MICROECONOMIC MODELS OF INTRA-HOUSEHOLD ACTIVITY TIME ALLOCATION

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Abstract: The primary purpose of this research is to analyze theoretically the group decision-making process leading to the allocation of activity time and the consumption of goods, with particular emphasis in the households. Each household is characterized as a group of individuals making joint decisions about their activity participations, alternative activity time allocations and consumption of various goods, such as independent and joint activity time allocations as well as private and shared consumption patterns. We firstly explore why individual-based models are not realistic in multi-person households, and secondly, we summarize various intra-household activity time allocation models based on different decision-making processes. All models are presented under microeconomic principle of utility maximization to represent the economic behavior of the households.

Key Words: Intra-household activity time allocation, unitary models, bargaining models, collective models

1. INTRODUCTION

Activity time allocation and duration models are the major focus in recent methodological developments and innovative transport demand models such as activity-based travel analysis. The underlying behavioral representation of such models, however, is not easy, as they require modeling of human behavior. There are number of sound conceptual and behavioral reasons for studying activity time allocation, such as to analyze travel behavior, to examine transport policy options and to evaluate transportation infrastructures, to name only a few. The research attempts for developing realistic and estimable models of daily activity time allocation and activity duration have been a subject of theoretical foundations and empirical explorations for at least 20 years in the field of transportation, and subsequently, there have already been significant progresses in some modeling issues.

In the development of the activity time allocation models, or related travel demand and activity behavior analysis, transportation researchers have to make a decision between individual-level analysis and household-level analysis. While most existing research are based on individual-level analysis, these models do not represent the realistic behavior of time allocation decisions because an individual usually live in a household with other family members. The household members usually interact each other to make time allocation and travel decisions. Some behavioral characteristics and attributes are only observable at the household level. Utility maximization can be thought of occurring at the household level. For example, an individual household member may wish too go for recreational trip, however, due to obligations related to another household member, instead, chooses to stay in the household and watch television. Identification of the linkages across different members of a household that reflect sharing of the same activity and/or the making of the joint travel is very important for travel and activity system analysis.

The primary purpose of this paper is to analyze the decision-making mechanism of a collective group leading to the allocation of activity time and to explore theoretically the possible microeconomic models of intra-household activity time allocation, with particular emphasis in households. Each household is characterized as a group of individuals making joint decisions about their activity participations and travel choices. Several decisions are made by collective groups and not by individual agents including independent and joint activity time allocation as well as private and shared consumption of goods. A brief review of existing literatures on activity time allocation modeling has been discussed in Section 2. We have summarized the advantages and importance of household-based models over individual-based models in Section 3. In Section 4, various mathematical models of intra-household activity time allocations are presented. The proposed models are explicitly derived within a microeconomic principle of utility maximization and social welfare theory that provides insights into the behavior of the households regarding alternative activity time allocation and travel decisions. Based on intra-household decision making strategies, two distinct intra-household models viz. unitary intra-household activity time allocation models and non-unitary intra-household activity time allocation models are presented. Section 5 concludes the paper along with the direction for future research.

2. LITERATURE REVIEW

Existing literatures in activity time allocation and duration models can be broadly grouped into three groups: microeconomic models (will be discuss below), structural equation system models (see Golob 2001), and hazard based duration models (see Mannering et al. 1994, Ettema et al. 1995, Bhat 1996). Among these, microeconomic utility maximization models are the basis of most existing research because of their well-established mathematical base. Microeconomic models assume that the individuals make choices concerning the allocation of time and money to different activities and consumption goods to maximize their daily total utility. The seminal paper by Becker (1965) that laid the foundation for explicitly incorporating time components in the direct utility function through 'final commodities' and time constraint in the utility maximization problem has greatly enhanced not only economists' interests but also time use researchers, urban planners and transportation professionals. Various extensions on Becker's model has been proposed and extended (see Jara-Dias 1998 and Kraan 1996 for detail discussions of the progresses). DeSerpa (1971) made an important extension to directly incorporate activity time allocation component in direct utility function in addition to consumption of goods and theoretically proposed three distinct components of

value of time; value of time as a resource (VOTR), value of activity time (VOAT) and value of saving time (VOST) in the consumption-time constrained activity.

Kitamura (1984) introduced random utility models of activity time allocations to discretionary activities, under utility maximizing principle, to formulate estimable models of activity time allocation. Yamamoto and Kitamura (1999) further extended these works incorporating interactions between working and non-working days. Bhat and Misra (1999) employed the same concept to model weekly discretionary activity time allocations between in-home and out-home and between weekdays and weekends. Recently, Meloni et al. (2004) analyzed the time allocations to discretionary in-home and out-home activities including trips using Nested-Tobit model. These models have used only activity time allocation components in their direct utility function with only time constraint. On the other hand, Kockelman (2001) developed a model for time and budget constrained activity demand analysis in microeconomic utility maximizing foundation using Roy's identity. Prasetyo et al. (2003) and Fukuda et al. (2003) considered the effects of motivational factors of time allocations under time and money constraints. The methodology for estimating value of activity time (VOAT) has been introduced in these papers.

These traditional microeconomic models of individual activity time allocation clearly lack a number of important considerations. First, the majority of these models have considered only activity time allocation components in direct utility function with only time constraint in constrained utility maximization. On the other hand, there are a lot of research works in household economic literatures, which consider only good consumption components in direct utility function with only income constraint in resource allocation problems. These two extremes of research are based on the same principle of utility maximization, but motivated from the self-interests in the sense that economists focus on goods and transportation researchers focus on time. The integrated model with both time allocation and good consumption components in directly utility function under time and money constraints are important for modeling activity time allocations. Some of the recent researches have considered the income constraint (Kockelman 2001, Prasetyo et al. 2003). Second, the existing researches are based on the assumption that the marginal utilities of all activities are equal. Their argument is that, if not equal, the individual is free to allocate more time to those activities whose marginal utilities are higher and finally allocates the optimal time to each activity with equal marginal utility. In reality, however, the marginal utilities of all activities might not reach to their optimal values because individual might be forced to reduce time allocations to some activities due to other constraints such as income, time pressures etc. The recent papers by Prastyo et al. (2003) and its extension by Nepal et al. (2004a) have explored this phenomenon and concluded that the marginal utilities of all activity types may not be equal. Nepal et al. (2004a) presented a framework to incorporate marginal utility differences considering variance heterogeneities across activity types. Third, the existing time allocation models ignored the latent determinants of activity time allocations such as needs, priorities, time pressures etc., which are difficult to measure directly, but they do have influential effects on activity time allocations. Recent paper by Nepal at al. (2004b) has derived a mathematical model to incorporate latent determinants of activity time allocations.

However, microeconomic models discussed so far are based on the notion of 'individual traveler', 'individual decision making process' and 'individual choice' regarding activity time allocations and travel decisions. These research works lack another important and realistic fact that each individual is more or less associated within the household, where each individual household member care other member(s) and, they also share common household

goods. The intra-household activity time allocation decisions are affected by the characteristics of the households they belong to, the resources available to them and the constraints they have to face to satisfy household needs. These household needs are usually achievable through participating to a number of activities that must be performed by one or more household members within a specific time period. Hence, the intra-household activity time allocations are generally derived from the characteristics of the household they belong to, the intra-household decision making process and the degree of association among household members. Household Activity-Travel Simulator (HATS) methodology, a game theoretic simulation, was used to better understand household travel decisions and the constraints within which those decisions are made (Jones, 1979). In this analysis, spatial components of activity-travel patterns are represented on the map, and temporal components are represented on the timelines, using activity diary data of all members of a household. When a policy measure is introduced, household members discuss together considering changes of constraints on the game board, and then new activity-travel patterns are simulated in this board. Such game theoretic simulation is especially interested in inter-personal linkages and constraints, gaining more realistic responses than simply asking hypothetical questions.

Existing microeconomic models to incorporate the household effects in time allocation modeling are using few explanatory variables related to household characteristics. To the best of our knowledge, none of the existing models have treated explicitly the household as the unit of analysis in activity time allocation modeling except few attempts in the last few years (Gliebe and Koppleman 1999, Zhang et al. 2004). The actual unit of analysis for modeling activity time allocations is the household just like the unit of analysis in the theory of consumption and the demand for travel is not only affected by the personal behavior but also by the household decision making process. Other important aspects to study household, as a decision-making unit, are the distribution/allocation of time and household income among the members within their time and money budget limits. These two constraints are conceptually different in the sense that the total time available to each member of the households is equal (for example one day) but the individuals' incomes are different. Household income plays very significant and different role than the individuals' time constraint and both constraints are equally important in the modeling of activity time allocation behavior. The issue of what determines intra-household activity time allocations is important to travel behavior analysis for the same reasons the study of intra-household consumption is important in household economics. Household models are useful for understanding joint and allocated activity participation and effects of household income in its members' time allocation decisions.

3. HOUSEHOLD AS THE UNIT OF TRAVEL BEHAVIOR MODELING

While the households as the fundamental units of analysis remain central to microeconomic consumer behavior and marketing theory to know how many consumption and/or marketing decisions are made by the households, it has received relatively insufficient attention, if not completely ignored, from scholars in the areas of transportation and travel demand modeling. This lack of attention is due to a restrictive notion of the role of households in activity time allocations and good consumption decisions. Research so far has focused mainly on individual traveler's final decision outcomes (who are seen to carry out the activities) and to a much lesser degree on decision processes (how do they arrive at that). As the question of who allocates the time to different activities has been explored extensively, findings became repetitive and interest in intra-household decision-making began to grow recently. At the same time, research that attempted to deal with household in terms of all its interpersonal

nuances has been hampered by a dearth of appropriate metaphors to talk about such behavior; e.g. most theories of behavior and personality in psychology are at the individual level and, given that family is not a simple sum of two or more individuals, individual theories of behavior and personality do not facilitate an explanation of behavior observed in households.

The household is the primary decision making unit. Household members carry out household decisions by engaging in various activities. Decisions to participate in different activities as well as who participates are the results of negotiation and role and task and time allocation within the households. Travel decisions are derived from the pursuit of activities to satisfy household needs. Most of the travel is habitual and travel patterns do not commonly shift day to day. Households adapt to sufficiently large stimuli by changing activity patterns and consequently, travel within time and money constraints. The household is an institution of social control that 'governs' the daily time and task allocations of household members to different activities by some informal household rules and control strategies. Intra-household resource allocation makes available important information on household dynamics that influence daily time allocation and, therefore, should prove a valuable contribution to efforts to model activity time allocation behavior and its impact on transportation.

It is well known that members of a household unit often interact in making decisions. It is not always the case that each individual inside the household have the same preferences. Heterogeneities in preferences do occur across members but they do also have some collective decision making process. Only recently, transport researchers are realizing the importance of intra-household decision-making process for alternative activity participations. How household members interact and make the decisions of time and task allocations before performing and allocating individual members and their times to different activities is very important for realistic representation of the activity time allocation behavior. The daily out-of-home activities are not only the independent activities but also the shared ones. The members of the household jointly involve on certain shared activities in space and time. These joint activities certainly require interaction and understanding of household members and, the decision of which is usually made at the household level. Going for the dinner tonight together or doing shopping jointly today or sharing the same auto up to the nearby transit station are some examples of shared activities. Even for some independent activities, the decisions are made at the household level. For example, decisions such as who is picking up the children from school or childcare center, who is doing the daily shopping activities today, who will join the work force and who is free today for recreation etc. are usually made from the consensus among the household members and involve task allocation (Jhang et al. 2004). In this sense, majority of decisions for activity time allocations and travel decisions are made at the household level rather than the individual levels.

The complex activity participation and/or travel decisions involving multi-persons household, result form a collective decision making process inside the household. However, the complexity and sparseness of interactive intra-household models has made the slow progress in the area of transport research. The most fruitful results of such models for activity based transportation planning is to better understand household joint (share) activity participation. Moreover, such models also allow identifying the relative influence or power of household members. The ability or inability of the individuals as members of the household unit to rearrange their schedules, share responsibilities, honor joint activity commitments and allocate tasks to each member comprise an often overlooked set of behavioral responses to perturbations in transportation environment (Gliebe and Koppleman, 2002). However, even still today, there is an absence of clear conceptual work on a collective model of intra

household time allocation. The existing models for intra-household activity time allocation are concentrated on how to define the individual utility function and household utility functions. One stream of the models assumes that the individual utility function is independent of the other members' arguments of utility, and interaction occurs from composite utility using interaction parameters (Zhang et al. 2004). In the other stream of the models, the interactions were introduced in such a way that one member's utility also depends on the other members' arguments of the utilities. In this research, we assumed individual member's utility is dependent on other household members' utility through joint activity participation and shared consumption bundles.

4. MICROECONOMIC MODELS OF INTRA-HOUSEHOLD ACTIVITY TIME ALLOCATION

4.1 Notations

W Twice continuously differentiable strongly concave household welfare function per period;

u^n Twice continuously differentiable strongly concave total utility of the individual n derived from the participation of different joint and independent activities and consumption of private and shared goods per period;

n Individual inside the household (total numbers of individuals are N);

T Total time available to each household member per period;

t_n^i Gross time allocated to independent activity $i \in I$ by an individual $n \in N$ per period (total number of independent activities $= I$) $= a_i^n + tt_i^n$;

a_i^n Net activity duration of independent activity $i \in I$ of an individual $n \in N$;

tt_i^n Travel time required to access to independent activity $i \in I$ for individual $n \in N$;

t_j Gross time allocated to joint activity $j \in J$ per period (total number of joint activities $= J$) $= a_j + tt_j$;

a_j Net activity duration of joint activity $j \in J$;

tt_j Travel time required to access to joint activity $j \in J$;

t_w^n Time allocated to market labor by individual $n \in N$ $= a_w^n + tt_w^n$;

a_w^n Working hours of an individual $n \in N$ per period;

w^n Wage rate of individual $n \in N$;

tt_w^n Travel time for work commute for individual $n \in N$;

x_k^n Private good $k \in K$ (total number of private goods $= K$) consumed by the individual $n \in N$ in the household per period;

x_s Shared good $s \in S$ (total number of shared goods $= S$) consumed by the household;

tc_i^n Travel cost to access to independent activity $i \in I$ for individual $n \in N$;

tc_w^n Travel cost to access to work location for individual $n \in N$;

tc_j Total travel cost to access to joint activity $j \in J$ for all individuals in the household;

p_k Market price of the independent good $k \in K$;

p_s Market price of the shared good $s \in S$;

y^n Unearned income of individual $n \in N$;

4.2 Groupings of Activities and Consumption Bundles

An individual member's total time can be allocated to the vector of independent activities $\mathbf{I}\,(1,...,i,...,I\,)$ or to the vector of joint activities $\mathbf{J}\,(1,...,j,...,J\,)$. Similarly, the household consumption can be either private consumption bundle $\mathbf{K}\,(\,1,...,k,...,K\,)$ or the shared consumption bundle $\mathbf{S}\,(1,...,s,...,S\,)$ as shown in Figure 1. Here, $\mathbf{I}$ is the universal set of independent activities and $\mathbf{K}$ is the universal set of private consumption bundle for all household members.
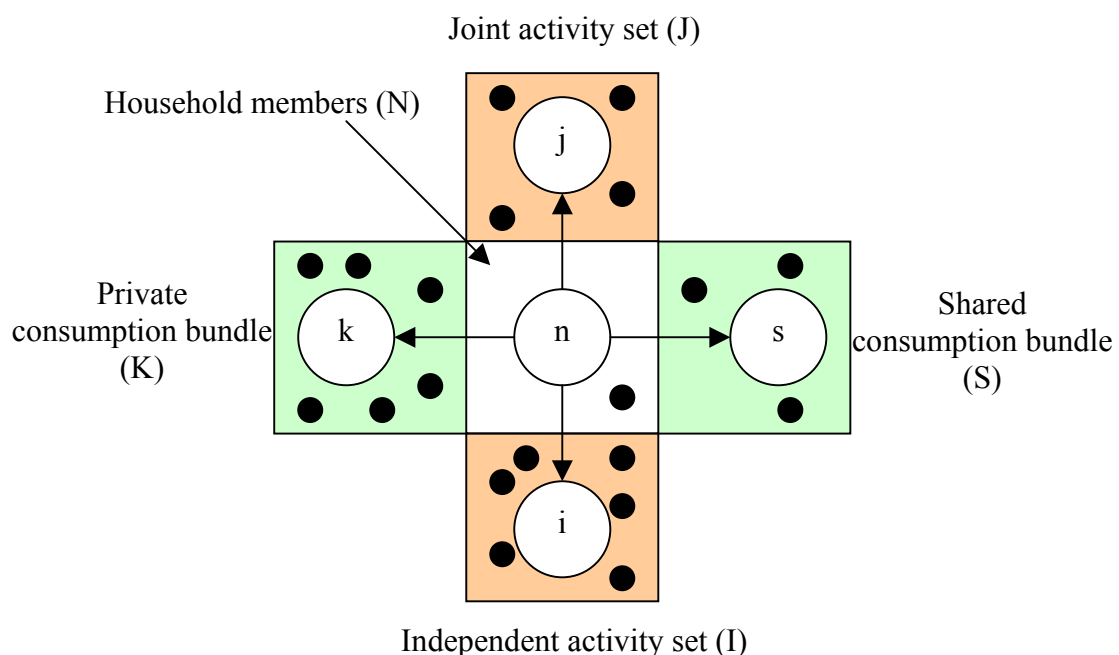

Figure 1. Activity set and consumption bundles for household members

4.3 Intra-Household Decision Making Process

Microeconomic theory is based on the model of rational individual, maximizing his/her utility. However, while most individual times and monetary incomes may accrue to individuals, the majorities of individuals live and make their decisions within multi-member households. Time and money expenditure decisions are not necessarily made by the isolated individual but by the individual within the framework of household society. It is, therefore, extremely problematic to consider decisions regarding allocation of time and money, which are the principal decisions made by the households, on the basis of individual utility functions.

As shown in Figure 2, the theoretical basis for understanding intra-household decision-making process of resource allocation from economic viewpoint has seen three distinct developments. The earlier attempts during 1950-1970's assume that a household, even if it

consists of different individuals, acts as a single decision making unit. In a nutshell, the unitary models say that the behavior of the household mimics that of utility maximizing individuals; the models of decision-making mechanism of a household are the justification of a simple utility-maximization model. Consequently, household decisions are the observable results of maximization of fixed household preferences (utility function) under resource constraints. Samuelson (1956) derives 'social indifference curves' for the households that have the properties as that of individual indifference curves. The economics of the family brought into mainstream by Gary Becker deal with this type of intra-household decision-making behavior and often called 'unitary models'. Unitary models assume the existence of only one set of preferences that matters when decisions are made and assuming that those preferences constitutes rational behavior; the household will behave in a rational manner. Such household behaviors are observable in the case of 'common preferences households' (everyone in the household has the same preferences in making household decisions) and 'dictator households' (All the household decisions are made by the 'BOSS' of household who has all powers and makes all the decisions according to his or her preferences without including the feelings of other members).
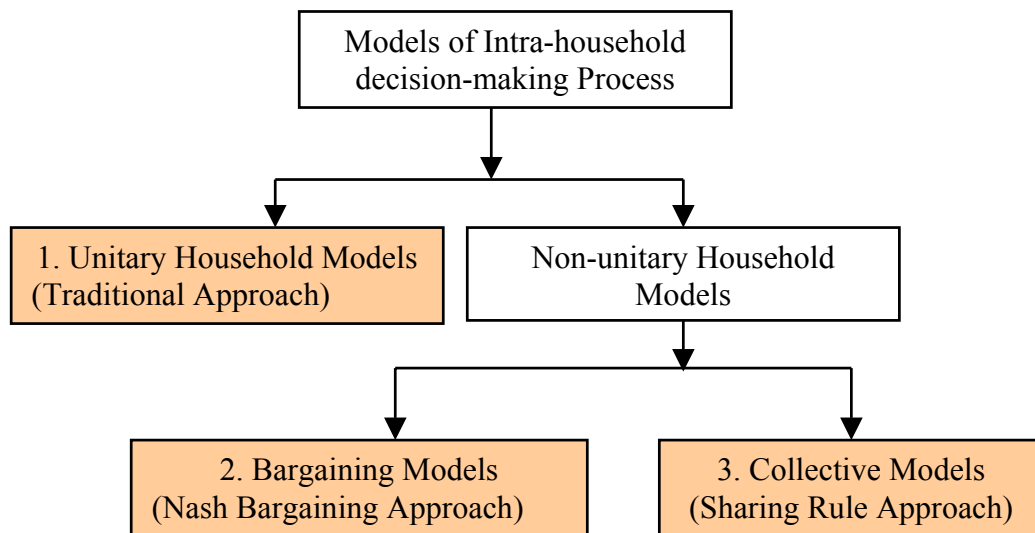

Figure 2. Models of intra-household decision-making process

The second approach, called Nash bargaining approach, analyzed the household decision making process from cooperative bargaining framework calling into question the earlier unitary model. The bargaining models differ from unitary models in that they seek to endogenize the bargaining power of different members of the households (Manser and Brown 1980, McElroy and Horney 1981). These bargaining approaches yield an efficient resource allocation. This is because of the implicit assumption that there are no imperfect information commitment problems within the household. Chiapori (1988) pioneered the third approach, called sharing-rule approach, of intra-household decision making that does not required an explicit bargaining frameworks. The only assumption made in this approach is that the household decisions are Pareto efficient. Non-unitary models either in the form of bargaining or the sharing rule approaches are the realistic, but complex behavioral representations of intra-household decision-making process inside the multi-person households.

4.4 Unitary Intra-Household Activity Time Allocation Model

The standard theory of consumer behavior is an example of the economic problem: households are needs and desires that they want to satisfy. But they have to make choices because they are limited in their possibilities. A fundamental assumption made in the unitary intra-household model is that the households needs and desires are fully captured by the rational preference ordering over alternative activities and goods so that they are well-behaved units. Unitary models treat each household as a black box; the models do not address how decisions are made but only what the outcome is. Such models are either 'common preferences' models or 'dictator' models in which household maximizes single household utility function with pooling of family incomes. The household preferences are usually assumed to be represented by a unique well-behaved household welfare function and explicit choices are deduced from the maximization of household utility function under resource constraints. Let us assume that the utility of an individual is derived form all activity participation and good consumption within the fixed period (DeSerpa, 1971) and the household welfare function is the constant function of individuals' utility arguments as shown in equation (1). Note that the time allocated to market labor (work time and commuting time) is not included in the direct utility function.

Maximize:

$$W = W\{(t_i^n, t_j, z_k^n, z_s), \ \forall n, i \neq w, j, k, s\} \tag{1}$$

Subject to:

$$T - t_w^n - \sum_i t_i^n - \sum_j t_j = 0 \qquad \forall n \tag{2}$$

$$\sum_n y^n + \sum_n w^n(t_w^n - tt_w^n) - \sum_k p_k \sum_n z_k^n - \sum_s p_s z_s - \sum_n tc_w^n - \sum_n \sum_i tc_i^n - \sum_j tc_j \geq 0 \tag{3}$$

Here, the household utility function with arguments of time allocations and consumptions of goods of all individuals inside the household is assumed to be constant and maximized under individual time constant and household budget constant to arrive at the optimal time allocations and good consumption bundles.

4.5 Non-Unitary Intra-Household Activity Time Allocation Models

The unitary models clearly lack several behavioral realisms. First, this approach does not explicitly takes into account the notion that the household is a group of individuals, with different preferences, and among whom an intra-household decision making process takes place. In fact, a household can be seen as a micro-society that consists of several individuals with their own rational preferences. Observed household time allocations and good consumption patterns can in this sense be considered as a social state chosen by the household members. Secondly, the unitary household model leaves no room to see the intra-household time and money allocations, and consequently, of welfare. To overcome such drawbacks of the unitary household model, non-unitary intra-household models that explicitly take into account the fact that multi-person households consists of several members which may have different preferences are proposed in economic literatures. Among these household members,

an intra-household bargaining approach and sharing rule approach (decision making process) is assumed to take place.

For all non-unitary intra-household models, the preferences of the household members regarding the optimal allocation of resources (time and money) need not be the same and they are assumed to be independent. Each person has the separate utility function of the form:

$$u^n = u^n\{(t_i^n, t_j, z_k^n, z_s), \forall i \neq w, j, k, s\} \quad \forall n \tag{4}$$

4.5.1 Nash-Bargained Intra-household Activity Time Allocation Models

The intra-household bargaining models explicitly address the question of how individual preferences lead to a solution of bargaining problem. The bargaining problem can be stated:

"A bargaining problem requires specifying a set of feasible payoff combinations and a payoff combination that obtains in the case of a breakdown of a negotiations".

Maximizing individual utility function (4) at the given level of utility of other members' utilities under individual time constraints and household total income constraint yields optimal solutions for time allocations and good consumption bundles. If the bargaining process ends without a solution, each individual obtains a disagreement payoff, which is also called the threat point payoff.

In the presence of joint activity participation and shared goods within the household and companionship, loving and caring etc, the intra-household bargaining problem is a cooperative game approach and now widely used in economics. The cooperation understood in the sense of game theory. The cooperative bargaining models has three basic assumptions: (i) There is no feasible payoff combination that has higher payoff for all players than a bargaining solution (ii) there is a bargaining process inside the household to intra-household decisions and (iii) the outcome of the bargaining problem shall be strictly better for all players than the disagreement payoff. The Nash-bargained solution to the resource allocation problem dictates that all members jointly choose the arguments in the utility function to maximize the gains from living together. All individuals inside the household solve the resource (time and consumption) allocation problem. The household decision process is assumed to lead to a Pareto efficient allocation, and household members jointly maximize the following household utility function:

Maximize:

$$W = \prod_n [u^n - \phi^n] \tag{5}$$

Subject to:

$$T - t_w^n - \sum_i t_i^n - \sum_j t_j = 0 \quad \forall n \tag{6}$$

$$\sum_n y^n + \sum_n w^n(t_w^n - tt_w^n) - \sum_k p_k \sum_n z_k^n - \sum_s p_s z_s - \sum_n tc_w^n - \sum_n \sum_i tc_i^n - \sum_j tc_j \geq 0 \tag{7}$$

The value of u^n is given by (4) and ϕ^n is the threat point (maximized indirect utility which member n would achieve outside of the household) and given by

$$\phi^n = \phi^n(p_s, p_k, y^n; E^n) \tag{8}$$

Bargaining models differ from the unitary models in that the decision making process within the household is explicitly specified. Furthermore, the emphasis in the bargaining models is on who actually controls the resources.

4.5.2 Collective Intra-Household Activity Time Allocation Models

Chiappori (1988) pioneered another approach to non-unitary household models that does not require an explicit bargaining framework. As emphasized by Browning and Chiappori (1998), the intra-household decision-making process cannot be represented by a unique household utility function. Each household is a political place, characterized by conflicts of interests, but also companionship and share. Each member in the household is an economic agent, endowed with a set of preferences. In sharing rule approach, each household decision is the outcome of the collective understanding and sharing between its members. The collective framework has the advantages of encompassing both unitary models and bargaining models. The general formulation of collective household model is to optimize individual utility function:

Maximize:

$$u^n = u^n\{(t_i^n, t_j, z_k^n, z_s), \forall i \neq w, j, k, s\} \qquad \forall n \tag{9}$$

Subject to:

$$T - t_w^n - \sum_i t_i^n - \sum_j t_j = 0 \qquad \forall n \tag{10}$$

$$\sum_n y^n + \sum_n w^n(t_w^n - tt_w^n) - \sum_k p_k \sum_n z_k^n - \sum_s p_s z_s - \sum_n tc_w^n - \sum_n \sum_i tc_i^n - \sum_j tc_j \geq 0 \tag{11}$$

These collective household models are more general and based on the assumption that the household wastes nothing- that is, its allocation is *Pareto efficient*. That is, chosen activity time allocation and consumption bundles are such that *an individual's welfare cannot be increased without decreasing the welfare of one of the other household members*. The Pareto efficiency is the most generalization of the assumption of the utility maximization in the unitary models with several household members. Thus, the collective household model can be formulated using the standard instruments of welfare economics. Household chooses consumption to:

Maximize:

$$u^n = u^n\{(t_i^n, t_j, z_k^n, z_s), \forall i \neq w, j, k, s\} \tag{12}$$

Subject to:

$$u^{n'}\{(t_i^{n'}, t_j, z_k^{n'}, z_s), \forall i \neq w, j, k, s\} = \bar{u}^{n'}, \forall n' \neq n \tag{13}$$

$$T - t_w^n - \sum_i t_i^n - \sum_j t_j = 0 \qquad \forall n \tag{14}$$

$$\sum_n y^n + \sum_n w^n (t_w^n - tt_w^n) - \sum_k p_k \sum_n z_k^n - \sum_s p_s z_s - \sum_n tc_w^n - \sum_n \sum_i tc_i^n - \sum_j tc_j \geq 0 \tag{15}$$

where $\bar{u}^{n'}$ is some required level of welfare for individual $n' \neq n$. Thus the maximization of this problem seeks an allocation that maximizes welfare of individual n at the given value of $\bar{u}^{n'}$, $n' \neq n$ and household full income constraint. By varying $\bar{u}^{n'}$, $n' \neq n$, all Pareto efficient allocations can be traced out. This set of Pareto efficient allocations forms the boundary of *utility Possibility Frontier*, which captures all attainable vectors of utility levels for the household. For the case of only 2 members household, this utility possibility frontiers can be shown in plan as shown below.
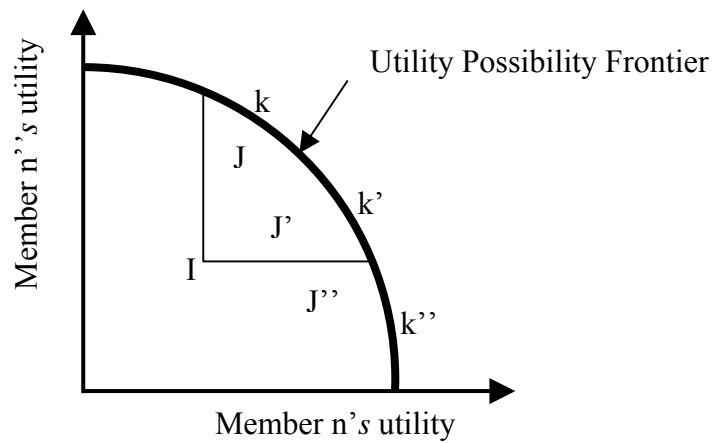

Figure 3. Utility Possibility Frontier

This is an important result because it allows us to characterize all Pareto efficient allocations as stationary points of the *linear social welfare function (Household Welfare Function)* for some positive welfare weights for both individuals. That is, the household allocation problem can be defined as the unique solution to the following maximization problem:

Maximize:

$$W = \sum_n \theta^n u^n, \qquad \sum_n \theta^n = 1, \ u^n = u^n \{(t_i^n, t_j, z_k^n, z_s), \forall i \neq w, j, k, s\} \qquad \forall n \tag{16}$$

Subject to:

$$T - t_w^n - \sum_i t_i^n - \sum_j t_j = 0 \qquad \forall n \tag{17}$$

$$\sum_n y^n + \sum_n w^n (t_w^n - tt_w^n) - \sum_k p_k \sum_n z_k^n - \sum_s p_s z_s - \sum_n tc_w^n - \sum_n \sum_i tc_i^n - \sum_j tc_j \geq 0 \tag{18}$$

where θ^n is the *Pareto weight or welfare weight or bargaining power* assigned to individual n. We have no theory about where this weight comes from. The welfare function (16) may be interpreted as being a sort of weighted average of individual preferences.

5. SYNTHESIS AND CONCLUSIONS

This research proposes general microeconomic models of intra-household activity time allocation, explicitly considering household as the unit of analysis. This is an important shift in the activity time allocation modeling paradigms from individual-based to household-based. We have discussed the appropriateness of household-based models over individual ones, summarized three different types of intra-household decision making strategies and presented various microeconomic models of intra-household activity time allocations. The proposed models underscore the realistic behavioral contexts for parameter estimation and econometric forecasting. If found acceptable from practical point of view, these models will be the cornerstone to model the activity time allocation behavior, and, hence, enhancement of activity based travel demand analysis.

There are more research works still to be done. First, the proposed microeconomic models have to be specified into estimable econometric models so that the model parameters could be estimated from the statistical data collected from the households. Second, development of an effective way of collecting information or data from the households are very important. This is because existing activity based surveys do not cover the information required by these household-based models. Third, the detail empirical analysis is required in order to analyze the practical efficiency of the models.

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