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A Copula based Joint Multinomial Discrete-Hazard model of Work Arrangement Choice and Telecommuting duration

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by

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Dedicated to

My Parents and my elder sister Jesmin

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Abstract

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by

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The University of Texas at Austin, 2009
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Two important dimensions of work related choices are work location and working hours. Telecommuting (working from home or any convenient place instead of commuting to the conventional working place) can potentially have a substantial impact on traffic demand distribution on a particular day by means of its replacement and displacement effect. Consequently, it is of interest to analyze the effect and extent of telecommuting adoption across the labor force. This study proposes a copula based joint discrete multinomial-duration model of choice accommodating the two dimensions of work related choices: work arrangement and aggregated duration of telecommuting episodes on a particular day. In the econometric model telecommuting episodes are defined so as the duration is at least 30 minutes and only home-based telecommuting is considered and sample is drawn from the ATUS, 2007 data. The results from the estimated model show that gender, higher-education, responsibility for child-care, family ties act as driving forces for adopting telecommuting. The sign of the Gaussian copula parameter or dependency parameter implies that the unobserved factors act in opposite direction on the two dimensions: work arrangement choice and aggregated telecommuting episode duration.

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CHAPTER 1: INTRODUCTION

1.1 Motivation for the Study

Activity based travel demand modeling has received growing attention among transportation policy makers and planners in recent years (see Bhat and Koppelman 1993, Pinjari *et al.* 2006, and Pendyala *et al.* 2005). Activity based approach views travel demand as derived from the needs and desires for activities that are distributed in time and space (see Axhausen & Garlin 1992, Pas & Harvey 1997). With an improved understanding of activity-travel behavior and progression in micro-simulations techniques, activity based modeling offers a comprehensive framework to assess the impacts of disaggregate-level policies (see Miller and Roorda, 2003, Kitamura *et al.* 1996). At a fundamental level, activity based modeling deals with the activity participation of an individual and focuses on the sequence or pattern of activities (analysis period may be a day or longer). Such activity activity-travel patterns depend on the work-arrangement choice[1] of an individual for a particular day (see Bowman and Ben-Akiva 2000). Accordingly, most activity based modeling frameworks use the concept that work arrangement governs the non-work activity participation attributes for employed individuals (see Bhat *et al.* 2006, Bowman and Ben-Akiva 2000).

Work-arrangement choices comprise of choices along several dimensions (see Yeraguntla and Bhat 2005). Among many forms of home-based work arrangements, telecommuting due to its implications for travel demand management has been a focus of

[1] Primarily activity based approach of modeling categorizes individuals into two broad groups: one group that has to carry out some out-of-home mandatory activities (*e.g.* regular workers and students) and another group that has no bindings in that manner.

interest for a long period. Telecommuting originates from the concept of remote-working that is defined as working at a location without the direct supervision of management. One might notice that remote working need not take place at one's home and use of information technology is not mandatory. When a person works using telecommunication related technology and this activity affects the commute pattern of the person in question for a particular day, the individual is presumed to be pursuing telecommuting. Thus, the focus of telecommuting is on the need to influence the commute and is not restricted to working at home. To conclude, telecommuting is a special form of both remote working and tele-working with the specific capability of affecting daily commute pattern of an individual (see Mokhtarian, 1991 for details).

1.1.1 Current Trends of Telecommuting

In the past decade, participation in telecommuting activities has increased substantially in United States. The number of Americans who worked from home or remotely at least one day per month is about 17.2 million in 2009, an increment of about 38% from approximately 12.4 million telecommuters in 2006 (Survey report by World-at-work, 2009). The recent advances in information technology, along with the increased affordability of the internet and personal computers, have enhanced work home connectivity for Americans. In fact, the home broadband usage has risen substantially over the past six years from 9.1% in September 2001 to 50.8% in October 2007(NTIA Report, 2007). The proliferation of high-speed connectivity and the explosion of hand-held devices that occurred during the early 2000s add flexibility to working patterns for many employers and employees. This increasing presence of high-speed internet provides the workers with the opportunity to opt for flexible work-schedules with provision of working from home. The offerings of the telecommuting option by the employers in USA have increased from 30 percent in 2007 to 42 percent in 2008 (See Telework Trend lines, 2009 by Dieringer Research Group Inc.). In Canada the increase has been higher, from 25 percent to 40 percent. Such a persistent rise indicates a growing recognition among employers of the potential benefits of offering telecommuting arrangements to employees.

1.1.2 Telecommuting and Travel Demand Management

The promise of telecommuting as a public policy measure largely stems from its conventionally viewed status as a substitute for commute trips (See Graaff, 2004; Lyons and Haddad, 2008; Pratt, 2007). According to the report of NHTS survey (2006), if each of the workers could telecommute one day a week, in a year they could save over 145 hours, or the equivalent of three and a half week's work – more free time than most workers take for an annual vacation. In this manner, expanding the telecommuting options can be an effective congestion reduction strategy contributing to the quality of life for millions of Americans.

But telecommuting also has effects on the overall travel pattern of a working individual. Along with the commute trip replacement, telecommuting may change travel patterns by changing the departure time, mode or even destination for other trips (see Borjesson, 2003). Telecommuting can affect land use as well because the acceptability of long distance commuting might rise with regular based telecommuting practice. Telecommuters might prefer places far from business centers which will have impact on the land use pattern in the long run. Mokhtarian (1998) suggests that telecommuting will make daily travel more flexible which results in greater number of leisure and non-work trips. Not making a work-trip by a person in the household makes the vehicle available for other members in the household.

It is important to recognize that different forms of home-based telecommuting will affect the daily commute pattern of a working individual in different ways. Telecommuting can be classified into two broad groups: home based and non-home based. As the term suggests, non home-based telecommuting includes all forms of telecommuting undertaken at places other than home (for *e.g.* nearby tele-centers). In the present research effort the focus is only on home-based telecommuting activity with duration of at least 30 minutes. Again, home-based telecommuting can take several forms and each form has its distinct implication on transportation demand. For our purpose, home-based telecommuting is categorized initially as full day home-telecommuting and part of day home-telecommuting. The former can be defined as an arrangement where the working individual telecommutes on a particular day of the week in which no work activity takes place at locations other than home. Whereas, part of day home-telecommuting describes an arrangement where the working individual combines home-based telecommuting with other work arrangement options those can occur at locations other than home on a particular day. These other locations can be the individual's working place, clients' office, a restaurant or any place where an activity related to work can be done. Part of day home-telecommuting can take different forms based upon the sequence of working episodes on a particular. An individual can work from home during the opening part of a particular day, then commute to her work place and the reverse of this sequence can occur as well. Even the sequence can be home-work-home or work-home-work depending upon choice of the working individual. By “work”, we mean any conventional work places other than home where any work or work related activity can be accomplished.

While full day home-telecommuting will most likely replace the commute trip to work for a particular day, part of day home-telecommuting will displace it in the temporal dimension. The displacement effect will not reduce the number of trips but it will reduce the peak traffic demand to a reasonable degree (see Lyon and Haddad, 2008). Since most of the earlier research works emphasize the commute replacement effect of telecommuting, part of day home-telecommuting has not received any attention. In this perspective, only full day home-telecommuting is taken into account for travel impact analysis. But as mentioned earlier, flexibility in working arrangements facilitated by cutting edge information technology and supported by potential employers is on the rise in the labor force of United States (some statistical reference). This growing flexibility allows working individuals to adopt and combine varied work arrangements on a particular day. The way we define part of day home-telecommuting it is clear that, flexibility will allow the workers to practice more part of day home-telecommuting. Therefore, from the viewpoint of transportation planner it is important consider the effect of part of day home-telecommuting in transportation demand.

Commute trips are not replaced in the temporal dimension on a particular day for a telecommuter, but are displaced in case of part of day home-telecommuting. Conforming to our definition part of day home-telecommuting individuals may schedule their work trips at different times other than the peak period of that day. Though most of the transportation planners and policy makers initially focus on the commute substitution effect of telecommuting, displacement effect of telecommuting has gained their interests with time and experience because of its potential impact on daily traffic demand management. Displacement of commute trips has a less desirable effect on congestion reduction compared to replacement of trips. But, the displacement of commute trips will change the distribution of the trips made over a day. So ignorance of displacement effect evidently will result in an ineffective management of travel demand for any transportation system.

1.1.3 Impact of telecommuting duration on travel pattern

In addition to the spatial-temporal variation of telecommuting the duration of telecommuting on a particular day is also important in the context of activity based travel demand modeling. Time plays an important role in framing the activity and travel patterns of an individual on a particular day. Activity duration and timing are directly association to travel demand management (TDM) strategies and transportation control measures (TCM). Two key aspects of temporal dimension of an activity are the timing and duration (time allocation) (Abkowitz 1981; Mahmassani & Chang 1985; Mahmassani & Stephan 1988). Therefore, both timing and duration of telecommuting activity are very important for assessing the travel pattern of an individual for a particular day (Pendyala and Bhat, 2004).

Activity schedule of an individual for a particular day composed of many activities. Each activity occupies a certain place in the temporal dimension. But any activity can be repeated for an individual. For ease of our explanation we can divide the whole day into some episodes of certain durations where activities take place (See Bhat, 2008). Each activity episode identifies the duration and timing of the activity concerned. Part of day home-telecommuting suggests that there can be more than one telecommuting episode[2] in a day for any working individual. It is necessary that, one has to incorporate timing and duration of telecommuting activity in the demand analysis in order to assess the travel patterns of an individual on a particular day (See Bhat, 2008). When an individual telecommutes, for him/her the commute to and from work location is no longer necessary. The time saved due to no work-commuting allows him/her to participate in other non-work activities. Besides this, telecommuting can also influence the day-of-time dimension. A worker, not adopting telecommuting has the tendency (see Bhat, 2008) participate in non-work activities in combination with the work commute when traveling to and from work place. On the other hand, a telecommuter has no option or any necessity to combine his/her non-work trips with work-commute trip.

In the case of part of day home-telecommuting the duration of telecommuting activity contains special implications. Since the trip is displaced in the temporal dimension it will have a clear impact on the daily traffic demand distribution. As a traffic planner one would like to know how the traffic demand distribution curve changes due to the trip displacement effect. If we can predict the duration of episodes through any econometric model, we will be able to find out two things. First, in which part of day and for how long the displacement effect will be active which will allow us to adjust the traffic demand curve. Second, duration will allow us to identify the timing of the work

[2] Each episode signifies home-based telecommuting activity which endures for at least 30 minutes on that day.

commute trip on the same day[3] that will help to define to demand distribution over whole day more accurately.

1.2 STUDY METHODOLOGY AND OBJECTIVES

In the current research effort, the objective is to contribute to the telecommuting adoption process literature by investigating different personal, economic, travel, and work related characteristics on home-based telecommuting. A generalized multinomial logit model will be used to explain the work-pattern choice of working individuals and a hazard based duration model will be used to estimate the aggregated duration[4] for telecommuting episodes. A hazard based duration model is adopted because of its capability of accommodating the dynamics of behavior in activity participation. Finally, using copula based approach telecommuting choice and duration are modeled jointly. Since, concept behind activity based modeling suggests that choices of activity type and episode durations are made not in a sequential manner rather as one package, a joint model of choice will be more effective to explain the mechanism of choices made.

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[3] We are considering "home-work", "work-home", "home-work-home", "work-home-work" or any possible combinations and "work" indicates any conventional work place where one can do work or work-related activities.

[4] While working from home an individual may work for a few hours, then participate in other activities (e.g. bring kids from school, cooking) and again can get engaged into work for a few more hours. So, it is more likely that activities representing home-based telecommuting may have more than one episode throughout the day. The sum of durations of all episodes occurring on a diary day is modeled in the proposed hazard based duration model.

1.3 Thesis Structure

The rest of this paper is structured as follows. The next two chapters describe related earlier research works and the econometric framework used in this study. Chapter 4 introduces the data sources used for empirical analysis and discusses some of the sample characteristics. Chapter 5 presents the empirical results. Finally, Chapter 6 summarizes principal results and distinguishes possible extensions of this study.

CHAPTER 2: LITERATURE REVIEW

The research community, recognizing the significance of telecommuting and its implications, has rigorously studied the adoption process and impact of telecommuting from diverse perspectives ranging from transportation planning and management, urban planning, information science, to organizational behavior, ethics, law, psychology, human resources management, and sociology (for details see Bailey et. al., 2002). This chapter provides an overview of the studies undertaken to understand the telecommuting adoption process and its effect on travel patterns.

2.1 EARLIER STUDIES

The telecommuting adoption process has been a focus of interest for a long time among researchers from diverse fields. The principal categories of telecommuting studies can be described as: qualitative studies concentrating on the driving forces and barriers for telecommuting adoption with comprehensive discussions on advantages and disadvantages of telecommuting, quantitative studies analyzing stated preferences data through econometric frameworks, and quantitative analysis of revealed preference data by means of probabilistic behavioral models. Early studies such as Pratt (1984), Gordon (1998), Niles (1988), and Kinsman (1987) explained the effect of personal attributes, household characteristics, and demographic attributes on telecommuting adoption process. With the advances in research methodology and increased availability of data, researchers started to focus on the quantitative analysis of telecommuting adoptions process. In this literature review, we limit ourselves to the review of quantitative studies employing both stated preference and revealed preference data.

The preliminary quantitative studies of telecommuting adoption were mostly based on stated preference surveys. There exists a substantial amount of literature exploring socio-economic, attitudinal, and work-related factors that affect the telecommuting adoption process as well as the frequency of telecommuting. Sullivan et al. (1993) estimated a multinomial logit model to analyze participation in telecommuting using a stated preference survey of employees in information-oriented firms located at Austin, Dallas and Houston. In another study, Bagley and Mokhtarian (1997) analyzed the telecommuting characteristics of the individuals who telecommute from a nearby business center or tele-center and also work from home. Bernardino, et al. (1993), Mahmassani, *et al.*(1993), Yen and Mahmassani (1994), and Mokhtarian and Salomon(1995) used various choice frameworks to explain the telecommuting adoption model using stated preference data. In accordance with the scope of the present research, tele-center based telecommuting or choice models based on stated preference data will not be our focus. Instead, we will consider studies considering the influence of home based telecommuting on actual choices made.

Mokhtarian and Salomon (1994, 1996) attempted to model the actual choice (revealed preference) and stated preference of telecommuting separately to find the reasons behind the difference between preferred and the actual choice in the case of telecommuting. Mannering and Mokhtarian (1995) used multinomial logit models to frame the telecommuting adoption process. Drucker and Khattak (2000) compared ordered logit, ordered probit and multinomial logit models for telecommuting adoption and concluded that, the ordered models were not as good as the multinomial logit models. Drucker and Khattak (2000) used the 1995 Nationwide Personal Transportation Survey to econometrically estimate the propensity to work from home. The data primarily focuses on general travel behavior, vehicle ownership and several socio-demographic attributes. Popuri and Bhat (2003) established a joint model of home-based telecommuting choice and weekly telecommuting frequency using a survey-data conducted by New York Metropolitan Council and the results from the research emphasize the socio-economic and occupational characteristics of individuals in the decision process. Tang et al.(2008) developed a multinomial logit model of work-at-home frequency using the survey data from eight neighborhoods in Northern California to capture the effect of neighborhood built-in environment on working at home.

2.1.1 Telecommuting from the perspectives of employees and employers

Several studies focusing on the advantages and disadvantages of telecommuting as perceived by the employed individuals (from both employer and employee perspectives) have been undertaken lately. A study by Henley Management College of British management (see Amble 2005) identified that one of the biggest disadvantages of telecommuting is the reliance on information technology. Inadvertent disruptions of connectivity might lead to a significant financial impact on business organization. Job suitability also can be a potential barrier against telecommuting (see Cox, 2009) in cases where physical presence is required for jobs. Again, supervisors find it difficult to handle group-project based task when any or some of the group members practice telecommuting. Setting objectives for projects and maintaining interactions with other team members are identified as most common problems when telecommuting is offered.

Additionally, telecommuting arrangement is often considered by employed individuals as a potential risk to their future careers. It is a common practice among many supervisors to evaluate the performances of employees by means of close monitoring. Since telecommuting does not provide this kind of opportunities, performance evaluation may become difficult for supervisors. So, career progression might face problems as well as the relation between supervisor and worker (see Neman and Grigg, 2008). A report published by IBM's Institute-for-Business-Value (see Amble 2005) suggests that many workers who telecommute frequently often feel alienated, under-appreciated and mistrusted due to their isolation from office and co-workers. Besides this, the IBM and Henley research (see Amble 2005) also mentioned that remote workers in many occasions work longer hours than conventional office-workers and this leads to family conflicts often times.

A few studies have disputed many of these negative impacts of telecommuting indicated above. Gajendran and Harrison (2007) conducted an extensive review of 46 studies on the telecommuting feature containing 12,883 individuals. In their studies, they identified some positive sides and also debunked some wrong presumptions about telecommuting. As noted by most managers relationships with supervisors suffer most with telecommuting arrangements (see Amble 2007). Since the supervisor gets fewer opportunities to monitor the worker who telecommutes, implicit distrust and communication gaps between them can easily be created. But, the study by Gajendran and Harrison (2007) shows that telecommuting can actually improve the supervisor-staff relationship. The casual chances to interact with supervisor are few for an individual who telecommutes. Therefore, both the supervisor and worker put some extra efforts to stay in touch and the worker shows more sincerity with work. Thus correspondence between supervisor and subordinate becomes more effective compared to casual meetings in conventional daily work-environment.

Besides enjoying flexibility in their work schedule, workers who telecommute also can rearrange their working environment while telecommuting (see Amble 2007). With a flexible schedule, individuals can integrate work and family responsibilities. Gajendran and Harrison (2007) mentioned in their research that workers with increased control over their work schedules can attend to their family obligations properly and are likely to be more satisfied with their jobs. Moreover, most people like the jobs where they feel respected, trusted, and enjoy reasonable autonomy and therefore, telecommuting can be taken as an effective approach for employers to attract and retain the employees.

2.1.2 Telecommuting and Environmental issues

Since promoting telecommuting can be a policy measure to reduce the automobile emissions and vehicle miles traveled, many studies focus on the effectiveness of telecommuting to obtain these benefits. Kitamura et al. (1991), Choo et al. (2003), and Collantes and Mokhtarian (2003) tried to find the links of residential location, emission, and VMT with telecommuting adoption. In a study of home-based telecommuters in the state of California Telecommuting Pilot Project in the early 1990s Koenig et el. (1996) found that the average number of daily vehicle trips for the telecommuters reduced by 27% and the VMT5 by 77%. Additionally using California's EMFAC7 emissions model they concluded that, these reductions in trips and VMT resulted in substantial emissions reductions (see Walls and Safirova, 2004 for quantitative details). In another study

Mokhtarian and Varma (1998) focused on effectiveness of telework centers in reducing VMT and emissions. According to their findings compared to non-telecommuting days, the total VMT was lower by 53% and emissions were lower by 15 % (computed using EMFAC7 model) on days the individuals telecommute. Similar studies by Kitamura et al. (1991), Henderson and Mokhtarian (1996), and Collantes and Mokhtarian (2003) reinforce the fact that telecommuting can effectively reduce vehicle-miles-traveled and vehicle emissions.

2.1.3 Studies related to choice of work hours

Choice of work hours is an important dimension in the framework for work arrangement. The decision process behind the choice of work hours is well analyzed and studied by many researchers. Yeraguntla and Bhat (2005) modeled dimensions of medium-to-long range work arrangements which are important in the day-to-day activity schedules using a web-based survey of Austin, Texas area commuters. In their research part time employment and teleworking choice were modeled using a binary choice model and an ordered response model was employed to model the frequency of teleworking. Many researchers emphasized on the factors like gender, household responsibilities like child care to explain the working-hours choice. Miller (1993) explained the part time employment of married women in the labor force using logit models.

Most of the studies have their efforts in modeling the choice options for work arrangement and working locations separately. Vana *et al.* (2008) had their research effort on modeling the choices of work-hour arrangement, locations, and frequency of telecommuting considering both tele-center and home based telecommuters. The results

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[5] Vehicle Miles Traveled

from their research indicate that, it is more sensible to model the work related decisions as a joint choice rather than examining individual dimensions of work decisions separately.

2.1.4 Studies related to duration of telecommuting

The study and analysis of telecommuting duration is important for a clear understanding of telecommuting adoption process. Moreover, it is of prime interest for planners and policy makers while implementing telecommuting as a travel demand management strategy. Most of telecommuting studies concern about the adoption process and frequency of telecommuting. Very few researchers concentrate on the duration of telecommuting. Krishna *et al.* (1998) in their study modeled the frequency and duration of tele-center use as a part of Neighborhood Tele-centers Project (NTP). The objective of the research program was to evaluate the effectiveness of telecommuting centers as a transportation demand management strategy. The study concluded that, 50% of the telecommuters quit within first 9 months. Graaf and Rieteld (2002) tried to find the factors of time spent on in-home and out-of-home paid work using a bi-variate regression model on revealed preference data. Table 1 summarizes important characteristics of most of the related earlier studies.

2.2 CURRENT RESEARCH IN CONTEXT

From the above discussions, the multitude of effects of telecommuting on various dimensions of transportation planning can easily be identified. Evidently, researchers have examined individual's propensity of telecommuting incorporating various demographic, socio-economic, attitudinal, work related characteristics and draw attention to some valuable insights. Also, Education level, attitude towards life, attachment with family and laid-back nature turn out to be significant factors for telecommuting adoption process. Telecommuting is often considered as a suitable option for improving work-life balance and the quality of working life (See Shamir and Salomon, 1985). Telecommuting is emerging as a standard business strategy due to its potentials to increase the productivity of employers by improving the quality of lives of the workers through better work-life balance (see Cox, 2009).Hartman, et al. (1991) tried to figure out the telecommuting satisfaction and productivity by examining employees at eleven organizations. The results revealed supervisor support and disruptions coming from family members while telecommuting are crucial factors for telecommuting satisfaction.

The decision factors behind telecommuting mainly include 1) Presence of (age<6) children, 2) Gender, 3) Education level, 4) Mobility-impairment, 5) Distance to work, 6) Job type suitability, 7) Attitudinal factors *etc*. Other than household structure and work related variables, policy and work trip related variables are also important in telecommuting adoption model because as the objective is not only forecast telecommuting but also find policy measures to promote it to effectively so that it can have positive impact on travel demand (see Borjesson, 2003). Compared to telecommuting adoption model, very few researchers focus on telecommuting duration. But no significant research effort is made to model durations of telecommuting episodes on a particular day according to the author's best knowledge.

Additionally, part of day home based telecommuting has been studied by very small number researchers and most of them followed qualitative approach. Due to significant implications in activity based modeling and impact on travel demand management it is necessary to take quantitative approach to analyze the pattern of part of day home based telecommuting. Again substantial number of the studies used different component models for different choices (*e.g.* one model for telecommuting choice and another for frequency of telecommuting). But in the context of activity based approach it is suggested that, decisions to participate in activities are not taken in a sequential manner rather as a package. Therefore, it is necessary to model the choices jointly instead of in a component based manner.

With these directions of enhancement, in the current research effort the aim is to develop a copula-based joint discrete-continuous model that accommodates telecommuting adoption and duration. A multinomial logit model will be used for the work arrangement choice. Each work arrangement is defined in two dimensions: hours of working indicated by work-status of the employed individuals (whether part time or full time) and the location where work or work related activities take place. The alternatives are: (1) Full time-not telecommuting, (2) Part time-not telecommuting (3) Full time- Full day home based telecommuting (4) Part time- Full day home based telecommuting (5) Full time- Part of day home-based telecommuting, (6) Part time- Part of day home based telecommuting. Afterward a model with a hazard duration structure (see Bhat and Pinjari, 2008) is framed to explain the aggregated durations of telecommuting activities on a particular day. An employed individual may have multiple telecommuting episodes[6] on a particular day and current research captures aggregated duration of telecommuting episodes instead of duration of a single episode. Finally, we use a copula-based sample

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[6] Total time available on a day can be divided into multiple time slots based on activity participation. From start time of an activity to its termination, the total time band is defined as an episode for that particular

selection approach that ties the discrete choice error component with the duration error component in a flexible manner that allows the testing of several types of dependence structures rather than pre-imposing restrictive distribution assumptions (see Bhat and Eluru, 2009 for an extensive discussion of the copula approach). The copula concept has been known in the statistics field for quite some time, but only recently its advantages have been explicitly recognized and employed in econometrics. It is simple to implement, and allows a rich and comprehensive variable specification.

activity. Thus aggregated duration of telecommuting episodes on a particular day refers sum of durations of all telecommuting activities on that day.

TABLE 2.1: SUMMARY OF IMPORTANT CHARACTERISTICS FROM EARLIER STUDIES RELATED TO TELECOMMUTING ADOPTION

Study	DATA sample	Framework	Focus of the Study	Brief description of study results
Walls, Safirova, Jiang(2006)	2002 survey of Southern California residents(N = 5000)	Standard probit model that can be estimated by a maximum likelihood estimation technique	Propensity to Telecommute	**Positive correlation:** Aged over 30, have a college degree, Caucasian, at least one other adult present in the household. **Negative correlation:** People who works in a small firm, part time workers.
Popuri and Bhat (2003)	New York and New Jersey (N=6532)	Choice(unordered) and frequency (Ordered) joint model.	Actual choice and frequency of telecommuting	**Positive correlation:** Female with children, higher age groups, married, licensed driver, number of vehicles, drive to work, work in a private company, length of service, fax availability, multiple phone lines at home. **Negative correlation:** Female, use of transit to work .
Mokhtarian and Salomon (1997)	San Diego (N=626)	Binary logit	Binary preference of telecommuting	**Positive correlation :** Disability/parental leave, stress, personal benefits, commute stress, commute time. **Negative correlation:**

TABLE 2.1: SUMMARY OF IMPORTANT CHARACTERISTICS FROM EARLIER STUDIES RELATED TO TELECOMMUTING ADOPTION

Study	DATA sample	Framework	Focus of the Study	Brief description of study results
				workplace interaction, concern of household distractions. Benefit
Yen and Mahmassani (1997)	(Austin, Houston and Dallas)(N=545) SP Survey	Dynamic Generalized Ordinal Probit (DGOP)	Stated preference for telecommuting adoption	**Positive correlation:** Increase in salary, number of children under 16 at home, number of personal computers at home, number of hours using computer per work day, commute distance, family orientation. **Negative correlation :** Decrease in salary, telecommuting cost faced by employee, number of hours communicating face-to-face with co-workers per day, average number of stops on the way back to work from home per week, job suitability.
Mokhtarian and Salomon (1996b)	San Diego (N=624)	Binary logit	Binary preference of home-based telecommuting	**Positive correlation:** Overtime, commute stress **Negative correlation:** Misconception about telecommuting arrangement, lack

TABLE 2.1: SUMMARY OF IMPORTANT CHARACTERISTICS FROM EARLIER STUDIES RELATED TO TELECOMMUTING ADOPTION

Study	DATA sample	Framework	Focus of the Study	Brief description of study results
				of manager support, job unsuitability.
Bernardino and Ben-Akiva (1996)	21 organizations across US (N=176 employees)	Multinomial Logit	Choice of telecommuting	**Positive correlation :** Change in lifestyle quality (flexibility of schedule, job satisfaction, social life, job opportunity, *etc*.), higher salary. **Negative correlation:** Change in work-related costs, lower salary to telecommuters.
Mannering and Mokhtarian (1995)	San Diego (N=433)	Multinomial logit	Actual telecommuting frequency Alternatives: Never telecommute, infrequently, frequently	**Positive correlation:** Household size, female with children, home office space availability, vehicles per capita household, supervisor, remote work indicator, schedule control indicators. **Negative correlation:** Clerical occupation indicator, unpaid overtime, lack of self discipline, family orientation indicator. **No significant effect:**

TABLE 2.1: SUMMARY OF IMPORTANT CHARACTERISTICS FROM EARLIER STUDIES RELATED TO TELECOMMUTING ADOPTION

Study	DATA sample	Framework	Focus of the Study	Brief description of study results
				Commute length, commute distance, managerial and professional occupation, amount of time spent on face to face contacts.
Sullivan *et al*. (1993)	Austin (N=360), Dallas (N=184), Houston (N=150) SP survey	Multinomial Logit	Stated preference of telecommuting frequency	**Positive correlation:** Round-trip commute time, commute stops per week, average time using computer per day, female with children, males' household income. **Negative correlation:** Length of time with firm, face-to-face communication, work end time, Higher age groups.
Bernardino *et al*. (1993)	USENET newsgroup survey (N=54) SP survey	Ordered probit	Willingness to Telecommute.	**Positive correlation:** Salary increase, number of children under 18 in the household, one way travel time saving (if < 40mins). available **Negative correlation:** Equipment and phone bills paid by employee, unpaid

TABLE 2.1: SUMMARY OF IMPORTANT CHARACTERISTICS FROM EARLIER STUDIES RELATED TO TELECOMMUTING ADOPTION

Study	DATA sample	Framework	Focus of the Study	Brief description of study results
				overtime work, salary reduction, number of years worked in the organization

CHAPTER 3: METHODOLOGY AND ECONOMETRIC FRAMEWORK

3.1 Model Structure

In the current research effort, the objective is to analyze the choice process of work-arrangements across temporal and spatial dimensions. Further, we discuss in detail the mathematical model for the aggregated duration of telecommuting episodes for individuals for a particular day. The framework for work arrangement choice takes the form of a multinomial logit model with six alternative arrangement choices. Each choice describes two dimensions: the place where work activity takes place and hours of working (part-time or full time). The aggregated duration of telecommuting episodes is captured using a non-parametric proportional hazard duration model. The non-parametric duration model enables estimation from interval-level duration data arising from the grouping of underlying continuous duration times (see Bhat and Pinjari, 2008 for a detailed review of duration models). Specifically, in time-use surveys, it has been well-established that individuals round their time-use in activities and travel to integral multiples of five minutes up to time duration of about 60 minutes, and then round to multiples of 10 or 15 minutes beyond one hour (Bhat, 1998). Therefore, we consider the time-use data as interval-level data and use a grouped response model that retains an interpretation that is identical to an incompletely observed continuous time hazard model.

Finally, these two dependent variables in the multinomial logit and hazard based non-parametric models are jointly analyzed by means of copula-based approach that enables flexible dependency in the latent properties of the dependent variables with different error distributions. In the following sections, the mathematical formulation of the econometric framework will be discussed.

3.2 FRAMEWORK OF WORK-ARRANGEMENT CHOICE MODEL

Let, n represent the index for individuals and i be the index for work-arrangement alternatives. Now if U_{ni} is the latent (indirect) utility accrued by individual n when choosing work-arrangement type i, then, we write:

$$U_{ni} = \beta^T X_{ni} + \varepsilon_{ni}, \qquad (1)$$

Where X_{ni} indicates a vector of explanatory variables, β represents vector of coefficients to be estimated, and ε_{ni} is a term capturing the unobserved factors. Assume that the ε_{ni} terms are identically and independently Gumbel distributed across outcomes i and individuals n with a location parameter equal to 0 and a scale parameter equal to 1.

According to utility maximization principle an individual n will choose alternative i only if alternative i renders utility greater than any other feasible alternatives. So, mathematically,

$$U_{ni} > \underset{j=1,2,....I \text{ and } j \neq i}{Max} U_{nj}, \qquad (2)$$

Now we can define a binary variable d_{ni} such that d_{ni} takes the value 1 when n-th individual chooses the alternative i. To formulate d_{ni} let us define,

$$\kappa_{ni} = \varepsilon_{ni} - \underset{j=1,2,....I \text{ and } j \neq i}{Max} U_{nj}, \qquad (3)$$

Now, from equation (1) and (2), we can write:

$$d_{ni} = 1, when\, \beta^T X_{ni} + \kappa_{ni} > 0, \qquad (4)$$

From equation (3) we can obtain the marginal distribution for κ_{ni} expressed below as follows:

$$F_i(\kappa) = P(\kappa_{ni} < \kappa) = \frac{\sum_{j \neq i} \exp(\beta^T Z_{nj})}{\exp(-\kappa) + \sum_{j \neq i} \exp(\beta^T Z_{nj})}, \quad (5)$$

Where Z_{nj} represents column vector of covariates specific to individual *n* for alternative *i*.

3.3 STRUCTURE OF NON-PARAMETRIC HAZARD BASED DURATION MODEL

In our formulation first two alternatives (*i.e. i*= 1, 2) represent work arrangements choices without adopting telecommuting. Now, for an individual *n* the hazard function for aggregated telecommuting episode duration in work-arrangement alternative *i (i = 3, 4, ..I)* at some specified time h on the continuous-time scale T can be defined using the proportional hazard specification. Let τ_{ni} represent the aggregated duration of telecommuting episodes of work arrangement I for individual *n*. Now the baseline hazard at time *h* can be written as (see Kiefer, 1988 for details):

$$\zeta_{ni}(h) = \lim_{\nabla \to 0^+} \frac{\Pr(h + \nabla \geq \tau_{ni} \geq h \mid \tau_{ni} \geq h)}{\nabla} = \zeta_{0i}(h) \exp(-\alpha' Z_{ni}), \quad (6)$$

$\zeta_{0i}(h)$ = The continuous-time baseline hazard at time h for work-arrangement type *i*,

$Z_{ni} =$ Vector of covariates for individual *q* and work-arrangement type *i*, and α is a vector of coefficients to be estimated. Using this again we can write an equivalent form (see Bhat, 1996a),

$$\tau_{ni} = \ln \Gamma_{0i}(\tau_{ni}) = \ln \int_0^{\tau_{ni}} \zeta_{0i}(T) dT = \alpha' Z_{ni} + \mu_{ni}, \quad (7)$$

Here, $\Gamma_{0i}(.)$ denotes the integrated baseline hazard for our model. If we assume μ_{ni} is extreme value distributed, then the distribution function can be defined as:

$$\Pr(\mu_{ni} < \mu) = G(\mu) = 1 - \exp[-\exp(\mu)], \quad (8)$$

The aggregated duration is a continuous unobserved variable in most of the cases, when duration data are available only in grouped form. But, the time intervals of activity participation Δt_{ni}, of an individual *n* for work-arrangement type *i* (*i*=3, 4…*I*) can be observed. If we denote the time intervals by an index *k* (*k* = 1,2,3,...*K*), in the continuous time dimension T in terms of bounds on the continuous time scale: $k = 1$ if $T \in [0,T^1]$, $k = 2$ if $T \in [T^1,T^2]$,..., $k = K$ if $T \in [T^{K-1},\text{inf}]$ (the duration interval thresholds can be different for different work-arrangement types; however, for ease of notation, we consider them to be the same for all work-arrangement types). Thus, $\Delta t_{ni} = k$ if the duration spell of individual *q* ends in time interval *k* for the chosen work-arrangement type *i (i=3, 4…I).*

3.4 FORMULATION FOR THE JOINT MODEL

System of equations for work arrangement choice model can be written as:

$$
\begin{aligned}
d_{ni} &= \beta' X_{ni} + \kappa_{ni} \\
d_{ni} &= 1, when\ d^*_{ni} > 0 \\
&= 0, Otherwise
\end{aligned}
$$

And, for the hazard based duration model,

$$
\begin{aligned}
&\tau^*_{ni} = \alpha' Z_{ni} + \mu_{ni} \\
and\ \Delta t_{ni} = k, when\ &\nabla_{i,k-1} < \tau^*_{ni} \le \nabla_{i,k} \\
&where, \quad \nabla_{i,k} = \ln \Gamma_{0i}(T^k) \\
&note\, that, \Delta t_{ni}\ is\ only\ observed\ when\ d_{ni} = 1 (i = 3,4,...I)
\end{aligned}
$$

The equation systems follow $\nabla_{i,k}$ = -INF and $\nabla_{i,k}$ = + INF for each alternative in the work-arrangement choice framework.

Now, in case of the joint model the probability that an individual will choose alternative *i (i =3 ,4 …I)* and participate for a grouped duration interval of *k* can be written using the equation systems mentioned earlier as :

$$
\begin{aligned}
&\Pr[d_{ni}=1,\Delta t_{ni}=k] \\
&=\Pr[\kappa_{ni}>-\beta' X_{ni},\nabla_{i,k-1}-\alpha' Z_{ni}<\mu_{ni}<\nabla_{i,k}-\alpha' Z_{ni}] \\
&=\Pr[\nabla_{i,k-1}-\alpha' Z_{ni}<\mu_{ni}<\delta_{i,k}-\alpha' Z_{ni}]-\Pr[\kappa_{ni}<-\beta' X_{qi},\nabla_{i,k-1}-\alpha' Z_{ni}<\mu_{ni}<\nabla_{i,k}-\alpha' Z_{ni}]] \\
&=G(\nabla_{i,k}-\alpha' Z_{ni})-G(\nabla_{i,k-1}-\alpha' Z_{ni})-\begin{pmatrix}\Pr[\kappa_{ni}<-\beta' X_{ni},\mu_{ni}<\nabla_{i,k}-\alpha' Z_{ni}] \\ -\Pr[\kappa_{ni}<-\beta' X_{ni},\mu_{qi}<\nabla_{i,k-1}-\alpha' Z_{ni}]\end{pmatrix}.
\end{aligned}
$$

, (10)

The above probability depends upon the dependence structure between the random variables κ_{ni} and μ_{ni} for each work-arrangement type *i*. The incorporation of the joint dependency effect can be effectively accommodated using a copula based approach where different parametric functional forms will be attempted for this bivariate dependency surface and the one that empirically fits the data best will be picked.

In the following sections, various copula structures with different parametric functional forms for bi-variate dependency surface will be discussed. Since copula approach does not require any predefined specification of the functional form of the dependency surface, we can try out different functional forms to identify the one that empirically fits the data best.

3.5 GENERAL BIVARIATE COPULA STRUCTURE

A copula can be described as a function that introduces a stochastic dependence relationship (i.e., a multivariate distribution) among random variables with pre-specified marginal distributions. According to Sklar's theorem (see Sklar, 1973) for any joint distribution function H with margins F and G there exists a copula C such that for all real *x, y* we can write,

$$H(x,y)=C[F(x),G(y)], \qquad (1)$$

The precise definition of a copula is that it is a multivariate distribution function defined over the unit cube linking uniformly distributed marginals. In the bivariate case, let *C* be a *2*-dimensional copula of uniformly distributed random variables U_1 and U_2 with support contained in $[0,1]^2$. Then,

$$C_\theta(u_1, u_2) = \Pr(U_1 < u_1, U_2 < u_2) , \qquad (2)$$

Where θ refers to a vector of dependence parameter. A copula, once developed, allows the generation of joint bivariate distribution functions with given marginals. For copula based estimation approaches one can use various types of copulas available for generating multivariate distribution functions with given marginals (for details see Bhat and Eluru, 2008; Trivedi and Zimmer, 2007).

In relation to our current formulation a bivariate distribution $J_i(\kappa, \mu)$ can be generated for the two random variables κ_{ni} (with margin F_i) and μ_{ni} (with margin G) using the following expression (see Sklar, 1973):

$$J_i(\kappa,\mu) = \Pr(\kappa_{ni} < \kappa, \mu_{ni} < \mu) = \Pr[U_1 < F_i(\kappa), U_2 < G(\mu)] = C_\theta[u_1 = F_i(\kappa), u_2 = G(\mu)]$$

A good number of bivariate copulas $C_\theta(u_1, u_2)$ can be deployed to obtain the dependence between the random variables κ_{ni} and μ_{ni}, including the Gaussian copula, the Farlie-Gumbel-Morgenstern (FGM) copula, and the Archimedean class of copulas (including the Clayton, Gumbel, Frank, and Joe copulas). For given functional forms of the margins, the precise bivariate dependence profile between the variables κ_{ni} and μ_{ni} is a function of the copula $C_\theta(u_1, u_2)$ used, and the dependence parameter θ. One might notice that, the dependence nature is independent of the pre-specified margins and governed by copula. A brief discussion about the bi-variate copulas will be found in Appendix-A.

3.6 ESTIMATION PROCEDURE

According to our model framework described in earlier sections, the joint model requires several parameters to be estimated. The parameters are as follows:

- Vector of coefficients for the explanatory variables in MNL component, β vector

- the (K-2) parameters, $\nabla_{i,k}$ for each work-arrangement type i (i=3,4…I),

- vector of coefficients of covariates for hazard model component, α vector

From equation (1), the probability of an individual choosing not to participate in any work-arrangement type involving telecommuting[7] can be expressed as the multinomial logit expression below:

$$\text{Prob } (d_{ni} = 1) = \frac{\exp(\beta' Z_{ni})}{\sum_j \exp(\beta' Z_{nj})}, \quad j = 1,2,\ldots,I. \text{ and } i = \{1, 2\}, \qquad (11)$$

The probability of an individual choosing an work-arrangement type i (i=3,4…I) and a duration interval k may be obtained from Equation (10) and the appropriate copula expression as:

$$\begin{aligned}&\Pr[d_{ni} = 1, \Delta t_{qi} = k] \\ &= G(\nabla_{i,k} - \alpha' Z_{ni}) - G(\nabla_{i,k-1} - \alpha' Z_{ni}) - \left[C_\theta(u_{ni1}, u_{ni,k,2}) - C_\theta(u_{ni1}, u_{ni,k-1,2})\right],\end{aligned} \qquad (12)$$

Where, $u_{ni1} = F_i(-\beta' X_{ni})$, $u_{ni,k,2} = G(\nabla_k - \alpha' Z_{ni})$.

Next, let $1[.]$ be an indicator function taking the value of unity if the expression in parenthesis is true and 0 otherwise. Thus, we can define the following dummy variables for i=3,4…I:

$$\Omega_{nik} = 1[d_{ni} = 1] \times 1[\Delta t_{ni} = k], \qquad (13)$$

Now, we can formulate the log likelihood function for the copula model as,

$$\log L = \sum_{n=1}^{N} \left(d_{n1} \log\left[\Pr(d_{n1} = 1)\right] + \sum_{i=3}^{I} \sum_{k=1}^{K} \Omega_{nki} \log \left[\Pr(d_{ni} = 1, \Delta t_{ni} = k) \right] \right), \qquad (14)$$

Once we have the log likelihood function, all the parameters will be estimated using maximum likelihood estimation method.

3.7 ESTIMATION SOFTWARE:

Estimation software GAUSS is used for the estimation.

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[7] In our choice framework first two alternatives denote work arrangement not incorporating telecommuting.

3.8 SUMMARY

This chapter described the econometric framework for current research purpose. First, the structures of the individual models for discrete work-arrangement choice and continuous duration of telecommuting episodes are discussed in details. Then, the framework for copula-based joint model is presented with a brief discussion of bi-variate copula distribution.

CHAPTER 4: DATA

In this chapter the data set used for empirical analysis is introduced and the sample characteristics are discussed in details. Additionally, the sample formation process is explained along with necessary assumptions made to account for limitations regarding data source.

4.1 DATA SOURCE

The data used in the analysis is compiled from the ATUS (American time use survey) 2007 survey. In ATUS, individuals are randomly selected from a subset of households that have completed their eighth and final month of interviews for the Current Population Survey (CPS). ATUS respondents are interviewed only one time about how they spent their time on the previous day, where they were, and whom they were with. The survey is sponsored by the Bureau of Labor Statistics and is conducted by the U.S. Census Bureau. The major purpose of ATUS is to develop nationally representative estimates of how people spend their time. The ATUS survey particularly collected information regarding spending time which encompasses unpaid works (*e.g.* own childcare, house work, volunteering *etc.);* non-market works, socializing, attending religious events, exercising, relaxing. The demographic information- including sex, race, age, educational attainment, occupation, income, marital status, and the presence of children in the household- for the respondent is available as well. But most of the demographic information is generated from the earlier CPS survey.

The data contains information of 12248 households and time use on a diary day for a selected individual of that household. The amount of time spent, location and, starting and ending time of each activity are specified in the records for each individual.

4.2 SAMPLE FORMATION

For present analysis our prime interest is only on the work and work-related activities. The data is being categorized to the individuals who have at least one work or work-related activities for 30 minutes on the diary-day. 4900 individuals with 11401 work episodes are distinguished after refining the data. Further, we confined our interest to only on the employed persons. Additionally, in order to eradicate ambiguity in the interpretation of telecommuting, the self employed persons (either working from home or conventional work places) are excluded from the data set. Therefore, the final data set comprises records for 2656 individuals and 532 among them are telecommuting at least once on the diary day. The data set also consists of the demographic attributes for each individual.

4.3 SAMPLE CHARACTERISTICS

In the sample, 53.4 % of the individuals are female and 46.6% are male. About 73.4 % of the individuals are in the range of age 26-55. Again, 64.7% of the sample has education below 4-year bachelor degree, 23.6% has education equivalent to 4-year bachelor degree and 11.7 % has above education level above bachelor degree. So, in terms of gender, age, and attained education there is no over representation of any attributes. The average weekly income for full time employed persons is 931.79 $ and is $333.63 for part time employed persons. The value is higher than the national average weekly earnings ($738 for full time employed persons). Since income is not an attribute of prime interest for our model, over representation of highly income individuals is not expected to impact the estimation.

From the descriptive analysis of demographic characteristics, some indicators of the choice process at hand are observed. Among the part-time employed persons, 71.6 % are female and among the individuals who are at least once telecommuting on the diary day the percentage of female in both part time and full time category is greater than males. So, it is clearly an indication that, gender plays a role in the work-hour-choice and telecommuting-adoption process. From the cross tabulations, metropolitan status, higher time use with family and friends, workaholic nature *etc*. characteristics are found to be positively correlated with telecommuting. Table 2 shows the descriptive for time-use pattern for the individuals along with mean values for of continuous variables.

As we mentioned earlier, only 532 individuals from the sample have at least one telecommuting episode on the diary day. For estimation we have used the aggregated telecommuting duration *i.e.* how much time an individual is spending for working at home or telecommuting. The mean duration is 38.25 minutes and the maximum is about 960 minutes. 65.4% of the sample has single episode and 21% has two episodes of telecommuting on the diary day.

4.4 SUMMARY

This chapter discussed about the data source used in our empirical analysis. Sample characteristics are stated in brief in this chapter. Next chapter will discuss the results from empirical analysis.

Table 4.1: Time use characteristics of the sample (for the diary day)

Variables	Mean
Total hours usually worked per week	38.76
Total time respondent spent alone [in minutes]	243.65
Total time respondent spent with customers, clients, and coworkers[in minutes]	13.25
Total time respondent spent with friends[in minutes]	44.6
Total time spent during diary day providing secondary childcare for household children < 13[in minutes]	141.02
Total time respondent spent with household family members[in minutes]	265.95
Total time spent during diary day providing secondary childcare for own household children < 13[in minutes]	134.43
Total time respondent spent with own household children < 18[in minutes]	151.68

CHAPTER 5: EMPIRICAL ANALYSIS

5.1 VARIABLE SPECIFICATION

The variables for the model are primarily specified based on earlier research and supported by intuition. For the empirical analysis the variables were categorized according to their attributes: 1) Household characteristics, 2) Personal attributes (including attitudinal characteristics), 3) Time-use, 4) Employment related, and 5) work-trip related attributes. Additionally, more variables are created to consider the interaction effects among attributes and the continuous variables (*e.g.* income, age, time-use) are tried in different functional forms (piece-wise linear, grouping *etc.*) to introduce non-linear effects. The final model specification is arrived through a systematic process of refining the initial models based on statistical significance, prudence in the representation of impact of variables, and most importantly intuitive consideration. The final specification includes few variables that are not highly statistically significant, but are included because of their intuitive nature and potential for future research. Table 5.1 summarizes the groups of variables considered in current framework.

5.2 MODEL FORMULATION

The empirical analysis involved estimating models with two different marginal distribution assumptions: one is for the error term of multinomial logit model of work-arrangement choice and another is for the error term of the hazard based duration model and seven different copula structures (independence, Gaussian, FGM, Frank, Clayton, Gumbel, and Joe)[8]. First, we estimated the copula based joint MNL-duration model of working-

[8] An independence copula is a copula that assumes independence between the marginal distributions.

arrangement choice and aggregated telecommuting episode duration. Since the marginal distributions are predefined (though not necessary), only seven functional forms are applied in our current empirical analysis. Since the dependency parameter of the copula based joint discrete-duration model is not statistically significant to a desired confidence level we can conclude there is no dependency (statistically significant) between the unobserved factors of the two models. Therefore, the working-arrangement choice and aggregated episode duration can be explained through two independent models: one multinomial logit model of choice for working arrangement and another hazard based duration model for aggregated telecommuting episode durations.

5.3 MODEL FITS AND STATISTICS

The log-likelihood function value for the joint copula based model is-3747.14 and for the two independent models the combined log likelihood function value is -3747.9 which implies that the combined model is better with respect to data fit. The dependency parameter in the joint copula model has a t-stat of - 1.119 that signifies the probability that the dependency parameter is different from zero (*i.e.* the two models are independent) equals to or 0.737. Among the seven copula models the Gaussian copula model provides the best data fit, with a corresponding Kendall's measure[9] of dependency of (-) 0.1483 and dependency value of (-) 0.2309 .The negative dependence between the error terms indicates that the unobserved factors act in opposite directions. This simply indicates that the unobserved factors that act as driving forces for full time telecommuting and flexible telecommuting result in an opposing

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[9] Kendall's measure of dependency (τ) transforms the copula dependency parameter (θ) into a number between -1 and 1 (see Bhat and Eluru, 2009). For the Gaussian copula, $\tau = \frac{2}{\pi}\arcsin(\theta)$. Where, θ = 0 signifies independence.

effect on the duration of telecommuting episodes *i.e.* shorten the duration of telecommuting episodes.

There is no change in the signs of the coefficients in the joint and independent models. The numerical values of the coefficients vary for some of the variables. For the MNL model of work arrangement choice, the absolute value of the coefficient for the variable representing workaholic nature increases from 0.11 in the joint model to 0.125 in the independent model, but the signs are negative on the both cases. Similar change is observed for the variable representing time spent for child care. The coefficients for the variables representing if the diary day is holiday and presence of children also experience slight decrease in the coefficient values. For the duration model, there are sign changes in the coefficients of the last two thresholds and the coefficients for the variables representing age and gender increase in their numerical values. Other coefficients representing variables: time spent with friends, for child care, race, and mixed working pattern experience slight reduce in their numerical values.

For a few of the variables the statistical significance changes quite a bit in the independent model compared to the joint copula model. The t-stat values for the variables representing workaholic nature, time spent for childcare and education level for the group if individuals who mix up work options with telecommuting increase to a certain degree. For the duration model there were not many changes in the t-stat values of the coefficients estimated by the independent and joint models. Table 5.2 represents the estimation results for the joint and independent models.

In the subsequent sections the empirical results will be discussed. Since there are no sign changes in the coefficients of the joint model and the independent models, we are not going to discuss the results separately. But, in case of the work-arrangement choice model the effect of the variables will be discussed separately on the different dimensions of choice: working hours and work-location. Finally, the empirical results of the hazard based aggregated duration model of telecommuting episodes on a particular day will be explained.

5.4 WORK ARRANGEMENT CHOICE MODEL

5.4.1 Working hour dimension

5.4.1.1 Effect of household characteristics

The results from the MNL work-arrangement model indicates that, location of individual residence (whether in a metropolitan area or else) is an important factor in working hour choice decision. Since, there are more opportunities and suitability for full time employment in the metropolitan area, when the household is located in a metropolitan area individuals will have more opportunities to choose full-time work options compared to part-time work. Our empirical analysis indicates that women with young children (age less than or equal to 5 years) will prefer full time work option relative to part time work which contradicts with findings of Blank (1989) and Crompton and Harris (1998). These studies indicate that, due to child care responsibilities most women with younger children will prefer part time work arrangement. In our empirical set up the choices are not stated preferences but revealing the actual choices made. So, it can be a possibility that individuals already have adjusted their full time work schedules according to responsibilities related to childcare.

5.4.1.2 Effect of personal attributes

In addition to household attributes, various personal characteristics like gender, age, educational level etc. are found to have significant effect on the work-hour choice dimension as well. Gender is a substantial factor for the choice process of work-arrangement option. The results suggest female workers are more inclined to choose part-time work option relative to full time work. As studies suggest (see Sermons and Koppelman, 2001 and Turner and Neimeier, 1997) that most of the household responsibilities are undertaken by the female individuals in a household, female individuals might prefer part-time work for to have an efficient and convenient time management of work-home responsibilities. Miller (1995) and Yeraguntla and Bhat (2005) reinforced this finding in their research. Results from the MNL model also show that individuals in the age group of greater than or equal to 27 years, more likely to choose full-time work option. Yeraguntla and Bhat (2005) in their research mentioned similar finding that young adults (age less than or equal to 25 years) like to choose part-time employment as work option compared to full time work and mentioned that may be most young individuals (age less than or equal to 25 years) are working part time along with study in the sample. Additionally one might consider that part time jobs are not secured and unstable whereas full time jobs are relatively stable and secured. With this perception, most of the individuals in the higher age groups may be showing preference for full time work option relative to part-time work.

5.4.1.3 Effects of work related attributes

The results imply that multiple job holders are more likely to choose full time work option relative to part-time working. Multiple job holders may not work for as many hours as a full time worker for a single job, but work for more than conventional hours in aggregated manner. So it is a possibility that, they might entitle themselves as full-time employed and creating positive correlation in our empirical analysis.

5.4.2 Work location dimension

5.4.2.1 Effect of household characteristics

The results represented in Table 4, indicate that, the individuals having their residences in a metropolitan area are more likely to adopt full day home based telecommuting. Since, in a metropolitan area the facilities and technical supports for telecommuting are more prevalent, it is easy for the workers to telecommute. Empirical results also show that when younger children (age less than or equal to 5 years) are present in the household, it is likely that individuals will prefer full day home based telecommuting. But, the results clearly indicate that, the individuals who spend or need to spend at least 2 hours in a day for child-care are inclined to choose part of day home based telecommuting option. It is interesting to notice that, this finding is effective for individuals irrespective of gender. Drucker and Khattak (2000), and Popuri and Bhat (2003) in their research pointed out that, generally women take the primary responsibility for taking care of the children in the household and so, employed women will prefer to work from home to maintain a convenient and flexible work schedule. Compared to these, results from our study emphasizes on the childcare responsibility factor for workers instead of gender related reasons.

5.4.2.2 Effect of personal attributes

The empirical results suggest persons in the age group of 55 years or more prefer to adopt part of day home based telecommuting. Again, individuals with at least 4 yrs bachelor education and adopting a part time work schedule are more prone to part of day home-based telecommuting. Bagley and Mokhtarian, 1997 suggested telecommuting is more prevalent in the groups with highly educated individuals because their job responsibilities suit telecommuting more compared to the less educated class. Further the results also imply that, individuals who spend more time with friends (that can be taken as a measure of outgoing nature) prefer part-time working over full time work option.

5.4.2.3 Effects of work related attributes

The estimation results suggest that few work related attributes such as hours of working, workaholic nature, and presence of technical support for telecommuting act as driving forces for telecommuting adoption for any worker. Sullivan et al. (1993) indicate similar findings that job unsuitability, lack of managerial support *etc.* factors act as constraints for adopting telecommuting. The empirical results in our model indicate persons who work more than usual hours (more than 35 hours for part-timer and 55 hours for full-timer) more likely to prefer full day home based telecommuting for a particular day. Working more than usual hours can be taken as an indirect measure of workaholic nature of the worker when a person is only working from home she can work as long as she wills and need not leave the office at 5PM or to be at the office at 9 AM which is the case in a conventional work place. According to findings from empirical analysis, the persons who work from home on holidays have preference for part of day home based telecommuting. The capability of working from home on holidays can be considered as indicator of availability of technical and managerial support for telecommuting from the employer.

5.5 HAZARD BASED MODEL

In accordance with hazard equations as we discussed in the methodology section, positive coefficients on the covariates will increase the telecommuting duration. In other words, it would reduce the hazard rate. Several personal, household, and work patterns related covariates are included in the non parametric hazard based duration model.

5.5.1 Effect of Household Characteristics

Empirical results show that, with the increase of number of children in household the durations of telecommuting episodes decrease. Number of children in a household can be a measure of distraction from work obtained from presence of children. On the other hand, with increase of family members the duration tends to increase. Greater family size can indirectly refer to strong bonding among the family members. Studies reveal that, family attachment is more prevalent in joint families with greater size (see Bengtson, 2001 and Olson and Gorall, 2003) and thus our results implies that workers who are highly attached with family are more likely to spend more time with family by adopting home-based telecommuting. In addition to these, results also imply that full time workers who practice part of day home telecommuting exhibit shorter duration of telecommuting episodes.

5.5.2 Effect of Personal Attributes

In addition to household characteristics, various personal attributes are also found to be significant in our research effort. Personal attributes like gender, age and race are showing correlation in the results as shown in Table 5.2. The estimation results suggest that employed female individuals are likely to spend more time in telecommuting episodes. Further, within groups of highly aged persons (greater or equal to 27 years) the durations of telecommuting episodes are higher as the estimates indicate in our model. Ethnicity of working individuals found to be significant for telecommuting durations and results show that Caucasians spend less time working at home compared to individuals of other ethnicities. It can be a possibility that ethnicity of individuals may be serving as indicator of attitudinal and life style related factors (for *e.g.* living style, attitudes toward life, outgoing nature, family bonding *etc.*) and showing the effect holistically.

5.4 SUMMARY

This chapter explains the results obtained from our empirical analysis. It also discusses the measures of data fit statistics. In the next chapter, implications based on our obtained results will be discussed.

Table 5.1: Variable specification for the model

Household characteristics	Personal Attributes	Attribute related to presence of Children	Attitudinal and family related Attributes	Job- Related attributes
Metropolitan status	Gender	Number of HH children	Attachment to family	Multiple job holder
Presence of Household children	Age	Presence of own Children	How much time is spent with friends/co-workers?	Availability of telecommuting arrangement
Vehicle availability	Personal weekly earnings	Age of own youngest child	Workaholic nature	Telecommuting on Holidays
Household Size	Highest level of Education attained	If child care is needed?	How much time is spent for recreational activities?	……………..
……………..	Presence of spouse	How much time is spent for child-care	How much time is spent for Physical Exercise?	……………..
……………..	Race	……………..	……………..	……………..

Table 5.2: Summary of Estimation Results

Explanatory Variables	Joint copula based model		Independence Copula Model			
			MNL-work arrangement model		Hazard based aggregated telecommuting duration model	
	Estimates	t-ratio	Estimates	t-ratio	Estimates	t-ratio
Constants						
Full time- Whole day Home based telecommuting	-2.0307	-7.733	-2.0856	-7.8	-	-
Part time- Whole day Home based telecommuting	-2.0588	-9.128	-2.1063	-9.785	-	-
Full time-Part of day Home based telecommuting	-2.2543	-10.436	-2.2409	-10.708	-	-
Part time- Part of day Home based telecommuting	-2.387	-13.348	-2.3687	-13.669	-	-
Full time- No home based telecommuting	0.0608	0.315	0.0428	0.229	-	-
Gender(1 if female; 0 otherwise)						
Full time working	-1.0587	-8.832	-1.0535	-9.301	-	-
Education level (1 if above Bachelor level; 0 otherwise)						
Full time working	0.2466	2.063	0.2456	2.061	-	-
Telecommuting –specific to part time workers	-0.1556	-0.982	-0.1626	-1.047	-	-
Age of a person(in Years)						
Age equal to or greater than 27 but less than 55 years						
Full time working	1.6965	11.644	1.7081	12.278	-	-
Age greater than or equal to 55 years						
Full time working	0.7596	4.621	0.7708	4.685	-	-
Both only telecommuting and Combining telecommuting with	0.278	2.134	0.3095	2.335	-	-

Table 5.2: Summary of Estimation Results

Explanatory Variables	Joint copula based model		Independence Copula Model			
			MNL-work arrangement model		Hazard based aggregated telecommuting duration model	
	Estimates	t-ratio	Estimates	t-ratio	Estimates	t-ratio
conventional work options						
Metropolitan status						
Full time Working	0.4866	3.597	0.4936	3.748	-	-
Only Telecommuting	0.2776	1.626	0.2892	1.666	-	-
Working more than usual hours(Indication of workaholic nature) (more than 35 hours for part time and 55 hours for full time And not a multiple job holder)						
Telecommuting	-0.1108	-0.779	-0.1253	-1.907	-	-
Presence children aged 5 years or less						
Full time working	0.4805	4.119	0.4812	4.212	-	-
Only Telecommuting	-0.158	-1.221	-0.1167	-1.088	-	-
Multiple job holder						
Full time working	0.4102	2.023	0.4078	2.042	-	-
The diary day was a holiday and individual was working from home						
Telecommuting	0.6095	1.743	0.5386	1.342	-	-
Time spent with Friends(in minutes)						
Full time working	-0.9817	-2.3	-0.9608	-2.482	-	-
Total time spent for taking care of own children						
Telecommuting	0.3053	1.195	0.3878	1.777	-	-

Table 5.2: Summary of Estimation Results

Explanatory Variables	Joint copula based model		Independence Copula Model			
			MNL-work arrangement model		Hazard based aggregated telecommuting duration model	
	Estimates	t-ratio	Estimates	t-ratio	Estimates	t-ratio
Duration model						
Threshold-1	-2.5472	-3.213	-	-	-1.752	-5.985
Threshold-2	-2.3957	-3.075	-	-	-1.6195	-5.618
Threshold-3	-1.9947	-2.666	-	-	-1.2702	-4.564
Threshold-4	-0.5099	-0.841	-	-	0.0175	0.066
Threshold-5	-0.1755	-0.305	-	-	0.3089	1.172
Threshold-6	0.0053	0.009	-	-	0.4669	1.775
Threshold-7	1.1111	2.344	-	-	1.4423	5.233
Gender(1, if female)	0.1746	1.332	-	-	0.1256	1.199
Age(in years)	0.005	1.125	-	-	0.0051	1.35
Household size	0.0852	1.306	-	-	0.0769	1.368
No. of children aged =< 5 yrs	-0.1184	-1.359	-	-	-0.1108	-1.472
Race (1, if white only)	-0.2854	-1.961	-	-	-0.2449	-2.004
Time spent with Family members	0.0002	0.86	-	-	0.0002	0.937
Work pattern(1, if combining telecommuting with other work arrangement option)	-0.2535	-1.004	-	-	-0.2547	-1.187
Copula Parameter(θ)	-0.2309	-1.119	-		-	
Log-likelihood function values	-3747.14		-2833.69		-914.21	

CHAPTER 6: CONCLUSIONS AND FUTURE DIRECTIONS

6.1 CONCLUSION

The current research proposes a copula-based joint multinomial discrete-continuous model that accommodates the work-arrangement choice and aggregated duration choices of telecommuting episodes simultaneously, while allowing for flexible dependence structure between the unobserved factors of the two marginal distributions. Efforts are made to capture these choices in a unified framework using a flexible copula based approach and to our knowledge this is the first formulation and application in the literature of a copula approach. But the dependency parameter is not statistically significant to a desired level. As a result, the implications of our research are limited to independent models of work arrangement choice and continuous durations of telecommuting episodes.

6.2 STRENGTH AND LIMITATIONS OF PROPOSED FRAMEWORK

The present research contributes to the literature on quantitative modeling of work arrangement choices. Attempts are made to overcome limitations as identified from the review of the previous works. Most of the earlier studies related to work arrangement choice use separate choice models for work hour and location choice and only a very few of them focus on the time use characteristics of the individuals. In addition to this, none of previous studies attempt to model the duration of telecommuting episodes to the author's best knowledge. In our current research, a multinomial logit model is used for work arrangement choice that accommodates hours of working (indicated by part-time /full-time work status) and location of work or work related activities simultaneously in the alternatives and time use characteristics are included in the model to have a better understanding of telecommuting adoption. Additionally, our model is estimated with most recent data (ATUS 2007) and expected to reveal the current trend of telecommuting in USA. Since the patterns of telecommuting arrangement adopted by the working individuals and the opportunities offered by employers are changing very rapidly, it is of utmost importance to analyze the most recent data possible to assess the impact of telecommuting with perfection.

The choice model of work arrangement carries special implications in the context of activity based travel demand modeling. Working schedule (*i.e.* location and working hours) of an employed individual acts as a primary key while predicting her activity participation decisions. Accordingly, the choice model proposed here can serve as a component module in a broader framework of activity based modeling. In addition to this, the model accommodates the group of individuals practicing part of day home based telecommuting that causes trip displacements in addition to trip replacement on a particular day. Therefore, our model by capturing the trip displacement effects represents a more accurate picture of the travel demand distribution throughout the day.

From the stand point of policy making, there exist important implications of our proposed model. As a travel demand management strategy, it is often desired to reduce the number of trips by influencing the purpose and timing of the trips. The idea behind this is that travel pattern will change for individuals throughout the day and peak demand will be reduced. Now, If home-based telecommuting is used as a measure to reduce the trips by offering flexible work arrangements to employed individuals, the model proposed in our research can be a starting point to determine what fraction of working individuals will adopt home-based telecommuting arrangement. Further, the model can be used to investigate the changes in travel demand distribution due to home-based telecommuting. Lyons and Haddad (2008) mentioned in their research that part-day working from home is more prominent among employed persons compared to full day home working. So the question is- will it be more effective to promote part-day home-based telecommuting instead of full-day home based telecommuting? The present attempts to answer this question.

Most of the estimation results can be explained in an intuitive manner. The estimated results show that gender effects are evident on the choice of part time or full time working. Further, time spent for childcare is found to be highly significant for choosing working from home option instead of working from other conventional work places. Interestingly, this effect is indifferent for male and female workers suggesting whoever is taking the responsibilities for child care is more likely to prefer working from home. For full day home based telecommuting and full time work, residence location in a metropolitan area acts as a driving force. Again, availability of technological and managerial supports from employer implies more possibilities of home based telecommuting.

The non-parametric hazard based duration model in our research effort explains the socio-economic factors that affect the duration of telecommuting episodes on a particular day. Several attributes like being a female, belonging to higher age groups, and more attachment with family *etc.* lead to greater durations of telecommuting episodes. On the other hand, presence of children and being a white-only ethnic individual reflect shorter duration of telecommuting episodes in general.

But there are some limitations embedded in the model estimation. The lack of work-trip related data does not allow us to explain anything regarding trade-off between telecommuting and travel to work place. Again, unavailability of changes in earnings before and after telecommuting does not allow us to explain the income effect elaborately. Finally, the copula parameter is not significant at the 95% level which is generally taken as norm for statistical models.

6.3 FUTURE RESEARCH

As a future research effort, one can compare nested logit models with multinomial logit models for work arrangement choice process and different other copulas can be tried to obtain a more statistically significant correlation parameter.

6.4 SUMMARY

Undoubtedly the empirical results obtained in the present research have useful implications in the context of travel demand management and transportation planning. Ignoring the limitations, assuming no endogeneity issues and violation of independence of the irrelevant alternatives property the model explains important factors in the choice process of work-arrangement when working from home is a potentially available option for an individual.

Appendix A: Bivariate Copula Distribution (see Nelsen, 2006 and Bhat and Sener, 2009)

Gaussian copulas

The Gaussian copula belongs to the class of elliptical copulas; since the Gaussian copula is simply the copula of the elliptical bivariate normal distribution (the density contours of elliptical distributions are elliptical with constant eccentricity). The Gaussian copula takes the following form:

$$C_\theta(u_1, u_2) = \Phi_2(\Phi^{-1}(u_1), \Phi^{-1}(u_2), \theta),$$

Where, $\Phi_2(.,.,\theta)$ is the bivariate cumulative distribution function with Pearson's correlation parameter $\theta(-1 \le \theta \le 1)$. The Gaussian copula is comprehensive in its coverage in that it is able to capture the full range of (negative or positive) dependence between two random variables.

Farlie-Gumbel-Morgenstern (FGM) copulas

The bivariate FGM copula (Morgenstern, 1956, Gumbel, 1960, and Farlie, 1960) takes the following form:

$$C_\theta(u_1, u_2) = u_1 u_2 [1 + \theta(1 - u_1)(1 - u_2)].$$

The presence of the θ term $(-1 \le \theta \le 1)$ allows the possibility of correlation between the uniform marginals u_1 and u_2. Thus, the FGM copula has a simple analytic form and allows for either negative or positive dependence. However, the FGM copula is not comprehensive in coverage, and can accommodate only relatively weak dependence between the marginals (see Bhat and Eluru, 2009).

Dependence structure

Both the Gaussian and FGM copulas assume the property of asymptotic independence. That is, regardless of the level of correlation assumed, extreme tail events appear to be independent in each margin just because the density function gets very thin at the tails (see Embrechts et al., 2002). Further, the dependence structure is radially symmetric about the center point in the Gaussian and FGM copulas. That is, for a given correlation, the level of dependence is equal in the upper and lower tails.

Archimedean Copulas

The Archimedean class of copulas includes many of the closed-form copulas accommodating a wide range of dependency structures, including comprehensive and non-comprehensive copulas, radial symmetry and asymmetry, and asymptotic tail independence and dependence (see Nelsen, 2006 and Bhat and Eluru, 2009 for a detailed discussion).

Clayton Copulas

The Clayton copula has the following form (Clayton, 1978):

$$C_\theta(u_1,u_2) = (u_1^{-\theta} + u_2^{-\theta} - 1)^{-1/\theta},\ 0 < \theta < \infty .$$

Independence corresponds to $\theta \to 0$. The above copula cannot account for negative dependence. The copula is best suited for strong left tail dependence and weak right tail dependence.

Gumbel Copulas

The Gumbel copula, first discussed by Gumbel (1960) and sometimes also referred to as the Gumbel-Hougaard copula, has the form provided below:

$$C_\theta(u_1,u_2) = \exp\left(-\left[(-\ln u_1)^\theta + (-\ln u_2)^\theta\right]^{1/\theta}\right),\ 1 \le \theta < \infty .$$

Independence corresponding to $\theta = 1$. Like the Clayton copula, the Gumbel copula cannot account for negative dependence. The Gumbel copula is well suited for the case when there is strong right tail dependence (strong correlation at high values) but weak left tail dependence (weak correlation at low values).

The Frank Copula

The Frank copula, proposed by Frank (1979), is given by:

$$C_\theta(u_1, u_2) = -\frac{1}{\theta}\ln\left(1 + \frac{(e^{-\theta u_1} - 1)(e^{-\theta u_2} - 1)}{e^{-\theta} - 1}\right), \; -\infty < \theta < \infty .$$

Independence is attained in Frank's copula as $\theta \to 0$. The copula allows for positive and negative dependence. However, like the Gaussian and FGM copulas, it is radially symmetric in its dependence structure and imposes the assumption of asymptotic independence. The dependence surface of Frank's copula show very strong central dependency (even stronger than the Gaussian copula) and very weak tail dependence (even weaker than the Gaussian copula).

The Joe copula

The Joe copula, introduced by Joe (1993, 1997), has the following copula form:

$$C_\theta(u_1, u_2) = 1 - \left[(1-u_1)^\theta + (1-u_2)^\theta - (1-u_1)^\theta (1-u_2)^\theta\right]^{1/\theta}, \; 1 \le \theta < \infty .$$

Independence corresponds to $\theta = 1$. The Joe copula is similar to the Gumbel, but the right tail positive dependence is stronger. In fact, from this standpoint, the Joe copula is closer to being the reverse of the Clayton copula than is the Gumbel.

APPENDIX B: Sample Characteristics

Table B1: Distribution of work-arrangement choice by Gender

Working hour and location joint choice	**Male**	**Female**	**Total**
Full time- Whole day Home based telecommuting	127[9.2%]	130[10.3%]	257
Part time- Whole day Home based telecommuting	19[3.2%]	46[1.5%]	65
Full time-Part of day Home based telecommuting	87[5.8%]	83[7.0%]	170
Part time- Part of day Home based telecommuting	11[2.0%]	29[0.9%]	40
Full time- No home based telecommuting	875[70.7%]	832[58.6%]	1707
Part time- No home based telecommuting	118[21.1%]	299[9.5%]	417

Table B2: Distribution of work arrangement choice by Education level

Work option	Education level below Bachelor	Bachelor	Above Bachelor	Total
Full time- Whole day Home based telecommuting	153[8.9%]	71[11.3%]	33[10.6%]	257
Part time- Whole day Home based telecommuting	48[2.8%]	14[2.2%]	3[1.0%]	65
Full time-Part of day Home based telecommuting	114[6.6%]	35[5.6%]	21[6.8%]	170
Part time- Part of day Home based telecommuting	29[1.7%]	7[1.1%]	4[1.3%]	40
Full time- No home based telecommuting	1063[61.8%]	422[67.4%]	222[71.4%]	1707
Part time- No home based telecommuting	312 [18.2%]	77[12.3%]	28[9.0%]	417

Table B3: Distribution of work arrangement choice by Metropolitan status

Work option	Metropolitan Status		
	NO	YES	Total
Full time- Whole day Home based telecommuting	34[7.81%]	223[10%]	257
Part time- Whole day Home based telecommuting	9[2.1%]	56[2.5%]	65
Full time-Part of day Home based telecommuting	24[5.5%]	146[6.6%]	170
Part time- Part of day Home based telecommuting	12[2.7%]	28[1.3%]	40
Full time- No home based telecommuting	266[60.9%]	1441[64.9%]	1707
Part time- No home based telecommuting	92 [21.1%]	325[14.6%]	417
Total	437	2219	2656

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