3f)$$

$$c^{hwc} = c_h^{hwc} = c_w^{hwc} = c_c^{hwc} \quad (3g)$$

$$c^{hc} = c_h^{hc} = c_c^{hc},\ c^{wc} = c_w^{wc} = c_c^{wc},\ c^{hw} = c_h^{hw} = c_w^{hw} \quad (3h)$$

$$c_i^{ind} \ge 0,\ c^{hwc} \ge 0,\ c^{hw} \ge 0,\ c^{hc} \ge 0,\ c^{wc} \ge 0,\ \ i = h, w, c \quad (3i)$$

where t_i^{ind} and c_i^{ind} are the time and the expenditure for an independent out-of-home leisure activity for an individual i, respectively; t_i^{hwc} and c_i^{hwc} are the time and the expenditure for a joint out-of-home leisure activity of all household members for an individual i, respectively; t_i^{wc} and c_i^{wc} are the time and the expenditure for joint out-of-home leisure activity of a wife and a child for an individual i, respectively; t_i^{hc} and c_i^{hc} are the time and the expenditure for a joint out-of-home leisure activity of a husband and a child for an individual i, respectively; t_i^{hw} and c_i^{hw} are the time and the expenditure for a joint out-of-home leisure activity of a husband and a wife for an individual i, respectively; $t_i^{\mathrm{hom}\,e}$ is the in-home leisure time for an individual i; T_i is the available time in a day for an individual i; and Y is the available household income in a day. The available time and the available income discount time and income for required activities and assume that no income is consumed in in-home fundamental and leisure activities. With regard to an individual i, h, w, and c indicate a husband, a wife and a child, respectively.

Specification of the model

It is assumed that an individual utility function consists of "sub-utility functions" associated with the types of activities, and the sub-utility function of each activity is a linear function of the "utility elements" associated with the time and expenditure for each activity. Further, it is assumed that the sub-utility of in-home leisure stems solely from the time consumption. This is because the expenditure for in-home leisure activities is considered as the sunk cost by most households in Japan. Then, the utility function of each household member is represented as

$$U_h = U_h^{ind}(t_h^{ind}, c_h^{ind}) + U_h^{hwc}(t_h^{hwc}, c_h^{hwc}) + U_h^{hw}(t_h^{hw}, c_h^{hw}) + U_h^{hc}(t_h^{hc}, c_h^{hc}) + U_h^{\mathrm{hom}\,e}(t_h^{\mathrm{hom}\,e}) \quad (4a)$$

$$U_w = U_w^{ind}(t_w^{ind}, c_w^{ind}) + U_w^{hwc}(t_w^{hwc}, c_w^{hwc}) + U_w^{hw}(t_w^{hw}, c_w^{hw}) + U_w^{wc}(t_w^{wc}, c_w^{wc}) + U_w^{\mathrm{hom}\,e}(t_w^{\mathrm{hom}\,e}) \quad (4b)$$

$$U_c = U_c^{ind}(t_c^{ind}, c_c^{ind}) + U_h^{hwc}(t_c^{hwc}, c_c^{hwc}) + U_c^{hc}(t_c^{hc}, c_c^{hc}) + U_c^{wc}(t_c^{wc}, c_c^{wc}) + U_c^{\mathrm{hom}\,e}(t_c^{\mathrm{hom}\,e}) \quad (4c)$$

where $U_i^{a}(t_i^{a}, c_i^{a})$ denotes the sub-utility function of activity a ($ind, hw, hc, wc, hwc, \mathrm{hom}\,e$) of an individual i.

Next, the sub-utility function of each activity is represented as

$$U_i^a\left(t_i^a, c_i^a\right) = U_{it}^a\left(t_i^a\right) + U_{ic}^a\left(c_i^a\right), \tag{5}$$

where $U_{it}^a\left(t_i^a\right)$ is the utility element associated with time and $U_{ic}^a\left(c_i^a\right)$ is the utility element associated with expenditure. It is assumed that the marginal utility element with respect to time and expenditure is decreasing following the neoclassical microeconomic theory as

$$\frac{\partial U_{it}^a\left(t_i^a\right)}{\partial t_i^a} < 0, \ \frac{\partial U_{ic}^a\left(c_i^a\right)}{\partial c_i^a} < 0 \cdot \tag{6}$$

Then, the utility elements are specified as a logarithmic function in the following manner:

$$U_{it}^a\left(t_i^a\right) = \alpha_{it}^a \ln\left(t_i^a + 1\right) \tag{7a}$$

$$U_{ic}^a\left(c_i^a\right) = \alpha_{ic}^a \ln\left(c_i^a + 1\right). \tag{7b}$$

The value of 1 is added to the time and expenditure of the utility element functions. First, the utility element function goes to $-\infty$ without adding some positive constant; therefore, 1 is added to the function. Second, 1 is used as the constant value because the utility element is negative unless the added positive constant is 1 or greater than 1. The utility function shown above has the linear-in-logarithms form which can be considered as the Cobb-Douglas utility function.

With regard to the parameters of the utility elements functions in equations (7a) and (7b), it is assumed that an individual's preference may change with her/his attributes. The parameters are specified as follows:

$$\alpha_{it}^a = \exp\left(\boldsymbol{\theta}_{it}^a \cdot \mathbf{x}_{it}^a\right) \quad \text{for } a = ind \tag{8a}$$

$$\alpha_{ic}^a = \exp\left(\boldsymbol{\theta}_{ic}^a \cdot \mathbf{x}_{ic}^a\right) \quad \text{for } a = ind \tag{8b}$$

$$\alpha_{it}^a = \exp\left(\boldsymbol{\theta}_{it}^a \cdot \mathbf{x}_{it}^a + \varepsilon_{it}^a\right) \quad \text{for } a \neq ind \tag{8c}$$

$$\alpha_{ic}^a = \exp\left(\boldsymbol{\theta}_{ic}^a \cdot \mathbf{x}_{ic}^a + \varepsilon_{ic}^a\right) \quad \text{for } a \neq ind \tag{8d}$$

where $\boldsymbol{\theta}$ is a vector of unknown parameters; $\mathbf{x}$ is a vector of individual attributes, ε_{it}^a and ε_{ic}^a are the independent error components that follow normal distribution with mean zero and variances σ_{it} and σ_{ic}, respectively. These error components are introduced because the heterogeneity in individual preference stems not only from the individual attributes $\mathbf{x}$ but also from other unknown factors especially in shared behaviors. Although it may be ideal that there are error components also in equations (8a) and (8b), we do not introduce them. This is because it may be difficult or impossible to derive the likelihood functions from our formulation when all parameters include the error components. The use of the exponential functions in (8a) to (8b) means that the marginal utility of three sub-utility functions is always positive. The explanatory variables in (8a) to (8d) will influence the marginal utility through the three sub-utility functions. Thus, when a parameter of an explanatory variable is positive, the variable influences the marginal utility positively.

Model Estimation

The Lagrange function is defined for the optimization problem of equation (3) with the specified functions in equations (4) to (8). Following this, the Kuhn-Tucker theorem is applied to them. The first-order optimality conditions include

$$Z_{it}^{\hom e} = \ln\left(\frac{t_i^{\hom e}}{t_i^{ind}}\right) - \left(\boldsymbol{\theta}_{it}^{\hom e} \cdot \mathbf{x}_{it}^{\hom e} - \boldsymbol{\theta}_{it}^{ind} \cdot \mathbf{x}_{it}^{ind}\right) \begin{cases} = \varepsilon_{it}^{\hom e}\left(t_i^{\hom e *} > 0\right) \\ \geq \varepsilon_{it}^{\hom e}\left(t_i^{\hom e *} = 0\right) \end{cases} \tag{9a}$$

$$Z_t^{ij} = \ln\left[\frac{\exp\left(\boldsymbol{\theta}_{it}^{ind} \cdot \mathbf{x}_{it}^{ind}\right)}{t_i^{ind}} + \frac{\exp\left(\boldsymbol{\theta}_{jt}^{ind} \cdot \mathbf{x}_{jt}^{ind}\right)}{t_j^{ind}}\right] + \ln\left[\frac{t^{ij}}{\exp\left(\boldsymbol{\theta}_{it}^{ind} \cdot \mathbf{x}_{it}^{ind}\right) + \exp\left(\boldsymbol{\theta}_{jt}^{ind} \cdot \mathbf{x}_{jt}^{ind}\right)}\right] \begin{cases} = \varepsilon_t^{ij}\left(t^{ij*} > 0\right) \\ \geq \varepsilon_t^{ij}\left(t^{ij*} = 0\right) \end{cases} \tag{9b}$$

$$Z_c^{ij} = \ln\left[\frac{2\exp\left(\boldsymbol{\theta}_{ic}^{ind} \cdot \mathbf{x}_{ic}^{ind}\right)}{\exp\left(\boldsymbol{\theta}_{ic}^{ij} \cdot \mathbf{x}_{ic}^{ij}\right) + \exp\left(\boldsymbol{\theta}_{jc}^{ij} \cdot \mathbf{x}_{jc}^{ij}\right)} \cdot \frac{c^{ij}}{c_i^{ind}}\right] \begin{cases} = \varepsilon_c^{ij}\left(t^{ij*} > 0\right) \\ \geq \varepsilon_c^{ij}\left(t^{ij*} = 0\right) \end{cases} \tag{9c}$$

$$Z_t^{hwc} = \ln\left[\frac{\exp\left(\boldsymbol{\theta}_{ht}^{ind} \cdot \mathbf{x}_{ht}^{ind}\right)}{t_h^{ind}} + \frac{\exp\left(\boldsymbol{\theta}_{wt}^{ind} \cdot \mathbf{x}_{wt}^{ind}\right)}{t_w^{ind}} + \frac{\exp\left(\boldsymbol{\theta}_{ct}^{ind} \cdot \mathbf{x}_{ct}^{ind}\right)}{t_c^{ind}}\right] + \ln\left[\frac{t^{hwc}}{\exp\left(\boldsymbol{\theta}_{ht}^{ind} \cdot \mathbf{x}_{ht}^{ind}\right) + \exp\left(\boldsymbol{\theta}_{wt}^{ind} \cdot \mathbf{x}_{wt}^{ind}\right) + \exp\left(\boldsymbol{\theta}_{ct}^{ind} \cdot \mathbf{x}_{ct}^{ind}\right)}\right] \begin{cases} = \varepsilon_t^{hwc}\left(t^{hwc*} > 0\right) \\ \geq \varepsilon_t^{hwc}\left(t^{hwc*} = 0\right) \end{cases} \tag{9d}$$

$$Z_c^{hwc} = \ln\left[\frac{3\exp\left(\boldsymbol{\theta}_{hc}^{ind} \cdot \mathbf{x}_{hc}^{ind}\right)}{\exp\left(\boldsymbol{\theta}_{hc}^{hwc} \cdot \mathbf{x}_{hc}^{hwc}\right) + \exp\left(\boldsymbol{\theta}_{wc}^{hwc} \cdot \mathbf{x}_{wc}^{hwc}\right) + \exp\left(\boldsymbol{\theta}_{cc}^{hwc} \cdot \mathbf{x}_{cc}^{hwc}\right)} \cdot \frac{c^{hwc}}{c_h^{ind}}\right] \begin{cases} = \varepsilon_c^{hwc}\left(t^{hwc*} > 0\right) \\ \geq \varepsilon_c^{hwc}\left(t^{hwc*} = 0\right) \end{cases} \tag{9e}$$

where $i = h, w, c$ and $ij = hc, hw, wc$. In order to derive the above equations, the error components in the individual utility function were assumed to be common if the individuals shared the time or the expenditure in the joint activity. This is because we expect that the non-observed factors of the time or the expenditure in the joint activity are common in any kind of shared activities.

The unknown parameters can be estimated by the maximization of the total likelihood function of all observed households based on equations (9a) to (9e). The model shown above can be referred to as the non-linear Tobit model because it considers the inequality conditions for the likelihood maximization.

EMPIRICAL ANALYSIS

Activity Diary Survey

The activity diary survey was designed and conducted by a study team from the University of Tokyo including the researchers of this study. A questionnaire was designed for a paper-based household survey on a daily activity using the socio-demographic data. Four types of questionnaire were prepared for each household: for the household head, for a husband, for a wife, and for the children. The questionnaire for the household head included general information questions about the household such as the number of household members, the household structure including gender, age, job, and residence location. The jobs are categorized into a company employee, a member of the directors' board, a public servant, a self-employed business owner, a home-maker, an organizational official, a part-time worker, unemployed, and the other. The questionnaires for household members requested the respondent to record her/his activities on a work day and on a non-work day along with the time schedule.

The survey days were November 14, 2003 (Friday) and November 16, 2003 (Sunday). The activity episodes included all types of activities from waking up in the morning to going to bed at night. The respondents were requested to provide the time and expenditure allocated to each activity with the names of those who participated in any joint activities. In the survey sheet, the activities were classified as obligatory activity, out-of-home leisure activity, and in-home leisure activity. The respondent was requested to choose one of the following three sub-categories for the obligatory activity: out-of-home work, in-home work, and learning at school. With regard to the sleep, a respondent was asked to record the times of waking up and going to bed. The out-of-home leisure activity was categorized into five sub-categories: sight-seeing, shopping, playing sports, pursuing a hobby, and having a meal at a restaurant. In addition to the types of activities, the respondents were requested to record the travel episode when they traveled from one place to another. The travel episode covered the travel mode, travel time, and travel cost.

The survey was conducted in Toyama city, Japan. Toyama is the prefectural capital of Toyama Prefecture located in the Hokuriku district. As of 2003, Toyama city had a population of about 420,000 living in a space of 1,240 square km. In order to distribute the questionnaires across Toyama city to the households with children, the local primary schools were approached for their support. In Japan, primary school education is obligatory, and it covers children between the ages of six and twelve. Three local schools in Toyama agreed to assist in conducting the survey. First, the teachers were requested to randomly select the grades and the classes in their schools. Then, they were requested to explain the purposes and methods of the survey to the children; further, the teachers were asked to distribute the survey sheets to the children and collect them upon completion. The research team worked closely with the teachers providing training and information on the study purpose/results. All the teachers supported the survey enthusiastically and their dedicated assistance contributed to the smooth and successful survey administration. In all, the questionnaires were distributed to 1,114 households and 303 responses were obtained, for a response rate of approximately 27% (survey details are presented in Matsumoto (*50*)).

Table 1 presents the observed allocations of time and expenditure of the responding households. The first point of interest is that more than half the available time is allocated to in-home leisure on both a weekday and a weekend day. Second, the time and expenditure allocated to any type of activity is larger on a weekend day than on a weekday. The only exception is the time and expenditure allocated to the individual out-of-home leisure of a wife, which is larger on a weekday than on a weekend day. This is reasonable because the majority of observed wives are housewives who can allocate more individual time on a weekday than on a weekend day. Third, the households allocate the highest amount of expenditure to the joint out-of-home leisure of all household members.

A correlation between time and expenditure for all types of activities on both days was examined; however, no strong correlation was found between them. This may be because the types of activities are not categorized in detail. However, in reality, the detailed types of activities have notable variations. This variation in the types of activities requires a different proportion of time and expenditure and this may result in the weak correlation between them.

TABLE 1 Time and Budget Allocation for Household Activities in Toyama

			Toyama (N=303)	
Variables	Definitions	Unit.	Weekday	Weekend day
T-home(h)	Time for in-home leisure activity of husband	mins.	132.3	307.5
T-ind(h)	Time for individual out-of-home leisure activity of husband	mins.	60.1	104.5
T-home(w)	Time for in-home leisure activity of wife	mins.	176.8	266.2
T-ind(w)	Time for individual out-of-home leisure activity of wife	mins.	76.3	45.1
T-home(c)	Time for in-home leisure activity of child	mins.	266.1	439.4
T-ind(c)	Time for individual out-of-home activity leisure of child	mins.	37.0	61.3
T-hc	Time for joint out-of-home leisure activity of husband and child	mins.	4.2	31.1
T-wc	Time for joint out-of-home leisure activity of wife and child	mins.	51.5	88.1
T-hw	Time for joint out-of-home leisure activity of husband and wife	mins.	12.5	16.0
T-hwc	Time for joint out-of-home leisure activity of husband, wife and child	mins.	53.8	162.6
C-ind(h)	Expenditure for individual out-of-home leisure activity of husband	yen	1019.3	1135.7
C-ind(w)	Expenditure for individual out-of-home leisure activity of wife	yen	2095.5	1150.2
C-hc	Expenditure for joint out-of-home leisure activity of husband and child	yen	16.2	426.1
C-wc	Expenditure for joint out-of-home leisure activity of wife and child	yen	784.1	1455.4
C-hw	Expenditure for joint out-of-home leisure activity of husband and wife	yen	56.1	364.1
C-hwc	Expenditure for joint out-of-home leisure activity of husband, wife and child	yen	278.1	3258.1

Results

The model's unknown parameters were estimated using data from the survey. In order to simplify the analysis, it was assumed that households allocate resources as if they had a single representative child. If a survey household had more than one child, the data of a child who attends primary school was used as representative of all the children in the household. However, if there are two or more children attending primary school, the data of the eldest child was used as representative. This assumption is only reasonable if all children always behaved simultaneously. However, in reality, the other children may significantly influence their household resource allocation. Thus, in the event that a household which has a non-representative child who significantly impacts the household behavior is found, the data of that household was eliminated from the original dataset.

Travel time and travel costs are assumed to be included in the time and expenditure of activities corresponding to the travel. Moreover, the basic period of household joint resource allocation is assumed to be a day, although the households may allocate their time over two days or more, for example, a private journey including an overnight stay. The data concerning on overnight stay was also eliminated from the original dataset for the parameter estimation process.

Although the original formulation of the household utility function shown in equation (3a) has the individual weights w_i , these weights are not identified through our parameter estimation. This is because the individual weights are incorporated into the parameter of the utility element functions of equations (7a) and (7b), when equations (8a) to (8d) include the constants and dummy variables.

Table 2 shows the estimation results of the household resource-allocation models for a work day and a non-work day. The estimated parameters show the characteristics of the marginal utility with respect to time and expenditure associated with the types of activities of each household member.

Table 2 reveals the following common characteristics between a weekday and a weekend day. First, the joint activity of the husband and child on a weekend day has higher significance in the household welfare if the child is a boy than if the child is a girl. This may reflect the social or cultural fact that the husband is fond of being with boys rather than girls. Second, the husband's or wife's individual out-of-home leisure activities have higher significance in the household welfare, as he or she has more non-work days in a week. This may be because the household members allow him or her to have his/her individual out-of-home activities since he/she takes enough care of children on non-work days. Third, the husband's in-home leisure activities have higher significance in the household welfare when he is in his forties than when he is not. This is probably because the husband working at a company in his forties is so busy that the household members expect him to stay at home longer.

Table 2 also shows the following different characteristics between a weekday and a weekend day. First, the more children a household has, the lower significance the wife's individual out-of-home leisure time has in the

TABLE 2 Estimation Results of the Household Joint Resource Allocation Model in Toyama

Variables	Weekday			Weekend day		
	Parameters associated with variables	Coeffcients	t value	Parameters associated with variables	Coeffcients	t value
Variance w.r.t. time	–	5.47	48.9	–	6.08	47.2
Variance w.r.t. expenditure	–	3.81	44.3	–	5.70	43.8
Number of children	T-ind(w)	–0.14	–1.3	T-ind(w)	0.44	2.9
Child's gender (1:girl, 0:boy)	C-hc(h), C-hc(c)	–4.26	–3.2	C-hc(h), C-hc(c)	–1.83	–2.3
Child's age	T-ind(c)	–0.04	–1.7	T-ind(c)	0.10	3.1
Weekly ratio of non-work days of husband	C-ind(h)	12.46	3.4	T-ind(h)	3.92	2.7
Husband's allowance for a work day	C-ind(h)	0.12	5.1			
Husband's allowance for a non-work day				C-ind(h)	0.02	1.9
Dummy variable of husband's age (1 if in his 40s and 0 otherwise)	T-home(h)	0.68	1.4	T-home(h)	2.22	3.8
Dummy variable of husband's job (1 if employee and 0 otherwise)	T-home(h), T-home(w)	1.13	2.9	C-hw(h), C-hw(w)	–5.18	–5.8
Dummy variable of husband's job (1 if self-employed and 0 otherwise)	C-hwc(h), C-hwc(w), C-hwc(c)	2.20	1.8	C-ind(h)	2.52	2.9
Constant for expenditure of husband's individual out-of-home leisure	C-ind(h)	5.14	5.5	C-ind(h)	4.56	9.9
Weekly ratio of non-work days of wife	C-ind(w)	12.31	6.5	C-ind(w)	7.88	3.7
Wife's allowance for a week day				C-ind(w)	–0.08	–1.9
Wife's allowance for a weekend day	C-ind(w)	0.03	1.2			
Dummy variable of wife's age (1 if in her 30s and 0 otherwise)	C-ind(w)	–0.97	–1.6	C-ind(w)	0.93	1.2
Dummy variable of wife's job (1 if housewife and 0 otherwise)	T-home(w)	3.55	6.0	C-hwc(h), C-hwc(w), C-hwc(c)	5.05	7.4
Dummy variable of wife's job (1 if part-time employee and 0 otherwise)	C-wc(w)	1.10	1.2	T-home(w)	1.29	1.5
Constant for expenditure of wife's individual out-of-home leisure	C-ind(w)	4.22	7.0	C-ind(w)	1.06	1.3
Number of observations	303(909)			303(909)		
Initial log-likelihood	–37856.0			–46059.2		
Final log-likelihood	–11799.7			–14711.3		
Likelihood ratio	0.688			0.681		

household welfare on a weekday, while the higher significance it has on a weekend day. This is probably because the household members request the wife to take care of children on a weekday, while they request the husband to do so on a weekend day. Second, the older the child is, the lower significance the child’s individual out-of-home leisure time has in the household welfare on a weekday, while the higher significance it has on a weekend day. This is probably because the elder elementary school children are expected to do homework harder at home rather than playing outside on a weekday, while the children are expected to play outside more as she or he is getting older on a weekend day. Third, when a wife is in her thirties, her individual out-of-home leisure expenditure has lower significance in the household welfare on a weekday, while it has higher significance on a weekend day. In our sample households, it is expected that the wives in their thirties have younger children than the wives not in their thirties. Thus, the household members with young children request the wife to stay at home on a weekday, while the household members, especially the husband, may allow her to be free from child-care on a weekend day.

CONCLUSIONS

This paper investigates household joint resource allocation, including time and monetary expenditure, using empirical data from an activity diary survey. The proposed model considers a child explicitly in addition to its parents. The model considers not only the time allocation but also the monetary budget allocation of the household.

A choice of activity-duration as well as activity type is analyzed and the intra-household interactions between a weekday and a weekend day are compared. The results of empirical analysis reveal what type of activities contributes to the household welfare significantly. We find the characteristics influencing the household interaction such as the social or cultural backgrounds relating to the husband's preference on child gender, the household child-care role sharing between the husband and wife, and the husband's involvement in his work. By comparing the results between on a weekday and on a weekend day, we find the different characteristics influencing the household interaction. For example, the wife takes a role of child-care on a weekday while the husband takes it on a weekend day. The elder children are expected to do homework at home on a weekday while they are expected to play outside on a weekend day. These results should be useful in understanding the household interaction.

Although the current study has overcome some difficulties that have been pointed out in previous research, there remain issues that need further examination. First, this study assumes households have a single representative child; this is clearly a simplification since children undoubtedly behave differently, and this simplification may bias the data analysis. On the other hand, if a joint-household resource-allocation model is developed with a consideration of many children, a more complicated model structure would be required. Thus, a trade-off between reality and complexity needs to be examined. Second, the model considers time and expenditure allocation on a single day. However, individuals may allocate resources across a week or more. If the resource allocation is undertaken for a week as Axhausen *et al.* (*51*) point out, a weekly resource-allocation model must be used. Finally, a child who is old enough to be able to contribute to the household decision-making is considered. However, if a child is too young to judge his or her own resource allocation, there may be a need to focus on the resource allocation of parents, mainly the wife who is entrusted with childcare; examples of this perspective are Gronau (*52*), Ribar (*53*) and Michalopoulos *et al.* (*54*).

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