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Activity-based Travel Demand Model with Time-use and Microsimulation incorporating Intra-household Interactions

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Activity-based Travel Demand Model with Time-use and Microsimulation
incorporating Intra-household Interactions

DISSERTATION

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Dedication

To my family

for letting me pursue my dream

for so long

with endless love and encouragement.

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I would like to thank my committee chair, Professor Michael G McNally, for his constant guidance and support throughout the years of my Ph.D. studies and for giving me so much freedom to explore and discover new areas of activity-based travel demand model. My other committee members have also been very supportive. Professor Will Recker and Professor R. Jayakrishnan have both been an inspiration to me at various points over these years and always provided me with valuable advice and comments on my doctoral research.

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Abstract of the Dissertation

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Doctor of Philosophy in Civil Engineering

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Michael G. McNally, Chair

The activity-based travel demand model recognizes that travel is derived from the demand for activity participation distributed in space and time. The focus on intra-household interactions and linkages between people's behavior and social and physical environment has been identified as emerging features of the activity-based approach that would be important to travel behavior research. The dissertation is dedicated to an in-depth exploration of the within-household interactions by theoretical specification and empirical development of the household activity time allocation models based on a utility maximization framework with the household as the unit of analysis. Furthermore, the

dissertation also aims to propose a model of the household activity scheduling process primarily focusing on task allocation mechanisms on the basis of the human agents adjusting themselves to the built social and physical environment.

Development of the activity time allocation model in this dissertation includes two types of structural time allocation models. First, the collective models based on two assumptions that household heads have their own utility functions and that decisions by them reach Pareto-efficient outcomes are introduced to develop intra-household activity time allocation models for leisure demand and housework activity. Secondly, intra-household time allocation to housework activity is further examined through the estimation of time allocation to the different types of activities by the different types of household members along with extensive exploration of various theories and identification of related interactions.

This dissertation proposes a household activity scheduling process with a model design based on a weekly pattern system, which is expected to keep various advantages compared to a deterministic daily model system. Along with learning and adaptation procedures, the human being as a learning agent is designed to prepare strategic schedules of behavior to achieve individual goals through interactive environments, and implement those plans via activity execution. At the household level, the household and its members as decision agents are also designed to optimize the allocation of the available household labor resource under the presence of the uncertainties of the physical and social environments. After describing the mathematical framework and solution procedure, a simulation experiment is conducted within a hypothetical environment to demonstrate how the proposed model works.

Chapter 1

Introduction

1.1 Introduction

As innumerably stated so far in the majority of research on activity-based travel demand modeling, the development of the activity-based approach to travel demand analysis has generally been driven by the recognition that individual trips do not stand in isolation, but are motivated by the desire to pursue activities distributed in space. Furthermore, the recognition that the nature of activities, from which the travel derives is interdependent with a complicated physical and social milieu, has been accepted as an essential research foundation in activity-based travel demand modeling. The focus on inter-personal interactions, the interdependence among events and spatio-temporal features in previous research will be viewed as attempts to capture the linkages between features of the human environment and the activities in which humans engage.

The transition of the needs for transportation planning decisions from evaluating long-term, large-scale, investment-based, capital improvement strategies to understanding travel behavior responses to shorter-term, small-scale, congestion management policies has produced an underlying momentum to give prominence to activity-based travel demand modeling.

There has been a diversity of theoretical, methodological, and empirical approaches employed, though they seem to merely reflect the exceedingly comprehensive objective of attempting to understand the complex phenomena that is travel behavior. McNally (2000) identified several interrelated themes characterizing such activity-based approaches; methods and models generally reflect one or more of these themes.

1. Travel is derived from the demand for activity participation
2. Sequence or patterns of behavior, and not individual trips, are the relevant unit of analysis
3. Household and other social structures influence activity and travel behavior
4. Spatial, temporal, transportation, and inter-personal interdependencies constrain activity and travel behavior
5. Activity-based approaches reflect the scheduling of activities in time and space

The first is the restatement of the derived nature of travel demand and the second point attempts to further expand the concerns into interrelationship among multiple sequential activity episodes as a trip-chaining behavior in trip-based modeling. A variety of interactions within household and other social structures may produce inter-family constraints and a necessity for the linkages between people's behavior and social contexts. The emphasis on spatio-temporal constraints and transportation attempts to capture the activity and travel behavior dictated by the scarcity of time and resources in the built environment. Activity scheduling behavior under the human condition featured by interactions within such an environment that both motivates and constrains behavior is the focus of activity-based approaches. The motivational view of human behavior to engage in activities (Chapin, 1974; Bhat and Kopperman, 1993) and the constraints from time-space geography as a paradigm for understanding human movement (Hägerstrand, 1970) offer the potential to better understand how such linkages in physical and social structures affect the system.

Activity time allocation studies have been paid scattered research attention in a variety of disciplines over the last couple of decades. Time allocation behavior has been a major stream of research within a framework of activity time-use analysis to examine activity-based travel patterns. *Activity time-use analysis* generally focuses on the examination of time allocation behavior to different types of activities (work, maintenance, and leisure) over a specified time period (often, a day or a week), without direct consideration of the context in which activities are engaged (such as duration, location, and sequence)

It has been emphasized as one of themes above that activities are conducted by members of multi-person households subject to *intra-household interactions*, since ignoring the behavioral issues arising from within-household interactions on time or person allocation to various activities and travel can cause erroneous and misleading travel demand estimates. However, time-use behavior in the field of transportation has been largely examined based on the utilitarian resource allocation theory with an individual as the unit of analysis. In addition, although there have been a few recent exceptions in activity time-use analysis that consider intra-household interactions and group decision-makings, models of the household joint decisions with utility maximization framework tend to be for discrete choices.

In terms of household time consumption behavior spent in household maintenance activities, there has been some rigorous theoretical and empirical agreement based on *traditional gender roles* (i.e., the man at work and the women at home). However, increased participation of married women in the market work force over the past few decades implies the households with women actively participating in the market work force have to adjust the timing and organization of their daily activities accordingly. Moreover, there have been several reasons for which women increase their earning powers that are theoretically characterized as a crucial determinant in a task allocation mechanism at household level, including a late marriage, a steep fall in fertility rate, and a sharp rise in divorce rates. As a result, such changes in the social environment leading to higher wages for women may initiate a shock to the traditional social system, and thus induce us to investigate the corresponding mechanism of how total household labor resources are utilized in the family. In this respect, it should be noted that a specific population group interested in this research would be dual-worker households.

Along with an activity time-use analysis, *an activity episodes scheduling process* in activity-based travel analysis has been an intense focus in estimating individual activity patterns (an ordered sequence of activity episodes with associated attributes). Intra-household interactions and group decision-making mechanism within the context of the modeling of activity episodes participation have been receiving increasing research attention. The essential part of the group decision-makings in a household for the activity episodes scheduling process includes the task allocation process with household maintenance activities. However, the daily model system which is a dominant activity scheduling process may have a critical limitation because household maintenance activities (or individual leisure activities) may have a longer inter-episode duration than single day, which causes *uncertainties of the activity participation* within the daily model framework. In this reason, it is necessary to consider stochastic optimization problem or multi-day framework. From the perspective of utility maximization theory, a multi-day framework can be used to generate a household activity program, which is transformed into an individual activity program within a multi-person framework, based on underlying assumption of having long-term, total household utility maximized from the activity participation by selected members across activities over days. In addition to uncertainties of activity participation, the stochastic characteristics of urban environment such as *uncertainties of transportation network* need to be taken into account in the activity scheduling model. Such an activity episode scheduling process can be incorporated, with intra-household interactions in a new model framework, to develop new generation of activity-based microsimulation models of travel demand.

In sum, despite of various advantages of activity-based approach, such as the theoretical soundness and positive potential for policy evaluation, the activity and travel pattern from current activity-based travel demand analysis still seems to be insufficient to properly estimate and predict the relevant travel behavior.

1.2 Research Motivation

As mentioned above, the research effort to understand how household member interact each other to optimize household available resource had been made in many disciplines. This is probably because the study of time and task allocation behavior in the household has been consistently capable of capturing the attention of scholars in different areas of study. Consequently, a research effort to relevantly integrate these different theories and approaches constitutes a substantial path on which to make progress in activity-based travel demand analysis.

In the field of economics, there has been continuous research interest to investigate intra-family interactions regarding household time consumption, with optimal combination of market labor work and individual leisure demand by each household member. On the basis of the seminal work by Becker (1965), three main theoretical models have been developed in this line of research: the unitary model, the cooperative bargaining model, and the collective model. Among them, the household resource allocation model in collective settings from the pioneering work of Chiappori (1992, 1997) has achieved theoretical and empirical support in a number of prior studies. Since the collective model has a minimal assumption that a household as a unit of analysis is characterized by each member's utility function and decisions by them reach Pareto-efficient outcomes, it appears to have features to fill a gap existing in a current activity time-use analysis.

Moreover, intra-family interactions with respect to total household labor hours (sum of market work hours and housework hours) also need to receive substantial research attention to closely examine the sensitive response to the change of social context over a couple of decades. Various theories previously proposed about the intra-family division of total household work-load can be used to explain and/or estimate an actual pattern in current society. Possible interactions that we want to focus on in the division of total household labor hours among family members include "within-person activity interactions" and "cross-person interactions".

An activity scheduling process attempts to incorporate the set of choice facets in an interlinked decision stream to derive estimates of the activity and travel pattern decisions, subject to physical and social constraints. This research to model how households allocate household maintenance activities is motivated by numerous prior models and statistical evidences on activity time-use, and is further motivated to develop the household activity scheduling model which takes care of uncertainties originated from stochastic nature of urban environment. In particular, "gender convergence" between household heads with respect to total labor hours can be considered as the most important foundation to develop a modeling framework for a task allocation process in the household activity scheduling model. Further specifically, this study attempts to find a way to reflect the claims for the *equality* matters at individual level and the needs for *optimality* problems at household level at the same time based on the plausible evidences provided by empirical data.

1.3 Research Objectives

The dissertation is dedicated to an in-depth exploration of within-household interactions by theoretical specification and empirical development of a household resource allocation model based on a utility maximization framework with the household as the unit of analysis. Furthermore, the dissertation presented here also aims to propose a model of a household activity scheduling process with a task allocation mechanism based on plausible evidence based on a literature of empirical research.

To develop a leisure demand model along with domestic production function, the structural model of household resource allocation in a collective setting is constructed by beginning with a specification of indirect utility and parallels to Roy's identity. In addition, to examine how to share responsibilities for market work activities (i.e., paid work) and housework activities (i.e., unpaid work) in a household, a simultaneous equations model is specified and tested by balancing various plausible interactions against possible competing theories. Data availability from the 2004 KTUS (Korean Time-Use Survey) provides a subjective opinion on a traditional view of gender-specific roles in a family and allows us to develop an ordered probit model to explore the inter-relationship between attitude on the traditional gender roles and socio-demographic characteristics, as well as the actual hours spent on paid work and housework at the individual level. More importantly, after formalizing and estimating these model structures, regardless of the location of activity participation, the same modeling framework is applied to the case where the hours spent on out-of-home activities are only considered to closely examine the time allocation behavior for the activities that directly induce travel demand.

For the household activity scheduling model, a three stage modeling framework is proposed, where the model employs a joint decision-making process for household task allocation at the household level and individual activity sequencing process at the individual level. The key idea of the proposed mechanisms for the household collective decision process is that household members attempt to undertake the activities with higher priority while achieving some degree of the fairness on the time expenditure for household sustenance. Furthermore, the model is designed to incorporate a *week-based* *stochastic repeated simulation* with learning mechanism to capture the systematic variations over different days of the week and the uncertainties from urban environment such as activity duration and travel time.

1.4 Organization of the Dissertation

The major focus of this dissertation is to develop activity-based models originating from two main research directions in activity-based travel demand analysis: an activity time-use analysis and an activity episode scheduling analysis. To this end, this research is organized as follows.

Chapter 2 provides an overview of the relevant theory, models, and analysis techniques that are prevalent not only in the activity-based travel demand analysis literature but also in other related disciplines such as economics. Intra-family resource allocation models, belonging to activity time-use analysis, are theoretically structured and empirically developed in Chapter 3 as structural models of household resource allocation in collective settings and intra-household time allocation to housework. Chapter 4 proposes an ordered probit model to explore the inter-relationship between an attitude regarding traditional gender-specific roles and individual and social characteristics of each decision maker. Chapter 5 describes the development of household activity scheduling model and conducts small simulation experiments to demonstrate the proposed framework within the hypothetical environment. Finally, Chapter 6 concludes by summarizing the contribution of this research and further suggesting some directions for future research.

Chapter 2

Literature Review

2.1 Activity-based Modeling of Travel Demand

The activity-based approach is gradually replacing the conventional trip-based model, commonly referred to as the four-step model, over the last few decades. The four step model has been proven sufficient for evaluating the relative performance of capital-intensive transportation infrastructure investment over the years characterized by rapid growth in population and economic activity. Since 1970, however, the shortcomings originating from such macroscopic structures have been recognized as not sufficient to consider more complex policy actions such as travel demand management. Therefore, a more behaviorally-oriented activity-based approach to travel demand analysis is evolving to replace the traditional statistically-oriented trip-based modeling approach. The derived nature of the travel demand to participate in activities dispersed spatially is the other important motivation for activity-based approach to now dominate transportation system analysis research.

2.1.1 Theoretical Foundation

The seminal works by Hägerstrand (1970), Chapin (1974), and Fried et al. (1977) have been accepted as the intellectual underpinnings in the field of activity-based travel demand modeling.

Hägerstrand (1970) introduced the time-geographic consideration of human behavior that limits the options of activity engagements in the form of constraints. These constraints include coupling constraints, authority constraints, and capability constraints. Coupling constraints take place when we participate in activities in the presence of the other persons or with some other resource links. The activity associated with joint participation or automobile resources to be shared in a household would be examples. Authority constraints arise from the institutional restrictions to the physical and social resources that control activity participation. Examples include store opening hours, land owners' property rights, and public transportation schedules and routes. Capability constraints define activities that are restricted by biological needs, like food and sleep.

Chapin (1974) posited the motivational theory of basic human desires to engage in activities. Although it has been difficult to explicitly model what motivates people to engage in activities, various factors were found to impact activity participation pattern including household memberships, commitments, and responsibility in social life. Following the long line of motivation theory from the beginning of human history, Maslow (1970) also proposed a hierarchy of human needs, consisting of five levels with a pyramid structure. The four lower levels are grouped together as deficiency needs associated with physiological needs, while the top level is termed growth needs and is associated with psychological needs.

Fried et al. (1977) postulated that the urban structure in which individuals continue to adapt his or her behavior not only motivate behavior but also constrain it by physical and social resources. The adaptation process in their theory reduces the imbalance between current or expected needs and resource opportunities and constraints in the structure (Bhat and Koppelman, 1999). The dynamic process of behavioral adaptation by Fried et al. (1977) has been viewed as the first to encompass the major theoretical features addressed above, constraint and motivation, in a single system.

2.1.2 Definitions

Much progress on the studies of activity patterns and time uses has been made in a variety of disciplines by linking the concepts and theories developed in other disciplines to their specific concerns over the last couple of decades (Ettema and Timmermans; 1999). Consequently, it will be necessary to provide a consistent terminology with the concepts used in various areas of study.

In the most general form of the activity-based approach, the term activity refers to a collection of episodes of the same type or purpose over any time horizon. The term activity episode, which has been often used indistinguishably with the activity, refers to discrete activity participation over some time unit without interruption by the same person and at the same location.

This study classifies activity into three categories, as in the most disciplines (which usually have slightly different terminology): Work, Household Maintenance and Leisure. In this research, these names of three types of activities can be interchangeably used with some other terms. For example, the work activity is interchangeable with the market work (or paid market work), a general term used in economics. Household maintenance and leisure activities are meant to be same as housework and social activities, respectively, in this study.

Work (or paid market work) activity refers to supply of work and work-related activities. Household maintenance (or housework) activities represent the household chores/errands that are performed to satisfy the common needs for household maintenance by one (or more) of household members. Household maintenance (or housework) activities include meal preparation, shopping, house cleaning, child care, and picking up/dropping off passengers. The sum of hours spent on work (or paid market work) activity and household maintenance (or housework) activity is often called total work hours. On the other hand, leisure (or social) activities refer to a kind of activities that are more closely related to individual interests than household needs. Therefore, such activities belonging to individual leisure needs are unlikely involved in the allocation components for intra-family task distribution process. Leisure (or social) activities motivated by personal cultural and psychological needs include recreational, and entertainment activities.

The activity and travel pattern is a basic unit of analysis and drives from a rather complex decision process for scheduling and execution of household activity program. *A* *household activity program* represents a subset of a household's activity agenda[1] that household members jointly determine to perform over some particular time horizon. An individual activity program is taken as an outcome from the household joint decision process to allocate the household responsibilities to household members in a manner subject to environmental and household constraints over a specified time period (a single day or week). More detailed explanation for the generation of a household activity program and an individual activity program is provided later in section 5.2.2.

An individual activity program may contain allowable information about the attributes of activity such as duration, location, frequency or time-window for participations, and turns into an individual activity pattern through an individual activity sequencing process. The activity schedule, the major focus of activity-based travel demand modeling, is a planned trajectory by the appropriate sequencing of activities within the activity program.

2.1.3 Activity-based Travel Patterns

As pointed out by Bhat and Koppelman (1999), activity-based travel analysis can be

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[1] *Household activity agenda* represents the universal demands to engage in activity over an open time horizon.

broadly characterized with two different modeling issues: activity time-use analysis and activity episode analysis[2]. Activity time-use analysis relates to an understanding of how individuals or households allocate time to different types of activities (work, maintenance, and leisure) over a specified time period (often, a day or a week). Activity episode analysis refers to the elaborate structure to generate individual activity episodes and determine their associated attributes such as spatial, temporal, sequencing, and travel decisions of participation. Since activity time-use analysis will be considered in the subsequent sections in more detail, the following section will primarily focus on the activity episode analysis.

Activity episode analysis

The studies in activity episode analysis can be explored from many different angles. Some studies focus on participation decisions regarding a single activity episode, where other studies analyze individual decisions associated with multiple activity episodes and

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[2] Note that *activity time-use analysis* and *activity episode analysis* are often interchangeably termed *activity time allocation analysis* and *activity episode scheduling analysis,* respectively, in some literature.

their sequencing. Activity analysis with multiple activity episodes can be further categorized by whether focusing on activity episode scheduling with the generation of activity episodes and their attributes as exogenous inputs, or on both activity episode generation and scheduling simultaneously. In this chapter, we explore the studies in activity episode analysis from two major classes based on methodological application: Econometric-based Applications and Simulation-based Applications.

Econometric-based Application

Econometric-based model has been extensively applied to the conventional trip-based travel demand model system because of its well-established theoretical basis, empirical tractability, and professional familiarity. Econometric-based model mainly represented by Random Utility Maximization (RUM, McFadden, 1973) model relies heavily on multinomial logit and nested logit choice models in travel demand modeling. The model system originates from consumer choice behavior in micro-economic theory and assumes that individuals maximize the utility with a finite choice set of alternatives. The choice dimensions in the conventional travel demand model were confined to the individual trips or trip chains in the daily schedule. On the other hand, the daily activity schedule system explicitly represents the choice of a daily activity pattern (Bowman and Ben-Akiva, 1996).

The daily activity schedule system producing daily activity pattern involves a number of choice elements. A decision in the RUM model should be made to either consider the daily activity pattern as s single simultaneous choice or consider it as the outcome set of sequential choices (Rindt, 2003). The simultaneous choice model uses the measures of expected utility, where the utility of a conditional choice influence the utility of a conditioning choice by the expected utility (Adler and Ben-Akiva, 1979; Recker et al., 1986b). The sequential choice model is implemented as a nested logit system, where the choice of tours takes place at higher level of the nesting and more detailed attribute choice at lower level (Kitamura, 1984b; Bowman and Ben-Akiva, 2001).

Criticisms, however, are primarily associated with the facts that RUM is limited to specifying the final choice with main attribute variables rather than the actual choice process (Garling et al.,1994) and that individuals do not seem to make optimal choices with simultaneous utility maximization under the complex choice situations before performing actions (Lee and McNally, 2003).

Simulation-based Application

Computational Process Models (CPM) have been a key part of simulation-based model application based theoretically on Hägerstrand's time-space prisms. Computational Process Models (CPMs) using context-dependent heuristics have been identified as suitable to explore how individuals might use heuristics to solve their scheduling problems as an alternative to conventional discrete choice modeling (Garling et al., 1994). Several models classified into CPMs are reviewed in what follows.

STARCHILD (Recker et al., 1986b) often referred to as the first operational activity based model consists of three comprehensive components. In the first step, the household activity program is generated exogenously. Secondly, the household activity program is reduced to set of feasible patterns using a method extended from Lenntorp (1976) and CARLA. Finally, a pattern choice model selects one of the feasible patterns. This model has been criticized because the assumption of individuals' exhaustive search for feasible patterns and the simultaneous pattern choice model appear to be still unrealistic.

SCHEDULER (Garling et al., 1989) focused on the choice of activities, location, and departure times could be identified as a model closer to the basic conceptual framework of CPM about how individuals organize their activities. There are two kinds of long-term memory in the model: a Cognitive Map stores information about spatiotemporal constraints and a Long Term Calendar contains information on duration and the utility of activities. The Long Term Calendar selects a set of activities with the highest priority and corresponding duration. For these activities, decisions of when and where they can be performed are made by the Scheduler Module, under the spatiotemporal constraints in the Cognitive Map.

SMASH (Ettema et al., 1993; 1996), as an extended version of SCHEDULER, attempts to compute utilities for the choice rules of inserting, deleting, or substituting activities from activities already scheduled as well as those to be scheduled, to build a complete schedule. This model relies on a given detailed activity program similar to that required by STARCHILD, and assumes unrealistic human computational capacity to evaluate all possible choices.

AMOS (RDC, 1995) is a policy-specific switching model, which starts with a given detailed activity schedule and adjusts it in response to changes in the travel environment. Initially, a Response Option Generator employing a neural network (trained with input of both revealed and stated preference data) chooses basic responses to a baseline schedule and a policy change. Next, an Activity Travel Pattern Modifier inspects the feasibility of the resulting, adjusted activity travel pattern based on a context-specific search rule, and then the Acceptance Module assesses whether the feasible activity pattern will be accepted or rejected. If no adjustment and acceptable alternatives are found, the process goes back to initial step. This model has the potential to predict short-term responses to specific policy changes, but it also has some weaknesses in that it requires much survey data, a validation process, and an exogenous forecast of a baseline schedule for each application of the model. Thus, this model is not considered as a general model but as a very specific application to a particular data set and problem.

ALBATROSS (Arentze and Timmermans, 2000), viewed as the most advanced computational process model, consists of three main components (in its current development) to reflect the complete activity scheduling process. Firstly, the Scheduling Engine acting, as a core of the system, employs sequential steps to produce a daily activity schedule through correspondence with other two components: an Inference System and Decision Rules. Broadly speaking, mandatory activities from long-term commitments or from household responsibilities initialize the schedule, and then determine the position of flexible activities and the profile of added activities in a sequential way. The Inference System, working with fixed rules, provides the scheduling engine with information on space-time constraints and choice heuristics for location choices to replicate the human decision process. Every step in scheduling engine needs to use the decision rules represented as a collection of condition-action pairs derived from observed data. ALBATROSS proposed the fundamental issue that choice behavior is continuously adapted through day-to-day learning. However, ALBATOSS relies on cross-sectional diary data and is still not implementing learning and adaptation features on the short-term basis in its present form.

2.2 Resource Allocation Model

2.2.1 Development in transportation

Regarding the resource allocation problem, this section covers the developments in transportation on two issues: time-use modeling and intra-household interactions. Opposed to activity episode (scheduling) models reviewed in section 2.1.3.1, time-use analysis examines the allocation behaviors of time to some specified target activity types over a specified time window, ignoring the duration, location, sequence, and the time of day (or day of the week) of activity engagement.

2.2.1.1 Time-use modeling

Extensive efforts have been made on individuals' daily allocation of time to different types of activities in a number of research areas. The theoretical bases underlying the time-use research have primarily been on utilitarian resource allocation theory (Kitamura, 1984a). As initially explained in Kitamura (1984a), the utility within the utility maximization setting theoretically satisfies the assumption of an increasing utility function with diminishing marginal utility. In this framework, most of previous research takes the form of utility as a function of time allocated to a specific activity and exogenous variables (Kitamura et al., 1996; Fujii et al., 1999; Bhat and Misra, 1999; Meloni et al., 2007). In addition, various types of discrete-continuous choice model have been developed for activity engagement and time allocation in discretionary activities because of "selectivity bias" problem (Kitamura, 1984a). Note that *selectivity bias* arises when the discrete choice of activity engagement is not exogenous but endogenous to the continuous time allocation problem. Such a consideration occurs when time allocation behavior is examined over a relatively short period of time (a day, in most studies) in which some types of activities such as discretionary activities may or may not be performed on a given day.

Decisions regarding the activity engagements based on the assumption of maximization of individuals' satisfaction (utility, in the more general term) necessarily involve time or money expenditures. In general formulation, utility is derived from the consumption of market goods and services through activity participation that requires time and money input (DeSerpa, 1971; Evans, 1972). The trade-off between time and money expenditures is well described in the interactions between labor work time and money available for the consumption of goods. For example, the more hours in labor work activities, the more money available to consume market goods, but the less time available to spend on other activities (Kraan, 1997).

The consumption of market goods by the expenditure of out-of-pocket money is an important element to investigate in some research areas of economics. It is often necessary to purchase market goods and durable goods to participate in some types of activities. In general, the participation on some types of activities requires money costs, whereas labor activity generates an amount of money. However, the data collection on money expenditures on separate activity types, along with time expenditures, is difficult to complete. On the other hand, time-use data collection (as reviewed in section 2.3) has been conducted in many countries over the world. Moreover, the research efforts made in resource allocation models by transportation researchers tend to be focused on time expenditures rather than on money expenditures. Thus, most literature (reviewed below) belonging to time-use analysis in the transportation area are based on the some assumptions for the research to focus on time expenditures only.

Kitamura (1984a) proposes a discrete-continuous model of activity engagement and time allocation decisions in which engagement in and allocation of time to out-of-home discretionary activities and mandatory activities is modeled. In order to consider the substitution between in-home and out-of-home activities, Kitamura et al. (1996) formulates a doubly-censored Tobit model that extends a previous model by incorporating two types of discretionary activities (i.e. in-home and out-of-home activities including travel time). Such an extension arises from the particular interests from the perspectives of travel demand analysis in that activity participation at different locations is strictly correlated with the generation of trips. Thus, the examination of substitution effects between in-home and out-of-home activities has been a significant theme in some time-use literature by different modeling structures (as reviewed by Lawson, 1996; Lu, 1996; Kraan, 1996; Bhat and Misra, 1999; Meloni et al., 2007).

Kraan (1996) proposes a weekly time allocation model accounting for the allocation of time to in-home, out-of-home, and trips for discretionary activities. Since the model uses one week individual time use data, the frequency for discretionary activities is incorporated in the model. Possible question on the relationship between the number of times an activity is performed and the total travel distance (or time) for that activity seems to be ignored by assuming independency between two variables. Unlike any other models in the stream of time-use research, Kraan does not incorporate personal characteristics as explanatory socio-demographic variables. Instead, Kraan subdivides total population into several groups by the amount of their time and money budgets in the sense that the allocation pattern of time and money will be different for various population groups depending on people's life-cycle stage. Specifically, classification of time and money budgets is given by employment status (i.e., working full-time, part-time or unemployed) and income level. Thus, the parameters estimated for particular population groups are assumed to represent personal characteristics as the exogenous variables.

Misra and Bhat (1999) proposes a continuous utility-maximizing resource allocation model between in-home and out-of-home locations and between weekdays and the weekend. The model focuses on the fractional time allocation of total weekly discretionary activity time such that a continuous model structure becomes valid. They also analyze macro level of the temporal characteristics with differentiation of weekend from weekdays.

Meloni et al. (2007) formulates a model to separate the time spent traveling from the total amount of time engaged in out-of-home activities using the form of a two-level N-Tobit model for reproducing a sequence of coupled choices. In the first level, a modified

Tobit represents individuals' decision-making that divides overall discretionary time into in-home and out-of-home activities. A Tobit structural system in the second level involves how the time is rebudgeted among three types of activities (i.e., in home, out-of-home and trips) by two equations for describing the time trade-off between activities inside and outside the home and between trips and in-home activities.

2.2.1.2 Intra-household interactions

The activity-based approach for travel demand modeling focuses on modeling the activity scheduling process of individuals over a period of time (e.g. a day or week). However, it has been accepted that individuals would not be independent decision makers, isolated from other household members regarding activity and travel participation (Bhat and Pendyala 2005). Rather, household members interact with each other, and thus the activity travel patterns by them are necessarily inter-dependent. Consequently, the primary motivation for investigating intra-household interactions would be the belief that the modeling such travel behaviors will have important practical implications to evaluate various types of traffic management strategies. For example, the responses to traffic management systems and real time traveler information may be differently estimated when considering household interactions and resulting allocation of household tasks through a bargaining process within household, compared to assuming an individual-level model. In this respect, intra-household interactions and group decision making mechanisms that consider both individual preferences and household requirements have been receiving increasing research attention within the context of the modeling of the activity and travel participation.

Broadly speaking, the previous research works associated with the collective decision making of household members have focused on how tasks and resources of the household are allocated (Golob and McNally, 1997; Wen and Koppelman, 2000; Vovsha et al., 2004) and/or how the joint participation of the activity and travel is determined among household members (Fujii et al., 1999; Scott and Kanaroglos, 2002; Gliebe and Koppelman, 2005; Bradley and Vovsha, 2005; Srinivasan and Athuru, 2005; Zhang et al., 2005). A number of previous studies tend to explain the intra-household interactions in the household tasks allocation process by including the presence of other household members or other member's characteristics as the explanatory variables in the utility specification of individuals. However, there have been increasing research efforts to accommodate the interactions more explicitly in the varying modeling structures. In this framework, it should be noted that the decision making entity should be household not the individual, which has been a typical unit of decision making in the standard econometric models such as discrete choice models.

Recent research in this area of activity participation or activity allocation within explicit household interaction frameworks can be classified into three broad categories[3]: (a) time allocation, examining the propensity of household members to allocate time to various types of activities in a daily or episode level (Gliebe and Koppelman, 2002; Zhang et al., 2005; Srinivasan and Bhat, 2005), (b) person allocation, focusing on which type of household members (i.e. role-level (head/spouse), segment-level (male/female), employment status (worker/nonworker) or person level) undertake given household tasks (Bhat and Srinivasan, 2004; Vovsha et al., 2004; Srinivasan and Athuru, 2005; Srinivasan and Bhat, 2005), and (c) tour (pattern) allocation, defining daily activity (or tour) patterns of all household members and estimating choice models (Gliebe and Koppelman, 2005; Bradley and Vovsha, 2005).

Researches reviewed above have been mainly based on econometric models such as structural equations models (Golob and McNally, 1997; Fujii et al., 1999), seemingly unrelated regression models (Srinivasan and Bhat, 2005; Zhang et al., 2005) and discrete

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[3] Some literature may fall into more than one category due to the complexity of the model structure.

choice models (Gliebe and Koppelman, 2002; Vovsha et al., 2004; Bradley and Vovsha, 2005; Srinivasan and Athuru, 2005; Gliebe and Koppelman, 2005; Srinivasan and Bhat, 2005), and they have reported explicit recognition of intra-household interactions and group dynamics for activity and travel participation.

2.2.2 Development in economics

The consumer theory in the microeconomics shows how a utility function can represent the preference of the consumer, in which an individual economic agent is assumed to choose actions that maximize their utility function subject to a budget constraint. This framework has provided essential support for empirical analyses of individual behavior in numerous economical and sociological situations. In a similar context, the process of household decision making has been understood by adoption of utility theory, now called neo-classical family economics. Therefore, economists have been actively emphasizing that economic models for household resource allocation have to take into account the interaction effects among household members that are fairly plausible even in the individual decision making process. This argument equivalently means that the unit of analysis regarding the resource allocation problem should be the household instead of the individual.

2.2.2.1 Household leisure demand and labor supply model

The seminal work known as the "New Home Economics" (NHE) theory by Becker (1965) has underlain a variety of subsequent household theories with fairly fundamental concepts in which households are assumed to combine time and market goods to produce more basic commodities that directly enter their utility functions. Whereas the conventional economic model directly includes market goods in the utility function, the "commodities" in his theory are produced through the combination of market goods as well as a certain amount of time, and produce direct utility. In addition, household theory often requires specific assumptions about household technology to transform goods and time into commodities.

In fact, a major contribution of Becker's model was to draw attention to the possibility of applying economic analysis to the allocation of time among activities. For example, if we assume that a consumer derives no process benefits from time spent in domestic production or in the market, then the problem of the person reduces to allocating time among home production, market work, and leisure consumption so as to maximize utility (Pollak, 1999). The market labor work is necessarily assumed to require time spent in the market and provide money income that will be the input for the consumption of market goods or service (Becker, 1981). More broadly, the discussion about time allocation in a household starts at the point that each individual is concerned with the five determinants: leisure time, the home-produced commodity, time devoted to home production, the market goods, and time devoted to market work. Under these conditions, additional assumptions about the structure of preferences on household or its members are needed to find the combinations of time spent in each activity under which household optimally utilize the household resource. There are three preference structures (as summarized in Browning et al., 1994): altruistic preference, egotistic preference, and caring preference.

$$\begin{aligned}
&Altruistic: U_i = F_i(l_m, c_m, l_f, c_f; z),\ i = m, f \\
&Egotistic: U_i = v_i(l_i, c_i; z)\ i = m, f \qquad (2.1) \\
&Caring\ \ : U_i = F_i(v_m(l_m, c_m; z), v_f(l_f, c_f; z)),\ i = m, f
\end{aligned}$$

where m and f denote male and female, l_i denotes i's leisure time and c_i represents i's goods consumption.

The altruistic form is the more general structure, where the consumption of leisure and goods by partner enters into each other's utility function. On the other hand, egotistic preference lets each person only care about his or her own consumption. In caring preference, each person cares about the other's private consumption only insofar as it produces the other person's some individualistic welfare. The egotistic framework can readily be extended to the case in which agents are "caring" (Chiappori 1992).

In the early stage of research on household leisure demand and labor supply, it is almost universally assumed that the multi-person family can be treated as though it has single set of goals (Blundell et al., 1986; Blundell and Walker, 1986). However, the realization of the fact that this stands on weak grounds justifies replacing this traditional approach with more complicated alternatives (Apps and Rees, 1988; Chiappori, 1992; Lundberg and Pollak, 1996; Apps and Rees, 1997; Chiappori, 1997), as explained in the following.

Unitary model

Application of neo-classical utility theory to household behavior and welfare primarily raises the distinct issue of the identity of the decision maker. Moreover, it requires a proper answer on how to reconcile the individualistic theory of the consumer with the reality that people tend to live, eat, work and play in families.

The initial approach on household consumer demand and labor supply was the "unitary" model assuming that all household members act as if they maximize a unique, well behaved, single utility function with a single pooled budget constraint. This unitary model has been called by various different names, including the consensus model (Samuelson, 1956), the altruist model (Becker, 1981), and the common preference model (Lundberg and Pollak, 1996).

The consensus model by Samuelson was grounded in the assumption that each family member with own utility function that depends on a private consumption of goods and services, necessarily agrees to maximize a consensus social welfare function of their individual utilities subject to a joint budget constraint. This outcome of consensus among family members might be interpreted as an outcome of decision making by a person who has a dominant power such as a household head or the oldest member in the family. While the consensus model does not provide an explanation of how this consensus is achieved in the family, Becker's altruist model explains how resources are distributed within the family. Becker presumes that one altruistic parent whose utility function reflects a care for the happiness of other family members is enough to induce the purely selfish but rational kids to choose actions that maximize the joint family income by acting in an apparently unselfish way. As a result, the distribution of resource ends up maximizing the altruist's utility function, subject to the family's resource constraint.

Although the unitary model is very simple and convenient for generating demand functions, it will not be very beneficial primarily because neo-classical utility theory applies to individual and not to households (Browning and Chiappori, 1998). Along the line of this criticism, a large number of empirical studies have shown that the specific restrictions imposed by unitary model are rather weak and rejected.

In particular, the family income pooling assumption has been strongly rejected in many empirical studies (Schultz, 1990; Bourguignon et al., 1993; Phipps and Burton, 1993; Fortin and Lacroix, 1997; Browning and Chiappori, 1998). The rejection of income pooling implies that earned and unearned income received by the husband or wife significantly affects demand patterns when total income or expenditure is held constant (Lundberg and Pollak, 1996). In addition, the unitary model imposes the hypothesis of symmetry of the Slutsky matrix[4], and a number of empirical studies have found the hypothesis to be inconsistent with household data (Kooreman and Kapteyn, 1986; Fortin and Lacroix, 1997). The rejection of symmetry implies that a constrained maximization problem with a single utility function can not produce the outcome to rationalize the choices of household (Browning et al., 1994).

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[4] The Slutsky restrictions impose the symmetry of cross wage effects on the compensated labor supply of each household member.

Cooperative bargaining model

The family can be characterized by cooperation and conflict. Since late 1970s, intra-family bargaining models have been examined because unitary model could not take into account the intra-household gender interaction with heterogeneous preferences and bargaining power distribution between household members. Bargaining structure based on cooperative game theory was first established for this cooperative bargaining problem. The cooperative bargaining model typically assumes two-member household each with a utility function (U^M, U^F) and a threat point (T^M, T^F). The threat point represents the reservation utility received when an agreement is not reached in the bargaining process.

The solution of this problem in the utility space can be characterized as shown in Figure 2.1. The Nash bargaining solution satisfying Pareto efficient outcome lies on the utility-possibility frontier, meaning that the bargaining solution is the allocation that maximizes the product of agent's utility on the bargaining set given by the function:

$$Max \;\; N = (U^M - T^M)(U^F - T^F)$$

subject to the full income constraint.

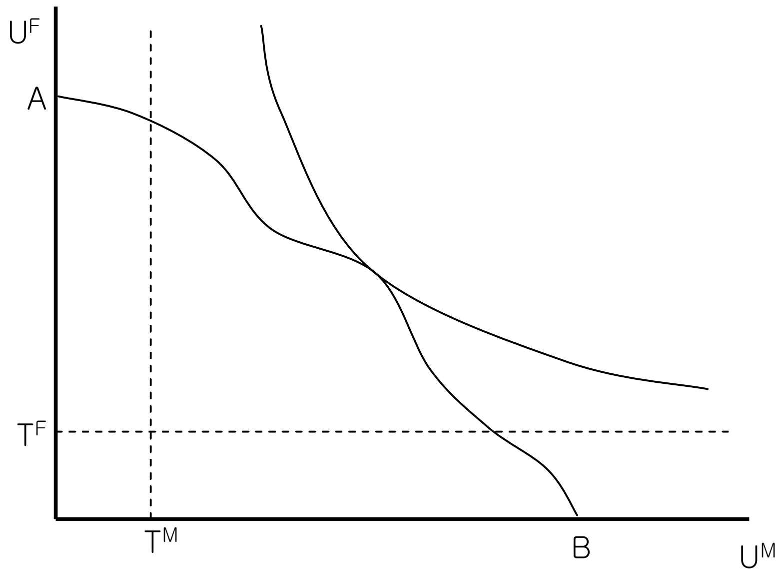

Figure 2.1: The Nash Bargaining Solution

The threat point is a critical element for each member's utility in the Nash bargaining solution, along with prices and household total income. There are two approaches depending on how to define the threat point: the divorce-threat bargaining model and the separate spheres bargaining model.

In the divorce-threat bargaining model by Manser and Brown (1980) and McElroy and Horney (1981), it is assumed that people choose to get married because the utility received after marriage is bigger than the utility before marriage. Thus, the threat point in the divorce-threat bargaining model is the solution to the constrained maximization program of each person subject to his or her respective budget constraints outside the marriage. McElroy (1990) proposes that the threat point depends on, in addition to prices and individual income, an extrahousehold environmental parameter (EEP). EEP may include conditions in the remarriage market, policies regarding marriage, and income available to divorced male and female. Therefore, family demands as the solution from divorce-threat marital bargaining will be influenced by these parameters.

The divorce-threat bargaining model has been criticized because the divorce threat point, external to the marriage, seems unrealistic, and binding and enforceable agreements are assumed. The separate spheres bargaining model of Lundberg and Pollak (1993) identifies the threat point that is internal to the marriage within the framework of Nash bargaining model with non-cooperative threat point. The threat point in the separate spheres bargaining model is given by an inefficient non-cooperative equilibrium within marriage in the provision of household public goods. For example, even during household conflict, each spouse voluntarily takes the responsibility of household public goods, maximizing his/her own utility subject to own budget constraint in an inefficient marriage, given the actions of their spouse. The allocation of marital responsibilities may reflect social norms rather than preference or productivity difference between spouses in a particular marriage (Lundberg and Pollack, 1996). Although divorce may be the ultimate threat available to marital spouses in disagreement, a non-cooperative marriage may be a more plausible threat in day-to-day marital bargaining (Lundberg and Pollak, 1996). Moreover, such a cooperative bargaining model with non-cooperative threat bargaining model does not assume to involve binding and enforceable agreements, leading to self-enforcing.

Collective model

As pointed out above, there has been evidence from a number of studies that one cannot treat many-person households as a single decision maker as in the unitary model. On the other hand, as a viable alternative to the unitary model, Chiappori (1988, 1992) suggests household models in the collective settings explicitly taking into account the individualistic elements of the situation. In other words, the collective model typically represents households by a pair of individual utility functions, together with a particular decision rule. The two assumptions of the collective model are that each person in the household has his/her own preferences, and that the outcomes of intra-household conflict and collaboration are Pareto-efficient resource allocation.

Usually, the household consists of two individuals ($i = m, f$), where m denotes the male and f denotes the female, each characterized by a utility function u_i. The decision process is cooperative, thus leading to Pareto-efficient outcomes. Following the Chiappori (1992), member i consumes leisure time (assignable and observed) in quantity l_i and a Hicksian composite consumption goods (unobserved) in quantity x_i, whose price is set to unity.

The collective model with the most general framework is that member i's welfare can depend on his or her spouse's consumption of goods and labor supply, which is consistent with altruism. As shown above, altruistic member i's preference is represented by well behaved utility function $U_i = F_i(1-t_m, x_m, 1-t_f, x_f; z)$, where t_i represents time spent on market work activity and x_i denotes market goods consumption. However, it should be noted that information on only labor supplies is not sufficient to uniquely identify this type of the collective model (Chiappori et al., 2002). Therefore, they impose additional identifying assumptions that each household member is egotistic. Formally, the form of individual utilities is $U_i(1-t_i, x_i; z)$, where U_i is strictly quasi-concave, increasing and continuously differentiable, for $i = m, f$.

Let z denotes a N-vector of preference factors, such as education or number of children. Also, w_m, w_f, and n are the wage rate of male and female and household non-labor income respectively. In addition, let T represent total time available.

In the collective framework, the Pareto-efficient solution comes from:

$$\underset{(l_m, l_f, x_m, x_f)}{Max} \quad \mu U_m + (1-\mu) U_f$$

$$\textit{subject to} \qquad (2.2)$$

$$x_m + x_f \leq (T - l_m) w_m + (T - l_f) w_f + n$$

where, $\mu = \mu(w_m, w_f, d, n; z)$ is a continuously differentiable weighting factor belonging to [0, 1]. As is well known, any point on the Pareto frontier can be obtained as a solution to a program of this type (for some well-chosen U). The vector of distribution factors, d, only contained in the weighting factor is defined as variables that affect the household member's bargaining position but neither preferences nor the joint budget set. The examples of distribution factors, d, include sex ratio on the marriage market and the rules governing divorce. Thus, a change in d does not affect the Pareto frontier but only the equilibrium location on it. Therefore, in the case where μ is assumed to be constant, the collective model corresponds to the unitary model with weakly separable household preference (Chiappori et al., 2002).

The second fundamental welfare theorem enables the Pareto-optimal solution of Equation (2.2) to be decentralized in a sharing rule interpretation as below (Chiappori, 1992). More specifically, under the egoistic preference framework and the existence of some sharing rule function, $\Phi_i(w_m, w_f, d, n; z)$, each individual i solves the following program:

$$\underset{x_i, l_i}{Max}\ U_i(x_{i,} l_i; z)$$

$$subject\ to \qquad (2.3)$$

$$x_i \le w_i t_i + \Phi_i(w_m, w_f, d, n; z) \text{ for } i = m, f$$

where $\Phi_i = \Phi$ if $i = m$ and $\Phi_i = n - \Phi$ if $i = f$.

Chiappori (1992) shows that the income sharing rule interpretation is exactly equivalent to the initial setting (Eq 2.2), that is, that the existence of a sharing rule implies efficiency of the collective decision process. The sharing rule interpretation of the collective model postulates that the allocation decisions can be seen as if they were generated by a two-stage procedure. In the first stage, decisions are made on the allocation of non-labor income between household members. In the second stage, each member separately maximizes their utility subject to the budget constraint allocated to them in the first stage, consequently determining individual labor supply (or, equivalently, leisure demand)[5]. In this procedure, the function Φ (called the sharing rule) describes how non-labor income is distributed, as a function of wages, non-labor income and other

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[5] For now, total time available is only used for labor supply and leisure time so that labor supply demand and leisure demand are just like a mirror image.

observable characteristics. The sharing rule reflecting the outcome of the decision process can be seen as a reduced form of the actual procedure. Browning et al. (1994) emphasize that this is suggested based on the hypothesis that allocation decisions can be seen, instead of considering this decision process as the actual procedure, as if such a two-stage program were yielding them if preferences are egotistic (or caring) and outcomes are efficient.

Chiappori (1992) also shows that the collective framework with egotistic preferences imposes certain restrictions on the labor supply (or, equivalently, leisure demand) functions as follows.

Let

$$\begin{aligned} t_m &= t_m(w_f, \Phi_m(w_f, w_m, d, n; z); z) \\ t_f &= t_f(w_f, \Phi_f(w_f, w_m, d, n; z); z) \end{aligned} \qquad (2.4)$$

be the Marshallian labor supply function derived from the maximization of Equation (2.3) assuming an interior solution for both t_m and t_f.

Using equation (2.4), define $A = t^m_{w_f} / t^m_n$, $B = t^f_{w_m} / t^f_n$, $C_l = t^m_{d_l} / t^m_n$, $D_l = t^f_{d_l} / t^f_n$. Then, whenever $t^m_n . t^f_n \neq 0$, the following results hold,

$$
\begin{aligned}
\Phi_{w_m} &= \frac{AD}{D-C} \\
\Phi_{w_f} &= \frac{BC}{D-C} \\
\Phi_{y} &= \frac{D}{D-C} \\
\Phi_{d} &= \frac{CD}{D-C}
\end{aligned}
\qquad (2.5)
$$

Chiappori (1992) shows that the derivatives of the sharing rule Φ can thus be recovered up to an additive constant using the estimated labor supply parameters. Several empirical applications and hypothesis testing (Fortin and Lacroix, 1997; Blowning and Chiappori, 1998; Blundell et al., 2001; Chiappori et al., 2002) have been found not to be able to reject the collective view of intra-household decision and have been successful in recovering the partial of the sharing rules, using data on individual labor supply of two-earner households.

2.2.2.2 Household labor supply with domestic production in a collective model

As reviewed in the previous section, the issue of intra-household decision behaviors has been continuously exploited in collective settings since the pioneer work of Chiappori (1988, 1992). To consider the bargaining power between household members, the household's decision in his theory is modeled as if the individuals first shared their combined non-labor income and then maximized their individual utilities subject to separate budget constraints. He then shows that minimal assumptions are sufficient to yield testable restrictions on labor supply functions and enable the derivatives of the sharing rule to be recovered using observations on leisure for household members. The sharing rule describes the process of intra-household negotiation.

However, as Apps and Rees (1997) and Chiappori (1997) pointed out, an important drawback in the initial form of collective model is that the estimation of the sharing rule is generally based on an unsatisfactory definition of pure leisure. More specifically, all time not spent on the labor market is considered as pure leisure so that time devoted to domestic production can be measured as leisure time. Such a framework could easily provide a biased evidence on the within-household decision process as lower female labor market hours would be equated to a larger share of the household's full income in the corresponding sharing rule. The situation, however, might be the case that domestic production is being traded for monetary income, yielding little real leisure time. This argument is consistent with the important insight of Becker (1965): time not spent in market labor supply is used for household production as well as for pure leisure.

Chiappori (1997) also shows that the intra-household distribution of resources can be retrieved up to a constant when domestic goods are marketable and the household production function exhibits constant return to scale. Moreover, the income sharing rule can be identified up to an additive function of individual wages when the domestic goods are non-marketable with constant return to scale of the production function.

Model structure

According to Apps and Rees (1997) and Chiappori (1997), the Pareto-efficient decision process with domestic production in collective settings can be interpreted as a two-stage procedure where household members agree firstly on some efficient domestic production plan and then on how to distribute the resources within the household.

With the newly added domestic production function, the notation is the same as the models in the previous sections. Thus, three goods are involved: composite market consumption goods x, with price unity; domestically produced goods, y, whose implicit price is determined within the household when it is not traded externally; and pure leisure, l, whose price is the market wage. Let the production function of domestic goods be $y = H(h_m, h_f; z)$, where h_m and h_f represent time spent on domestic productions by male and female respectively. Therefore, individuals achieving Pareto-efficient resource allocation have strictly quasi-concave and increasing, twicedifferentiable utilities $u_i(x_i, y_i, l_i; z)$, $i = m, f$, where x_i and y_i denote a vector of consumption of market goods and domestic goods by member i, respectively.

The second theorem of welfare economics can be applied to show that the household equilibrium can be decentralized as follows (Chiappori, 1997). First, maximizing the profit or net value of domestic production produces the optimal allocation of time to domestic production. That is, with strict concavity of the domestic production function, the optimal allocation of time to domestic production is formally written as a profit maximization problem:

$$\underset{h_m, h_f}{Max} \ \pi = pH(h_m, h_f; z) - w_m h_m - w_f h_f \qquad (2.6)$$

where w_m and w_f denote marginal wage rates and p is the (shadow) price of the domestically produced goods. The imputed profit in the domestic production will be added to the other income flows below.

In the second stage, consumption is decentralized by the appropriate choice of shares $s_i (i = m, f)$ of total full income. Thus, individual i maximizes:

$$\underset{x_i, y_i, l_i}{Max} \ u_i(x_i, y_i, l_i; z)$$

$$\textit{subject to} \qquad (2.7)$$

$$x_i + py_i + w_i l_i = s_i^*$$

where s_i^* stands for member i's part of household's full income. In this case, the full income of the household can formally be written:

$$s_F = s_m + s_f = (w_m + w_f)T + n + \pi(p^*, w_f, w_m) \qquad (2.8)$$

where, $T(= t_i + h_i + l_i,\ i = f, m)$ represents a time constraint as the maximum hours available.

To be consistent with Equation (2.3), Equation (2.7) requires the additional explanation. The following derivation can allow us to understand Equation (2.7) in a similar way as Equation (2.3), and it also makes it easy to provide the identification condition of the sharing rule.

In the first stage, the household arrives at the optimal allocation with,

$$\underset{h_m, h_f}{Max}\ \pi = pH(h_m, h_f; z) - w_m h_m - w_f h_f \qquad (2.6)'$$

Individual i then maximizes:

$$\underset{x_i, y_i, l_i}{Max}\ u_i(x_i, y_i, l_i; z)$$

$$\textit{subject to} \qquad (2.9)$$

$$x_i + py_i \leq w_i t_i + (py)_i + \phi_i$$

With ϕ_i satisfying:

$$\phi_m + \phi_f = n \qquad (2.10)$$

$$w_m t_m + w_m l_m + w_f t_f + w_f l_f + (py)_m + (py)_f + \phi_m + \phi_f = s_F$$

where $(py)_f + (py)_m = py$, $\pi_i (= (py)_i - w_i h_i,\ i = m, f)$ is the profit share corresponding to the sharing of the value of household production, and $y(= y_m + y_f)$ is a constraint on the total consumption of household goods.

The parameter ϕ_i is a function of $(w_m, w_f, d, n, p; c, z)$ which reflects the way that non-labor income is distributed, as a function of wages, non-labor income, and distribution factors, as in the model with market work activities only, but now with the addition of the prices of domestically produced goods p and the characteristics of household production c.

2.2.2.3 Household interactions on time allocation to housework

Time is one of the most important economic resources in a household, and housework continues to consume a substantial fraction of household's time (Hersch and Stratton, 1994). Time, however, spent on household maintenance has gone largely unnoted compared to time spent on market labor work or leisure activities. It is probably because people think that women do the housework and it is not subject to change through policy (Sousa-poza et al., 2001). However, we are living in the days where more women are actively participating in the labor market, which leads us to pay more attention to understanding the mechanisms and the determinants of the allocation of time assigned to unpaid housework.

Becker's human-capital theory (1991) points out that benefits from specialization and exchange will lead to one member of a household specializing in home production and the other specializing in market work. He argues that such divisions of household's time are partly because of biological (or intrinsic) differences and partly because of different experiences and different investment in human capital. For example, even if a husband and wife initially have equal market ability, childbearing will cause the wife to put comparatively less energy and time on human capital investment for market work. Moreover, since housework is more effort intensive than leisure and other household activities, married women spend less energy on each hour of market work than married men working the same number of hours. Consequently, there may be a "vicious cycle" where a wife economizes on the energy expended on market work by seeking less-demanding jobs that, in turn, keeps the wife's earnings power lower than the husband with the same market human capital. Thus, the household will have more possibility to find it optimal for wife to specialize in home production and husband to specialize in market work. In this respect, Gronau (1986) and Becker (1991) propose that the wage plays a crucial role in the home production/specialization models as the shadow-price of time. Anxo and Carlin (2004) find the solid support in the closer test of the Becker/Gronau home specialization model. They show that the cross-wage elasticity on husband's share of housework is positive. Moreover, a negative own wage elasticity of housework for married women is recognized.

As review in section 2.2.2.1, the cooperative bargaining models of the family proposed by Manser and Brown (1980), McElroy and Horney (1981), and Lundberg and Pollak (1993, 1996) are also consistent with such a vicious or virtuous cycle. In a two-adult-member household (i.e., a husband and a wife), each spouse has a utility function that depends on his or her satisfaction, and the bargaining power of each person is related to the disagreement outcomes. If agreement is not reached, both spouses receive the payoff represented by a "threat point". Such cooperative bargaining models include divorce-threat bargaining model by Manser and Brown (1980) and McElroy and Horney (1981), and the latest model with separate spheres bargaining approach by Lundberg and Pollak (1993, 1996). Two models are differently characterized by derivation of threat point. That is, divorce-threat bargaining model defines threat point as the utilities associated with a default outcome of divorce and separate spheres bargaining model identifies the threat point with a non-cooperative equilibrium of time allocation within the marriage. In both models, higher wages for women raise the women's threat point, improving her bargained utility in the marriage, and thus she is more likely to reduce a share of home production, increase home consumption time (leisure) and/or invest in market-related human capital

(Carlin, 1991). Such a favorable circulation for women is called a “virtuous cycle” as opposed to the vicious cycle of the past.

Hersch (1991) shows that women spending more time on housework earn lower wages, but the same thing is not necessarily true for men. Hersch and Stratton (1994) discuss the amount of time spent on housework and the division of that time between working spouses. They also find a vicious cycle resulting from the anticipation of greater household responsibilities for women over their lifetime, and resulting in exacerbating the earnings differential, both directly and indirectly. On the contrary, they also report some evidences indicating that younger women are spending less time on housework and more time in the labor market, which might cause a virtuous cycle, meaning that gender difference in work histories and housework time may be diminishing.

2.3 Time-use Data Collection

Time-use behavior has been examined in a variety of study area such as economics, social science, and planning to examine how people allocate their time between work, family, leisure, and other activities. Activity-based travel demand modeling also requires time-use survey data containing all activities performed by individuals over the course of a day or longer periods. In particular, it is essential to understand the individual travel behavior derived from the analysis of both in-home and out-of-home activities in response to changing travel conditions. This is because an examination of how individuals substitute out-of-home activities for in-home activities can help us estimate when trips are generated or suppressed. Likewise, time-use data is expected to provide useful insight into how household members divide up their duties and thus help policy decision makers make more informed decisions, such as how a particular policy might affect people's behavior

Time-use data are collected and published on a regular basis in many countries, including Canada, Korea, United States, Germany, Australia, Japan, New Zealand, and South Africa etc[6]. Table 2.1 summarizes data collection methods and response rates of several international time-use surveys. With the exception of Canada, the countries represented were chosen because they collect diaries from more than one member of a household.

The next section will introduce American Time Use Survey (ATUS) and Korean Time

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[6] It is told that the ATUS coding system was designed to make sure that time-use information in the United States could be compared, at broad levels, with information from other countries.

Use Survey (KTUS) in more detail.

Table 2.1: Summary of Time-use Surveys (adapted from Schwartz et al., 2002)

Household survey and sponsoring agency	Sample	Methodology	Response rate
GSS 1998, Cycle 12, Time Use Survey, Statistics Canada	Sample of household obtained by random-digit dialing. One eligible respondent 15 years or older per household	Computer-assisted telephone interview of 24-hour-recall diary	78 percent at individual level
1997 Australia Time Use Survey, Australian Bureau of Statistics	All eligible household members 15 years or older in 4,100 households	Self-completed 24-hour diary	72 percent for all members of the household; 84 percent for one member of the household
1998/1999 Time use Survey, Statistics New Zealand, Ministry of Women's Affairs	National sample of 7,200 households. Two eligible respondents per household	Self-completed 48-hour paper diary, individual questionnaires, personal visits	72 percent for both members of the household

2.3.1 ATUS (American Time Use Survey)[7]

2.3.1.1 Historical background

Various organizations have conducted time-use studies in the United States in the past. In the earliest studies, time diaries were collected from farm housewives by the U.S. Department of Agriculture during the 1920s and early 1930s.

The University of Michigan and the University of Maryland conducted the majority of recent time-use studies. The University of Michigan conducted its studies in 1965, 1975-76, 1981, and 1982. The 1965 study surveyed adults ages 18 to 64 nationwide who lived in mainly urban areas and were employed outside the farm sector. Subsequent University of Michigan studies included all adults over 18 and their spouses. The University of Maryland conducted time-use studies of individuals nationwide in 1985, 1992-94, 1995, 1997-1998, and 2001. The 1985 study included data collection for children over 12. Subsequent University of Maryland studies focused mainly on adults age 18 and over.

Periodically, other private or government organizations conducted time-use surveys. These mainly targeted specific populations, such as children, or residents in a specific

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[7] http://www.bls.gov/tus/home.htm [lastly accessed : 02-05-2008]

metropolitan area. The American Time Use Survey (ATUS) is the first federally-funded, continuous time-use survey in the United States. It is jointly sponsored by the Bureau of Labor Statistics (BLS) and the U.S. Census Bureau. In 1997, BLS conducted the first pilot study and presented the results at a conference cosponsored by BLS and the MacArthur Network on Family and the Economy. The results of the pilot study were well-received, and BLS convened another working group that developed a more detailed plan. This plan became the foundation of the current American Time Use Survey. In 1999, BLS presented this proposal at a workshop sponsored by the National Academy of Sciences. The National Academy workshop endorsed the BLS proposal, and development continued.

2.3.1.2 Overview of ATUS

In 2000, the survey received official government approval and funding, and interagency collaboration between Bureau of Labor Statistics (BLS) and the U.S. Census Bureau began. The two agencies conducted a field test in 2001 and 2002. The American Time Use Survey went into full production in January 2003, and over 60,000 interviews have been completed through the end of 2006. BLS has already released findings from the 2003 through 2006 surveys. BLS is scheduled to release findings from the 2007 survey in the summer of 2008.

The ATUS sample is drawn from households that have completed their final month of interviews for the Current Population Survey (CPS), the Federal survey that is the source of the nation's unemployment rate. More specifically, households that have completed their final (8th) month of the current population survey are eligible for the ATUS. From this eligible group, households are selected that represent a range of demographic characteristics. Then, one individual age 15 or over is randomly chosen from each selected household to answer questions only once about his or her time use. This "designated person" is interviewed for the ATUS 2-5 months after his or her household's final CPS interview. In 2003, the sample consisted of approximately 39,000 cases, which yielded about 21,000 completed interviews. From 2004 to 2006, the sample was approximately 26,300 cases. This yielded an average of about 13,300 completed interviews per year in 2004, 2005, and 2006.

Reporting days are pre-assigned to respondents in order to eliminate any bias in the data that might exist if respondents reported at their convenience. Respondents are contacted for up to 8 weeks to conduct an interview on one of their pre-designated days.

All interviews are conducted over the telephone[8], with interviewers using Computer Assisted Telephone Interviewing (CATI), a system that automatically advances interviewers to the next question based on a respondent's answers to previous questions.

2.2.1.3 Limitation of ATUS

ATUS has been a very useful time-use data source to make statistical estimates across major demographic groups in United States, since 2003. Importantly, it is easy to access and download the ATUS microdata file (and it is free to get). However, ATUS has one major limitation to investigate the intra-household interactions in terms of time use behavior, which this study intends to focus on. This is because that ATUS has not included questions intended to measure the use of time by household members other than the individual who is selected as the "designated person". The designers of the ATUS, as well as many others, agreed that all adult members' time use in households should be measured to get valuable information on how household members make joint decisions

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[8] Households without telephones and those that did not provide a telephone number in the CPS can be selected for the ATUS sample. In a letter about the survey, BLS asks respondents in these households to call a toll-free number to complete the interview.

on their time allocation. However, on the basis of reasonable budgetary and data quality constraints, the ATUS has not decided to collect time use data from all adult household heads. Since the survey sample has been from the CPS, which gathers demographic and labor market information for the entire household, the background information from the CPS can allow the ATUS to be used in the analysis of the intra-household allocation of time. As pointed out in Schwartz et al. (2002), the absence of data on the time use of the respondent's spouse makes it difficult to analysis the distribution of time use across households, aside from examining averages. In particular, this study can not be satisfied with the measurement of time use by only one individual in a household.

2.3.2 KTUS (Korean Time Use Survey)

The 2004 Korean Time-Use Survey (KTUS) is the second survey to collect information on how Koreans spend time in their life, which have been conducted every 5 years since 1999. The data set is a representative sample of the Korea population. KTUS has used self-administrated paper diaries[9] to collect information on individual time use.

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[9] The paper diaries are essentially prospective because instructions in the survey are most likely "Tomorrow, write down all your activities", whereas telephone interviews are

The Korean Time-Use Survey consists of three questionnaires: a Household General Questionnaire, an Individual Questionnaire, and a Time-use Diary. The household general questionnaire collected data on household characteristics including house ownership, floor space, and vehicle ownership. The individual questionnaire collected data on individual characteristics including relationship to the head, gender, age, caring of infant, feelings about pressure of time, personal opinion on the traditional gender roles in the family, weekly working time, occupation, employment status, a monthly average of income, day-off, and subjective evaluation of time pressure and tiredness. In the time-use diary, as the main component of the survey, all household members aged 10 years and over were asked to record main and simultaneous activities in the time diary structured with 10 minutes intervals for the designated two days. All the self-recorded activities in the time-diary were coded into the three-digit activity codes designating 137 activity categories afterwards. All household members over the age of 10 were asked to keep the time-diary except those who were absent from home during the whole survey period, (or had serious physical or mental defects).

The sample frame for Time-Use Survey was generated from the multi-purpose

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retrospective by questions such as “What did you do yesterday?”.

household sample which was derived from the 2000 population and housing census using the three-stage stratified sampling methods. The 850 Enumeration Districts (ED) were selected from the multi-purpose household sample using the systematic sampling method and 15 households were selected in each ED. Thus, sample for 2004 Time-Use Survey consists of about 32,000 individuals aged 10 years and over and 12,750 households from 850 EDs.

At last, the number of respondents chosen in the final selection was 31,634 from 12,651 households, which implies 98.3% of valid response rate. Table 2.2 represents the distribution of the number of surveyed days according to day of the week.

Table 2.2: Distribution of the Number of Surveyed Days according to Day of The Week

Number of respondents	Number of days			
	Total	Weekday	Saturday	Sunday
31,634	63,268	37,955	12,704	12,609
-	-	60.0%	20.1%	19.9%

As shown in Table 2.3, paid work activity is performed more in weekday than in weekend by both genders, whereas both genders participate in housework and leisure activities during weekend days more than weekdays.

Table 2.4 represents the comparison of workers' average travel time for commute and business trip by 1999 and 2004. The average travel time for commute and business trip in 2004 has been increased from 1999 by 8minutes. On average, males appear to spend more time on commute and business trips than females, and employers spend more hours on both commute and business trips.

Table 2.3: Daily Average Hours spent in Activities by Gender and Day-of-week (age over 19, hour:minute)

	Weekday			Saturday			Sunday		
	Avg.	Male	Female	Avg.	Male	Female	Avg.	Male	Female
Total labor hours	8:37	8:33	8:41	7:30	7:11	7:47	5:57	5:11	6:41
Paid work	4:35	5:52	3:22	3:24	4:24	2:28	1:55	2:22	1:29
Housework	2:07	0:31	3:39	2:16	0:42	3:45	2:20	0:55	3:39
Study	0:12	0:14	0:10	0:06	0:07	0:05	0:04	0:05	0:03
Travel	1:43	1:56	1:30	1:44	1:58	1:30	1:39	1:50	1:29
Leisure hours	5:01	5:05	4:57	5:46	6:04	5:30	6:38	7:19	6:00
Others[1]	10:22	10:22	10:22	10:44	10:45	10:42	11:25	11:30	11:19

1 : Individual maintenance activities including sleeping, washing and eating, etc.

Table 2.4: Average Travel Time for Commute and Business Trip by Workers (hour:minute)

	Workers		Employee		Employer		Self-employed		Others	
	2004	1999	2004	1999	2004	1999	2004	1999	2004	1999
Total	1:20	1:12	1:29	1:22	1:44	1:30	1:01	0:59	0:40	0:38
Male	1:31	1:23	1:38	1:31	1:52	1:38	1:10	1:05	0:39	0:42
Female	1:05	0:57	1:16	1:08	1:05	0:51	0:43	0:44	0:41	0:37

Chapter 3

Intra-family Resource Allocation Model

3.1 Introduction

As in the Chapter 2, we will broadly classify activity-based travel analysis into two research areas: activity time-use analysis (ATA), and activity episodes analysis (AEA). The activity time-use analysis (ATA) examines how decision makers allocate analysis time to a different type of activities (work, maintenance, and leisure) over a particular day (of the week and/or weekend). It has been widely accepted that individuals with different characteristics may have different types (or amount) of substitution effects between different pairs of activities and between a particular activity and corresponding travel time. Therefore, investigation of the time allocation behavior to various activities and travel has satisfied the need to better understand an individual travel behavior. On the other hand, the activity episode analysis (AEA) generally focuses on the development of scheduling framework which attempts to simulate set of activity episodes to find individual activity pattern (see section 2.1.3 for a literature review in AEA). Such an activity scheduling model has been a main focus in the activity-based travel demand analysis so far.

Generally, as depicted in Figure 3.1, the core part of the resource to be allocated by human being would be 24 hours per day with the person specific ability (in other words, performance or productivity) that has been accumulated from previous experience and education thus far within a given social context. That is, each individual or decision maker need to deicide how to use their human resource to different types of activities. The participation in those activities will generate own outcomes; work activity will provide corresponding income, the commodity is defined as a output produced by housework activity and spending times in leisure activity is expected to generate pure utility. Depending on the type of preference of each individual, participation in work activity and housework activity may be also expected to generate utility. The income generated from work activity can be used housework activity and leisure activity to purchase market goods or services. The commodity produced by housework activity may be consumed in doing leisure activity. In this respect, time, 24 hours per day, with person specific ability would be considered as the core part of human resource to be allocated.

From the short term perspective, however, the number of hours at work activity and the amount of wage rate tend to be fixed because they would depend on the decision regarding job. Therefore, human resource allocation decision in a short run basis can be identified as how to allocate income and available hours to housework activity and leisure activity to produce maximum utility.

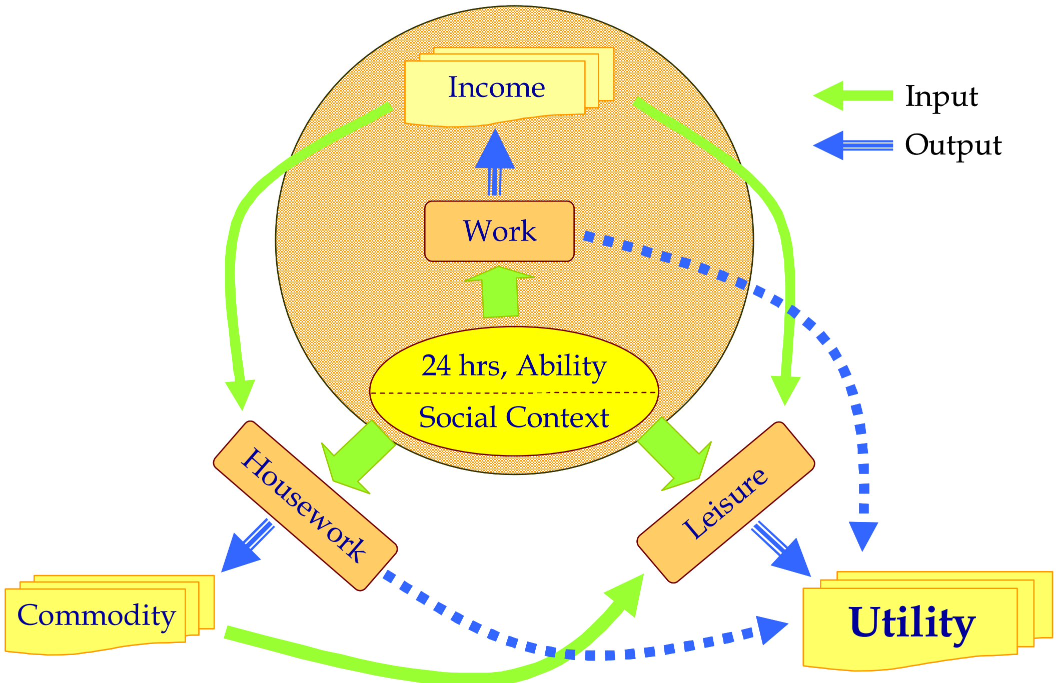

Figure 3.1: Human Resource Allocation Structure

Time-use behavior has been analyzed in the study area of economics as well as transportation for different purposes, as reviewed in Chapter 2. With a few exceptions, research works for the time-use behavior in the field of transportation have been largely focused on the model development based on the utility maximization framework at individual level. However, individuals live with other members in families whose membership confers rights and obligations that may influence the decisions that individuals make. Decisions regarding who or whether to participate in some household activities are most likely the results of the negotiation process for role or task allocation among household members. Further, travel decisions take place in the pursuit of activities to satisfy the household collective decisions. For example, the decisions possibly derived from the consensus among household members include: who will be engaged in paid market work; who is participating in the grocery shopping activities; and who is responsible for picking up/dropping off the household members who can not drive or do not have a driving license. Therefore, neglecting the behavioral issues arising from within-household interactions on time or person allocation to various activities and travels can cause erroneous and misleading travel demand estimates.

In this chapter, we will focus on the development of time-use model with the household as a unit of analysis. In particular, theoretical background and basic model structure follow the findings in economics. First of all, we develop the household labor supply model (or equivalently, leisure demand model) based on collective settings. In the earlier models, household labor supply model was developed without consideration of domestic production in collective settings. It, however, has been criticized primarily because a significant amount of time not used for market work might be used for domestic production so that the absence of domestic production can give rise to seriously misleading welfare conclusions (Apps and Rees, 1997; Chiappori, 1997). Thus, this study follows the theoretical and empirical attempts to estimate the leisure demand model with domestic production in collective settings. Secondly, since the collective model structure is relatively focusing on leisure demand model and the model for domestic production has some restrictions such as household production model with constant elasticity of substitution, we want to explicitly focus on household production model with time allocation behavior. This model development should be consistent with a set of theories that has been developed in many disciplines regarding household interactions in the household time allocation behavior. In this respect, intra-household time allocation to housework is modeled on the basis of various theoretical backgrounds. Lastly, a unified model will be proposed.

To minimize heterogeneity we shall be considering only paired male and female heads of households in which both partners participate in paid work activities. This restriction is necessary to eliminate any substitution effects among commodity demands and labor supply. We also assume that the selection into this group is exogenous for all the processes we deal with below.

3.2 Econometric Models and Data set

3.2.1 Econometric Models

In order to properly estimate the decision making process arising from an intra-family activity time allocation, the model system necessarily takes into account the reciprocal causation among household members. Thus, investigation of the time allocation behaviors to different types of activities within a household entails the system of equations that allows us to analyze complex relationships with several dependent or endogenous variables. In this section, we provide an introduction to the system of equations with focus on the model structures applied in this research: Seemingly Unrelated Regression Equations (SURE) and Simultaneous Equations Model.

Seemingly Unrelated Regression Equations (SURE)

The seemingly unrelated regression equations model (hereafter SURE model) structurally has a series of dependent variables that are considered as a group, but do not have direct interactions as simultaneous equations models do. In other words, the model system consisting of a series of equations has no apparent conceptual interdependence among the dependent variables. However, there is a mathematical relationship among the dependent variables, which makes it inefficient to estimate the equations with single equation techniques (Godwin, 1985).

The joint estimation of a system of equations which are seemingly unrelated implies that the error terms in the system of equations, at the same point in time, are correlated. This kind of correlation is often called contemporaneous correlation. The seemingly unrelated regression technique by Zellner (1962) considering this contemporaneous correlation in the error term can improves the efficiency of the estimates compared to OLS estimators. SURE follows the two-stage steps for the efficient parameter estimations. In the first step, a set of equations with cross-equation constraints are estimated but with a diagonal covariance matrix of error terms across equations. These estimates, in the second step, are used to calculate a consistent estimate of the covariance matrix of error terms, which is then used to obtain new parameter estimates.

For example, suppose that we are interested in the estimations of time-use behavior models for an individual to find the factors that affect time allocation behavior among market work, housework, and leisure activities. Possibly, any dependent variable among three time-use equations can not appear on the right hand side of any equation as independent variables. However, due to the time-available hypothesis of 24 hours per day for the individual, the identity relationships between three time-use equations arise, so that we can expect that there are three exhaustive and mutually exclusive types of time-use patterns. Therefore, dependent variables of three time-use equations for the individual are mathematically and empirically interrelated each other.

Another advantage of using SURE model is that the model is capable of joint estimation of system of equations which have cross equation restrictions pertaining to the some of equations.

In sum, equations that exhibit cross-equation correlation were called “seemingly unrelated” by Zellner (1962); the equations seem to be unrelated, but the additional information provided by the correlation between the equation errors means that joint generalized least squares estimation is better than single-equation least squares.

In the transportation literature, there have been few applications of SURE model so far. The recent applications include Srinivasan and Bhat (2005) and Zhang et al. (2005). Srinivasan and Bhat use SURE model to estimate daily in-home maintenance activity time invested by males and females, and Zhang et al. estimate the model of household time allocation spent on in-home and out-of-home activities using SURE framework.

Simultaneous Equations Model

The simultaneous equations model is an extension of the ordinary least squares (OLS) regression model, except that there are as many equations as there are dependent variables, some (or all) of which are interrelated. In other words, the simultaneous equations model estimates mutual relationships between multiple equations, where the dependent variables have no unidirectional causations but conceptually or mathematically interdependent relationships (Godwin, 1985). No temporal (or any other) ordering in causations among the dependent variables is an important premise for the theoretical specification of a nonrecursive model as a source of simultaneity.

The system of equations which are interdependent causes a potentially serious estimation problem if the structure of multiple equations system is not properly managed. This problem primarily arises because the estimation of multiple equations system using ordinary least squares (OLS) violates a key OLS assumption. For example, a correlation between regressors and error term will be present because of the inclusion of each endogenous variable in the right side of the other equation. This correlation violates the independency assumption between explanatory variables and error term in OLS specification.

The two-stage least squares (2SLS) method using instrument variables (IV estimator) can be used in this framework, which results in consistent estimators. More specifically, in the first stage, equation-by-equation ordinary least squares are estimated. In the second stage, two-stage least squares (2SLS) estimates for each equation in the system are obtained by using the estimated values of the dependent variables derived in the first stage as independent variables. However, as we have seen in the seemingly unrelated regression equations model, two-stage least squares would be inefficient compared with a generalized least squares (GLS) estimator that makes use of the cross-equation correlations of the disturbances.

In addition to two-stage least squares, the three-stage least squares(3SLS) method involves the third stage that uses a generalized least squares (GLS) approach for joint estimation of coefficients in the entire system of equations. The 3SLS in this process improves the efficiency of the estimates by taking into account all of the information about interrelationships in the system. For the comparison with the seemingly unrelated regression estimator, 3SLS does not provide the maximum likelihood estimator as SURE models do. The example of simultaneous equation problem may include a variety of cases in some transportation-related studies, one of which is how husbands and wives allocate their time in household tasks as this study intends to examine in the following sections. Based on the plausible assumption that husbands' and wives' time in a household are simultaneously determined within a family system, husband's time decisions (or wives' time decisions) have no unidirectional influence on wives' time allocation (or husbands' time allocation). Rather, causation takes place in both directions.

3.2.2 Data

The data used in this analysis are based on the 2004 Time-Use Survey for Korea. The Korean Time-Use Survey (KTUS) is a new comprehensive database of harmonized national time-diary data. The most important reason we choose to use KTUS data is that it contains all adult household members' use of time. Moreover, KTUS also collects time-use data for two days including weekdays and weekend days. The general introduction of the KTUS was detailed in section 2.3.2. As described in section 2.3.2, total valid sample size with the time-use interview is about 12,651 households with 31,634 individuals aged 10 years and over. The Time-Use Survey consists of three questionnaires: Household General Questionnaire, Individual Questionnaire, and Time-use Diary. All the household members over 10 years old were asked to record main and simultaneous activities in the time-use diary structured with 10 minutes intervals for two days.

For analysis purposes in this study, the data are intensively screened by several criteria as follows. First, we confine the sample to households with paired male and female household heads where both spouses are in the paid workforce. It is important to make sure that the underlying motivation of this study is that the basic decision unit is a household, not an individual. Therefore, data management from here on will be based on a household. Since the model systems in this study will necessarily use personal income and paid work hours to calculate the wage rate, households involving individuals who did not report personal income and positive paid work hours in the sample are discarded in the screening process. In order to avoid an unusual case, we also exclude the households with individuals who spent less than two hours in the individual maintenance activities which include sleeping activities.

After data screening so far, about 2,533 households remain in the sample available for the analysis. The last important point is that each respondent was asked to fill out the time-use diary for two days and thus they might be weekday-weekday, weekday-weekend or weekend-weekend. This study concerns about household time-use behavior in terms of market work, housework and leisure activities, and each type of activities has the different styles of time-use pattern on weekday or weekend. For example, for dual-worker households, leisure activities or even housework activities tend to concentrate on the weekend day unlike households with unemployed members. Therefore, to make sample data consistent as much as possible with this analysis, we decide to only focus on the households where both adult members have participated in the survey for two days with a weekday and a weekend diary each. Thus we end up with a sample of 1046 couple household. Table 3.1 provides the descriptive statistics for sample characteristics with means and standard deviation of the individual-specific and household variables used in this study. Statistics in the second column represent information about initial sub-sample data which is the one before we screen out the data not including either weekday or weekend diary (sample size is 2,533), whereas the third column describes the sample after the screening with the survey date standard (sample size is 1,046). The last column in Table 3.1 represents the sample data where we exclude households with individuals who have not spent their times on housework activities for two days at all (sample size is 770).

The average age in the sample is about 45 years for the men and about 41 years for the women. Education is classified into 3 categories (low, medium and high). Whereas more men have high level education, more women have medium level education. Men earn, on average, the monthly income about 1.9 times as high as women do. Relatively lower average income level of women than men may be attributed to the distribution of occupation types and proportion of full-time workers subsequently described.

Interestingly, the occupation type with the lowest proportion by male, service and sales workers, is the one with the highest proportion by female. On the whole, males are more likely to be employed in professional types of job than females, and females in service type of job. Although more men than women have a full-time job[10], the average working days per month[11] by both spouses have no differences. Furthermore, men spend more time commuting than women do, which is measured by more than a 1-hour commute to and from work. As household characteristics, the number of household vehicles is about 0.9 and the proportion of household with the presence of young child (0-7 years old) is about 20%. Unfortunately, the survey does not involve the question about the presence of child over 8 years old. Nevertheless, the number of children with an age under 7 years is very important measure to consider household time-use behavior in Korea because they need more care and attention from their parents.

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[10] To demarcate between the full-time workers and part-time workers, we use a question "How long time did you spend on paid work last week?". Full-time workers come under greater than 35 hours per week and part-time workers less than or equal to 35 hours per week.

[11] Average working days per month is decided according to a question "How many days did you not go to work last month".

Table 3.1: Sample Characteristics

Variables	Initial Sub-Sample	Second Sub-Sample	Third Sub-Sample
Age, male [means]	45.0 (9.6)	45.0 (9.4)	44.2 (9.7)
Age, female [means]	41.7 (9.1)	41.8 (8.9)	40.9 (9.1)
Educational attainment, male [%]			
- Low	23.06	22.56	20.34
- Medium	50.77	51.24	50.98
- High	26.17	26.20	28.68
Educational attainment, female [%]			
- Low	31.31	30.88	27.77
- Medium	53.22	53.82	55.02
- High	15.48	15.30	17.21
Monthly income level, male [means]	190.4 (111.1)	192.85(112.9)	198.9 (117.4)
Monthly income level, female [means]	106.7 (86.6)	107.6(93.0)	111.4 (99.2)
Occupation type, male [%]			
- Senior officials and professionals	9.87	9.94	10.56
- Associate professionals and clerks	23.37	23.71	25.68
- Service and sales workers	10.38	10.71	11.21
- Craft and machine operators	56.38	55.64	52.54
Occupation type, female [%]			
- Senior officials and professionals	8.65	8.89	9.91
- Associate professionals and clerks	19.70	18.07	20.86
- Service and sales workers	38.69	40.25	38.59
- Craft and machine operators	32.96	32.79	30.64
Full-time workers, male [%]	91.08	91.97	92.83
Full-time workers, female [%]	75.76	74.38	73.66
Monthly work days, male [means]	19.1 (7.2)	19.2 (7.1)	19.5 (6.9)
Monthly work days, female [means]	19.5 (7.0)	19.4 (7.1)	19.7 (6.8)
Commute hours > 1 hr, male [%]	32.49	27.25	24.12
Commute hours > 1 hr, female [%]	21.87	15.68	15.25
Number of household vehicles	0.9	0.9	0.9
More than one child < 8 years olds [%]	20.09	19.31	23.47
Number of observations	2,533	1,046	770

Average time-use patterns and income level by occupation type for male and female are presented in Table 3.2 and Table 3.3 based on the initial sub-sample and the third sub-sample, respectively. As explained before, the data based on the initial sub-sample contain the sample data regardless of a day-of-week surveyed, whereas the third sub-sample represent the data which involves individuals filling out the time-use survey for both a weekday and a weekend diary. Fir this reason, paid work hours in Table 3.2 are always greater than those in Table 3.3, whereas housework times and leisure times in Table 3.2 are always smaller than those in Table 3.3.

We provide time-use patterns and income level by occupation type because the model systems in the subsequent sections are concern about the statistical impact of individual wage rate on the household time-use pattern. Therefore, it is crucial to take a close look at the relationship between changes in time-use patterns and changes in income level. From Figure 3.2 and Figure 3.3 depicting average time-use patterns and average income level by occupation type, we can easily find that people belonging to occupation type with high income tend to decrease market work hours and increase leisure hours.

This pattern seems to represent the backward bending of the labor supply curve. As seen in Figure 3.4, if real wages were to increase from W1 to W2 then they would be willing to increase their hours worked from L1 to L2 because the worker will obtain a greater utility, due to their higher income. However, if the real wage increased from W2 to W3, then the number of hours worked per given period would fall from L2 to L3. This is because utility gained from an extra hour of leisure is greater than the utility gained from the income earned working. Basically, beyond the wage of W2 we see that the worker is being paid enough to sustain their current lifestyle without having to work more hours, therefore creating the backwards bend in the curve. (based on http://en.wikipedia.org)

Table 3.2: Average Time-use Patterns and Income Level by Occupation Type (Initial Sub-sample)

Occ. Type[1]	Proportion (%)		Paid work(hrs)		Housework(hrs)		Leisure(hrs)		Income (10^3won)	
	male	female	male	female	male	female	male	female	male	female
1	9.87	8.65	7.37	5.90	0.87	3.59	6.92	5.30	312	226
2	23.37	19.71	7.59	5.87	0.84	3.71	6.6	5.30	231	125
3	10.38	38.68	7.79	6.52	0.74	3.40	6.44	5.14	186	103
4	56.38	32.96	7.84	6.42	0.67	3.57	6.37	4.84	153	67
means	-	-	7.73	6.31	0.74	3.54	6.49	5.08	190	107

1. The occupation type consists of 4 categories as follows; 1: Senior officials and professionals, 2: Associate professionals and clerks, 3: Service and sales workers, 4: Craft and machine operators

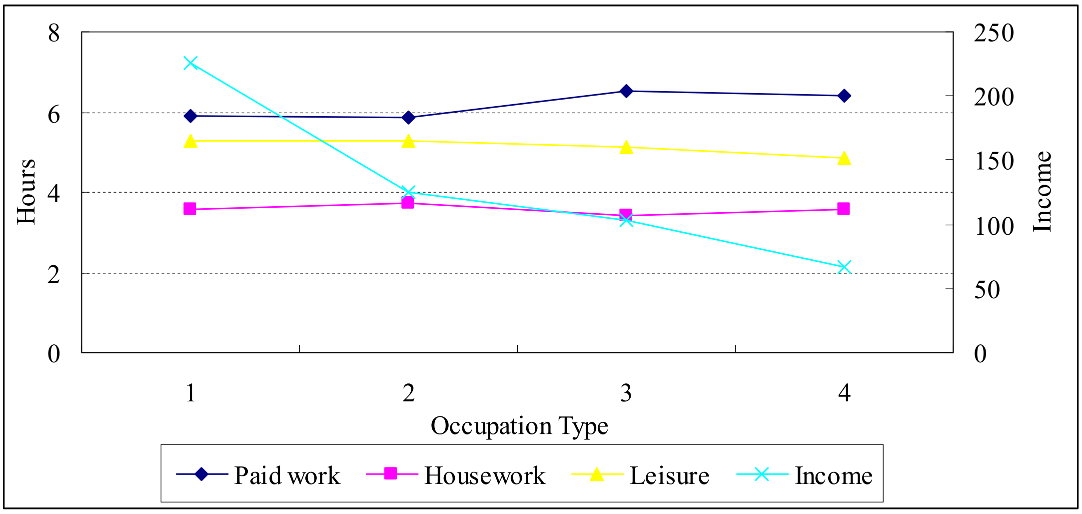

Figure 3.2: Female's Average Time-use Patterns and Income Level by Occupation Type based on Initial Sub-sample

Table 3.3: Average Time-use Patterns and Income Level by Occupation Type (Third Sub-Sample)

Occ. Type[1]	Proportion (%)		Paid work(hrs)		Housework(hrs)		Leisure(hrs)		Income (10^3won)	
	male	female	male	female	male	female	male	female	male	female
1	10.56	9.91	5.76	5.26	1.36	3.87	7.74	5.50	331	237
2	25.68	20.86	6.34	4.67	1.23	4.31	7.17	5.50	237	119
3	11.22	38.59	6.87	6.26	1.09	3.49	6.77	5.21	202	110
4	52.54	30.64	6.87	5.71	1.04	3.93	6.77	4.96	153	66
means	-	-	6.62	5.67	1.13	3.83	6.98	5.22	199	111

1. The occupation type consists of 4 categories as follows; 1: Senior officials and professionals, 2: Associate professionals and clerks, 3: Service and sales workers, 4: Craft and machine operators

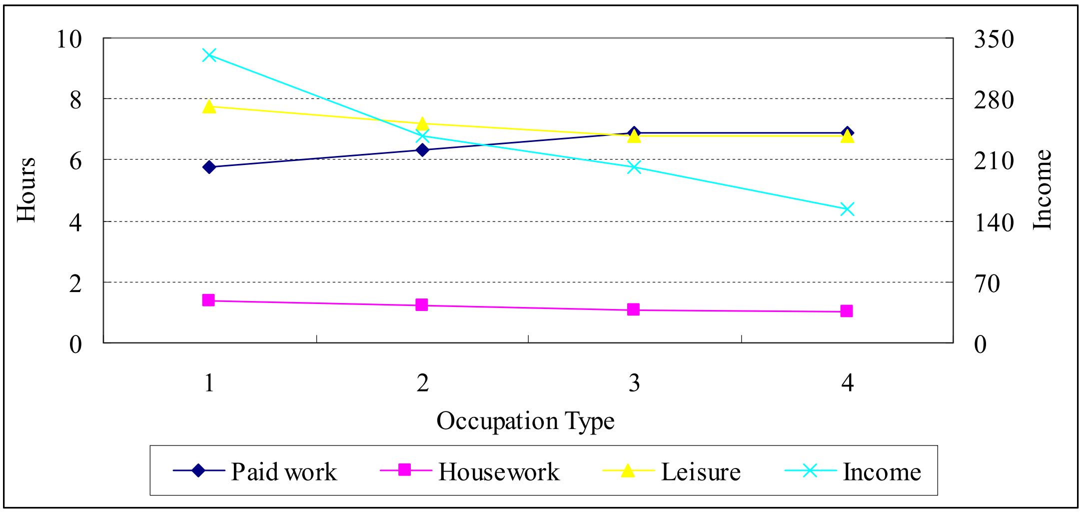

Figure 3.3: Male's Average Time-use Patterns and Income Level by Occupation Type based on Third Sub-sample

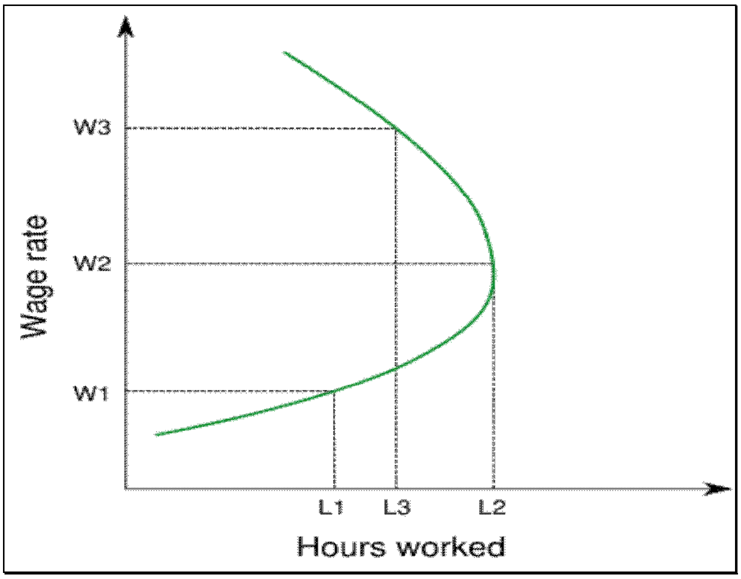

Figure 3.4: Backward Bending Labor Supply Curve

3.3 Structural Model of Household Resource Allocation in Collective Settings

3.3.1 Introduction

As seen in Chapter 2, there are alternative theoretical models to explain labor supply of households: the Unitary model, the Cooperative bargaining model, and the Collective model. That chapter provides theoretical developments and empirical findings based on the collective household resource allocation model that has been accepted as the most advanced model structure both on theoretical and empirical grounds. In the theoretical basis of collective model, a household member is characterized by his or her own utility function, and decisions by them are assumed to reach Pareto-efficient outcomes.

In fact, most previous empirical studies have concentrated research efforts in two areas. First, they try to test the parametric restrictions imposed in collective settings to achieve empirical support, and their results provide proper evidence in favor of the collective model. Second, they attempt to recover the intra-household distribution of income, which is a very important determinant in household collective decisions.

In this section, we accept previous empirical evidences as an underlying basis for the model system in this study. The purpose of this section is to develop the structural system of household resource allocation using observed behavior in collective settings. Two types of the models for household labor supply in the collective model were introduced in the previous chapter; one that is without domestic production, and the other where domestic production is internally considered. The focus of this study is on the estimation of the extended collective model with domestic production. Therefore, the system of equations simultaneously estimates domestic production plan, individual leisure consumption, and the intra-family distribution of household resource. We consider a two-member household where m represents the male (or husband) and f denotes the female (or wife).

The model structure in this section assumes the domestically produced goods to be tradable on the market. We can simply find many cases in which the same goods and services produced at home can be purchased on outside market, at a given price. For example, meals can be taken at home or at a restaurant, children can be kept at home or kindergartens and house cleaning can be done by household members or by someone hired from outside.

Two different sets of intra-family distributions on household resource allocation in collective settings are analyzed. First, the focus is on the application of the original model framework to the general case in which the entire time in doing any type of activity is considered no matter where the activities are performed (such as at home and outside the household). On the other side, in the second application, we use the same modeling framework to the case where the time spent on out-of-home leisure activities is considered. Travel is necessary to participate in leisure activities taken place in the separate locations outside home

3.3.2 Model Structure

We begin with formulating a theoretical model to provide a guideline for the econometric estimation of the household resource allocation model, taking account of some concerns raised in the previous chapter. As shown in the section 2.2.2.2, the second theorem of welfare economics can be applied to show that the household equilibrium in a collective setting with household production can be decentralized as follows (Chiappori, 1997). First, the optimal allocation of time to domestic production is found by maximizing the profit or net value of domestic production, which is equivalent to the marginal productivity conditions on the production function. In the second stage, consumption is decentralized by the appropriate choice of distribution of total full income under which individual finds consumption to maximize the individual utility function.

Domestic production model

The optimal allocation of time to domestic production is formally written as a profit maximization problem:

$$Max\ \ \pi = pH(h_m, h_f, m; z) - w_m h_m - w_f h_f - p_m m \qquad (3.1)$$

where, as before, h_m, h_f w_m and w_f denote hours spent on domestic production and marginal wage rates by males and females, respectively, $H(\cdot)$ is the household production function and p is the (shadow) price of the domestically produced goods.

Household production function represents the relationship of an output to input as a function of hours spent in domestic production by household members (h_m, h_f), intermediate goods purchased in the market (m) (whose price is represented by p_m), and the vector of characteristics of household and individuals (z). The intermediate goods imply production resources purchased in the market to be used as the input for domestic production.

We choose the conventional Cobb-Douglas functional form for the household production function:

$$H(\cdot) = h_m^{\tau_m} h_f^{\tau_f} m^{\rho} f(z) \qquad (3.2)$$

where $f(z)$` is the exogenous function explaining characteristics of household and individual with an exponential functional form: $\exp(\theta z)$. Thus, the objective function of the maximization problem (Equation 3.1) with production function and intermediate goods would be rewritten as:

$$Max \;\; \pi = ph_m^{\tau_m} h_f^{\tau_f} m^{\rho} f(z) - w_m h_m - w_f h_f - p_m m \qquad (3.3)$$

The first order condition of the maximization problem yields following equations in the endogenous variables h_m, h_f and m (for the derivation, see Appendix A):

$$\frac{w_m h_m}{\tau^m} = \frac{w_f h_f}{\tau^f} = \frac{p_m m}{\rho} = p_y H \qquad (3.4)$$

Substituting for $H(\cdot)$ with Equation (3.2) in Equation (3.4) and solving for the two endogenous variables for which we have data yields (for the derivation, see Appendix A):

$$\begin{aligned} \log(h_m) &= \vartheta_m + \beta_m \log w_m + \gamma_m \log w_f + \omega z + \varepsilon \log m \\ \log(h_f) &= \vartheta_f + \beta_f \log w_m + \gamma_f \log w_f + \omega z + \varepsilon \log m \end{aligned} \qquad (3.5)$$

where $\psi = (1 - \rho - \tau_m - \tau_f)$, $\beta_m = (\tau_f + \rho - 1)/\psi$, $\gamma_m = -\tau_f/\psi$, $\omega = \theta/\psi$,

$\varepsilon = -\rho/\psi$, $\beta_f = -\tau_m/\psi$, $\gamma_f = (\tau_m + \rho - 1)/\psi$

The parameter ψ reflects economies of scale. The characteristics of the Cobb-Douglas production function, assuming an elasticity of substitution between h_m and h_f of unity, impose the restrictions: $\gamma_m - \gamma_f = 1$ and $\beta_f - \beta_m = 1$. This constant elasticity of substitution can be clearly seen with rearrangement of the first two equations in Equation (3.4) as follows: $\log(h_m/h_f) = \log(w_f/w_m) + \log(\tau_m/\tau_f)$. In the final selection of model structure, the term with m is assumed to be absorbed into the intercept since there is no variability in m with cross-section data.

Leisure demand model

Given the production plan, the second decision problem is to maximize the individual utility function subject to the distribution of the household's full income. Utility is defined over three different goods: a composite market consumption goods, x, with price unity; a domestically produced goods, y, whose price p is determined on the market since it is assumed traded; and pure leisure, l, whose price is the market wage.

Thus, individual i maximizes the direct utility function with exogenously given wage rate w_i:

$$Max\ u_i(x_i, y_i, l_i; z)$$

$$subject\ to \qquad (3.6)$$

$$x_i + py_i + w_i l_i = s_i^*$$

where z denotes the vector of demographic characteristics of household and individuals and s_i stands for member i's part of household's full income. In this case, the full income of the household can formally be written:

$$s_F = s_m + s_f = (w_m + w_f)T + n + \pi(p^*, w_f, w_m) \qquad (3.7)$$

where $T(= t_i + h_i + l_i,\ i = f, m)$ is the maximum hours available, and n denotes household non-labor income.

Based on previous theoretical and empirical studies which are generally supportive of the collective model, this study proposes the semi-log functional form for leisure consumption as shown. To derive leisure consumption demand, we assume the following indirect utility functions (Stern 1986) that are consistent with the equations above and are composed of own wage rate, w_i, and sharing power, s_i:

$$\begin{aligned} v^m(w_m, s_m; z) &= (\exp(\delta_m w_m)/\delta_m)(\delta_m s_m + \lambda_m z + \alpha_m \log w_m) \\ &\quad - (\alpha_m/\delta_m)\int_{-\infty}^{\delta_m w_m} \exp(t)/t\,dt \end{aligned} \qquad (3.8a)$$

$$\begin{aligned} v^f(w_f, s_f; z) &= (\exp(\delta_f w_f)/\delta_f)(\delta_f s_f + \lambda_f z + \alpha_f \log w_f) \\ &\quad - (\alpha_f/\delta_f)\int_{-\infty}^{\delta_f w_f} \exp(t)/t\,dt \end{aligned} \qquad (3.8b)$$

The indirect utility functions are interpreted to give the consumer's maximal utility when faced with an amount of wage rate w_i and share of full income s_i. It represents the consumer's preferences over market conditions. This function is called indirect because consumers usually think about their preferences in terms of what they consume rather than wage rate.

In general, family member i's part of the full income, s_i, consistent with these equations, can be seen in a reduced functional form describing the determinants of the sharing arrangement:

$$s_i = s_i(w_m, w_f, n; z) \tag{3.9}$$

In this step, Roy's Identity is used to get a Marshallian demand function for an individual from some indirect utility function. More specifically, applying Roy's Identity to each of these indirect utility functions yields the individual leisure demand system as follows:

$$-v^m_{w_m} \big/ v^m_{s_m} = l_m(w_m, s_m) \tag{3.10a}$$

$$-v^f_{w_f} \big/ v^f_{s_f} = l_f(w_f, s_f) \tag{3.10b}$$

Roy's Identity is a major result in microeconomics having applications in consumer choice and the theory of the firm. The lemma relates the ordinary demand function to the derivatives of the indirect utility function. By solving the Equation (3.10a, b), we obtain the consumption of leisure demand, which is equivalent to the solution determined by Equation (3.6):

$$l_m = \alpha_m \log w_m + \delta_m s_m + \lambda_m \hat{z}$$
$$l_f = \alpha_f \log w_f + \delta_f s_f + \lambda_f \tilde{z} \tag{3.11}$$

System of equations for household resource allocation

Following the collective framework identified so far, we can construct the structural model for household resource allocation composed of domestic production and individual leisure demand together with the sharing function.

$$\begin{aligned}
\log(h_m) &= \vartheta_m + \beta_m \log w_m + \gamma_m \log w_f + \omega \dot{z} \\
\log(h_f) &= \vartheta_f + \beta_f \log w_m + \gamma_f \log w_f + \omega \hat{z} \\
l_m &= \alpha_m \log w_m + \delta_m s_m + \lambda_m \hat{z} \\
l_f &= \alpha_f \log w_f + \delta_f s_f + \lambda_f \tilde{z}
\end{aligned} \tag{3.12}$$

Note that $\hat{z}$ and $\tilde{z}$ denote vectors of exogenous variables that directly enter the demand function for leisure consumption by husband and wife, respectively, but do not appear in the sharing function, s_i. There may be variables in common among the vectors of $\hat{z}$ and $\tilde{z}$. The variables in $\hat{z}$ may not appear in $\tilde{z}$ (and vice versa); for example the age of husband may be in $\hat{z}$ but not in $\tilde{z}$.

The functional form of this model system is consistent with the case where domestic goods, y_i, can be sold or bought in the market. Thus, the price of household goods can be assumed to be exogenously determined on the market and identically applied to all households. As pointed out in Aronsson et. al. (2001), when domestic goods are tradable, the spouse's characteristics only influence the leisure demand through the sharing rule.

Formally, the male's relative share of household full income can be denoted by ξ_m such that $s_m = \xi_m s_F$, where $\xi_m \in [0,1]$. Of course, the female's relative share of full income can be represented by $\xi_f = (1-\xi_m)$. Consequently, these relative shares of full income reflect the ultimate outcome of the allocation decision process; it can be seen as a reduced form of the actual procedure.

As mentioned before, due to the identification problem in collective settings, we have to let κ denote a vector of exogenous variables entering the relative share function $\xi(\cdot)$ but not otherwise affecting individual leisure demands. In this case, the vector of the relative share function, κ, includes differences of variables that appear in $\hat{z}$ (or $\tilde{z}$) but not $\tilde{z}$ (or $\hat{z}$). In this study, we assume that these relative shares are determined by the differences in age, the number of years of schooling, wages rates between the household members, reflecting the income sharing arrangement. Therefore, the vectors $\hat{z}$ and $\tilde{z}$ will include the variables in common in the household, such as the number of children. Such a classification of the socio-demographic variables of household and individuals in this structured model system is consistent with the condition indicating that household goods are tradable on the market. We assume that the relative shares of full income can be modeled by a logistic function as follows:

$$\xi_m = 1/(1+\exp(\kappa)), \text{ and } \xi_f = 1 - 1/(1+\exp(\kappa)) \qquad (3.13)$$

As an econometric technique for model estimation, we consider the Seemingly Unrelated Regression Equations (SURE) model. In particular, Equation (3.12) contains not only interrelated multiple equations but also nonlinear relationships in some equations. Thus, the four equations in Equation (3.12) are jointly estimated using NonLinear Seemingly Unrelated Regression Equations (NLSURE) estimator [12]. As explained in section 3.2.1, it should be noted that the NLSURE model in this study can allow for the contemporaneous correlation of disturbances and cross equation restrictions on the parameters of the sharing rule equation and the domestic production equations.

3.3.3 Estimation Results

This section includes two different estimation results: one based on the total leisure

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[12] The econometric software package "LIMDEP, Version 7.0 by William H Greene" is used to estimate the coefficients of this model.

activity time and the other based on the out-of-home leisure activity time. The estimation results presented in Table 3.1 and 3.2 contain such two different versions of the empirical model.

Although the wage rates of both spouses are required as explanatory variables in the model framework, time-use surveys usually collect labor income data, not wage rate. The wage rates by each partner can be derived by dividing labor income by hours. Thus, gross monthly income (after tax) by individuals included in the time-use survey is used. Since gross monthly incomes were collected only in grouped form, mid-points are used in calculation. The time-use survey contains a question about the number of hours spent at work in the preceding week and the time-use diary with 10 minutes intervals for the surveyed two days. Since the results from the time-use diary are statistically more significant than those from responses to the question about the preceding week, this section presents the results based on the diary data.

The wage rate, as calculated above, may be more likely to contain measurement error and can be seen as endogenous to hours of work. To attack this problem, the imputed wage rates in this study are computed for males and females separately, which leads us to using instrumental variables estimates, rather than actual wages. OLS models are used to obtain the imputed wage rates on various instrument variables including age, education level, occupation type, the level of job positions, the type of home ownership, the number of vehicles, and some interactions terms of these variables. OLS models are assumed to be appropriate because the sample used in this analysis includes dual-worker households where both partners participate in paid work activities, so that no censoring data problem arises (i.e., selectivity bias).

The dependent variables in the SURE model are the logarithms of the number of hours spent on housework by male and female respectively, and the number of hours spent on leisure activities by the male and the female, respectively. The explanatory variables involve, in addition to own and spouse imputed wage rate, education level, a dummy variable for the presence of a child under 7 years of age, household income, a dummy variable for full-time worker status, and the number of autos.

Focusing on time-use behavior in housework activities, note first that the imputed own wage rates are found to have negative impacts on the number of own hours spent in housework, whereas spouse imputed wage rates are found to have positive impacts on the number of own hours in housework. Although the male wage rates turn out to be insignificant in both male and female housework time allocation, the general tendency of imputed wage rates by both spouses seems to be consistent with the household theory reviewed in the previous chapter. The impacts of wage rates on household time allocation will be discussed in more detail below.

The model in this study suggests that males with higher education spend more hours in housework than those with lower educational attainment. Educational attainment has been expected to have some influence on housework hours from two different theoretical perspectives. First, education is directly related to wage powers so that the specialization and bargaining models predict that individuals with higher education are highly likely to have comparative advantage on market work and a higher threat point in bargaining situations. Therefore, males with higher education may spend fewer hours on housework under the first theory. Second, Hersh and Stratton (1994) suggest that educational attainment may be positively related to egalitarian household values. If so, then highly educated households would tend to have a more equal distribution of housework time by gender. Under the circumstances of prevalent cultural norms of traditional gender roles in Korea so far, the positive impacts of male's education variable on housework hours can be interpreted as supported by egalitarian values. In addition, this result is consistent with the evidence in Table 3.3 showing that males in the group classified into occupation type 1, probably having higher educational attainment tend to participate in less hours of paid work and more hours of housework. Sousa-Paza et al. (2001) in their model for housework time allocation also show that high education of males increases their time spent on housework and child-care.

As we can expect, for the dummy variable for whether a household has a young child (0-7 years old) present, having a young child increases housework hours for both spouses, male and female. This result is very similar to the results from Hersch and Stratton (1994) and Aronsson et al. (2001). Hersch and Stratton (1994) find that both spouses increase their housework time when there are children under age 6 in the household, and Aronsson et al. (2001) also show that households with a child (for 0-6 years old) spend more time in housework.

Household total income effects are generally not significantly determined in the housework time allocations for either spouse in the first SURE model. The dummy variables for full-time worker indicate that both spouses who work full time significantly reduce housework time compared to people who are part time workers.

Turning to time-use behavior in leisure activities, the logarithm of imputed own wage rates for each spouse is significantly and positively related to the own leisure demand. The impacts of wage rates on household resource allocation in the collective settings will be properly interpreted when they are concurrently considered with housework as well as leisure time.

As already shown, the male's wage rate, although it is not statistically significant, is inversely related to the male's housework time and positively related to the female's housework time. The leisure time demand by a husband is significantly raised by the increase in the husband's predicted wage rate. In order to properly understand these time-use behaviors, we need to take a closer look at the time-use pattern by occupation type, as shown in Table 3.3. The table shows that males in occupation types with high income, on average, spend less time in paid work than those with low income, which results in increasing wage rates as income increases. We can also observe in that table that males with high income increase their housework time. However, according to specialization and bargaining theory, people with high income tend to participate in housework activities fewer hours than people with low income because they have higher bargaining power in deciding he housework allocation among household members. Therefore, time-use patterns across occupational classes in different types of activities are not supported by specialization and bargaining theory. Rather, they are closely related to the finding about time-use behavior by education level discussed above.

However, we also need to take into account the fact that about half the population belongs to the same category of occupation type (i.e., half of all males fall under category 4). Based on a simple linear regression to see the relationship between market work hours and individual income level in the same occupation category, we find that although it is not statistically significant, more work hours produce higher income. In this case, we can interpret this in a sense that people with higher income in the same occupation category have more opportunity to be excluded from the responsibility for housework as claimed in the specialization and bargaining theory. Consequently, the impacts of the male's wage on the male's housework time seem intertwined with other factors. This might be the reason why male's wage rate shows insignificant impacts on housework time by males and females. On the other hand, the impact of the female's wage rate is significant on housework time, as theoretically supported by specialization and bargaining theory.

In terms of leisure activities, people in occupation types with high income tend to spend more time in leisure activities. It is partly because they put relatively fewer hours on total household labor (i.e., sum of market work and housework) so that they have more time to enjoy leisure time compared to people in occupation types with lower income. In fact, these results regarding leisure demand are evident because the time-use data in this analysis is given by a sub-population who necessarily report time-use diaries on weekdays as well as weekends. The amount of time in leisure activities across different income groups will be better differentiated during weekends.

Household total income is insensitive to leisure demand for males, as in the case of male's housework time. On the other hand, the hours spent in leisure activities by the female increase steadily with the amount of household total income. Possibly, this is coincident with effects of increase in the wife's wage rate because high household income is more likely to be attributed to a higher contribution of the wife to household income. Therefore, females with high household income tend to avoid the responsibility for housework by using her surplus income to take more time to enjoy leisure time. Opposite to the case of housework time, the presence of young child induces male and female household heads to spend less time on leisure activities compared to people in households without young child.

Focusing on the determinant of the sharing rule, the model suggests that the income differences appear to matter, as well as age differences, to some extent. The important implication of this result is that the distribution of income within the household does matter for the leisure time allocation in the household, which provides evidence to reject the corresponding assumption in the unitary model of labor supply. Moreover, the possible interpretation of this significant positive effect of income differences in the sharing rule would be that higher-income partners receive more of sharing power and leisure consumption.

Table 3.4: Estimation Results of Household Resource Allocation with Total Leisure Demand in Collective Settings

Equation/parameter	Estimate	t-value
Male Housework		
Constant	-7.066	-4.86
Log(own wage rate)	-0.173	-1.57
Log(spouse wage rate)	0.667	9.88
Education level	0.206	3.19
Child dummy (0-7)	0.308	2.89
Household total income	0.0004	1.37
Dummy for full-time worker	-0.558	-4.09
Female Housework		
Constant	-4.181	-2.87
Log(own wage rate)	-0.333	-9.87
Log(spouse wage rate)	0.827	1.57
Child dummy (0-7)	0.247	1.42
Household total income	-0.0004	-1.34
Dummy for full time worker	-0.415	-3.01
Male Leisure		
Constant	-53.138	-46.63
Log(own wage rate)	5.753	61.62
Household total income	0.0002	0.64
# of auto	-1.141	-22.17
Child dummy (0-7)	-0.789	-9.88
Female Leisure		
Constant	-24.967	-41.02
Log(own wage rate)	2.975	64.09
Household total income	0.005	15.60
# of auto	-0.217	-5.47
Child dummy (0-7)	-0.180	-3.08
Sharing rule		
Income difference	0.003	7.15
Age difference	-0.027	-1.21
McElroy R-squared for the system	0.59386	
Log likelihood	-2423.039	

Table 3.5 contains estimation results of household resource allocation in collective settings when focusing on leisure activity time conducted at out-of-home locations. With exception of several explanatory variables, the general tendency of variables in the 4 equations is similar to what we have discussed relative to Table 3.4. Regarding the housework time equations for both partners, there are no changes for the coefficient estimates, but t-values show different values. This can arise from the changes of standard errors of variables due to the possible correlations between the equations in the system. An another exception with respect to housework time is that the imputed wage rate by males, which was not significant to housework time by both partners, turns out to be statistically significant (at the 10% level) with a negative relationship to the male's housework time and a positive relationship to the female's housework time. The same thing occurs with the dummy variable for the presence of young child, being statistically significant for female's housework time.

An interesting point to note in terms of leisure demand by males is that household total income significantly increases the hours spent on out-of-home leisure activities by males. This is different from the estimation results for total leisure demand which show that household total income has no impact on the male's leisure demand but a positive impact on the female's leisure demand. Recall that we found that high household income is more likely to be attributed to a higher contribution of the wife to household income. Therefore, although increases in household income caused by positive participation in market work by the wife may not influence the total amount of leisure demand by the husband, the out-of-home leisure activities by husband can be increased because the wife may want to share her out-of-home leisure opportunity, obtained by surplus income, with other household members.

With respect to the determinant of the sharing rule, the sharing rule with out-of-home leisure time is found to be positively and significantly affected by the commute time difference in addition to the income difference, which was a unique significant determinant in the case of total leisure time. Therefore, it can be stated that high-income partners, as well as long-commute-time travelers, receive more sharing power and leisure consumption that occur outside the home.

Table 3.5: Estimation Results of Household Resource Allocation with Out-of-home Leisure Demand in Collective Settings

Equation/parameter	Estimate	t-value
Male Housework		
Constant	-7.066	-5.45
Log(own wage rate)	-0.173	-1.78
Log(spouse wage rate)	0.667	10.34
Education level	0.206	3.26
Child dummy (0-7)	0.308	3.36
Household total income	0.0004	1.53
Dummy for full- time worker	-0.558	-4.12
Female Housework		
Constant	-4.181	-3.20
Log(own wage rate)	-0.333	-10.34
Log(spouse wage rate)	0.827	1.78
Child dummy (0-7)	0.247	1.64
Household total income	-0.0004	-1.46
Dummy for full- time worker	-0.415	-3.11
Male Leisure		
Constant	-19.73	-28.87
Log(own wage rate)	1.908	34.49
Child dummy (0-7)	-0.301	-6.66
Household total income	0.002	9.66
# of auto	-0.095	-1.81
Female Leisure		
Constant	-7.733	-13.30
Log(own wage rate)	0.775	17.88
Child dummy (0-7)	-0.265	-5.45
Household total income	0.004	13.29
# of auto	-0.264	-4.46
Sharing rule		
Income difference	0.001	3.27
Age difference	-0.036	-1.16
Commute time difference	0.278	2.86
Log likelihood	-3853.847	

3.4 Intra-household Time Allocation to Housework

3.4.1 Introduction

In the previous section, attention was focused on the investigation of household resource allocation through the estimation of intra-family time allocation for individual leisure consumption and domestically produced commodities in collective settings. The domestic production model assumed that domestically produced goods are perfect substitutes for market produced goods so that the choice between domestic production and purchasing at the market is entirely associated with opportunity cost.

In this section, instead, we will extensively explore various theories about the intra-family division of "total household labor hours"[13], focusing on housework. Along with the theoretical background, we estimate the time allocation for different types of activities by the different types of persons via the econometric analysis.

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[13] As explained in section 2.1.1, household labor hours can be generally classified into paid labor hours and unpaid labor hours (in other words, housework hours), and total household labor hours imply the combined time of two different labor hours. This concept is introduced by Schor (1991) to explain the sexual equality in labor hours and impacts of labor hours on leisure quality.

The importance of housework has been relatively ignored thus far. The traditional sexual division of household labor (i.e., the husband at work and the wife at home) has received widespread acceptance in a variety of disciplines. The large growth, however, in the market labor force participation of married women during the last several decades has been accompanied by other changes occurring in most industrialized countries. More specifically, there have been several reasons in which women increase their earning power over the last few decades, especially in Korea: a late marriage, a steep fall in fertility rate, and a sharp rise in divorce rates.

The late marriage and the fall of birth-rate are more likely than before to induce relatively new situations in which women can afford to attend higher educational programs and develop greater human capital for market work. This is because they have more energy and more flexible time to devote to market work instead of child care or housework. The social phenomenon of the growth in divorce rates enables women to realize the fact that they have to prepare for life after divorce, even though divorce is not currently being contemplated. In other words, married women have to invest more time in developing their own market human capital when they anticipate themselves to be employed because they are more likely to become divorced. Consequently, such changes in the social environment that lead to higher wages for women may initiate a shock to the traditional social system. Further, the shock may be self-reinforcing in a virtuous cycle that leads to less specialization in home production and future increases in earning power for women (Anxo and Carlin, 2004). In this respect, Becker's remark should be appreciated: A person's sex would then no longer be a valid predictor of earnings and household activities (Becker, 1991).

3.4.2 Theory

The set of theories addressing the intra-family division of household total labor hours reviewed in the Chapter 2 includes specialization models and cooperative bargaining models. In addition to these theories, only gender-based divisions of household labor, as reviewed earlier, may overpower any rules of intra-household time allocation.

The specialization model is based on the idea that each household member with a comparative advantage between market work activity and housework activity can contribute to the maximization of total household utility. In other words, each spouse can specialize by finding the type of activity where he or she has a comparative advantage. Thus, the optimal allocation of household resources can be obtained according to the comparative advantage for a couple. As shown in the section 2.2.2.3, specialization theory has been used to support in the past why women specialize in housework activity and men in market work activity. However, as pointed out above, various possibilities in the division of household work-load currently exist in the society and these models can be freely used to predict the actual pattern of intra-family division of total labor.

The cooperative bargaining models focus on how couple's decisions are made in a long-term relationship, such as marriage, in which transactions costs are high. The bargaining power of each person arises from the disagreement outcomes. If agreement is not reached, both spouses receive the payoff represented by a "threat point". How to define the threat point classifies the bargaining model into two different models: a divorce-threat bargaining model and a separate spheres bargaining model. The divorce-threat bargaining model defines the threat point as the utilities associated with a default outcome of divorce, and the separate spheres bargaining model identifies the threat point with a non-cooperative equilibrium of time allocation within the marriage. In the case where the husband has higher market wages than his spouse, both models are more likely to estimate his bargaining power stronger than the spouse's. This is partly because the husband with higher market wages is able to afford to purchase the services produced by his spouse in the market. The husband with stronger bargaining power may be observed with a lower share of housework time.

Both the specialization model and the bargaining model propose that the individual with higher earnings may be observed to share less time on housework, either because that individual has a comparative advantage in market work or because he or she has a higher bargaining power. In this manner, both models propose to use the wage rates of both spouses as explanatory variables, as was the case for the collective model before. However, data collected in the survey is most likely to be monthly labor income, not wage rates. Wage rates can be calculated, as explained earlier, by dividing labor income by work hours. Wage rates, therefore, intrinsically are more likely to contain some measurement errors.

In this study, we choose labor-market hours as a proxy for wage rates. This is partly because this study wants to explore various types of household interactions which may be related to household time-use patterns. As broadly mentioned before, the distribution of housework time over household members can be estimated from theoretical models such as the specialization model or the cooperative bargaining model. Therefore, it is expected that household interactions exposed by household time-use patterns can be used to determine which theory (among theories explained above) is more valid to explain the current time allocation behavior in the household.

3.4.3 Intra-Household Interactions

Different types of interactions may arise in family decision-making. Since we are concerned about distribution of total household labor hours, we have to consider the total workload of paid market work and unpaid housework activity. Thus, the interactions between the different types of activities need to be carefully investigated. In particular, what is important here is that family members can obviously interact with each other because they are assumed to share the responsibility for household subsistence. The interactions between the different types of activities should be examined in the frameworks that consider “within-person activity interactions” as well as “cross-person interactions”.

In the development of model structure, such interactions must be taken into account and have to reflect that not only does every individual faces time budget constraint (e.g. 24 hours in a day, that needs to be allocated to work activities, leisure activities, etc), but also that housework may directly affect earnings by limiting energy and effort in the family. For example, the more time and effort spent on housework activity, the less time and effort are available for participating in market work activity and leisure activity.

Although the arguments in the specialization and bargaining models vary, both theories tend to produce the same predictions about the interactions between the spouses' paid market work and unpaid housework. This study examines three different types of interactions for individual and for couples. The first interaction is the within-person interaction between different types of activities, for example the interaction between market work activity and housework activity for the same person. In both models, we expect a negative relation between own labor-market hours and own housework hours, probably due to the binding time budget constraint: The more work time in the labor market, the less time available for housework.

The last two interactions take place between spouses for the same type of activity or for different types of activities; there are cross-persons interactions. The interactions between couples with the same type of activity imply the relation of market work activities or housework activities between each member. Both the specialization model and the bargaining model will be expected to predict a negative correlation between spouses' market work hours or between spouses' housework hours. In fact, we might expect the correlation to be positive in certain environments based on different reasoning basis. For example, some people might get married to individuals that are like themselves in some respects (such as an education level and a preference for indoor or outdoor activities). In that case, both spouses, contrary to the specialization and bargaining models, are expected to delight in spending some share of their time in the same type of activities possibly together.

Third, we are concerned about the interaction between spouses with different type of activities. For example, the interaction indicates the correlation between one person's market work activity (or housework activity) and the other's housework activity (or market work activity). Both the specialization model and the bargaining model will be expected to predict a positive correlation between one person's market work activity and the other's housework activity. Since the more hours anyone works in the labor market, the higher bargaining power he or she can command, the partner with lower bargaining position needs to do more housework activities. As in the case of the second interaction, the reverse also can hold for this interaction. Since some couples are like each other and have similar preferences, the correlation between one spouse's market work activities (or housework activities) and the other's housework activities (or market work activities) might be negative.

As mentioned above, if no significant interactions between spouses, regardless of the sign, are found, we can interpret it as a gender-based division of household labor. In that case, the gender-based division arising from cultural or social norms may overpower any rules of the intra-household time allocation

3.4.4 Model Framework

As before, the model proposed in this section considers the sample of households of two-adults of opposite sex, with or without children. Further, the two-adult members (i.e., husband and wife) are only assumed to share responsibilities for market work activity and housework activity.

As in the previous section, two different sets of intra-family distribution on total household labor hours are analyzed. First, the focus is on the general model framework reflecting the interaction between market work and housework activities with no distinction whether the activities are performed at home or outside home. In addition, we also apply the same modeling framework to the situation with out-of-home housework activities only. The out-of-home housework activities include the activities taking place outside the home that are required to satisfy household common needs (such as household errands and grocery shopping).

In the econometric analysis, two major concerns arise when we construct and estimate an appropriate model system. First, it should be noted that the model system has to incorporate the behavior of both spouses as determined jointly within the family system, and thus analyze these behavioral relationships in a simultaneous framework. As a statistical tool in this regard, this study applies a simultaneous equations method, specifically, three-stage least squares (3SLS)[14]. Simultaneous equations methods allow a researcher to analyze complex relationships in a system of two or more equations where the dependent variables in the equations have a conceptually or mathematically interdependent relationship (Godwin, 1985). Simultaneous equations models were reviewed in section 3.2 in more detail.

Second, because we are using daily time-use diary data, there are the cases where activity times are censored distributions; some individuals do not report housework[15] and negative hours cannot occur. A proper statistical tool in this respect is a Tobit model.

We classify structural frameworks for the simultaneous equations method into two types based on how to deal with market work activities. First, we can assume that the market work time and housework activity time for both spouses might be mutually affected. Second, we also can assume that market work time can affect housework time but that market work time will not be affected by housework time. The choice of model

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[14] The econometric software package "STATA, Version 9.1" is used to estimate the coefficients of the 3SLS model.

[15] Since we consider two-worker households where both spouses have reported the positive market work hours, we do not need to care about the case with zero hour of market work activity by any spouse.

specification between these two types may be related to the alternate viewpoints. The second specification is based on the sequential approach in which the work time allocation has the primary decision priority, with other decisions conditional on that allocation. This approach assumes that household market work time is decided in the life-cycle context (which provides lifetime path of work hours, fertility, etc). Then decisions about housework time allocation would be the next order decision. In this study, both models are estimated. The results from the second model are included in the next section and the results from the first model are included in an Appendix[16].

As before, let h_m, h_f, t_m and t_f denote hours spent on housework and market work, by husband and wife, respectively.

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[16] The model structure shown in Appendix will include additional equations into Equation 3.14, as follows:

$$t_m = \gamma_1 t_f + \gamma_2 h_m + \gamma_3 h_f + \gamma_4 z_m + \zeta_m$$
$$t_f = \tau_1 t_m + \tau_2 h_m + \tau_3 h_f + \tau_4 z_f + \zeta_f$$

where γ_i and τ_i $, i = m, f$ are parameter to be estimated, and $\zeta_j, j = m, f$ is error or random disturbance term. In this case, the simultaneity arises among all dependent variables: h_m, h_f, t_m and t_f.

$$h_m = \alpha_1 h_f + \alpha_2 t_m + \alpha_3 t_f + \alpha_4 z_m + \varepsilon_m$$
$$h_f = \beta_1 h_m + \beta_2 t_m + \beta_3 t_f + \beta_4 z_f + \varepsilon_f \qquad (3.14)$$

where z are vectors of exogenous variables, α_i, β_i are parameters to be estimated and $\varepsilon_j, j = m, f$ is error or random disturbance term. The simultaneity in Equation 3.14 arises between h_m and h_f because of the theoretical nonrecursive specification, where a temporal (or any other) ordering of causations in a unidirectional manner does not exist. In terms of the relationships between market work time and housework time, even if the sequential approach is correct, we might think that market work time allocation is still correlated with the error term, $\varepsilon_j, j = m, f$. Thus, the model in Equation 3.14 endogenously estimates market work time for both spouses (t_m, t_f) through instrument variables and uses predicted market work time as explanatory variables in the simultaneous equations for housework time allocation. Since this simultaneous equations method can not consider a Tobit specification, we use sample data which report the positive hours spent on housework activity.

For comparison to the model above, we also analyze household time allocation by a Tobit model with endogenous regressors[17] as follows:

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[17] The econometric software package "STATA, Version 9.1" is used to estimate the

$$h_m^* = \alpha_1 h_f + \alpha_2 t_m + \alpha_3 t_f + \alpha_4 z_m + \varepsilon_m$$
$$h_m = h_m^* \quad if\ h_m^* > 0 \qquad (3.15)$$
$$= 0 \quad if\ h_m^* \le 0$$

and

$$h_f^* = \beta_1 h_m + \beta_2 t_m + \beta_3 t_f + \beta_4 z_f + \varepsilon_f$$
$$h_f = h_f^* \quad if\ h_f^* > 0 \qquad (3.16)$$
$$= 0 \quad if\ h_f^* \le 0$$

This Tobit model structure can not explicitly consider the simultaneity between spouses' housework times, so that partner's housework time is endogenously estimated through instrument variables and the endogenous predicted housework time is used as explanatory variables in the Tobit model structure for own housework time.

3.4.5 Estimation Results

Estimation results are presented in the Table 3.6 and Table 3.7 based on the 3 stage least square model (3SLS) and the Tobit model with instrument variables (IV-Tobit), respectively. The results from the two different modeling frameworks show similar time allocation behavior.

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coefficients of the Tobit model with endogenous regressors (the model command is "ivtobit").

With respect to interactions among spouses' time-use behaviors, we will extensively explore three types identified in the previous section: within-person interaction between different type of activities, cross-person interactions between the same type of activities, and between different types of activities. First of all, it should be noted that all of coefficients reflecting the time-use interactions turn out to be statistically significant at the 1% level.

The interactions from within-person interaction between different types of activities include interaction between male market work time and male housework time, and interaction between female market work time and female housework time. The model results show the negative signs for this interaction implying substitution effects exist in own activity time relationships. This is quite straightforward because an increase in one's market hours will reduces total hours available for all other activities due to the time budget constraint.

The second type of interactions, cross-person with same type of activities, is represented by the positive correlations between partners. This result indicates that if one spouse has higher housework hours, then the other spouse spends more hours in housework activities compared to the same gender member in other households, with all other things being equal. Therefore, we might conclude that husband and wife complement each other in household production activities. The possible explanation for this is that husband and wife in the dual-worker household appear to spend time together for household maintenance activities and to have similar preferences for home-making or childcare. Note that no specialization and bargaining theories are supported in this type of interaction.

The last type of interactions, cross-person with different type of activities, show a positive relationship, indicating that an increase in one spouse's market work time leads to a rise in the other spouse's housework time. This result can be interpreted indirectly from specialization and bargaining theory in that the more market work one spouse participates in, the more housework the other spouse participates in.

We can obtain further insight regarding household time allocation mechanisms by considering further estimation results. Note first that we use estimation results from 3SLS (in Table 3.6) and IV-Tobit (in Table 3.7) together as a sort of boundary because they differ in modeling background but show very similar results.

An increase in the wife's market work hours would increase her husband's housework hours and decrease her housework hours. More specifically, one hour increase in a wife's market work time would increase her husband's housework time by about 12-15 minutes and decrease her housework time by about 25-27 minutes. Therefore, we can expect that a household with a female member who strongly participates in market work activities will spend less time on housework activities compared to a household without such a female. Possibly, this explanation implies that the household with a strong participation in market work activities by female member might be likely to buy market goods and service substituted for commodities produced by housework, and/or have lower quality of home-making. On the other hand, when a husband spends one hour more in market work activities, the husband decreases his housework time by about 10-13 minutes and his wife increase her housework time by about 16-17 minutes. Although there are not very significant differences, this result suggests that there is the opposite tendency from the previous case.

In this way, the marginal effects on housework time-use behavior by any given changes of both market work hours are always quite bigger for females than for males. Even though this analysis is focused on dual-worker couples, the cultural norms (i.e., housework is the female's job) is still valid. Therefore, males take relatively smaller responsibility for housework and thus the housework hours by males may be less sensitive to any given changes of either spouse's market work hours than for females. Another interesting point to note is that the strong indicator to determine the amount of housework time for both male and female member is the market work hours by female rather than male's market work hours. An imbalance also takes place between male's housework hours by changes in female's housework hours and female's housework hours by changes in male's housework hours.

The coefficients of the socio-demographic variables for housework hours for both partners show the similar results to those from the SURE model presented in the previous section (except for small changes in significance level). The male with higher education level increases the housework hours by male and the presence of young child increases the housework hours by female. As explained before, this result indicates that well-educated male is less traditionally oriented than the poorly educated and supports egalitarian household values. In terms of household total income, the signs of the coefficients for both spouses are the same as the previous SURE model (in Table 3.4), but 3SLS and IV-Tobit model estimates more significant than before. As argued with leisure time allocation in the SURE model, the female is more likely to be the greater contributor to the higher household income than the male is. Therefore, high household income can be in favor of the bargaining power by the female so that the female decreases her housework time with the increase of household total income, but the male increases his.

Table 3.6: Estimation Results from Housework Allocation Model with Total Housework Time using 3 Stage Least Square (3SLS) Model

Equation/parameter	Estimate	t-value
Male Housework		
Constant	-0.629	-0.82
Spouse housework time	0.399	3.63
Own work time	-0.173	-3.80
Spouse work time	0.195	2.53
Education level	0.10	1.69
Household total income	0.001	2.03
Number of working days	-0.005	-1.11
Female Housework		
Constant	4.087	3.97
Spouse housework time	1.205	2.67
Own work time	-0.499	-8.76
Spouse work time	0.273	3.49
Child dummy (0-6)	0.376	1.95
Household total income	-0.001	-3.54
Number of working days	-0.015	-1.98
Male Market Work		
Constant	6.805	26.30
Child dummy (0-6)	0.345	1.69
Number of working days	-0.040	-3.22
Commute time	2.169	10.77
Female Market Work		
Constant	4.773	6.25
Education level	-0.638	-4.04
Age	0.026	2.22
Number of working days	0.034	2.53
Commute time	2.506	10.14

Table 3.7: Estimation Results from Housework Allocation Model with Total Housework Time using IV-Tobit Model

Equation/parameter	Estimate	t-value
Male Housework		
Constant	-1.685	-3.16
Spouse housework time	0.559	5.80
Own work time	-0.230	-13.83
Spouse work time	0.245	6.20
Education level	0.089	1.22
Household total income	0.001	2.90
Female Housework		
Constant	3.325	3.34
Spouse housework time	1.648	2.71
Own work time	-0.407	-16.06
Spouse work time	0.284	3.34
Household total income	-0.001	-3.29
# of working day	-0.015	-1.64

The estimation results of the housework allocation model focusing on out-of-home housework activity time are presented in Table 3.8 and Table 3.9 based on the 3 Stage Least Square model and Tobit model with instrument variables, respectively.

Table 3.8: Estimation Results from Housework Allocation Model with Out-of-home Housework Time using 3 Stage Least Square (3SLS) Model

Equation/parameter	Estimate	t-value
Male Housework		
Constant	-0.337	-0.52
Spouse housework time	1.184	3.43
Own work time	-0.137	-2.35
Spouse work time	0.156	1.87
Child dummy (0-6)	-0.303	-2.51
Household total income	0.000	1.06
Female Housework		
Constant	0.354	0.354
Spouse housework time	1.018	3.35
Own work time	-0.133	-2.20
Spouse work time	0.109	1.98
Child dummy (0-6)	0.255	2.95
Household total income	-0.000	-1.06
Male Market Work		
Constant	7.039	21.26
Child dummy (0-6)	0.247	1.03
Number of working days	-0.052	-3.26
Commute time dummy	1.757	6.65
Female Market Work		
Constant	5.188	10.99
Education level	-0.855	-4.50
Household total income	0.002	3.03
Number of working days	0.050	2.97

All of coefficients reflecting the time-use interactions within partners based on out-of-home housework activity have the same signs with those in the case of total housework activity. Therefore, there are no differences between the two cases in providing the proper explanations about overall interpretations of the model results regarding predefined interaction behaviors.

An interesting point to note is that the marginal effects on housework time allocation in response to changes of the male's or female's market work activity time by one hour remains stable at about 7-9 minutes[18] for either spouse. The interpretation of this stable pattern is that unlike the case with total housework time allocation, the effects from the cultural norms on the allocation of out-of-home housework activities among household members seem to be weakened. Cross-person interactions with respect to housework hours are significant positively, but have no big difference between husband and wife.

[18] We use boundary value to reflect the outcomes from two different model systems (3SLS, IV-Tobit) showing a bit different results.

Table 3.9: Estimation Results from Housework Allocation Model with Out-of-home Housework Time using IV-Tobit Model

Equation/parameter	Estimate	t-value
Male Housework		
Constant	-0.911	-2.27
Spouse housework time	1.295	4.24
Own work time	-0.122	-6.90
Spouse work time	0.138	3.97
Household total income	0.000	1.83
Commute time	-0.279	-3.36
Female Housework		
Constant	0.137	0.37
Spouse housework time	1.305	2.94
Own work time	-0.149	-11.27
Spouse work time	0.106	3.34
Child dummy (0-6)	0.206	2.10

3.5 Hybrid Household Model

Table 3.7 and Table 3.8 presented household resource allocation model in collective settings using the Seemingly Unrelated Regression Equation (SURE) model based on total leisure demand and out-of-home leisure demand respectively. These models are different from model framework in section 3.3 that uses a Cobb-Douglas functional form for the household production function, whereas the model system in this section uses the model framework used in section 3.4 for the housework time allocation model.

Table 3.10: Estimation Results of Household Resource Allocation with Total Leisure Demand in Collective Settings 2

Equation/parameter	Estimate	t-value
Male Housework		
Constant	0.520	1.45
Spouse housework time	0.206	5.08
Own work time	-0.136	-5.76
Spouse work time	0.088	4.19
Education level	0.175	2.74
Number of working days	-0.008	-1.24
Female Housework		
Constant	4.875	26.46
Spouse housework time	0.396	8.85
Own work time	-0.362	-22.23
Spouse work time	0.099	7.82
Education level	0.186	3.82
Child dummy (0-6)	0.652	5.65
Household total income	-0.001	-4.28

Number of working days	-0.320	-5.01
Male Leisure		
Constant	-53.138	-38.74
Log(own wage rate)	5.753	50.79
Household total income	0.0002	0.68
# of auto	-1.141	-20.51
Child dummy (0-6)	-0.789	-10.66
Female Leisure		
Constant	-24.967	-31.80
Log(own wage rate)	2.975	48.14
Household total income	0.005	12.12
# of auto	-0.217	-5.32
Child dummy (0-6)	-0.180	-1.95
Sharing rule		
Income difference	0.003	5.54
Age difference	-0.027	-1.02
McElroy R-squared for the system	0.8217	
Log likelihood	-2911.45	

Table 3.11: Estimation Results of Household Resource Allocation with Out-of-home Leisure Demand Model in Collective Settings 2

Equation/parameter	Estimate	t-value
Male Housework		
Constant	0.585	1.77
Spouse housework time	0.196	4.78
Own work time	-0.137	-7.66
Spouse work time	0.086	4.17
Education level	0.158	2.71
Child dummy (0-6)	0.152	1.48
Number of working days	-0.008	-1.32
Female Housework		
Constant	4.875	32.75
Spouse housework time	0.396	8.73
Own work time	-0.362	-25.93
Spouse work time	0.099	7.79
Education level	0.186	3.87
Child dummy (0-6)	0.652	8.19
Household total income	-0.001	-5.41
Number of working days	-0.320	-5.01
Male Leisure		
Constant	-19.69	-28.27
Log(own wage rate)	1.910	33.42

Household total income	0.002	10.18
# of auto	-0.057	-1.71
Child dummy (0-6)	-0.296	-6.45
Female Leisure		
Constant	-7.495	-12.00
Log(own wage rate)	0.761	16.11
Household total income	0.003	11.05
# of auto	-0.050	-1.28
Child dummy (0-6)	-0.255	-4.66
Sharing rule		
Income difference	0.001	3.14
Age difference	-0.042	-1.15
Commute time difference	0.218	2.17
McElroy R-squared for the system	0.36457	
Log likelihood	-4343.331	

3.6 Summary and Conclusions

Intra-family interactions with respect to time allocation behavior to different types of activities among household heads are explored using two types of household resource allocation models.

The first model (NLSURE model) is the structural model consisting of individual leisure demand models with domestic production functions within the theoretical framework of the collective model. The logarithm of imputed own wage rates for females are significantly related to the own (male) housework time with negative (positive) relation (although the male's wage rate is not statistically significant on spouses housework time). The imputed own wage rates are found to have significant positive impacts on the own leisure demand. Males with higher education or a young child spend more hours in housework than those with lower education or absent a young child. The presence of young child induces both household heads to spend less time on leisure activities compared to households without a young child. Household total income shows positive impact on female's leisure demand, and full time workers spend less time on housework activities than part time workers. In terms of out-of-home leisure activity, the tendency of time use behavior by both spouses is similar to the total leisure activity except that male's out-of-home leisure activity increases with the household total income.

The second model (3SLS model) focuses on model development of intra-household time allocation to housework. Three types of interactions for the division of total household labor hours in the family decision-making are explored.

The within-person interactions between different types of activities by both heads indicate negative correlations, but the magnitude of effects of market work time on housework time is greater for females than for males.

Contrarily, the cross-person interactions with different type of activities by both heads indicate positive correlations, indicating that an increase in one spouse's market work time leads to a rise in the other spouse's housework time. Similarly to the prior interactions, however, the magnitude of the effects of market work time on housework time is greater for females than for males.

The cross-person interactions with same type of activities are represented by the positive correlations between partners. The possible explanation for this is that husband and wife in the dual-worker household appear to spend time together for household maintenance activities and to have similar preferences for home-making or childcare. An interesting point to note is that the marginal effects on housework time-use behavior in response to changes of both market work hours are always greater for females than for males. The coefficients of the socio-demographic variables for housework hours for both partners show the similar results to those from SURE model.

Chapter 4

Gender Roles and Intra-family Time Allocation

4.1 Introduction

How individuals engage in a set of activities over a period of time is critical to understanding the associated travel behavior. Individuals, in the activity scheduling process, have to jointly decide which activities to perform, at what time, where, for how long, with whom, with which mode, along with the overall sequence of activities. An increase in research activity in this area has been due to the recognition that activity scheduling behavior in households with multiple members needs to be considered within the framework of intra-household interactions and group/family decision mechanisms rather than as an individual decision-making process. In such framework, individuals in the multi-person households take part in the household decision process in terms of not only activity generation but also in the allocation of generated activities to individual members for execution (Scott and Kanaroglou, 2002).

Traditional gender roles have been often reported as one of the most important determinants within the context of the household tasks allocation (Srinivasan and Bhat, 2005; Srinivasan and Athuru, 2005; Gliebe and Koppelman, 2005). However, the propensity of gender-based household tasks allocation to members in this research is likely to represent general household structure. According to some recent literature (Scott and Kanaroglou, 2002; Golob and McNally, 1997) who separately model household interactions by household type (such as how many workers are in the household), it appears that traditional gender roles persist only in couple, one–worker households.

A 'gender role' often refers to a set of behavioral rule that is socially enforced, associated particularly with males or females, in a given social group or system. Parsons and Bales (1955) viewed that the feminine role involved expressive types of activities, whereas the masculine role was an instrumental one. They believed that the expressive role of the woman was supposed to satisfy internal functions, for example to strengthen the bonds between the family members. The man, on the other hand, fulfilled the external functions of a family, such as providing monetary support. Parsons proposed two models which are capable of contrasting and illustrating extreme positions of both sides on gender roles. At one extreme, referred to total role segregation model, housekeeping and child care are the primary functions of the woman; participation of the man in these functions is only partially wanted. At the other extreme, referred to as total disintegration of roles, all housework is done by both parties to the marriage in equal shares. In reality, however, actual behavior of individuals is usually somewhere between these poles rather than the extreme positions. Moreover, attitudes on gender roles are constantly negotiated between individuals and can influence all kinds of behavior, such as choice of spouse, choice of work, and personal relationships.

Traditional ideas can, on the one hand, be viewed as product of action but it may, on the other hand, also be considered as conditioning elements of further action (Kroeber and Kluckhohn, 1967). Consequently, the personal attitude toward roles of each household member in his or her family plays an important part in the allocation process of the household tasks, and the actual decisions under varying physical and social constraints in turn influence the formation of individuals' habits and attitudes on any imaginable aspect of life. Therefore, it will be meaningful to explore the inter-relationship between an attitude of gender-specific roles and individual and social characteristics of each decision maker. In particular, the underlying hypothesis in this study is that actual hours spent on paid market work and/or housework are related to the formation of attitudes on gender roles in the family at the basic individual level. Moreover, it will be plausible to assume that the distribution of actual hours spent on paid work and/or housework between household members will be more likely to relate to the household structure, especially in terms of the number of workers in the family.

Data in 2004 Korean Time Use Survey include a question asking respondents for a subjective opinion on the traditional idea of gender roles in a family, using a four-point Likert-scale. Accordingly, this Chapter aims to explore statistical connection between these explicit statements and actual choices under physical and social constraints.

4.2 Data

As in the Chapter 3, the data used in this analysis are drawn from a 2004 Time-Use Survey for Korea (KTUS). This is the second survey to collect information on how Koreans spend times in their daily life, being conducted every 5 years since 1999. More detailed information of this survey was reviewed in section 2.3.2 and section 3.2.2..

Since this Chapter aims to investigate the relationship between an attitude on traditional gender roles in the allocation of household tasks and actual hours spent on paid work and/or household works by household members who have the responsibility to share them, the age group for the analysis is set to the people between 19 and 64 years of age. In addition, this study uses two data sets: one including the whole surveyed population and the other including only married people. Table 4.1 shows the sample characteristics in this study.

Table 4.1: Sample Characteristics (aged 19 to 64 years)

Variables	General Population	Married Couples
Age, male (means)	40.8	44.5
Age, female (means)	40.3	42.4
Educational attainment, male		
- Low (%)	18	20
- Medium (%)	58	53
- High (%)	24	27
Educational attainment, female		
- Low (%)	30	32
- Medium (%)	55	54
- High (%)	15	14
Marital status (married) (%)	74	100
House Owners (%)	65	67
More than one child < 8 years old (%)	11	14
Number of observation	22,094	15,072

The average daily actual hours spent on paid work and housework for males and females aged 19 to 64 years on different sub-population groups are summarized in Table

4.2. In particular, the average daily actual hours in married couples are separately calculated by household types in terms of the number of workers in the household such as dual workers household and single worker household. The dual workers couples are defined as married or common-law couples in which both partners are employed. Moreover, the average hours are presented in two ways: population and participants. Participation in Table 4.2 indicates the proportion of the population (or sub-population) that reported spending some time on the given activity. At the population level, the average daily amount of times that general populations spent on paid work and housework combined for males and females were 7.2 and 7.8 hours, respectively. In addition, married men increased the average time they spent on paid labor possibly because of increased participation rates, but their participation time in housework has remained relatively stable after marriage. On the contrary, the female significantly increased housework, possibly because of children, and decreased the average time spent on paid work after marriage.

Table 4.2: Times spent on, and participation in, Paid Work and Housework (aged 19 to 64 years)

	Male (Husband)				Female (Wife)			
	GP[1]	MC[1]	DWC[1]	SWC[1]	GP[1]	MC[1]	DWC[1]	SWC[1]
Average hours per day (population[2])								
Paid work	6.4	6.7	7.3	6.6	3.7	3.2	5.6	0.7
Housework(In[3])	0.4	0.4	0.3	0.4	3.2	4.0	3.0	5.0
Housework(Out[4])	0.3	0.3	0.3	0.3	0.9	1.0	0.7	1.3
Total[5]	7.1	7.5	8.1	7.4	7.9	8.2	9.4	7.1
Average hours per day (participants[6])								
Paid work	7.3	7.3	7.3	7.2	6.0	5.7	5.6	6.3
Housework(In)	0.7	0.7	0.6	0.8	3.4	4.0	3.0	5.0
Housework(Out)	0.8	0.8	0.8	0.8	1.2	1.2	1.0	1.5
Total	7.4	7.6	8.1	7.5	7.9	8.2	9.4	7.1
Participation (%)								
Paid work	84	91	100	90	58	55	100	10
Housework(In)	54	54	55	53	94	99	99	99
Housework(Out)	39	43	44	40	74	81	74	89
Total	97	98	100	98	99	99	100	99

1. GP: General Population, MC: Married Couples, DWC: Dual Workers Couple, SWC: Single Worker Couples
2. The total time all respondents reported spending on a given activity divided by the population in the each group
3. In-home household maintenance activity
4. Out-of-home household maintenance activity
5. Numbers may not add due to rounding
6. The average time spent by participants who actually participated in that activity on diary days

At the participant level, the male shows relatively stable participation times on every activity type regardless of marriage status and household types. On the other hand, the number of hours participated in activities by the female fluctuate. Interestingly, paid work hours by the female in the single worker couples are higher than those in the dual workers household. The explanation for this is that the females who participate in paid work in the dual workers couples could be one of earners in the family, but the female in the single worker household would be more likely a full time worker who earns the only household income (consisting 10% of the single worker households). It should be noted that total times spent on housework activity in the family become the lowest in the dual workers household structure. The reason for this would be that more workers often bring higher earnings, which in turn can offer some relief from housework by providing the means to hire someone else to do it or to buy substitute service outside such as eating dinner at restaurants.

The survey includes questions concerning a subjective judgment on some issues. In particular, the survey asks respondents a question about a personal attitude toward the traditional gender roles in a family, reflecting the individual's ideological point of view. The question is "Do you agree or disagree that a man's task in the family is to earn money and a woman's task in the family is to look after the home and family". Answer is given on a four-point Likert scale ranging from ‘strongly agree’ to ‘strongly disagree’, which is a forced choice method where the middle option of "Neither agree nor disagree" used in a five-point scale is not available.

Distributions of responses on this question are shown in Table 4.3 by marriage status and household types. General population (the whole sample) reflects that males slightly favor traditional gender roles, but females are significantly against the traditional idea on gender roles regarding household work allocation. These tendencies tend to move along the same direction when focusing on married couples only. That is, the male and female in married couples more prefer traditional gender roles compared to general population, although the female is still against them. However, when we take a closer look on married couples with single and two workers household type, we can find that they have extremely different attitudes on traditional gender roles. The male in dual workers couples has significantly different attitude from the male in the other type of household structure. In other words, the male in single worker household remarkably answers the affirmative, whereas the male in dual workers household has the propensity to argue against for the gender-based specific role allocation between partners. The positive tendency by the male in married couples seems to be primarily caused by the strong attitude in favor of traditional gender roles by the male in single worker household. The female, except in a single worker household, is broadly against traditional gender roles. Nearly 70% of the females in dual workers household disagree. However, the negative attitude by the female is somewhat weakened in single worker couples.

Table 4.3: Distributions of Responses on Question about Traditional Gender Roles (%)

	General Population		Married Couples		Dual Workers Couples		Single Worker Couples	
	Male	Female	Male	Female	Male	Female	Male	Female
Strongly agree	6.1	2.7	7.1	2.7	5.1	2.9	8.8	2.1
Agree	45.4	32.8	48.3	35.6	43.2	29.2	53.8	41.9
Disagree	45.1	56.0	42.0	54.8	48.6	59.6	35.2	50.3
Strongly disagree	3.4	8.5	2.6	6.9	3.1	8.3	2.2	5.7

4.3 Model Estimation

Data explicitly provided on a point of view regarding gender-specific roles are used to explore the effect of various factors on the formation of the attitudes at the basic individual level. We use an ordered probit model with the opinions on traditional gender roles as a function of actual hours spent on paid work and housework, and respondent's socio-demographic characteristics at both the household and the individual levels. In order to appropriately account for the ordered nature of the dependent variable, not only a standard logit model but also a nested logit or probit model is discarded. The linear regression models instead of the ordered probit model can also provide substantially different conclusion with the ordered categorical response data (Zavoina and McElvey, 1975).

In this model structure, it may be assumed that respondents have some level of utility or opinion associated with the object of the question and will answer the question based on how great this utility is (Train, 2003). Even though the respondent's opinion can take many different values showing the level of the utility, the person can only express the opinion in one of given categories ("strongly agree", "agree", etc). From the perspective of the researcher, the opinion is expressed in an unobserved latent variable as a linear function of explanatory variables by:

$$y^* = \beta' x + \varepsilon \qquad (4.1)$$

where the x's are vectors of observed exogenous variables, the β's are corresponding vector of parameters to be estimated, and ε is the vector of random error terms which are assumed to be distributed identically and independently across individuals in accordance with standard normal distribution. The response data from the survey provide an indication of the range of each category by finding the cut-off points, as follows:

$$
\begin{array}{lll}
y = 1 & if & y^* \le \mu_1, \\
y = 2 & if & \mu_1 \le y^* \le \mu_2, \\
y = 3 & if & \mu_2 \le y^* \le \mu_3, \\
 & \vdots & \\
y = J & if & \mu_{J-1} \le y^*
\end{array}
\qquad (4.2)
$$

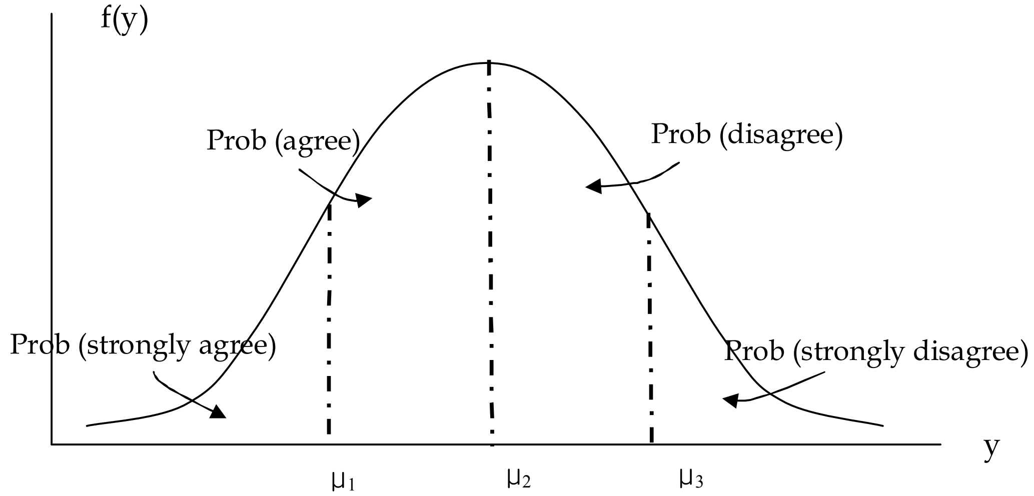

Figure 4.1: Distribution of Attitude on Traditional Gender Division of Housework Task

The y 's are the observed and coded discrete measure of response for J ordered response categories, and the μ 's denote threshold parameters to be estimated along with the $\beta^{'}$s. For example, if a respondent thinks that the opinion level perceived is in the range bounded by μ_1 and μ_2, the person will check category 2.

In this study, J, the number of alternatives, is four with following statements:

1: strongly agree, 2: agree, 3: disagree, 4: strongly disagree.

Thus, the probability that researcher observes a respondent answering “agree” is the probability that y^* is above μ_1, implying that the person doesn’t strongly agree on that, but is below μ_2. Consequently, the probabilities for observing various outcomes of the dependent variable corresponding to specific values for the attitude on traditional gender roles, are given by:

$$\begin{aligned}
&\Pr(\text{"}\textit{strongly agree}\text{"}) = \Phi(\mu_1 - \beta' x) \\
&\Pr(\text{"}\textit{agree}\text{"}) = \Phi(\mu_2 - \beta' x) - \Phi(\mu_1 - \beta' x) \\
&\Pr(\text{"}\textit{disagree}\text{"}) = \Phi(\mu_3 - \beta' x) - \Phi(\mu_2 - \beta' x) \\
&\Pr(\text{"}\textit{strongly disagree}\text{"}) = 1 - \Phi(\mu_3 - \beta' x)
\end{aligned} \qquad (4.3)$$

where $\Phi(\cdot)$ denotes the standard cumulative normal distribution

Table 4.4 presents the estimation results for general population aged 19 to 64 years. As shown in Table, five variables with respect to socio-demographic characteristics are found to significantly influence the attitudes on the traditional views regarding gender roles in a family. A positive (negative) signs for explanatory variables indicate more liberal (conservative) attitudes on traditional gender roles. For example, older people have higher propensity to view that the traditional gender roles have to be held than younger people do.

Table 4.4: Estimation Results for General Population (aged 19 to 64 years)

Variables	Coefficient	Std. Err.	z	P>z
Socio-demographic characteristics				
Age	-0.0157	0.0009	-17.41	0.000
Sex (1 = Males)	-0.3624	0.0198	-18.22	0.000
Marital (1 = Married)	-0.1029	0.0215	-4.77	0.000
Children < 8 years present	-0.0766	0.0226	-3.39	0.001
Education attainment	0.0942	0.0131	7.15	0.000
Time use attributes				
Busy (1 = yes)	-0.0335	0.0095	-3.52	0.000
Average time spent on paid work related activities (females)	0.0249	0.0028	8.77	0.000
Average time spent on household Maintenance activities (males)	0.0454	0.0151	3.02	0.003
Threshold values				
μ_1	-2.5302	0.5834		
μ_2	-0.9161	0.0562		
μ_3	0.9011	0.0564		
Summery statistics				
Number of observations = 22,094				
Log likelihood at convergence = -21571.577				
Model $\chi^2(8)$ = 1820.29				
Prob > χ^2 = 0.0000 (i.e., P-value)				

Respondents that were males, married people and the presence of young children (less than 7 years old) have a propensity in favor of the traditional gender roles, meaning that they are more conservative compared to females, unmarried people, and people without young children. On the other hand, educational attainment variable represents that education tends to positively influence people to have a liberal attitude toward gender role.

Three variables with respect to time use attributes are found to significantly relate to the way of thinking regarding the traditional gender roles. The respondents in the 2004 Time-use survey were asked to answer if they felt that they have been busy in daily normal life with a four-point Likert scale ranging from 'yes, always' to 'no, not at all '. These answers were used as a dummy variable in this model taking one if they said yes, 0 otherwise. As a result, people who felt busy in normal life tend to prefer to hold the traditional gender roles compared to people who did not feel busy. Females having spent more time on paid work and related activities are positively related to the liberal attitudes on the traditional gender roles. Similarly, males having spent more time on in-home household maintenance activities are positively related to the liberal attitudes on the traditional gender roles compared to males having spent less time on in-home household maintenance activities.

Table 4.5: Estimation Results for Married Couple (aged 19 to 64 years)

Variables	Coefficient	Std. Err.	z	P>z
Socio-demographic characteristics				
Age	-0.0132	0.0011	-12.10	0.000
Sex (1 = Husband)	-0.5149	0.0282	-18.24	0.000
Education attainment	0.1090	0.0155	7.03	0.000
Household type dummy				
Female in Dual workers household	0.1751	0.0341	5.14	0.000
Male in Dual workers household	0.3793	0.0264	14.34	0.000
Time use attributes				
Average time spent on paid work related activities (females)	0.0218	0.0045	4.79	0.000
Average time spent on household Maintenance activities (males)	0.0702	0.0179	3.92	0.003
Threshold values				
μ_1	-2.1675	0.0693		
μ_2	-0.5118	0.0671		
μ_3	1.3235	0.0683		
Summery statistics				
Number of observations = 15072				
Log likelihood at convergence = -14594.154				
LR $\chi^2(7)$ = 1208.37				
Prob > χ^2 = 0.0000 (i.e., P-value)				

So far, the analyses have been focused on the general population aged 19 to 64 years including all of surveyed people regardless of marriage status. The results of them are reasonably interpreted as well. In particular, marriage and having children tend to make people more conservative on attitude toward a traditional view of gender-specific roles. However, what we suspected was that persons in dual workers households among the married couples might have different propensities on attitudes to traditional gender roles. Table 4.5 presents the estimation results for the people consisting of only married couple. The effects of socio-demographic characteristics including age, sex, and education attainment are found to be same as discussed for the general population. More importantly, people in the dual workers household tend to have the positive attitudes on the traditional gender roles, meaning being more liberal. Interestingly, males in the dual workers household have the tendency against the traditional gender roles more than males in the other type of household structure, even than females in the dual workers household.

4.4 Summary and Conclusions

This analysis explored the inter-relationship between an attitude on traditional gender roles and socio-demographic characteristics, as well as on actual times spent on paid work and housework at the individual level. As mentioned, the majority of previous research found that the gender-specific roles regarding household tasks allocations persist in a family. However, this chapter suggests that people in different household structures, in terms of the number of workers in the household, might have the different attitudes on traditional gender roles.

The values of the coefficients from the estimation results for general population were as expected. For example, males, married people, and the presence of young children (less than 7 years old) have a propensity in favor of traditional gender roles. However, when we focus on the persons in dual workers household among married couples, they show the significantly higher tendency against the traditional gender roles compared to persons in the other household types. Possible interpretation of these results is that although traditional ideas can influence the current decisions, the current environment with physical and social constraints can also influence the attitude on varying aspects of life. The different features of couples with dual workers compared to the other couples deserve more attentions, in particular for the country in which the portion of dual workers households is increasing in a very high speed.

Chapter 5

Household Activity Scheduling Model

5.1 Introduction

Understanding the decision-making process regarding activity participation is critical step in developing a framework for activity-based modeling. In the previous chapters, activity time use behavior has been examined via the developments of time use models based on household as an analysis unit. We have also examined the significance of the traditional gender role in household task allocation, which has been reported as a dominant determinant in the transportation literature. In this study, the traditional role allocation based on gender specification was found insignificant in dual-worker household structure.

In the past few decades, the main focus of activity-based research has been on the investigation of the activity episodes scheduling process by which a household (or individual) activity program is transformed into an individual activity pattern. The individual activity pattern represents an analytical description of an individual's actual behavior over time, producing the spatial and temporal linkage of the trips. Moreover, the activity patterns can be regarded as *the result of an allocation problem* in the sense that the decision maker (individual or household) has to decide how to allocate time and other available resources within a particular time horizon to specific activity episodes and travels (Ettema and Timmermans, 1997).

In particular, intra-household interactions and group decision-making mechanisms within the context of the modeling of activity episode and travel participation have received increased research attention. It has been accepted that individuals are not independent decision makers, isolated from other household members regarding activity and travel participation. As reviewed in Chapter 2, the research efforts, with few exceptions, made to investigate intra-household interactions have relied on discrete choice model frameworks.

In this chapter, we develop a model of household activity scheduling process focusing on task allocation mechanism in a household. The primary focus of this study is on the exploration of a model system that taken direct interactions into account between household members with person level constraints rather than more aggregated divisions based on gender or role in the household. Moreover, we examine ways to reflect claims for the gender equality matters at individual level and the needs for optimality problems at household level.

Of particular concern, in terms of activity types, are household maintenance activities because such activities are most likely to be shared as responsibilities by multiple persons and to have inter-episode cycles longer than one day. Consequently, the household activity scheduling behavior in this study will be modeled by a system reflecting multi-persons and a multi-day framework.

5.2 Model Framework

5.2.1 Household Interactions with a Multi-person and Multi-day System

Following the definition in the section 2.1.2, we classify activities within a household activity program into three categories: work activities, household maintenance activities, and leisure activities. This categorization is based on the characteristics of each type of activity. Work activities are likely mandatory and fixed in terms of spatial and temporal choices, and thus less likely to relate to the choices faced on a short-run basis. For example, decisions about the duration and frequency for the market work do not take place once one decides to get a job working eight hours a day. The choices on the long-term basis may consist of changing jobs, moving houses, or getting married, which mostly creates corresponding constraints for short-term behavior.

The category of household maintenance activities creating intra-household interactions within multi-person household structures includes the activities related to household tasks to satisfy the common needs of more than two household members. This type of activity is more or less obligatory in the sense that some household member has to participate in the activity, but there is a large choice in frequency, duration, location, and the person who conducts the tasks. For example, the shopping activity is required to satisfy the needs of household members, but small shopping every day at a close range can be another option instead of a large shopping activity once a week.

To determine how to implement the activities within a multi-person household, not only independent decision-makings by the individuals but also collective decision-making in the household are simultaneously involved. We break down the subjects of the joint decision-makings in the multi-person household into four different elements: task allocation, household resource allocation (i.e., household vehicles, household income), joint travel, and joint activity participation. The connections between three activity types classified above and the elements of the joint decision-makings in the household are shown in Table 5.1.

Table 5.1: Relation between Activity Types and Joint Decision-makings in Household

	Task (role) allocation	HH Resource allocation	Joint travel participation	Joint activity participation
Work	◦	◉	◉	◦
Maintenance	◉	◉	◉	◉
Leisure	✗	◉	◉	◉

◉: positively relevant

◦: positively relevant in the long-term decision

✗ : never directly relevant

The decision attributes for work activities are not directly related to the choices for the task allocation process and joint activity participation in the short-run basis. However, some attributes for participation in work activities may be affected by decisions of who will use a family vehicle (i.e., household resource allocation) or car-pool decisions (i.e., joint travel participation) among family members. The type of leisure activity motivated by individual cultural and psychological needs (including recreation, entertainment, and social activities) is more likely associated with individual interests than household needs. Therefore, leisure-type activities are not directly relevant to the task allocation problem between household members, thus those activities may be excluded from primary consideration in this study. The type of maintenance activity undertaken for the upkeep of the household would be the common targets to be negotiated among household members in the allocation process, in the sense that it would have a high degree of substitutability among household members. In addition, according to the survey in Lee and McNally (2003), work and maintenance activities are allocated with a large proportion of the time budget on both daily and weekly levels.

In the studies of the activity based modeling, much of literature has employed a daily activity model system based on the desire to obtain a picture of typical travel patterns averaged across individuals and days of week. However, the day-based model implicitly assumes uniformity and independence in activity participation decision from one day to the next, and thus is restricted in examining variability of the behavior over longer periods of time.

In other words, the day, as the basic cycle for activity scheduling, can not capture the systematic variations over different days of the week, and thus can not evaluate policies that influence the weekly patterns of activities, such as shortening the work week (Hirsh et al., 1986). Therefore, early work in this direction questioned the usefulness of a single day data to accurately assess policy actions in activity and travel behavior. Thus, they put more efforts to examine the extent of day-to-day variability in activity-travel pattern as well as the influence of individual characteristics on the level of the variability (Hanson and Huff, 1986, 1988a, 1998b; Huff and Hanson, 1986, 1990; Jones and Clarke, 1988;

Pas, 1988; Pas and Koppelman, 1987; Kunert, 1994; Pas and Sundar, 1995). As a result, such longitudinal observations of the changes in terms of activity engagement and travel decisions enable us to witness the necessity of the multi-day dynamic frameworks which can model the behavioral adaptation based either on a short-run basis or on a long-term perspective.

On the other hand, as explicitly indicated in papers by Hanson and Huff (1986, 1988) and Pas (1988), prior research is in part based on the evidence that people with similar socio-demographic characteristics are more likely to have similar weekly activity-travel behavior, in the short-term. Moreover, they argued that a small number of "best days" may be used to represent most of the daily activity-travel patterns. Recent research (Axhausen et al., 2002; Bhat et al., 2004, 2005) examines the temporal rhythms in activity and travel participation over a multi-week period using hazard-based duration models. In these models, the likelihood of participating in an activity depends on the length of elapsed time since the previous participation. They found that the inter-episode duration of participating in maintenance-related activities formed *a weekly rhythm*, although in detail the duration dynamics may be influenced by activity types and socio-economic characteristics of individuals.

5.2.2 Theoretical Model Framework in a Utility Maximization Structure

Figure 5.1 depicts the general procedure of an activity-based scheduling model that will produce an individual activity pattern in a multi-day and multi-person framework. *A household activity agenda*, as explained in section 2.1.2, involves a universal set of activities required to satisfy not only the household common demand but also personal leisure demand in an open time horizon. The household common demand can be satisfied by the activity episodes undertaken by some member of the household, and the benefit from the satisfaction is shared by every member of the household who has responsibility for the demand. The housework (or household maintenance) activities definitely belong to this type of activity, and market work activities can be considered as this type of activity in that market work activities provide a household with the income to consume market goods and service by any members of the household.

A household activity program, the agenda of activities which can or must be performed over some specified time-window (day, week, etc), can be viewed as outcomes of a decision-making process regarding the combination of frequency (e.g., day of the week) and duration for each activity episode in a multi-day framework. From utility maximization theory, the solution for the optimal combined choice of frequency and duration for a particular activity episode locates on the point where the long-term total utility is maximized for the activity episode. After (or simultaneously with) the decision to generate the household activity program, *an individual activity program* can be found through optimal person-activity combinations which produce equal marginal utility from the combination based on an individual's heterogeneous performance on the work activity and the housework activity.

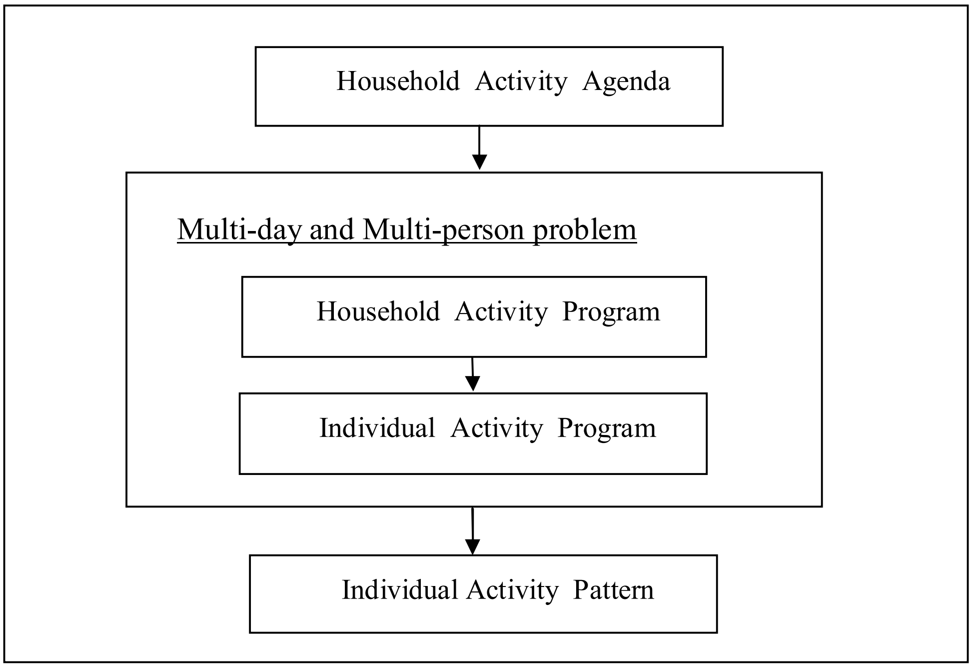

Figure 5.1: General Procedure of Activity-based Scheduling Model

Activity and Utility

Individuals can derive person-specific utility from engagement in individual (or joint) leisure activities and undertake the activities related to a households common demand to accept a responsibility in a household. Participation in individual leisure activities are most likely to produce an increasing positive utility over times (and diminishing marginal utility), but housework activities may have more complex relationships. Undertaking housework activities can generate a direct positive utility for types of persons who derive personal pleasure from taking care of other household members. However, the direct positive utility from the housework activities may not exist for other types of persons. Instead, we can expect that, even though housework activities may not have any direct impact on utility, undertaking housework activities requires time and energy consumption so that a member may have to sacrifice utility that might be derived from personal leisure activities. Therefore, housework activities can be assumed to yield an indirect negative utility because of physical constraints (such as having 24 hours available).

Such utilities derived from the participation of individual (or joint) leisure activities or housework activities must vary depending on the attributes of the activity episode (such as duration, time of day, day of the week, member who performs the activity episode, and location). In particular, the decision on attributes associated with time allocation behavior over activities, days, and persons is a primary concern in this study because of its significance of impact on utility measure.

Household Activity Program Generation with Multi-day System

An activity program in most previous activity scheduling models (i.e., SCHEDULER, SMASH, HAPP, and ALBATROSS) is assumed to be exogenously given as a uniquely defined list of activities. Moreover, they usually employ a daily model system in which the attributes of activity episodes within the activity program are also assumed to be deterministic. However, it is argued that the prior assumptions would be too strict because some attributes of activity episodes or even participation of some activity episodes might be characterized with some level of uncertainty in a daily model system. For example, some activity episodes could not be sure to be performed on a particular day since they could have a longer inter-episode duration of participation than a single day. Thus, a daily model system constructed in a deterministic environment may fail to properly capture the stochastic nature of activity participation. In this respect, with maintaining a single day as basic unit of analysis, the prevalent approach to accommodating such uncertainties has been to rely on stochastic optimization principles.

In other words, the activity engagement and travel decisions associated with uncertainties are assumed to be governed by maximizing the *expected utility* (or minimizing *expected disutility*) computed with the pre-specified probability. Therefore, an activity scheduling model in a daily model systems incorporating stochastic optimization problem must assume that not only the activity program is exogenously prescribed but also the probability associated with uncertainties of stochastic activities is known. Alternatively, stochastic simulation (such as Monte-Carlo simulation relying on a repeated random (or probabilistic) computation) may be applied as a solution methodology in the case where the number of dimensions is too large or the stochastic parameters are continuously distributed.

In this dissertation, we propose that household activity program generation need to be considered within a multi-day framework regardless of what type of activity scheduling model is employed (such as daily or longer period system). Specifically, the time allocation mechanism to each activity episode over days is an important element for the generation process of activity program. Basically, the type of activities of interest would be those with participation interval greater than a single day. The satisfaction derived from the specific activity episode may increase or decrease as a function of how many times (or days) have elapsed since the last participation of the same activity episode.

Moreover, the satisfaction is assumed to increase with duration of the activity episode. Therefore, activity program generation in a multi-day system is closely related to the simultaneous decisions regarding how frequently one participates in activity episodes over days (or during a week) and how much time one spends on the activity episodes for each participation. These two decisions are inherently interrelated to each other.

The characteristics of most activity episodes continuously repeated in a normal life style allow us to simply assume that each activity episode is more likely to have a cyclical nature of participation. It must be noted that some studies have found that the inter-episode duration of participation in household maintenance-related activities formed a weekly rhythm. At the same time, the activity duration choice for the each participation is strongly correlated with the cyclic pattern of inter-episode duration. As mentioned earlier, utility maximization theory predicts that the optimal combination of inter-episode duration and episode duration of participation for a particular activity episode can be found when the long-term total utility is maximized from the activity episode. In other words, the decision whether a particular activity episode will be included in the activity program for a particular time period (e.g., next day or next week) and the duration choice of the activity episode (if it is included) have to produce an outcome of maximum total utility in a long-term basis. Such optimal combinations are obtained if and only if the marginal utilities from the participations of activities are equal across the activities over days. In addition, the property of diminishing marginal utility may generally imply that high frequency with short-duration episodes produces higher total utility than low frequency with long-duration episodes. However, most activities have the minimum required duration to start producing a positive utility. Thus, if the minimum required duration is greater than the duration with high frequency, the calculated optimal duration will produce inefficient outcomes of the total long-term utility.

Individual Activity Program Generation with a Multi-person System

Housework activities arise from a multi-person household structure to satisfy household common demand. Multiple members in a household can satisfy (or induce) the household common demand by taking the responsibility for housework activities, and some of members who actually do not participate in the housework activities may benefit from the activities that other members conduct. An individual activity program includes an outcome from the collective decision process in a household that selects the person who conducts housework activities.

The allocation of housework activities to household members in multi-person household arises because it is reasonable that each household member may have different performances (as similar terms, specialization, or productivity) on housework activities (even on work activities) to satisfy household common demand. In other words, a certain person selected for an activity episode in the household may be able to generate higher utility than another choice. Therefore, after (or simultaneously with) the decision to generate the household activity program for a specified time period, it is necessary to find the optimal person-activity combinations based on the member-specific productivity on total labor work activities (i.e., work activity and housework activity).

As argued above, the participations of household maintenance activities may or may not be assumed to produce direct positive utility by satisfaction via caring for other members in the household depending on the type of person. However, it is evident that they can generate some indirect utility by sacrificing the opportunity for the other activity (due to physical constraints). Therefore, household joint decisions regarding the person selected for housework activities probably are influenced by the indirect utilities that vary across persons in the household. Selection of the person who conducts the housework activities is optimal when the total utility is maximized. Thus, such optimal selections are also obtained if and only if the marginal utilities from the participation in activities by selected members are equal across the activities.

In addition, the assumption regarding the non-identical (or heterogeneous) perceptions between members about household common demands and individual performances on total labor work activities may require a more general framework for the activity program generation in the multi-day and multi-person system.

5.2.3 Proposed Household Activity Scheduling Mechanisms

The model framework, shown in Figure 5.2, describes the overall household activity scheduling mechanisms that we apply in this research. The activity scheduling mechanisms are designed to ultimately produce individual weekly activity patterns for each household. From the perspective developed above, the activity scheduling process with a daily model system, incorporating uncertainties of stochastic activity, requires a household activity program and the associated probability optimally generated from a household activity agenda through multi-day analysis. However, this research decides to employ a *weekly model system* which has been proposed as an important analysis framework and activity diary survey framework (Hirsh et al., 1986; Doherty and Axhausen, 1999; Doherty et al., 2000; Lee and McNally, 2003). The weekly model system is expected to be able to accommodate the systematic day-to-day variations occurring in a weekly cycle and interdependencies of activity engagement and travel decisions among the days of the week. As argued in the literatures (Hirsh et al., 1986;

Bhat et al., 2005), the examination of cycles associated with the various activities conducted by the individual reveals that the most common regular cycle is the week, especially for non-home activities, and the effect of cycles longer than the week on regular behavior is relatively low.

However, the proposed model system does not internally incorporate the multiple-day-based optimization framework, but assumes that the generation of a weekly household activity program from a household activity agenda is externally determined from long-term decisions. That is, it is assumed that a deterministic household activity program for a particular household demographic is exogenously given with a weekly cycle. It should be noted that even though some activity episodes have the same purpose, they might be identified as different activity episodes in the deterministic household activity program when they have different activity episode attributes. For example, a grocery shopping activity with 30 minutes duration and a grocery shopping with 60 minutes duration would be identified as separate activity episodes in the weekly household activity program. Accordingly, the household activity scheduling process within a week-cycle model system consists of the household task allocation process with a weekly household activity program, and the individual activity scheduling and execution process with an individual activity program. To this end, the model system can be divided into three working stages.

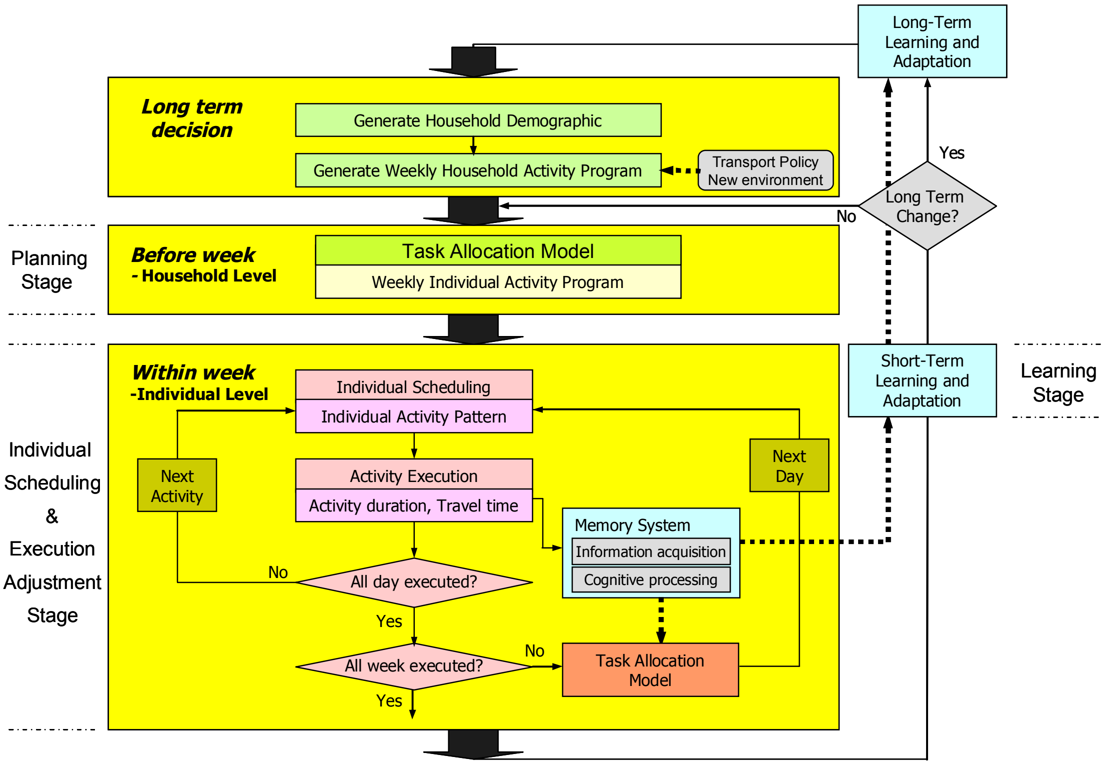

Figure 5.2: Proposed Household Activity Scheduling Process

As shown in Figure 5.2, the proposed model system basically contains two different types of decision-making processes, applied at different levels. First, the planning stage is designed to determine how to share the responsibility for household weekly maintenance activities at the household level, before starting the week, based on knowledge accumulated up to that time. Household members, at the household level in the planning stage, try to find a set of activity episode combinations among household members through the intra-household decision-making process (detailed in the subsequent section). It should be noted that although a household activity program is assumed to be deterministic in a weekly cycle, each household has to optimize the allocation of the maintenance activities under the presence of the uncertainties of the physical and social environment (e.g. activity duration or travel times). As argued above for uncertainties of activity participation, the uncertainties from the physical and social environment (such as transportation network) also could be addressed by the stochastic optimization based on the assumption of perfect knowledge about the degree of uncertainty. However, in this study, we employ *the stochastic repeated simulation with a weekly cycle*. The stochastic repeated simulation system updates the uncertainties as households experience the given environment, and the updated knowledge will have influence on how to allocate household task by household members and how to sequence set of activity episodes by individuals iteratively. This stage yields the individual activity program which may include not only assigned household maintenance activities but also other activities such as work, personal leisure, and social activities.

In the second stage, each household member attempts to optimize the sequence for the set of activities in the individual activity program, which produces time-of-day and day-of-week pattern for each household member. That is, the household members at the individual level attempt to seek how to schedule the assigned activities. The second stage also includes the execution process of the scheduled activities. Individuals, in this process, may obtain new knowledge (such as corresponding travel times and required activity durations) arising from the uncertainties of the physical and social environment, and thus may need to adjust their scheduled activities. The current version of the model system assumes that the location and duration of activity episodes are fixed as given in the upper level.

The third stage corresponds to the short term learning and adaptation process, which attempts to integrate various sources of information on the given environment (such as personal experience, word of mouth, and public messages). The perception updating process primarily derived from accumulation of past experiences would feed the task allocation process performed at the beginning of the week with the updated knowledge about the social and physical environment. In addition, if household members face discrepancies between expectation and experience in any day, they may conceptually need to revise the role scheduled for the remaining days of the week.

5.3 Model Development

5.3.1 Planning Stage

Significant much research has been undertaken to understand the mechanisms of household interaction in joint decision-making for activity and travel participation by household members using a variety of econometric models. The presence of various types of intra-household interactions and group dynamics for activity and travel participation were identified. Moreover, it was reported that life-cycle stage and demographic characteristics of individuals and households are closely related to the process of household task assignment to household members.

In particular, research has frequently identified the existence of traditional gender roles indicating that females are more likely to undertake household maintenance activities (and a non-worker is also more likely to undertake the activities). However, these findings largely result from models with general household structures, which do not explicitly distinguish between one-worker household and dual-worker household along with the gender divisions. Thus, validity of traditional gender roles in some transportation literature might be interpreted as an average propensity to participate in maintenance activities over all households.

Therefore, to apply household interaction mechanisms to an agent-based system, it is important to develop the model considering the attributes of all members in the household simultaneously. In this regard, Scott and Kanaroglou (2002) attempted to take household interactions into account according to the household types classified by the number of heads employed simultaneously with gender. The model analyzes the daily number of non-work, out-of-home activity episodes. As a result, they have found that a high degree of traditional gender roles persist only in couple, one-worker households (in which male is a worker and female is a non-worker). In other household types, household heads share, to some extent, responsibilities for out-of-home maintenance activities. Especially for couples in two-worker households, temporal constraints imposed by work schedules necessitate the sharing of such responsibilities, which can lead to breaking the rule associated with the traditional gender roles for the maintenance tasks allocation process.

These findings are consistent with those from Golob and McNally (1997) where the distribution of maintenance activities is highly likely to become more balanced between partners as the female significantly increases work participation. The strong positive impact of the available time window of household members on maintenance activities found by Vovsha et al. (2004) implies that, all else being equal, a household maintenance task will be assigned to the household member with the most available time, regardless of the gender.

Recently, time-use surveys conducted in many countries have been providing a greater research opportunity to examine the characteristics of time allocation behavior to various types of activities by different group of people (Marshall, 2006; Gershuny, 2000; Fisher et al., 2006). More specifically, Marshall (2006) provides interesting statistical evidence of equal partnership of couples in the sharing of household responsibilities with time-use survey data for Canadians aged 15 and over in 2005. According to the study, dual-earner households account for 69% of total husband-wife families with children under 16 at home in Canada. The study found that the wife's proportion of household time spent on paid work and housework within the dual-earner couples was one half. When wives have an income of $85,000 or more, the division of paid labor and housework between partners is more likely to be split equally.

Gershuny (2000) presents a time use analysis of twenty post-industrial societies using independently collected cross-national time use data. He uses the term "work" to denote both paid market work and unpaid housework together, and the two are analyzed simultaneously and in an integrated way as part of the same "time-budgeting". This corresponds to his theme representing the reciprocal relationship between work activity and leisure activity. The primary point made by Gershuny is that patterns of times devoted to work (paid and unpaid) and leisure have shown three types of convergence between 1960 and 1990: a national convergence, a convergence across different status groups, and a gender convergence. The "gender convergence" coincides with the well-known observation that, while women always have done and still do more unpaid housework and less paid market work than men, these gender gaps are narrowing (Robeyns, 2004). The general trend in unpaid housework between 1960 and 1990 is a slight increase in men's participation in core domestic work and a decrease in women's housework time. The reverse holds for paid market work.

A complex evidence of continuing gender convergence in paid work and unpaid housework is also observed using harmonized national time-use diary data on almost 40 years of daily life in America (Fisher et al., 2006). They show, during these years, an overall reduction in the total productive work time (the sum of paid work and unpaid housework), and a relative increase in time for activities outside production (including leisure and consumption). Figure 5.3 represents the changes in the daily activities of women and men in the USA in terms of total work hours. More specifically, total work time has reduced almost 15 percent from 1965 to 1985. The gender convergence is strikingly reaffirmed in their decline, as well as in the amount of total productive activity, and appears to be converging for men and women, (although there are different compositions in terms of work and housework ratios for men and women).

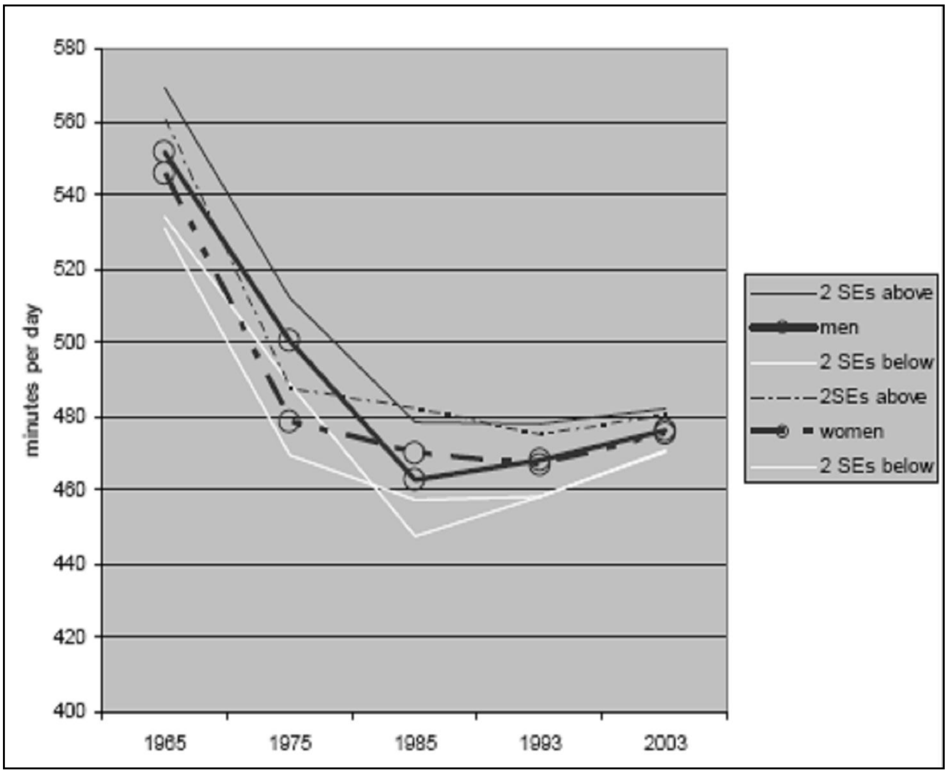

Figure 5.3: Trends of Time-Use in Total Work Hours (Work and Housework) for Man and Women with 95% Confidence (Adapted from Fisher et al., 2006)

Problem settings

As explained in section 5.2.2, we can deploy a utility maximization framework to generate an individual activity program based on household joint decision mechanisms within multi-day and multi-person systems. Although the process by which a household activity program is generated is an important component of the ultimate overall model, it is considered as beyond the scope of this research and thus it is taken as exogenous to the process of scheduling in the short term. We assume that the generation of a weekly household activity program from household activity agenda is externally determined from long-term perspective, instead of internally determined from applying the optimization framework with multi-day analysis. It is assumed that a deterministic household activity program with a week basis for a particular household demographic group can be given by a statistical classification dependent on various characteristics of household life cycle and style. Nonetheless, this research does incorporate an important property of the multi-day framework to account for the daily variability systematically occurring in a weekly cycle and interdependencies of activity engagement among the days of the week by using the household activity program assumed to be given with a weekly cycle rather than a daily system.

Therefore, the primary focus is on the development of model framework to examine the task allocation mechanisms in household. According to utility maximization theory articulated above, the distribution of housework activities to household members is assumed to rely on the relative productivity of member's time, which maximizes a long-term total utility of household.

Further additions to the present housework allocation mechanisms include two important determinants: equality and priority. In terms of equality, evidence was provided showing overall trends of a "gender convergence", which is generally against the traditional gender-based role allocation. In this research, the gender convergence can be viewed as a tendency of the household that tries to attain some degree of equality between household members in time use for household sustenance. Therefore, it should be incorporated in the model system that a household tends to pursue the equality of time expenditure among household members to equitably share the responsibility for household total labor time (i.e., paid market work and unpaid housework).

In addition to equality matters, we incorporate the concept of "priority" to precisely identify the solution domain. It might be expected that priority can be measured in several ways depending on the model development environment. Two types of measurements and corresponding implications for the definition of priority are defined in this research as follows.

-Preference measure : the higher priority on some activity episode, the higher individual satisfaction level by participation in the activity episode

-Performance measure : the higher priority on some activity episode, the higher contribution to household total utility by participation in the activity episode

These two measurements are simply considered as one in an integrated concept: the more preference, the higher performance. It is also possible to suppose that an individual preference may not coincide with the level of its contribution to the household total utility.

Based on the two determinants, equality and priority, the key idea of the proposed mechanisms for a household collective decision process is that household members attempt to undertake the activities with higher priority while achieving some degree of the fairness on the time expenditure.

As we assumed above that household life style and cycle may correspond to a statistical generation of a certain type of household activity program, we can also expect that a specific household life-cycle structure is more likely to be associated with the specific configuration of the priority measure for each household member. In other words, it is assumed that household members in any specific household life-cycle structure could be characterized with some representative pattern of priorities associated with a given activity program. Therefore, the mathematical formulation and simulation experiment in the subsequent sections are based on the premise that the priorities in the weekly household activity program for each household head could be measured with a set of ascending ordered numbers, in which number 1 implies the most preferred activity or the most contributable activity.

Mathematical formulation

To examine a weekly activity pattern, a week in this study is broadly divided with two time schemes: day of the week and time of day. Since one of the intentions is to examine the impact of day-to-day variations of network performance on the task allocation process, it would be natural to divide a week into single days. Moreover, we divide each day into several time periods for a more detailed representation of an activity pattern. For example, daily pattern for workers can be characterized by following time periods:

a) Before work, in which the activity/travel is performed before leaving home to work;

b) Commute, in which the activity/travel is conducted during home-to-work and work-to-home;

c) During work, in which the activity/travel is undertaken at work or from work to work;

d) After work, in which the activity/travel is pursued after arriving home at the end of the work-to-home commute.

Depending on the extent of details of time-of-day, a time period may contain more than one activity or tour that should be allocated to any person in the household.

The objective function of the formulation is to minimize the sum of priority measures of all assigned activities after the full allocation. Therefore, every activity is designed to be taken by a household member who has a lower priority value (meaning a higher priority) among them. At the same time, in order to consider a household that cares about equality in the allocation of housework activities, the equality measures of time expenditure devoted to total household labor time are included in the set of constraints. The constraint for the equality problem can be described as the difference of free times among household members as following:

$$\sum_{k,l}\left|\sum_{d}\sum_{s}\sum_{n}(T^{k}-\pi_{ns}^{kd}\cdot x_{ns}^{kd})-(T^{l}-\pi_{ns}^{ld}x_{ns}^{ld})\right|\leq\delta \qquad (5.1)$$

where, indices for the household members are denoted by k and l, T^{k},T^{l} are the total time budget for household member k, l respectively, π_{ns}^{kd} is the decision variable which takes the value one if household h decides that household member k participates in activity episode n at time period s on day d of the week, and x_{ns}^{kd} is the total time required for household member k to participate in activity episode n at time period s on day d of the week. It should be noted that for simplicity of mathematical formulation, hereafter, subscripts, d and s, are contractions of d_n and s_d^n respectively. Therefore, d as a contraction of d_n represents possible days of the week for activity episode n, and s as a contract of s_d^n denotes possible time periods for activity episode n on day d of the week. Therefore, some activities in the household activity program can be done at one of multiple possible time windows in terms of day-of-week and time-of-day by household members, whereas the others should be done only at a specific day of the week and a specific time period.

Since it is reasonable for each household member to have the same total time budget for a day or a week, the constraint can be expressed as follows,

$$\sum_{k,l}\left|\sum_{d}\sum_{s}\sum_{n}(\pi_{ns}^{kd}\cdot x_{ns}^{kd}-\pi_{ns}^{ld}x_{ns}^{ld})\right|\leq\delta \qquad (5.2)$$

Equation (5.2) containing absolute term can be expressed as following,

$$\left[\sum_{d}\sum_{s}\sum_{n}(\pi_{ns}^{kd}\cdot x_{ns}^{kd}-\pi_{ns}^{ld}x_{ns}^{ld})\right]\leq\delta \quad and \quad -\left[\sum_{d}\sum_{s}\sum_{n}(\pi_{ns}^{kd}\cdot x_{ns}^{kd}-\pi_{ns}^{ld}x_{ns}^{ld})\right]\leq\delta$$

(5.3)

Thus, the complete mathematical programming formulation is in Equation (5.4). The mathematical formulation is dependent on how travel time, t_{ns}^{kd} is handled. The travel time for each activity episode varies with scheduling decisions for the full set of activity episodes. The solution algorithm for the mathematical formulation under the consideration of travel times from all possible activity sequences for all set of activity episodes belongs to the full enumeration procedure in the next subsection. Thus, the full enumeration method for the mathematical formulation can calculate a solution of household activity allocation and individual activity scheduling simultaneously. However, presented herein is the heuristic sequence approach in which households are assumed to separately conduct the decision-makings for household activity allocation and individual activity scheduling process. A detailed explanation follows in the subsection for solution procedure.

$$
\begin{aligned}
& Min\ \ z = \sum_d \sum_s \sum_n \left(p^{k\,d}_{n\,s} \cdot \pi^{k\,d}_{n\,s} + p^{l\,d}_{n\,s} \cdot \pi^{l\,d}_{n\,s} \right) && (1) \\
& subject\ \ to: && \\
& \quad \sum_d \sum_s \sum_{h \in (k,l)} \pi^{h\,d}_{n\,s} = 1 \quad \forall\, n && (2) \\
& \quad x^{h\,d}_{n\,s} = a^{h\,d}_{n\,s} + t^{h\,d}_{n\,s} \quad \forall\, d, s, n, h \in (k,l) && (3) \\
& \quad P\left(r^{h\,d}_{n\,s} - b^{h\,d}_{n\,s} - t^{h\,d}_{n\,s} \geq 0 \right) \geq \sigma \quad n \in c_a, \forall\, d, s, h \in (k,l) && (4) \\
& \quad \pi^{h\,d}_{n\,s} \in \{0,1\} \quad \forall\, d, s, n, h \in (k,l) && (5) \\
& \quad p^{h\,d}_{n\,s} > 0 \quad \forall\, d, s, n, h \in (k,l) && (6) \\
& \quad \sum_d \sum_s \sum_n (\pi^{k\,d}_{n\,s} \cdot x^{k\,d}_{n\,s} - \pi^{l\,d}_{n\,s} x^{l\,d}_{n\,s}) \leq \delta && (7) \\
& \quad -\left(\sum_d \sum_s \sum_n (\pi^{k\,d}_{n\,s} \cdot x^{k\,d}_{n\,s} - \pi^{l\,d}_{n\,s} x^{l\,d}_{n\,s}) \right) \leq \delta && (8)
\end{aligned}
\qquad (5.4)
$$

where, as noted above, d and s are contractions of d_n and s^n_d respectively. Moreover, a $a^{k\,d}_{n\,s}$ is activity duration required for household member k to participate in activity episode n at time period s on day d of the week. A $t^{k\,d}_{n\,s}$ represents the expected travel times required for household member k to access the location of activity episode n at possible time periods s and on possible days d of the week for the activity episode. Depending on the solution procedure, a $t^{k\,d}_{n\,s}$ may have multiple values when multiple activity episodes are supposed to be conducted at same time period on same day because different activity sequences of those multiple activity episodes in the time window may produce different travel times. A $b^{k\,d}_{n\,s}$ is the possible earliest time for household member k to begin traveling for participating in activity episode n at time period s on day d of the week, a $r^{k\,d}_{n\,s}$ is the time required to be arrived for household member k to participate in activity episode n at time period s on day d of the week, a p_{ns}^{kd} is the priority measure for household member k to participate in activity episode n at time period s on day d of the week. However, it may be more reasonable to assume that the priority measure will be identical over all possible time period and day of the week for same activity episode. A c_a is a set of activities that needs to be commenced at a particular time

Equation (5.4.2) ensures that each activity episode is assigned to only one person in any possible time windows. The second constraint indicates that total time includes the duration for the activity and corresponding expected travel time to access the location for the activity. In addition, the travel time implies the shortest travel time from a previous activity location to a current activity location. Equation (5.4.4) is the time-space constraint to ensure that an activity start time constraint is fulfilled. This equation implies that a household member can take responsibility for the activity (c_a) only when he/she can successfully arrive in time with a probability greater than a predefined threshold (σ). The fourth constraint specifies the set of values that the binary decision variables may take. The priority of activities in the Equation (5.4.6) must be a positive integer, where the smaller a number is, the higher the priority would be. Equation (5.4.7) and (5.4.8) imply that the difference of the total times for the activities between household members should not exceed a predefined value, playing a role for the equality on the time expenditure of activities. The magnitude of the predefined value in the equations corresponds to the extent to which the household type considers fairness as important value.

5.3.2 Individual Scheduling and Execution Adjustment Stage

Once the individual activity program has been generated, the next step is to schedule these activities, which incorporate the set of choice facets in an interlinked decision stream to explain and predict where individuals conduct activities, when, for how long, sometimes with whom, and the transport mode used for a given time frame. However, this research postulates that most attributes, except the sequence of activities, are given by the activity program as fixed attributes for each activity episode. Therefore, what is needed to be done by each individual in the second stage includes sequencing the set of activities undertaken in the planning process, executing those planned activities and updating corresponding knowledge. Determining the sequence implies both decisions of time-of-day and day-of-week for the set of activity episodes in the individual activity program. The sequencing problem arises either because some types of activity episodes have multiple available time windows for participation or because a single time window contains multiple activity episodes to be scheduled. It is also postulated that individual decisions for the timing of individual activity program are made only by minimizing total travel time. In fact, individuals also need to know the sequences of activities during the task allocation adjustment process in the first stage because when and in which order the activities are executed have different effects on the degree of satisfaction from the activities. However, the proposed model system based on the heuristic sequential approach makes the assumption that an individual does not tend to fully consider whole effects from taking the activities in the negotiation process at household level. Instead, in the individual scheduling and execution steps, each household member attempts to optimize individual sequence of activities and executes the planned activities for each day. On the other hand, the full enumeration approach in the subsequent section considers a household task allocation and an individual activity sequence process simultaneously.

To find the optimal sequence of a given individual activity program, the traveling salesman problem (TSP) can be applied. TSP is a famous linear optimization problem in network analysis. It comes from graph theory and tries to find a Hamiltonian node with minimum cost. With given activity locations, an order is found that minimizes required travel cost to visit all the given activity locations. All locations should be visited just once and a tour should be terminated at home.

TSP is a NP-hard problem (Non-deterministic Polynomial-time hard), so there is no exact solution algorithm for a real-size transportation network. Therefore, the choice of solution algorithm is heavily dependent on the size of network. If network size is small, then exact algorithm can be used. Exhaustive search algorithm (i.e., full enumeration), branch and bound algorithms, and dynamic programming techniques each fall into this category. Consequently, if a real-size network must be solved, no exact algorithm is available, thus, only heuristic algorithms can be used. K-opt algorithms, genetic algorithms, simulated annealing, tabu search, and neural networks are classified into this second category. In this research, a scheduling problem is solved on a small network, so the optimal solution can be found with an exhaustive search algorithm.

The execution process is designed to implement an actual participation of planned activities, which results in new knowledge such as required activity duration and travel time. In general, each household member may have different capacities and processes to accumulate new experience in the context of bounded rationality. It also should be noted that each household member will have their own specific knowledge based on their own experience. All acquired knowledge in the memory system is connected to the learning and adaptation process belonging to the next stage. In addition, the weekly activity pattern determined in an uncertain environment may require an adjustment by reallocation of household activities during days of the week because of updated knowledge about given transportation network performance. However, since the network performances in this study are assumed to be independent between days of the week, the adjustment process for the remaining days of the week only takes into account the equality measure caused by realization of expected travel time.

5.3.3 The Learning Stage

The third stage in this study examines how household members adapt collective decision-making for household task allocation and an individual activity scheduling behavior to the given physical environment, which is characterized by the uncertainties derived from the transportation system.

In contrast to the dominant task allocation studies focusing on optimization mechanisms, the model framework in this study assumes time (or experience) dependent variations in decision maker's perception regarding expected travel time. Thus, household members in this model framework are assumed to keep finding the solution for household maintenance allocation and scheduling an individual activity program as the expected travel time for the given transportation network is updated via the weekly learning process. In fact, household members tend to integrate various sources of information for the transportation network such as personal experience, word of mouth, and public messages whenever they get a chance to obtain any of them. This study takes the perception updating process into account through the accumulation of past experiences of household members.

Moreover, it should be noted that although household members experience individually, the unit of the learning process would be the household. In other words, the minimum learning unit is more likely a household rather than an individual in the joint decision-making process among household members. For example, new information found by a husband in performing a particular activity last week would be used as shared information if a wife needs to perform the same activity this week. To analyze the daily dynamics within a week, it is also reasonable that a household tends to store and update experienced knowledge in the different memory slots for each day of the week, thus the household may have different expected travel times depending on the day of the week even for the same route.

5.3.4 Solution Procedure

The overall process of the model follows the type of model with week-based stochastic repeated simulation with learning mechanisms, in response to the stochastic characteristics of the social and physical environment. In this framework, human agents interact with other agents and the environment to attain their goals. Ideally, most choices of the agents are assumed made within a rather complex mechanisms constrained by the choices made by others. Human agents in this environment must have a tendency to make a behavioral adjustment. The model structure based on the stochastic and dynamic process can be more suitable, because it is concerned with the nature of the adjustment process that depends on the knowledge accumulated through past behavior (Goodwin et al., 1990). In other words, if the household activity scheduling process including household activity allocation is assumed to be performed based on the uncertain travel times calculated via traffic network simulation, the household activity scheduling process is iteratively updated through a stochastic and dynamic simulation process with a weekly cycle.

Regarding the household activity allocation process, which is the key part of the entire model, the assumptions about the nature or the capability of individuals allow two types of model structures. The first is the *heuristic sequential approach* that may reflect the human cognitive process based on the assumption of bounded rationality. As argued in computational process model based on the psychology and cognitive theory, people may often be satisfied at a local optimal solution which is usually found through a sequential iteration process (Ettema and Timmermans, 1997). To resolve the individual activity scheduling and execution problem in this research, a heuristic approach is employed to focus the direction of the study on a better understanding the household activity allocation process

The other model structure is the *full enumeration approach* which aims to find the global optimal solution over the whole domain using an exhaustive search method. In contrast to the heuristic approach, the full enumeration approach takes all possible cases for the household activity allocation into account. Therefore, the solution procedure with full enumeration approach can be depicted by replacing the solution finding the household activity allocation and individual activity scheduling in Figure 5.4 with the full enumeration method. More specifically, households in this approach are assumed to calculate every possible combination of household tasks allocation as well as corresponding sequences of the tasks simultaneously every time they update uncertain aspects of activity attributes through the simulation in a week cycle. The full enumeration approach also covers the individual sequencing process (to be addressed in the next subsection), which implies that a solution procedure with full enumeration only includes individual execution for the heuristic sequential approach. The results from this approach are used to make a comparison and evaluation with the results from the heuristic approach.

The subsequent subsections provide detailed explanations of the heuristic sequential approach in terms of household activity allocation and individual activity sequencing and execution. The activity execution procedure will be also applicable to the full enumeration approach.

5.3.4.1 Household activity allocation

This subsection describes how a heuristic approach with a sequential procedure finds the proper allocation of household maintenance activities. As depicted in Figure 5.4, the initialization stage calculates the initial perceived travel time distribution by a sampling method, initial role allocation is simply carried out by allocating an activity to household member who has higher priority on the activity one by one, and the initial activity sequence for initially assigned activities is calculated. After realization of travel times from activity execution, the optimality test is performed. That is, to test the optimality of the initial set of roles of activities, the difference of time expenditure on participation in total household labor activities among household members is evaluated. Activity episodes considered here include not only the assigned household maintenance activities but also work-related activities. If the difference of times that household members spend on the assigned activities is less than a given criteria, the initial set can be accepted as the optimal solution. Otherwise, household members need to start finding a solution which satisfies the constraints.

This study proposes a heuristic, iterative method in this step. First of all, household needs to distinguish between a person who gives an activity episode and a person who receives the activity based on times spent in activities. For simplicity, two household heads are assumed as the members who can undertake the household maintenance activities in this study. Once the model decides a person who gives an activity episode, it needs to find the activity episode to be transferred. To maintain minimizing the sum of priority of activities, an activity episode which has the smallest difference of priority between household members in the giver's set of activities is assumed to be taken in this step. However, if there are multiple activity episodes with the same priority difference, the consideration would go to the free time difference between household heads. That is, an activity episode which contributes most to minimizing the free time difference would be the one selected among the activity episodes with the same priority difference. Importantly, to calculate the change of free time difference between household heads due to giving and taking activity (the gap minimization process in Figure 5.4), this step may require a new sequence of activities to evaluate the performance of the activity. In this regard, this study does not apply the full consideration employed in the individual scheduling stage. Instead, in this step we use an “inserting method” that uses an element algorithm to skip or connect activity episodes with the most adjacent one. This swapping process is carried out in the same way after every execution of the scheduled activities until the equality of time expenditure is satisfied. This sequential procedure might not guarantee to find a global optimal allocation of household activities. Nevertheless, the sequential approach has some advantages such as simplifying the calculating procedure and reflecting the human cognitive process based on the bounded rationality.

5.3.4.2 Individual sequencing and execution

For individual activity scheduling process, TSP was introduced in the previous section. Since this study will be applied to relatively simple experiment, the full enumeration process is employed even for the heuristic sequence method. To reflect interactions with the physical transportation environment in the activity execution stage, this research uses a Monte-Carlo type simulation which is useful for a model environment with significant uncertainty reflecting random distribution of input. After all, the activity execution model for actual demand and transportation networks should be replaced by the activity simulation model using traffic network simulation. After the realization of travel time based on the simulation, the mechanism for updating expected travel time through accumulating experienced knowledge is as follows.

$$N_{d,a}^{n,s}(k) = N_{d,a}^{n-1,s}(k) + S_{d,a}^{n-1,s}(k) \quad (5.5)$$

where,

$N_{d,a}^{n,s}(k)$: The number of frequency of travel time interval k for path a at time period s on day d of the week until the n[th] week.

$S_{d,a}^{n-1,s}(k)$: The number of sample of travel time interval k experienced by family members for path a at time period s on day d of the week during (n-1)[th] week.

Then, the expected travel time for path a at time period s on day d of the week in the end of nth week, $\tilde{t}_{d,a}^{n,s}$ is,

$$\tilde{t}_{d,a}^{n,s} = \frac{\sum_{k \in T} (t^{ave}(k) \cdot N_{d,a}^{n,s}(k))}{\sum_{k \in T} N_{d,a}^{n,s}(k)} \quad (5.6)$$

where, $t^{ave}(k)$ is a middle value for travel time interval k

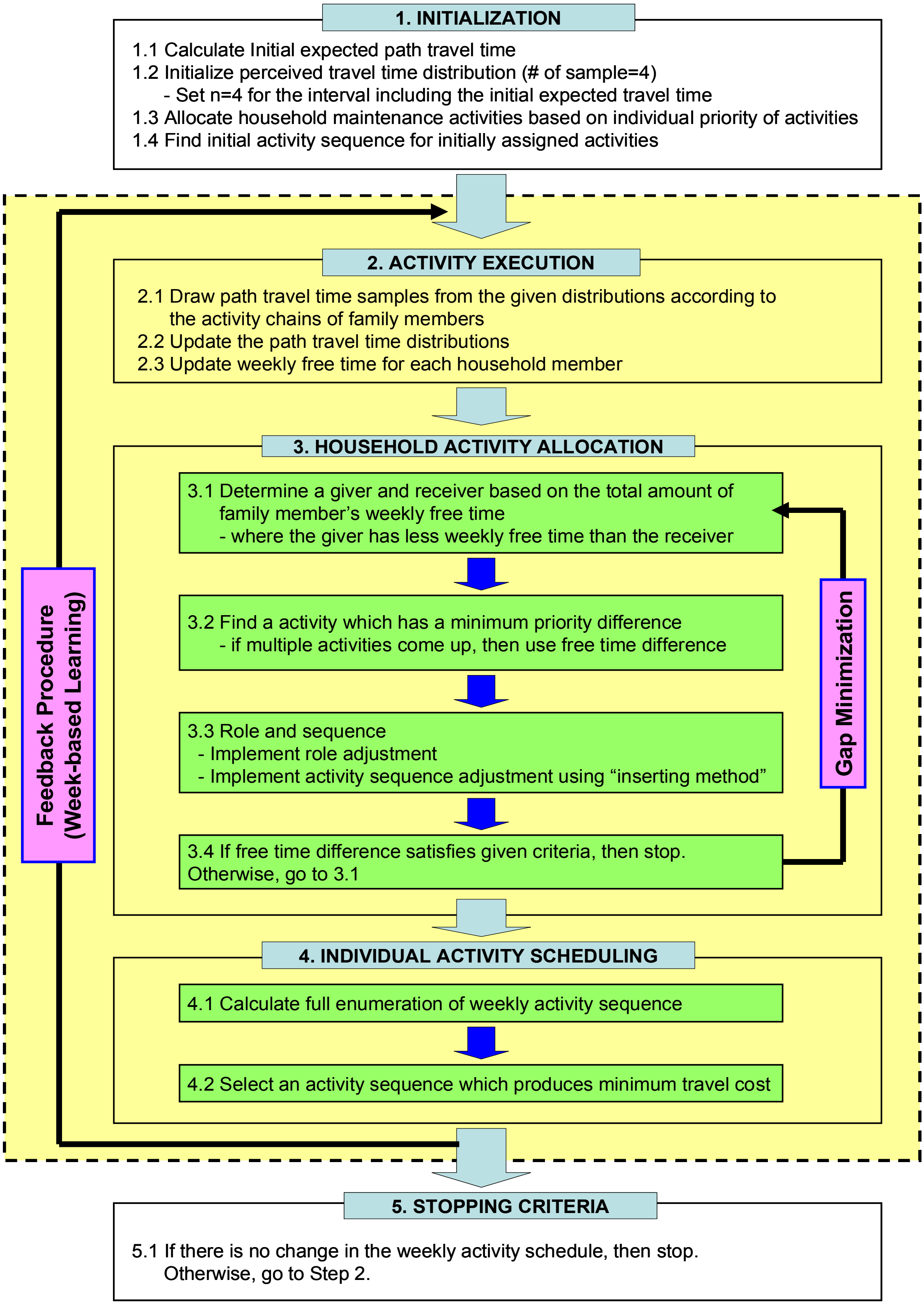

Figure 5.4: Solution Procedure with Heuristic Approach

5.4 Simulation Experiment

A simulation experiment is implemented to demonstrate the utility of the proposed framework within the hypothetical environment. The ultimate intention of the model framework proposed in this study is to investigate activity and travel patterns within an interactive environment consisting of households with varying decision-making mechanisms. This study focuses, however, on testing the model with one household structure and a simple transportation network as described in the subsequent section.

5.4.1 Activity Program and Network Set-up

Table 5.2 describes a weekly household activity program including market work activities and household maintenance activities. Both household heads have a fulltime job with daily work duration for the husband of eight hours and for the wife of seven hours per day. Because of early work start time of the husband, the husband can not undertake drop-off activity for children regardless of priority level in this experiment. The maintenance activities consist of in-home and out-of-home activities, and four of them (#No. 7, 10, 11, 12) are supposed to be performed once a week and rest of them are once a day. Whereas activity # 7 is designed to be performed on any day of the week, activity

#10, #11, and #12 are restricted to be conducted on specified days. Activity #10 should be performed on either Monday or Tuesday, and activity #11 and #12 are allowed to be conducted on either Thursday or Friday. In the individual activity scheduling process, each individual needs to decide which day of the week the activities will be performed based on the total travel time. As explained in the previous section, the weekly household activity program identifies grocery shopping activities with different amount of durations as separate activity episodes. As mentioned before, duration and location of activities are assumed given. Moreover, all activities set in Table 5.2 have feasible time windows to be executed. These feasible time windows are related to the time periods introduced in the mathematical formulation. The time periods for the representation of a daily activity and travel pattern for each household member in this simulation is divided as follows: a) Before work, in which the activity/travel is performed before leaving home to work, (for example meal preparation); b) Commute, in which the activity/travel is conducted during home-to-work and work-to-home, (for example pick-up and drop-off); c) During work, in which the activity/travel is undertaken at work or from work, (for example working or lunch); d) After work, in which the activity/travel is pursued after arriving home at the end of the work-to-home commute, (for example grocery shopping or cleaning home).

Table 5.2 Weekly Household Activity Program List

No	Activity episodes	Desti-nation	Dura-tion[1]	Feasible time window		Priority pattern 1		Priority pattern 2		Priority pattern 3	
				Start	End	H[2]	W[3]	H	W	H	W
1	Work[4]	2	480	8:00	16:00	-	-	-	-	-	-
2	Work[5]	3	420	9:00	16:00	-	-	-	-	-	-
3	Meal preparation 1 (morning)[6]	1	20 (60)	7:00	7:30	7	8	7	4	1	3
4	Meal preparation 2 (morning)[7]	1	20 (40)	7:00	7:30	9	10	8	5	1	3
5	Meal preparation 1 (evening)	1	40 (80)	17:00	18:00	8	7	9	6	1	3
6	Meal preparation 2 (evening)	1	40 (120)	17:00	18:00	10	9	10	7	1	3
7	Cleaning home	1	30 (150)	19:00	21:00	1	4	1	10	2	1
8	Drop-off kids	4	5 (25)	8:00	8:30	3	1	6	8	2	1
9	Pick-up kids	4	5(25)	16:00	16:30	4	2	5	3	2	1
10	Grocery shopping1	5	20	19:00	21:00	6	5	2	9	3	2
11	Medical care	6	30	19:00	21:00	2	3	3	1	3	2
12	Grocery shopping 2	5	60	19:00	21:00	5	6	4	2	3	2

*1: min/day (min/week) 2: husband 3: wife 4: work activity of husband 5: work activity of wife 6: The front part of the weekdays 7: The rear part of the weekdays

In this study, three kinds of priority patterns for two set of activities that belong to two household heads are assumed to examine how the household distributes the activity episodes in the model. Priority pattern 1 represents a kind of household that has two heads with a similar preference pattern of activities. On the other hand, two members in priority pattern 2 show relatively different priorities of activities. Typically, the wife prefers in-home activities and husband prefers out-of-home activities. Instead of assigning a priority value for each activity, priority pattern 3 categorizes the set of activities by characteristics of activities and provides the same priority level to the activities in the same category.

The transportation network used for this experiment consists of six zones and seven paths. It is assumed that each zone is the location for a particular activity and corresponding paths represent the shortest path that can be used between zones. This study does not include the shortest path finding program. The multiple-run simulation with learning mechanism is used to realize the travel time experienced by each activity and travel choice. Although the activity and travel choices of the simulated household in this experiment are not interactively related to the travel times of corresponding paths, a consistent travel time is exogenously generated based on the assumed travel time distributions for every path. Moreover, since one of intentions in the study is to see the influence of uncertainties from daily variations in the transportation network, the different patterns of travel time on each day of the week are assumed. In addition to application of the proposed model in the base situation, the other scenario is tested as well. As described, the current duration of work activity for husband is eight hours, but a new situation of shortening the work time by 30min everyday is introduced. Thus, this situation causes 150 minutes decrease of the total work time for husband a week.

5.4.2 Simulation Results

Table 5.3 shows the simulation results in a base scenario according to three priority patterns. The initial results in the table imply the allocation results of activities when no constraints are applied. The simulation confines the final acceptable thresholds for free time difference to 5 percent between two household heads, (5% time differences corresponds to about an hour which is close to the largest activity durations).

The first priority pattern shows 14% of the free time difference between two household heads without constraints for the equality of time expenditures. That is, husband spends about 250 minutes more than wife does per week in the initial situation. However, with constraints of free time difference under 5%, wife is expected to assume more activities than the initial situation. Heuristic approach found that wife needs to undertake two more in-home activities, which reduces the objective function value from 48 to 50 but reduces the free time difference to 1.9%. On the other hand, full enumeration method found a solution that yielded a better objective value (49) than heuristic approach. Here is a possible explanation. While the heuristic algorithm starts the task allocation module with initial allocation based on the individual priority of activities, the full enumeration method takes every possible combination into account from the start. As explained in the previous section, model structure based on day-to-day adjustment process may be affected by initial start point because of path dependency. In other words, knowledge that has not further updated by new experience will remain, and it may not be updated if it was the worst. That is, the solution from full enumeration was not the feasible point with more than 5% of difference. But, in the full enumeration approach, the point becomes a feasible point with a 4.3% difference during the learning process with full knowledge. Under the second priority pattern, the husband initially undertakes three activity episodes, including the work activity, which leads to about a 7% free time difference (which is about 90 minutes a week). Since the wife spent more time than the husband in this initial pattern, husband assumes one activity (No. 9) from the wife. Both approaches show the same results although they have little different values of free time difference. In the third priority pattern, the wife does not prefer doing in-home maintenance activities, but to equalize the total time expenditure for whole activities the wife will undertake more in-home activities. The solutions from heuristic and full enumeration approach show a similar relation with the results shown in the priority pattern 1.

We further tested the model system for the case when work duration of husband is to be decreased. Thus, this case intends to see how the household manages the increased free time caused by reducing work time of one of the household members. Apparently, we can find that the joint decision-making mechanism within the household level shows more reasonable behavior in dealing with a changed situation compared to the individual level scheduling process. In this case, the husband is assumed to obtain an extra 150 minutes of free time a week by shortening his work time. This may lead to changing the activity schedule of only the husband himself in the individual level scheduling model. However, the proposed model represents that extra time tends to be shared between household heads, in this case by the husband undertaking some of household maintenance tasks from the wife to satisfy equal level of expected free time between them.

As shown in Table 5.4, shortening the husband's work duration leads to decreasing the free time difference of pattern 1 and 3, and increasing the difference of pattern 2 in the initial situation, but no change of activity allocation occurs. On the other hand, when the equality measure of free time difference is taken into account, household members start exchanging activities and the husband in every case ends up undertaking more activities than before. Patterns 1 and 3 reach the better solution than before introducing the reduction of work time in terms of the objective value. For pattern 1, shortening the work time of the husband reduces the free time difference to under 5%. Thus, the solution for this case is the same as the initial allocation. Since the husband spent less time in pattern

2 of the base scenario, allowing extra free time for husband makes the objective value worse.

Table 5.3 Activity Allocation Results in a Base Scenario

Act.	Pattern 1			Pattern 2			Pattern 3		
No	Initial	Heuristic	Full E.	Initial	Heuristic	Full E.	Initial	Heuristic	Full E.
1	H[1]	H	H	H	H	H	H	H	H
2	W[2]	W	W	W	W	W	W	W	W
3	H	W	W	W	W	W	H	W	H
4	H	W	H	W	W	W	H	H	H
5	W	W	W	W	W	W	H	H	H
6	W	W	W	W	W	W	H	W	W
7	H	H	H	H	H	H	W	W	W
8	W	W	W	W	W	W	W	W	W
9	W	W	W	W	H	H	W	W	W
10	W	W	W	H	H	H	W	W	W
11	H	H	H	W	W	W	W	W	W
12	H	H	H	W	W	W	W	W	W
Obj.[3]	48	50	49	39	41	41	13	17	15
Diff.[4]	14%	1.9%	4.3%	7%	2.0%	1.0%	22%	3.9%	4.7%

1: Husband 2: Wife

3: Objective value (sum of priority values)

4: percentage of free time difference between household heads

Table 5.4 Activity Allocation Results from the Case of Shortening Work Times on Husband

Act. No	Pattern 1			Pattern 2			Pattern 3		
	Initial	Heuristic	Full E.	Initial	Heuristic	Full E.	Initial	Heuristic	Full E.
1	H[1]	H	H	H	H	H	H	H	H
2	W[2]	W	W	W	W	W	W	W	W
3	H	H	H	W	W	W	H	H	W
4	H	H	H	W	W	W	H	H	H
5	W	W	W	W	W	W	H	W	H
6	W	W	W	W	W	W	H	H	H
7	H	H	H	H	H	H	W	W	W
8	W	W	W	W	W	W	W	W	W
9	W	W	W	W	H	H	W	W	W
10	W	W	W	H	H	H	W	W	W
11	H	H	H	W	H	W	W	W	W
12	H	H	H	W	H	H	W	W	W
Obj.[3]	48	48	48	39	45	43	13	15	15
Diff.[4]	4.2%	1.5%	1.4%	15%	3.4%	2.2%	12.6%	0.2%	2.2%

1: Husband 2: Wife

3: Objective value (sum of priority values)

4: percentage of free time difference between household heads

5.5 Summary and Conclusions

A household activity scheduling model has been developed. The model employs a joint decision-making process at the household level and individual activity sequencing process at the individual level. The model also incorporates a week-based learning mechanism to capture the systematic variations over different days of the week, possibly derived from uncertainties of daily activity participation of household maintenance activities. Furthermore, in order to accommodate uncertainties from the environment (such as the transportation network), learning and adaptation mechanisms are also incorporated. Based on statistical findings from existing time use analyses for within-household interactions, theoretical formulation is proposed and numerically simulated for household collective decision-making behavior for the allocation of household maintenance activities within a household activity scheduling process. The rationale behind the joint decision-making model for household activity allocation is that the household members attempt to undertake activities with higher preference while achieving some degree of the equality on time expenditures for household sustenance. The model allows for the examination of the characteristics of the household task allocation process and how households might respond to a situation such as shortening work duration in its activity scheduling and execution process.

The results of the simulation analysis can be summarized as follows. First, the task allocation process appears to more quickly stabilize than the learning process for travel time. Basically, the task allocation process is dependent of the extent of travel time learning. However, once a household has learned a network performance at a certain level, task allocation tends to maintain stability because such an allocation process does not react sensitively to the small variations of expected travel time. Second, how a household adjusts to a changed situation has been investigated. The model system produces the plausible results for a household where increased free time of one of household members tends to be shared to achieving a more equitable distribution of extra free time. This would be more reasonable than one from an individual scheduling model in which an individual cares how to use the extra free time selfishly.

Chapter 6

Conclusions and Future Research

6.1 Conclusions

Individuals live with other members in families whose membership confers rights and obligations that may influence the decisions that individuals make. Therefore, neglecting the behavioral issues arising from within-household interactions on time or person allocation to various activities and related travel can create erroneous and misleading travel demand estimates. Further, individuals also live in a particular social context that both motivates and constrains the individual behavior. The aim of this dissertation has been to focus on these essential themes of the activity-based approach through the theoretical developments and empirical findings in two major branches of activity-based travel demand modeling: activity time allocation and activity episode scheduling.

Development of an activity time allocation model in this dissertation includes two types of structural time allocation models based on the critical assumption that a household and its members should be a basic analysis unit. First of all, the collective models based on two main assumptions that two household heads have their own utility functions and decisions by them reach Pareto-efficient outcomes have been introduced to develop intra-household activity time allocation models for leisure demand and household maintenance activities. In particular, the model estimations are performed based on two different variables : total leisure time and out-of-home leisure time. Estimation results from out-of-home leisure time indicate that own wage, household total income, and child presence play a significant role in the activity time allocation model.

Secondly, intra-household time allocation to housework has been further examined through the estimation of time allocation for different types of activities (i.e., market work activity or housework activity) by different types of persons (i.e., husband or wife) along with extensive exploration of various theories and identification of related interactions. Estimation results from the constructed simultaneous equation model show that distribution of housework time between household heads appears to be complementary (i.e., assortative mating) rather than supported by specialization theory and cooperative bargaining theory. Further, and interestingly, focusing on the marginal interactions with total housework time (i.e., sum of in-home housework and out-of-home housework time), the model predicts that household with a wife spending one hour more on market work activity may spend fewer hours on housework activity compared to household without such a wife. The possible explanation is that the household with a strong participation in market work activities by female member might be likely to buy market goods and service substituted for commodities produced by housework, and/or have worse quality of home-making. However, when it comes to out-of-home housework time only, relatively equitable marginal interactions are found, implying that total household out-of-home housework activity time would not be sensitively influenced by changes in spouse's market work hours.

In order to further discuss the housework allocation in a family, traditional gender roles that had been often reported as one of the most prominent determinants within the context of the household tasks allocation mechanisms have been examined by exploration of the inter-relationship between a personal attitude of gender-specific roles and individual and social characteristics of each decision maker. It is postulated that the personal attitude toward roles of each household member in his or her family play an important part in the allocation process of the household tasks, and the actual decisions under varying physical and social constraints in turn influence the formation of individuals' habits and attitudes on any imaginable aspect of life. As expected, males, married people and the presence of young children (less than 7 years old) have the propensity in favor of the traditional gender roles. However, when we focus on the persons in dual workers household among married couples, they show the significantly higher tendency against the traditional gender roles compared to persons in the other household types. Possible interpretation of these results is that although traditional idea can influence the current decisions, the current environment with physical and social constraints can also influence the attitude on varying aspects of life.

This dissertation has proposed a household activity scheduling process with a model system designed for weekly activity patterns. The weekly pattern system for the household activity scheduling process is expected to hold various advantages compared to a deterministic daily model system. That is, the weekly pattern system will be capable of accommodating the systematic daily variations occurred in a week cycle and interdependencies of activity participation and travel decisions over different days of the week.

Based on the assumption that weekly household activity program is exogenously determined, the proposed model system consists of three stages: a planning stage, an individual scheduling and execution adjustment stage, and a learning stage. The learning and adaptation procedure is incorporated to take into account uncertainties generated from stochastic nature of the environment (such as transportation network). Thus, the human being is viewed as a learning agent, which should prepare strategic plans of behavior to achieve its individual goal through interactive environment and operationalize those plans via activity execution requiring the participation of other agents. The planning stage as a main focus of the entire model system is designed to determine how to share the responsibility for prescribed weekly household maintenance activities at the household level based on updated knowledge obtained up to the time of decision-making. Thus, in this stage, the household and its members as a decision agent has to optimize the allocation of the household available labor resource under the presence of the uncertainties of physical and social environment. Unlike a pure utility maximization theory, the proposed model system identifies two important determinants, equality and priority, based on the near unanimous empirical finding from many disciplines regarding gender convergence.

Based on the two determinants, the key idea of the proposed mechanism for the household collective decision process is that household members attempt to undertake the activities with higher priority while achieving some degree of the fairness on the time expenditure. After describing a mathematical framework and solution procedure, a simulation experiment was conducted within a simple hypothetical environment. The model system produced plausible behavioral results for a household that increased free times by one of household members by shortening work duration. The free time tended to be shared for achieving a more equitable distribution of extra free time instead of using the extra free times selfishly as in the individual level model.

6.2 Future Research

The models developed in this dissertation would be improved in a variety of ways. Firstly, for household activity time allocation model, the model can be re-estimated with a longer observation data (e.g. longer than a week). In fact, the original intention of the household activity time allocation model was to directly use the results from the model in the activity scheduling model. The household activity time allocation model with longer observation data integrating a hazard duration model for inter-episode duration might be applicable for the generation of household activity program. Each model to examine household activity time allocation behavior has been estimated with two different data sets (i.e., in-home activity time, out-of-home activity time) to see the behavioral differences in time allocation. In the future, the models need to be further refined to explicitly examine substitution behavior among in-home activities and out-of-home activities and corresponding travel times.

The household activity scheduling model proposed in this dissertation aims to examine the explicit representation of the activity and travel decisions subject to the intra-household interaction using an agent-based microsimulation model. Since application of the model in this study deals with only a single household and individual type, the model framework needs to be extended to reflect general application. To this end, the model system should include decision agents expressing various strategies in the negotiation process for the household activity allocation based on a personal evaluation toward various types of activities.

The extension of the proposed model system for the household activity pattern can be identified by exploring the components of the model. More specifically, the internal model systems with human agent component for the activity scheduling and execution stage and learning and adaptation stage can be extended to represent more general model system in terms of physical and social environment.

The interaction of human agents with the physical built environment can be explored by developing specific models for various choice elements not included in the model system. For example, the model systems need to contain more decision attributes for the activity and travel participation such as location choice within built physical environment. Furthermore, integration with micro-traffic simulation would be the most important improvement to properly implement the interactive features among human agents and physical structure in an agent-based simulation for the weekly household activity pattern. An existing external simulator for the transportation system can be simply incorporated for use with the agent-based system.

Similarly, the social environment can be explored in a variety ways. First, the population generator for a multi-agent simulation framework is needed to cover the representative household and social structure from socio-economic and demographic datasets. The statistical way to identify and generate the weekly household activity program and corresponding priority measures needs to be extended in the current model system using multi-day activity participation datasets. Ultimately, however, extension of the model system to the embedded multi-day problem would be a proper branch for the future direction of this study as an alternative to exogenous generation of household activity program. Particular emphasis should be placed on the social interactions by investigation of how social and leisure activities are engaged in. The integrated representation of how agents build social and leisure activities within a current “social network” of individual agents and how the engagements in such activities in turn weaken or reinforce the social network would be included.

The interplay between the activity scheduling process and the activity execution process needs to be leveraged to incorporate the activity rescheduling behavior in response to the presence of unexpected events and time pressure. Improvement of learning models for adaptive agents in diverse realm also needs to be achieved for the future model system.

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