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Using Virtual Accessibility and Physical Accessibility as Joint Predictors of Activity-Travel Behavior

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Using Virtual Accessibility and Physical Accessibility as Joint Predictors of Activity-Travel Behavior

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Dedication

To this moment.

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To my parents, for your unconditional support and love.

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Abstract

Using Virtual Accessibility and Physical Accessibility as Joint Predictors of Activity-Travel Behavior

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This study proposes a conceptual and analytic framework anchored on the concepts of physical and virtual accessibility (the "ease" with which opportunities or activities can be reached in the physical and in the virtual space, respectively) to investigate the rich interplay between virtual and physical activity engagements in multiple activity purposes, while controlling for information and communication technology (ICT) use measures, physical accessibility measures, and demographics. The framework considers that activity-travel choices are consequences of the individual, household, and work characteristics that are mediated by virtual accessibility and physical accessibility. As part of the analysis, activity chaining characteristics during travel are analyzed to study any fragmentation impacts caused by ICT use on activity engagement and scheduling. Using the data from the 2011 and 2012 National Travel Survey in Great Britain, this research applies Bhat's (2015) generalized heterogeneous data model (GHDM) to jointly model multiple activity and travel outcomes. The results provide important insights for social welfare, work-life

balance, and equity policies, and suggest the possible use of virtual accessibility as a quality-of-life enhancing instrument.

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Chapter 1: Introduction

We live in a world in which we can do almost anything online, and we can be online nearly anytime and anywhere. The combination of the Internet (the media), smartphones (the tool), and LTE networks (the infrastructure) is providing users with ubiquitous virtual access to other people, information, goods, services, and activities. Although the effects of information and communication technologies (ICT) on personal activities and related travel is not a new topic in the transportation literature (see Andreev et al., 2010 and Aguilera et al., 2012 for reviews), continuing and renewed attention to this topic is needed because of recent technological evolution and significant penetration of mobile ICT devices in our society. On the latter point, for example, data published by the Office of National Statistics (ONS, 2016a) shows that 82 percent of adults (41.8 million) in Great Britain in 2016 used the Internet daily or almost daily, compared to 35 percent in 2006. According to the same data source, in 2016, 70 percent of adults accessed the Internet on-the-go using a mobile phone or smartphone, nearly double the 2011 estimate. Goods or services were bought online by 77 percent of adults, up from 53 percent in 2008.

As ICTs become more popular, and the digital world permeates into our everyday lives, the divide between the virtual and physical worlds begins to blur as we make continuous and joint decisions about which activities we can, need, and want to perform in person or virtually. Because of the interdependency across choices associated with different types of activities in one's schedule (due to, for example, time allocation, geography, trip chaining, and joint participation), it is expected that the opportunity to conduct an activity virtually or, at the other extreme, the lack of opportunity to access an activity physically, will affect the overall activity planning of the individual. Thus, although approaches that analyze isolated interactions between specific single types of tele-

activity and their immediate location-based counterparts (for example, online shopping versus in-store shopping) can provide important insights on immediate substitution and complementarity patterns, they are limited to their ability to guide future transportation and land use planning.

In this study, a comprehensive modeling framework, anchored on the concepts of virtual and physical accessibility (the "ease" with which opportunities or activities can be reached in the virtual space and in physical space, respectively), is developed to examine and capture interactions in activity-travel choices associated with both virtual and physical participation and for multiple activity purposes at the same time (in this paper, the term "physical activity participation" implies out-of-home (OH) activity participation undertaken in physical presence, as opposed to virtually). In particular, this research defines virtual accessibility and physical accessibility as two latent constructs that mediate individuals' activity engagement decisions (both virtually and physically). Data from the 2011 and 2012 National Travel Survey of Great Britain is used to test the framework.

The following three sections present a very brief review of studies on the relationship between ICT use and physical activity-travel behavior participation, beginning with studies that do so in the context of a single activity purpose, followed by those that consider multiple activity purposes and activity fragmentation/multi-tasking considerations. Section 1.2 discusses the concept of virtual accessibility. Finally, Section 1.3 indicates the links between this research and the already extensive body of knowledge in this topic and states the contributions.

1.1 IMPACTS OF ICT ON PHYSICAL ACTIVITY-TRAVEL BEHAVIOR

1.1.1 Single Activity Purpose Studies

A significant amount of the empirical work investigating the relationship between ICT use and physical activity-travel behavior builds upon the typology developed by Salomon (1986) that establishes four main impacts of ICT on personal activities and travel: substitution (replacement of a location-based activity by a tele-activity, thus eliminating travel), complementarity (a virtual or tele-activity leads to new location-based activities), modification (virtual or tele-activity changes the timing, duration or place of a location-based activity), and neutrality (there is no observed effect of the virtual or tele-activity on the location-based activities). These effects have generally been studied by examining specific tele-activities and their direct location-based counterparts such as telecommuting and commuting or online shopping and in-store shopping. Telecommuting has been the most widely studied tele-activity, and a general consensus today is that it allows for travel substitution resulting in the reduction of the number of trips and sometimes in distances traveled even if in small proportions (see, for example, Zhu, 2012, Hu and He, 2016). Online shopping has also been extensively studied, but this activity seems to predominantly have a complementarity effect on in-store shopping, at least in terms of frequency of shopping episodes (see, for example, Ding and Lu, 2017, and Lee et al., 2017). Complementarity effects have also been observed by studies that analyze the impact of cell phone and smartphone ownership and intensity of use on the frequency of out-of-home leisure activities (Lee-Gosselin and Miranda-Moreno, 2009; Astroza et al., 2017).

1.1.2 Multiple Activity Purpose Studies

Analyses that focus on a single activity purpose can provide useful insights to understand general tendencies of behavioral patterns. But, they underestimate the true potential that ICT use has in re-shaping individuals' schedules and activity-travel choices. A few studies in the literature have taken a more comprehensive approach to identify substitution, complementarity, modification, and neutrality patterns while taking into account multiple activity purposes as well as activity durations (Wang and Law, 2007, Ren and Kwan, 2009, Lila and Anjaneyulu, 2016). These studies point to the limitations of earlier studies that focus solely on a single type of activity and underscore the intricate and complex nature of the interactions between the digital and the physical world. For example, as suggested by some of these studies, the combination of online shopping and in-store shopping can increase the overall efficiency of shopping activities and reduce the overall time spent shopping, which in turn can increase the frequency and/or time spent in leisure activities (virtually or physically). At the same time, as some of these multiple activity purpose studies suggest, in examining the impacts of an increasingly ICT-driven world, it is important to consider not only ICT accessibility/use, but also simultaneously consider physical activity accessibility in the form of physical built environment (BE) variables. In particular, not controlling for BE attributes can result in the attribution of land use effects to ICT-based effects, causing misleading inferences.

1.1.3 Activity Fragmentation and Multitasking

Besides substitution, complementarity, modification, and neutrality, two other important concepts studied in the literature regarding ICT and activity-travel behavior are "activity fragmentation" (Couclelis, 2000, Hubers et al., 2015) and "multitasking" (Kenyon and Lyons, 2007, Berliner et al., 2015). Activity fragmentation (also called spatiotemporal

flexibilization by authors such as Schwanen and Kwan, 2008) can be considered an effect of modification and entails the splitting of a certain activity into several smaller pieces that can be performed at different times and locations. ICT facilitate activity fragmentation because of their space-time adjusting characteristic that allows remote and continuous access to files, information, and people. Multitasking, on the other hand, is the simultaneous realization of two or more activities during the same time period. Such practice becomes significantly easier with ICT availability since the individual can be physically in one location filling a specific need while also performing another activity remotely via ICT. For example, an individual can be teleworking or be shopping online while traveling as a passenger at the same time.

Despite the theoretical appeal of the fragmentation and multitasking concepts to explain ICT use-related impacts on human behavior, few empirical studies have focused on these topics. The main challenge is associated with data because traditional activity-travel diaries become burdensome if respondents are required to provide disaggregated and detailed records of multiple simultaneous activities or the fragmentation of activities. Lenz and Nobis (2007) identify different fragmentation patterns of work activities. Although they establish clusters of individuals that have different fragmentation and travel behaviors, they cannot conclude whether individuals with high levels of fragmentation also have higher trip rates due to ICT use or due to self-selection. Hubers et al., (2008) developed a framework to identify activity fragmentation based on the number, sizes (duration), and configuration (spatial and temporal distance between activity episodes) of activity episodes. Their framework allows for clear identification of activity fragmentation, and although their results show mostly positive relations between ICT and fragmentation, the relations differ for the kind of ICT and type of activity investigated (similar results were obtained by Ben-Elia et al., 2014). Hubers et al., (2008) emphasize that basic demographic

and residential living variables were always related with fragmentation more strongly than ICT ownership and use. More recently, Alexander et al., (2010) and Hubers et al. (2015) focused on the analysis of spatiotemporal fragmentation of paid labor (using the same measures of fragmentation as Hubers et al., 2008). Both studies find a clear association between ICT use and work fragmentation. Hubers et al. (2015) also identify significant gender differences in ICT use and fragmentation patterns, which they associate with different coping strategies to accommodate work and domestic responsibilities.

Empirical evidence on multitasking and travel behavior is also scarce and does not necessarily measure the impacts of ICT use (ICT use is just associated with certain types of multitasking). It mostly focuses on the types of activities undertaken as part of multitasking when traveling (Ettema and Verschuren, 2007, van der Waerden et al., 2009, Rasouli and Timmermans, 2014, Berliner et al., 2015). Similar to the majority of substitution and complementarity analyses mentioned earlier, most of the fragmentation and multitasking studies also focus on a single type of activity or context (such as multitasking during the work commute).

To summarize, there is a need to analyze all the six possible types of ICT-based effects just discussed on activity-travel and to consider multiple types of activities of an individual's everyday life in a single comprehensive framework. The next section presents the concept of virtual accessibility and how it may be the key element in a more comprehensive understanding of the use and impacts of ICT on overall activity-travel behavior.

1.2 Translating ICT Use, Tele-Activities, and Virtual Activities into a Virtual Accessibility Concept

Thus far, the interaction between ICT use and an individual's physical activity-travel behavior have been modeled in one of three broad ways: (a) by including exogenous variables that directly represent ICT ownership and/or use in models of frequency and/or duration of location-based activities (for example, Lee-Gosselin and Miranda-Moreno, 2009 and Ben-Elia et al., 2014), (b) by simultaneously modeling frequency and/or duration of tele- and location-based activity episodes to study potential complementarity/substitution effects between the two pathways to pursue an activity, but without consideration of ICT ownership or use (for example, Ren and Kwan, 2009 and Lee et al., 2017), or (c) by considering ICT ownership/use along with modeling tele- and location-based activity episodes (for example, Alexander et al., 2010, Cao et al., 2012, and Lila and Anjaneyulu, 2016). The last of these broad ways explicitly recognizes the influence of ICT use on the trade-offs and interactions in decision-making when people choose between pursuing an activity episode as a tele-episode versus a location-based episode. For example, real-time traffic information obtained through ICT use may determine (or modify earlier decisions on) whether an individual travels to a store or tele-shops, and may also impact the duration of the episode. This represents an ICT use-based choice and modifying behavior that cannot be studied if ICT ownership/use is not considered as a determinant variable.

A concept that can simultaneously characterize both the access to virtual or tele-activities causing complementarity or substitution, as well as ICT use-based choice behavior, is "virtual accessibility." Kenyon et al., (2003) and Kenyon (2010) define virtual accessibility as the "Internet enabled accessibility [that] provides an alternative to reaching opportunities, goods, services, and social networks, providing access without physical

travel . . . [it] acts to substitute for physical mobility. . . It can also act to supplement for [physical] accessibility where previously there was a deficit." Virtual accessibility can represent more than access without travel; it can also characterize the enhancement of the travel experience and physical accessibility by the use of real-time information provided by ICT use (van Wee et al., 2013, Lu et al., 2014).

Although implicit in most of the studies that examine the impact of ICT on travel behavior, the concept of virtual accessibility has seldom been explored. The use of this term allows a parallel with physical accessibility and can also incorporate constraints and behavioral aspects associated with ICT adoption and use. For instance, the level of virtual accessibility that one may experience should depend on at least five aspects: (1) the ownership of an ICT device; (2) the subscription to a network provider (can refer both to Internet and calls) and the coverage of such a network; (3) the ability (or knowledge) to use the gadget and available functionalities (also known as technology-savviness); (4) the ability to conduct activities virtually (for example, if the individual's job requires physical presence at the workplace, then his/her virtual accessibility is immediately limited, at least as related to the work activity purpose); and, (5) the overall time available to the person to pursue specific types of activities (for example, time available after work to pursue shopping or leisure). Considering such abilities and constraints to virtual accessibility is fundamental to understanding the potential impacts of ICT since it is well known that there is a large gap between technology development, technology adoption, and technology impacts on behavior. As discussed earlier, starting with the concept of virtual accessibility, and its interaction with physical accessibility (formed on the basis of perceptions of the built environment), has the advantage of appropriately recognizing the trade-offs and related interactions in the decisions that drive tele- and location-based activity-travel patterns. As importantly, this approach lends itself nicely to an examination of the impacts

of ICT use and other relevant personal characteristics (such as demographic and work characteristics) on tele- and location-based channels for pursuing multiple activity purposes (rather than simply focusing on a single activity purpose). It also enables the examination of the effects of ICT and personal characteristics on virtual activity episodes (such as socializing through Facebook during leisure) that do not have a strict location-based counterpart (this study will use the more general term "virtual" activities, even when the reference is to a strictly tele-based notion of activity engagement that has a direct location-based counterpart).

1.3 THE CURRENT PAPER

The research in this paper aims to contribute to the literature by conducting a comprehensive analysis of the interplay between virtual and physical activity engagements in multiple activity purposes while controlling for ICT use measures, physical accessibility measures, and demographics. The framework considers that activity-travel choices are consequences of individual, household, and work characteristics that are mediated by virtual accessibility and physical accessibility. As part of the analysis, activity chaining characteristics during travel are analyzed to study any fragmentation impacts caused by ICT use on activity engagement and scheduling.

In the literature, six main effects of ICT that have an impact on physical- activity-travel patterns are identified: substitution, complementarity, modification, neutrality, spatial or temporal fragmentation, and multitasking. Effects of real-time information and other direct effects of ICT use such as better synchronization with other activity participants may be included under the modification umbrella. In this study, all these potential effects, except for multitasking, are accommodated. Multitasking could

potentially be incorporated into the framework, but it is constrained by data availability. More importantly, though, earlier literature that uses the terminology above can be seriously limited in the sense that it implicitly assumes that ICT use first leads to decisions regarding virtual activities, which then impact decisions on physical activity engagement. That is, there is the implication that virtual activity participation is exogenous to physical activity participation decisions. This study adopts a different perspective in that ICT use and availability first impact the virtual accessibility latent construct, which along with the physical accessibility latent construct determines both virtual and physical activity participation. Acknowledging the stochastic nature of the virtual and physical accessibility latent constructs, this research models virtual and physical activity participation as a joint package decision. As a result, the emphasis in presenting the results will be on the effects of the virtual and physical accessibility constructs on both virtual and physical activity engagements, and the impacts of ICT use measures (which will be more broadly referred to virtual accessibility measures in parallel with the notion of physical accessibility or BE measures) on the virtual and physical accessibility latent constructs. The analysis framework is based on the Generalized Heterogeneous Data Model (GHDM) proposed by Bhat (2015).

Section 2 presents the research design. Model results are discussed in Section 3, followed by an analysis of the relationship between virtual and physical accessibility and its policy implications. The final section presents the conclusions, identifies limitations of the current paper, and suggests future research directions.

Chapter 2: Research Design

This study proposes the use of virtual and physical accessibility as mediators when modeling the impact of ICT on individual activity participation and travel behavior. These mediators are considered as latent constructs that represent the subjective perceptions of every individual, based on (and impacted by) measures of accessibility, as discussed next.

2.1 Accessibility as a Latent Construct

Accessibility can be broadly defined as the ease with which opportunities or activities can be "reached". Accessibility is a multidimensional concept and a result of the interaction among multiple factors, including the needs and abilities of the individual depending on such characteristics as age, income, educational level, and household context (Geurs and van Wee, 2004). Although the literature presents an extensive list of possible physical accessibility measures (see Páez et al., 2012, for a review), the characteristics of individuals and their specific needs, as just mentioned, are usually not incorporated. When the focus is to understand accessibility experienced by individuals and how these reflect on their activity-travel behavior, focusing on objective measurements of the built environment, transportation system, and even temporal constraints (associated with business hours, for example) may not be adequate. Individuals living in very similar locations may present distinct travel behavior characteristics that cannot be explained simply by available objective location-based or transportation based accessibility measures. The differences may be due to differences in time budgets and space-time restrictions resulting from engagement in fixed activities, or even differences in overall perceptions associated with personalities, societal roles, and lifestyles. For instance, employed mothers may perceive physical accessibility differently than their male

counterparts because they generally have to juggle paid work, childcare, and household responsibilities. These same women may also have different perceptions of safety relative to their male counterparts, and therefore experience accessibility differently. Indeed, Curl et al. (2011) conducted semi-structured interviews with Local Transport Authorities (LTA) in England to investigate how the measures of accessibility often used by planners may not assess the complex social interactions, perception, and behaviors that influence travel. A number of respondents suggested that a good measure of accessibility would incorporate how people perceive accessibility.

Similar to other psychological constructs, however, there is not a single or specific measure to quantify perceived accessibility. Therefore, it is appropriate to consider that perceived accessibility is an underlying latent (to the analyst) factor that gets manifested in the form of multiple expressed indicators. This latent variable may have a structural relationship with (be explained by) individual characteristics and objective physical accessibility measures, and also have a stochastic component to account for individual-perceived and analyst-measured errors. This notion of a latent construct for accessibility and modeling approach applies to both virtual and physical accessibility, and if both types of accessibility are used in the same model, the relationship between the two stochastic types of accessibility can be quantified by the correlation between the two latent constructs. Further, the presence of individual-specific stochasticity in these latent constructs, and the impact of these latent constructs on participation characteristics in virtual activity (such as working from home, and shopping for food/other goods online) as well as physical activity (such as participation and duration in OH mandatory, maintenance, and discretionary activity episodes) immediately implies jointness in decision-making across virtual and physical participation. Such a framework offers better insights into the rich interactions between virtual accessibility measures (ICT ownership/use), physical accessibility

measures (BE attributes), virtual activity behavior, and physical activity-travel behavior. It also enables us to capture any additional recursive impacts among the virtual and physical activity-travel behaviors, after accounting for the jointness among these behaviors.

2.2 Data Source and Conceptual/Analytic Framework

The 2011 and 2012 National Travel Survey in Great Britain collected detailed information on socio-economic and demographic characteristics of households and individuals. It also asked every individual in the household to maintain a seven-day travel diary. Details of the data set and survey administration are available in the technical report (Taylor et al., 2013). For the current analysis, this study selected the individual in the household who was both a worker (full-time and part-time) and the main person responsible for food shopping (for reasons explained in the next paragraph). The final sample in the analysis comprises 3370 workers.

The outcomes related to virtual activity engagement (VAG) collected in the survey pertained to the frequency of working from home, whether the household's main method of food shopping was online and/or by phone, and the frequency of food and goods purchased online or by phone (and delivered to the house). The frequency variables, however, are not actual count variables but are collected in ordinal categories. For example, the frequency of food purchased online/by phone and delivered to the house (which will be simply referred as the "frequency of food deliveries", and similarly this study will refer to the frequency of goods purchased online or by phone and delivered to the house as the "frequency of goods deliveries") is collected in four ordinal categories: less than once a year, less than once a month, less than once a week, and one or more times per week. Since the VAG outcomes are focused primarily on food purchases, this research focus the

analysis on the individual in the household who is the main responsible person for food shopping for the household.

The virtual accessibility measures (VAMs) impacting virtual activity engagement (VAG) frequency (as well as physical activity engagement (PAG) characteristics to be discussed later) in the analysis included (a) occupation type (managerial/professional jobs relative to other occupation types as a binary variable) that may play a role in determining virtual accessibility, and (b) internet availability within the home (a binary variable). While additional information related to ICT ownership/use such as the availability of laptop computers and smartphones would have been ideal as VAMs, these were not collected in the survey.

In terms of physical activity engagement (PAG), the number of OH weekly activity episodes (a count variable) and the average OH activity episode duration (a continuous variable) in each of the mandatory, maintenance, and discretionary activity purposes were computed. The reason for the focus on average activity episode duration, in addition to the count of weekly activity episodes, is to examine potential activity fragmentation caused by the virtual accessibility measures and the virtual accessibility itself. Within the category of PAG, the analysis also considered vehicle ownership (another count variable). While not an activity engagement variable per se, it represents a closely related travel-related variable that can be impacted by the latent accessibility constructs. Further, there is a reason to believe that vehicle ownership and PAG patterns are jointly decided on as a package, which implies that vehicle ownership needs to be treated as being an endogenous variable and not exogenous. Finally, to characterize activity scheduling in physical activity engagement, the average number of activity episodes per tour over the seven days of the week, and the average distance across all trips undertaken between successive pairs of activity episodes in a tour (that is, the average trip distance per tour) were also computed. A tour in this study

is defined as a home-based tour (a sojourn starting and ending at home). Both of these tour-related variables are continuous variables.

The physical accessibility measures (including BE measures, or more generally PAMs) impacting (virtual and physical) activity engagement frequency characteristics included respondent-provided non-auto (walk/transit) travel times from their homes to the closest railway station, hospital, and shopping center. The study also collected travel times to other services such as general practitioner, chemist, grocery, and post office. However, the vast majority of the sample have access to these services within very close proximity, contributing little to heterogeneity across individuals in these measures. Therefore, only travel time to the closest railway station, hospital, and shopping center are used in the model.

Finally, the data also allowed the model to use indicators for the physical accessibility latent construct. To be clear, the VAG and PAG variables discussed earlier also are effective indicators of the virtual and physical accessibility latent constructs, but this framework will characterize these activity engagement variables as outcomes (because these outcomes are of primary interest as the endogenous variables in the analytic framework). In terms of the indicators of the physical accessibility latent construct, the data provided information on the following four respondent-provided perception variables: (a) ease of commute without a car, (b) ease of shopping without car, (c) quality of bicycle lanes in the vicinity of the respondent's residence, and (d) quality of roadway pavement in the vicinity of the respondent's residence. All of these were collected in ordinal categories.

The entire conceptual and analytic framework is presented in Figure 1. The virtual accessibility measures (VAMs), physical accessibility measures (PAMs), and socio-demographics (age, gender, presence of children in the household, housing type and tenure status, full-time or part-time employment, and household income) impact the virtual

accessibility latent stochastic construct (VALSC) and the physical accessibility latent stochastic construct (PALSC). The double-headed arrow between the VALSC and PALSC represents correlation effects across the unobserved components of the two constructs. The identification of the PALSC is facilitated by the four indicators just discussed in the previous paragraph. The VALSC and PALSC, in turn, and along with the VAM, PAM, and socio-demographics, impact the virtual activity engagement (VAG) and physical activity engagement (PAG) patterns. Finally, this research tests endogenous effects between (and within) the VAG and PAG outcome variables after controlling for common unobserved effects (through the VALSC and PALSC). These endogenous effects must be strictly recursive for identification and logical consistency reasons (see Bhat, 2015). This is represented by arrows in each direction between VAG and PAG in Figure 1. The proposed model is a classic fit within Bhat's (2015) GHDM framework that enables the consideration of different types of indicator and outcome variables within a joint system. Details on the GHDM formulation, including the model set-up, sufficiency conditions for identification of model parameters, and the maximum approximate composite marginal likelihood (MACML) estimation approach for the formulation may be found in Bhat (2015).

2.3 SAMPLE DESCRIPTION

This section will present the statistics related to the VAM, PAM, socio-demographics, and the four indicators of the PALSC. The statistics associated with the VAG and PAG endogenous outcomes are described in detail since these variables are important for the study.

A summary of VAM and PAM statistics are shown in Table 1. Almost ninety percent of the individuals in the study have access to the Internet at home, showing a high

penetration of this technology. Another variable used to explain virtual accessibility is related to occupation type. Managerial and professional occupations comprise 9.5 percent of all occupations, while routine, manual, and intermediate occupations make up the remaining 90.5 percent of occupations. Table 1 also displays the PAM that are based on the travel time[1] to some key services such as railway stations, shopping centers, and hospitals.

Table 2 summarizes the socio-economic and demographic characteristics of this sample. Women constitute 69.8 percent of the sample because the sample was filtered by the "main food shopper" criterion. 11.9 percent of the sample are under the age of twenty-nine years, and 10.1 percent are over sixty years. As for the household structure, 34.6 percent of the sample individuals have children in their households. This sample exclusively focuses on workers, with full-time workers comprising 64.1 percent of the sample. Of these workers, 9.5 percent are self-employed. Most of the households (32.3 percent) live in a semi-detached house, while 29.6 percent live in a townhome, another 22.6 percent live in a detached house, and 15.1 percent live in an apartment/flat. Regarding household tenure status, 71.2 percent of the sample are owners, while 28.1 percent of them are tenants. Moreover, a large percentage of the sample (71.6 percent) are residents in a non-metropolitan area. The household income of the sample is almost evenly distributed across the three categories.

Four indicators of the PALSC are presented in Table 3. Most of the sample respondents felt it was "very easy" to shop (32.2 percent) and to commute (38.1 percent) without a car. More people felt it was "very difficult" to commute (25.7 percent) than to

1 The individuals are asked to report or estimate the travel time to these services on foot or by public transport using whichever is the quickest.

shop (13.7 percent) without a car. The majority of the people have a positive perception of pavement quality. The perception of bicycle lanes is not as positive as pavement facilities.

Table 4 provides the descriptive statistics on the VAG and PAG outcome variables. The first variable under the VAG category is the frequency of working at home. Even though the majority of the people telecommute only twice a year or less, there is still 8.1 percent of the sample that telecommutes weekly and 3.1% of the sample telecommutes more than three times a week. With respect to food-purchasing behavior, for a vast majority (93.1%) of individuals, the main purchase channel for food is to travel to the grocery store rather than do so online. This is also reflected in the distribution of the frequency of food delivery, with two-thirds of respondents purchasing food online and having it delivered to their respective homes less often than once a year. However, a non-significant percentage (8.7%) of respondents have food delivered to their house one or more times per week. Individuals have goods delivered more often than food, with 27.8 percent of respondents having goods delivered one or more times per week.

Among the PAG outcome variables (the lower row panel of Table 4), the mean of mandatory activity episodes is 3.86, which is reasonable given the level of telecommuting as well as individuals not working at all on some days of the week (due to vacation, illness, or other personal considerations). On average, the number of maintenance activity and discretionary activity episodes pursued during the survey week is 2.09 and 3.05, respectively, well below the number of mandatory activity episodes. The average duration of a work episode is about five hours, which is not inconsistent with the fact that a little more than a third of the respondents work only part-time. The corresponding average durations of maintenance and discretionary activity episodes are a little shy of an hour (about 57 minutes) and a little more than 1.5 hours, respectively. The average number of

vehicles in the household in the sample is 1.48, the average number of activity episodes per tour is 1.45, and the average trip distance in a tour is 9.5 kilometers.

Chapter 3: Results and Discussion

The final variable specification was obtained based on a systematic process of eliminating statistically insignificant variables, supplemented with a healthy dose of judgment and results from earlier studies. However, within this context, this study examined a host of different functional forms for variables, variable specifications, and directionalities of possible recursive effects among the many VAG and PAG outcomes, and obtained the specification that provided the best statistical fit, based on the non-nested model comparison measures discussed in Bhat (2015). In some cases, a variable is included in the specification even if it had only a marginally significant statistical effect, because of the intuitiveness of the effect of the variable and its potential to guide future research.

3.1 Relationship between Exogenous Variables and the Latent Accessibility Constructs

The results of the structural equation component of the model that relates the two latent accessibility constructs of VALSC and PALSC as a function of demographic attributes is presented in Table 5 and discussed below.

3.1.1 Virtual Accessibility Latent Stochastic Construct (VALSC)

The results in Table 5 suggest that individuals aged fifty or over have lower levels of virtual accessibility compared to younger individuals. While younger individuals (millennials, for example) grew up in an era of ubiquitous ICT availability, baby boomers had to adapt to such technological changes in adulthood. As pointed by Helsper and Enyon (2010), older individuals can learn to use digital devices as proficiently as younger individuals; however, it requires a greater effort, which can decrease the perception of

access to opportunities in the virtual environment. Moreover, older people tend to have a more conservative attitude toward technology (van Wee, 2016). The results in Table 5 also suggest that a higher household income (relative to a lower household income) is associated with a higher virtual accessibility, presumably because wealthier people can afford a larger number of technological devices and are usually the first individuals to have access to new technologies that are typically more expensive when first released. Indeed, multiple studies find this positive association between income level and technology use or technology-savviness (see, for example, Lavieri et al., 2017a and Liu and Yu, 2017).

Finally, two of the three variables representing the exogenous virtual accessibility measures (VAM) also have the expected effects. Workers pursuing managerial/professional jobs have a higher VALSC than those holding routine, manual and intermediate jobs. That workers in the former occupations tend to have more work flexibility than those in the latter is a finding well established in the literature (Singh et al., 2013). This flexibilization of the work activity for individuals in the managerial/professional profession may be associated with an enhanced potential for re-arrangement of other activities, thereby leading to a higher virtual accessibility level. The absence of internet connectivity in the household, as expected, reduces the individual's virtual accessibility, since the lack of connectivity is a direct constraint to accessing the digital world (Yu and Shaw, 2008, Tranos et al., 2013).

3.1.2 Physical Accessibility Latent Stochastic Construct (PALSC)

As discussed earlier, the indicators used for PALSC correspond to the ease of commuting and shopping without a car, along with the quality of bicycle lanes and roadway pavement in the vicinity of the respondent's residence. Therefore, the PALSC in this study

will be more reflective of an individual's perception of physical accessibility to opportunities by non-auto modes of travel.

Table 5 indicates that, among the socio-demographic variables, men and women with children in their households have a lower PALSC relative to individuals with no children in their households (a child is defined as an individual 15 years or under). This result may not only reflect the additional challenges in traveling with a child, but also be a consequence of time poverty effects in adults in the presence of children in a household. Bernardo et al. (2015) note that such time poverty effects lead to reduced physical mobility perceptions and even social exclusion. Interestingly though, the results also suggest that women appear to be less negatively impacted by the presence of children than men, in their perception of the reduced physical accessibility. This may be related to a social conditioning environment in which mothers are usually the ones responsible for transporting children (see Bhat et al., 2016a, Motte-Baumvol et al. 2017, and Scheiner and Holz-Rau 2017), and thus are more resilient to, and feel less dissuaded by mobility challenges. The perception of physical accessibility also seems to decrease with age, which is expected since older individuals tend to face increasing mobility limitations and constraints. Indeed, as developed countries face aging populations, potential social exclusion due to diminished physical accessibility for elders is a concern and is garnering increasing attention in both the transportation and psychology literature (see, for example, Walsh et al., 2016 and King, 2016).

Residence type and tenure status also present the expected results on PALSC. Living in a townhome or an apartment/flat is associated with higher urban densities around one's residence, and is therefore naturally associated with a higher perception of physical accessibility than when living in a detached or semi-detached single family housing unit. For similar reasons, renting a residence, rather than owning a residence, is also associated

with an increase in PALSC. Finally, the location-based measures (PAMs) indicate the expected negative effect of travel time (to important activity opportunity locations) on PALSC.

3.1.3 Correlation

The correlation between VALSC and PALSC is negative, but not statistically significant. This may be suggesting a canceling out of multiple unobserved effects, some that lead to a positive correlation between VALSC and PALSC, and some that lead to a negative correlation. Importantly, though, it is only through the accommodation of such a correlation that we can determine whether or not there is an unobserved correlation. In other contexts and situations, the result could be very well quite different.

3.2 Relationship between VAG/PAG and Exogenous Variables, VALSC, and PALSC

This section presents the discussion of the effects of exogenous variables, VALSC, and PALSC on the virtual accessibility engagement (VAG) outcomes and the physical accessibility engagement (PAG) outcomes. As a by-product, the results also obtain the loadings of the PALSC construct on the four ordinal indicators of ease of commute without a car, ease of shopping without a car, quality of bicycle lanes in the vicinity of the respondent's residence, and quality of roadway pavement in the vicinity of the respondent's residence. The results for these auxiliary components of the model system are not discussed in detail. Suffice it to say that the PALSC had the expected strong positive loading on each of these indicators.

3.2.1 Virtual Accessibility Engagement (VAG) Outcome Variable Results

Table 6 provides the results for the VAG outcomes. The dependent outcome variables are arranged column-wise, and the exogenous variables are arranged row-wise. The estimates provide the effects of the exogenous variables on the latent propensities underlying the VAG outcomes. Other endogenous outcome variables are also allowed to impact the ordinal frequency of VAG outcomes (frequency of work from home, frequency of food delivery, and frequency of goods delivery) and the binary VAG outcome (whether main food shopping method is online or not) in a strictly recursive fashion, and any such statistically significant effects are presented at the bottom of the table. In Table 6, these effects correspond to the total weekly work duration variable (which is effectively an endogenous PAG outcome variable obtained as the product of the number of work episodes and average OH work episode duration) and the number of vehicles owned by the respondent's household (another endogenous PAG outcome); note, however, that this does not mean that PAG outcomes are first decided on, and then VAG activities are determined in a sequential fashion; the modeling framework is a true joint model of both VAG and PAG outcomes because these outcomes are affected by the common underlying stochastic VALSC and PALSC constructs; any endogenous effects in Table 6 (and Table 7 later) represent strictly recursive effects after accommodating the jointness in decision-making among all the VAG and PAG outcomes.

The constants associated with all four VAG outcomes, as well as the thresholds between the frequency categories for the three ordinal VAG outcomes, do not have any substantive interpretations. In terms of variable effects on the frequency of working from home, women have a generally lower propensity to work from home than do men. In another relatively recent study, Singh et al. (2013) found that working women tend to be less likely to have the option of telecommuting, possibly because of the nature of their jobs

and/or the lower autonomy and bargaining power they still seem to wield in the marketplace. Working women with children are even less likely to work from home, perhaps some combination of feeling pressure to be in the workplace as a way of ensuring career prospects continue to be in place for them and/or a conscious choice to take a break away from child-caring and rearing. The results also indicate that part-time workers have a lower propensity to work from home than full-time workers. This result has been observed by many telecommuting studies in the recent past (for example, see Asgari et al., 2014). It is possible that, since part-time employees already work for limited hours, employers are less willing to allow such employees to work frequently from home. Alternatively, it is also possible that part-time employees view their employment partly as a socializing break from home and consciously avoid working from home. Self-employed workers, on the other hand, have a higher propensity to work at home than salaried employees. Many studies have reported that the choice of self-employment corresponds to a preference for independence (see, for example, Benz and Frey, 2008, Dawson et al., 2014). Also, self-employed workers are free to choose their workplace, and can work from home without constraints placed by supervisors or company rules. Not surprisingly, a higher VASLC implies a higher propensity to work from home, while a higher PASLC suggests a lower propensity.

The effects of the variables on the main food shopping channel (online or otherwise) reveal that women are more likely than men to indicate that their household's main method of food shopping is online. While the respondents were selected so that she or he was the main food shopper for the household, women continue to be largely responsible for preparing food in the household (Food Standards Agency, 2016). Given these responsibilities, and the fact that all respondents are workers, women may be more time-constrained, and so may shop more online as the main food purchasing method for

the household. Indeed, Jabs et al., (2007) reported that employed mothers experienced the greatest time scarcity. Further, the Office for National Statistics (UK) (ONS, 2016b) has also observed that women are more likely to buy food online. Income has the expected positive impact on the propensity that the main method for food shopping of a household is online (the net result is that the positive effect of income on online food shopping gets reinforced because income positively affects VALSC too, and VALSC also impacts the main food shopping channel, as discussed later). The positive income effect may be a combination of three considerations: (1) shopping for food online incurs delivery fees that increase the overall food expenditures, and higher income households are more easily able to absorb the higher costs; (2) shopping for food online allows for a better selection of products as well as the purchase of refined and hard-to-find items, which are usually expensive and only consumed by wealthier individuals; and (3) higher incomes may be associated with higher workloads and work hours, reducing the time budget for food purchase in person and encouraging online shopping. Cao et al. (2012), for example, find that higher household incomes are associated with increased frequencies of online searching and purchase but not in-store shopping. Living in a metropolitan area (relative to living in non-metropolitan areas) negatively impacts the propensity that the main food shopping method will be online, consistent with the presence of a variety of grocery shopping places in proximity to metro areas (though this effect is not statistically significant at the 95% confidence level). Not surprisingly, a higher VALSC leads to a higher inclination for online food shopping. A higher PALSC also increases the inclination for online food shopping. This is interesting, and appears to be counter-intuitive to the less statistically significant effect of the "metropolitan residence area" variable. However, there are two possible explanations for the result. The first is that this may be reflective of individuals who indeed shop online and then travel to the shop to pick the groceries up (as

opposed to having it delivered), as is an increasing trend (see, for example, Farag et. al., 2007, Lee et. al. 2017). It is possible that respondents were not clear in how to interpret the "main food shopping method being online" query. This possibility is reinforced by the fact that PALSC does not impact the "frequency of food deliveries", as discussed in the next paragraph. In any case, there is a clear implication that survey instruments eliciting VAG engagement need to be carefully designed to reduce ambiguity. The second explanation is that a higher PALSC may present opportunities for individuals to partake in more pleasurable (than maintenance activities) social-recreational activities in person (a finding confirmed later), leading an individual to make the participation in maintenance activities more efficient through online food shopping. More broadly, we should also acknowledge here that the consideration of PAMs (respondent-reported travel-related level-of-service variables to key activity opportunities) could be substantially improved in future research through geocoding surveys, even if in national surveys, so as to be able to use a richer set of BE attributes for the PAMs. Finally, under the category of recursive endogenous effects, the absence of vehicles in the household positively impacts the main online food shopping channel, which is intuitive as it is more convenient to have food delivered directly to the home rather than carrying the items in non-motorized modes or transit.

The variable effects corresponding to the frequency of food delivery suggest that women with children (relative to men with or without children, and women without children) have a higher frequency of food being delivered to their household. This result reinforces earlier results, and probably reflects the constrained time budget for food preparation on a daily basis by working mothers who usually are also responsible for child care and escorting activities (Motte-Baumvol et al., 2017). Additionally, the presence of a child can pose mobility constraints (Hernández et al., 2011). Age also has a significant effect on the frequency of food delivery. Older individuals (>40 years), relative to younger

individuals, have a lower propensity to order food online or by phone and have the food delivered to their homes. This result may reflect habitual effects (habituated to traveling to the supermarket for groceries), or the fact that older individuals face more barriers while shopping online, as noted by Lian and Yen (2014). Consistent with earlier results, higher income households appear to have a higher frequency to have food delivered relative to lower income households. As expected, VALSC has a positive impact on the propensity determining the frequency of food delivery, reinforcing the direct age and income effects just discussed and tempering the "female with children" effect (which also indirectly affect the frequency of food delivery through the VALSC factor). Finally, workers with long weekly work durations have a higher food delivery frequency, reflective of time constraints.

The results for the frequency of goods delivery are similar to the above, except for the absence of the direct "female with children", age and total work hours effects, though these variables do have an impact through the positive and expected VALSC effect. Living in a metropolitan area has a marginally positive impact on the frequency of goods delivery, though the same caveat holds that geocoding and better BE representation is needed in future research.

3.2.2 Physical Activity Engagement (PAG) Outcome Variable Results

Table 7 provides the results for the PAG outcomes (the number and the average duration of OH activity episodes in mandatory, maintenance, and discretionary activity purposes, the number of vehicles in the household, the average number of episodes chained per tour, and average trip distance within a tour). The dependent variables are again arranged column-wise.

For the count outcomes (the number of activity episodes by purpose and the number of vehicles in the household), the coefficients in Table 7 represent the effects of the row exogenous variables on the thresholds in the generalized ordered-response recasting of the count models (see Castro et al., 2012), and the effects of endogenous variables (strictly recursive effects if present) and the latent constructs on the underlying latent propensity of the count variable. Also, the constant coefficients for these count outcome variables do not have any substantive interpretation. For the coefficients for the other exogenous variables, a positive coefficient shifts all the thresholds toward the right of the count propensity scale, which has the effect of reducing the probability of the zero count (see Castro et al., 2012). On the other hand, a negative coefficient shifts all the thresholds to the left of the count propensity scale, which has the effect of increasing the probability of the zero count. In short, a positive coefficient increases the non-zero count, while a negative coefficient increases the zero count. In addition to the effects mentioned above, for each count variable, a general count structure against a simpler Poisson structure was tested. In the empirical analysis, the final model specifications for all the count outcomes collapsed to a Poisson generating process.

For the continuous variables (average episode durations in each of the three activity purposes, the average number of episodes chained per tour, and average trip distance within a tour), the coefficient effects are straightforward.

Mandatory activities: The results in Table 7 indicate that women with children are associated with fewer work episodes than women without children or men. On the other hand, men with children are associated with the highest number of work episodes. These results are consistent with the traditional roles in our society where mothers are heavily in charge of household responsibilities, while fathers are the main (income) providers (Fan, 2017, Gjerdingen and Center, 2005, and Bianch and Milkie, 2010). Employment-related

variables such as employment status (part-time versus full-time) and employment type (employee versus self-employed) are good indicators of spatiotemporal characteristics associated with the work activity. As expected, part-time workers tend to have fewer work episodes than full-time workers. There is not a significant effect on average work activity episode duration, which may be a consequence of full-time workers leaving the office for lunch and breaking the work activity in two episodes that can be equivalent to a part-time shift. This study interacted gender with employment status and observed that full-time working women have a longer average duration of mandatory activity episodes compared to part-time working women and full- or part-time working men. Together with the previous result, the implication is that full-time working women have less flexibility to fragment temporally their work activities compared to full-time working men. This diminished ability to fragment work may be associated with the nature of the jobs that women predominantly hold (ONS, 2013, ONS, 2016c, and ILO, 2016), or the elimination of the lunch break in exchange for leaving earlier to meet other household responsibilities (Johnson et al., 2013, and Fan, 2017). There is no statistically significant difference between self-employed individuals and employees in the number of work episodes, but self-employed individuals have a lower average duration of each work episode. As mentioned earlier, self-employed individuals are responsible for their own business and have higher levels of work flexibility. Workers living in metropolitan areas are likely to undertake fewer work episodes and work longer per episode, relative to their counterparts residing in non-metropolitan areas. For instance, data from the UK Office of National Statistics show that in London, in 2015, workers worked an average of 1.3 more hours per week than in the rest of the UK (ONS, 2016d).

Finally, virtual accessibility reduces both the number and the duration of work episodes, suggesting a substitution effect on out-of-home work episodes of ICT

accessibility. The suggestion also is that virtual accessibility fragments the work activity in both the time and space dimensions. The substitution between telecommuting and commuting, as well as work activity fragmentation due to ICT use, have frequently been observed earlier by studies that focus exclusively on work activities (see Alexander et al., 2010, and Hubers et al., 2015). The physical accessibility latent stochastic construct (PALSC) does not have statistically significant effects on the number or duration of work activity episodes; individuals are usually willing to overcome physical accessibility barriers to travel to work.

Maintenance activities: In Table 7, older individuals (fifty years of age and older) tend to have more non-zero shopping activity episodes (which is reinforced by the indirect effect of age through the VALSC variable), a finding supported by Zhou and Wang (2014). As observed earlier, the fifty-plus age segment is the age group with the lowest virtual accessibility and does not tend to shop online frequently, which may encourage in-store shopping. Additionally, older individuals tend to have more free time than their younger counterparts. Age, however, does not have a significant direct impact on average maintenance episode duration. Part-time working men are associated with more maintenance episodes, and part-time working women tend to have the longest duration per maintenance episode, the latter result not inconsistent with time availability considerations. Living in a metropolitan area is associated with an increase in physical maintenance activity engagement, in keeping with the negative effect of this variable earlier on the "main food shopping method being online".

VALSC negatively impacts the number of maintenance activities and duration, suggesting a substitution effect of virtual accessibility on physical maintenance activities (especially when combined with the positive effect of the VALSC variable on online food shopping and the frequency of food deliveries in Table 3). Curiously, the PALSC construct

also negatively impacts the number and duration of maintenance activities. While not immediately intuitive, this does support the possible notion introduced earlier that a higher PALSC raises the attractiveness of leisure/discretionary activity pursuits in person, thereby making people spend less time on maintenance activities by using online shopping as their primary channel for food shopping as well as reducing physical participation in OH shopping episodes and their durations. Also, notwithstanding the fact that the PALSC construct could be enhanced by having better BE attributes in the PAM set, the takeaway is that there is a need to consider both PALSC as well as VALSC jointly, as well as consider the comprehensive set of VAG and PAG participation in multiple activity purposes simultaneously, as this framework undertakes.

The effect of the endogenous outcome variables suggests that individuals who work from home one or more times in a week are less likely to pursue maintenance episodes at the grocery store, perhaps because such individuals are tech-savvy in general or have a general inclination to do things virtually. In addition, as the frequency of goods delivery increases, the number of visits to the grocery store reduces, a clear substitution effect between goods deliveries to the home and physical grocery visits. Individuals who work long hours have fewer maintenance activity episodes (consistent with the positive effect of this variable on the frequency of food delivery to the home).

Discretionary activities: The results for discretionary activity participation related to the presence of children need to be considered together with the effects related to the interaction of gender and the presence of children. Overall, the presence of children in the household is associated with fewer out-of-home discretionary activity episodes for both men and women, while also having the effect of increasing the duration of such episodes. Children do place responsibilities on parents, which may explain the fewer participations, though strategically chosen and scheduled so that the few participations can be longer in

duration. The negative effect of the presence of children is more pronounced for men, an effect that is further reinforced through the positive PALSC effect on discretionary activity participation (see later). Higher income increases the average duration of discretionary activities, but does not significantly affect the number of discretionary activities. Again, an income effect further reinforced through the effect of income on VALSC. Individuals who live in metropolitan areas appear to undertake fewer discretionary activity episodes, a finding that once again needs to be investigated more carefully with additional BE attributes in the future.

A higher virtual accessibility (VALSC) is associated with an increased number and duration of out-of-home leisure and social activity episodes. People with high virtual accessibility have expanded access to knowledge about recreational events. Kenyon (2010) found that interaction with the internet increases the in-person physical social interaction and Wang and Law (2007) also concluded that ICT use has a positive impact on time allocations to out-of-home recreational activities, suggesting a complementarity effect. The impact of PALSC on both the number and duration of OH discretionary activity episodes is positive, corroborating the notion that increased physical accessibility to activity opportunities tends to lead to increased engagement in OH leisure.

Auto ownership, episode chaining, and average trip distance results: Multi-worker households are more likely to own vehicles than single-worker households, consistent with the typically higher need of vehicles in households with multiple workers. The effect of residing in a metropolitan area (as opposed to non-metro areas) is precisely the opposite, again consistent with better transit facilities in metropolitan areas and the lower need for personal vehicles there. In this analysis, the virtual accessibility VALSC measure does not present a significant effect on vehicle ownership. However, it is possible that newer data sets with travel behavior data that already incorporate the use of carsharing

and ridesourcing services would provide evidence that virtual accessibility decreases vehicle ownership. For example, Lavieri et al., (2017a, 2017b) found that tech-savvy individuals are less likely to own vehicles. Higher levels of PALSC measures (based on accessibility by non-auto modes) are, as expected, associated with lower vehicle ownership levels.

Episode chaining behavior, in this analysis, is based on examining the average number of episodes per home-based tour. Part-time working women chain episodes more than full-time workers (men and women) and male part-time workers. As discussed earlier, women are usually responsible for most household shopping activities and child escorting, especially when employed part-time; therefore, it is not surprising that they perform more complex tours to fit all their responsibilities in their schedules (see Primerano et al., 2008 for a similar result). On the other hand, being self-employed and having a high household income level are associated with a lower episode chaining intensity. Virtual accessibility decreases episode chaining propensity, an indication of increased efficiency in travel through undertaking some errands virtually. The physical accessibility PALSC measure, on the other hand, has a strong negative effect on episode chaining, perhaps because of the ease of reaching activities independently from the household.

Finally, lower average trip distances within a tour are observed for individuals living in households with children. Children usually attend schools and have other activities located close to the residence, which may explain the above result. VALSC increases the average distance traveled per trip, suggesting that virtual access encourages individuals to expand their activity space, as also observed by Miranda-Moreno et al. (2012). Finally, the recursive endogenous effect associated with individuals who work at least once a week from home shows lower trip distances within a tour, or a more compact activity space.

3.3 SUMMARY OF RESULTS, IMPLICATIONS, AND MODEL FIT

The results above indicate the intricate and interwoven effects of virtual and physical accessibility (as characterized by VALSC and PALSC, which are themselves impacted by VAMs and PAMs) on both virtual and physical activity engagements (VAG and PAG) for multiple activity purposes. Particularly important to note is that each of the VALSC and PALSC impact multiple VAG and PAG measures simultaneously, immediately underscoring the notion that studies that consider VAG as exogenous variables in analyzing PAG measures are fraught with a fundamental endogeneity problem. In particular, based on the results, after controlling for observed factors, unobserved factors that increase the propensity to engage in VAG (the VAG includes frequency of work from home, and shopping for goods online) through the VALSC latent construct also impact all the PAG outcomes (except for the number of vehicles in the household, which is a long-term choice). For example, a person who has a dynamic, ebullient personality, and is tech-savvy too may be more likely to work from home and also participate intrinsically more and for longer durations in out-of-home (OH) discretionary pursuits. But, even without working from home, this person would be more pre-disposed to OH discretionary pursuits than her or his observationally equivalent peers. Not taking this into account can result in an incorrect conclusion that telecommuting, by itself, leads to an increase in discretionary activity participation. Indeed, in this analysis, when the model considered a simpler model ignoring the VALSC stochastic construct, there was a statistically significant (and "incorrect") positive influence of working from home on the frequency of discretionary activity episodes (which vanished when the VALSC construct is considered). Similarly, there are correlations engendered across the VAG and PAG outcomes solely through the PALSC measure, which, if ignored, can show up incorrectly as substitution or

complementarity effects across the many VAG and PAG outcomes as well as within the set of VAG and PAG outcomes.

The analysis includes multiple activity purposes at the same time, both virtually and physically (though the analysis would have been substantially enhanced if the data had had some measures related to online socializing and recreation, in addition to online maintenance activity participation). By considering multiple activity purposes, this framework is able to provide the rich interactions and interplay in activity engagement across both the virtual and real worlds, as already discussed. But it also enables us to see the "big picture" regarding overall activity accessibility afforded to specific segments of society. For example, the analysis indicates that women, relative to men, have a generally lower propensity (ability/opportunity) to work from home than do men, have less flexibility to fragment temporally their work activities (especially when working full-time), pursue maintenance activities for longer durations per episode and have more episode chaining as part of their daily and weekly activity patterns (when working part-time). Further, parents (fathers and mothers), in general, perceive lower physical accessibility levels and tend to pursue fewer discretionary activity episodes. The clear implication is that women and parents of small children suffer from both low physical accessibility as well as less flexibility to telecommute, appear to be time-poor, and tend to be socially excluded. These results suggest that, even if women have access to the internet, they may not be able to harness that access to increase their overall activity engagement experience. Perhaps there is a need to rigorously evaluate and continue to consider the implementation of work-friendly policies for women and parents in general. Policies that promote physical activity and or provide recreational opportunities in the workplace may also be beneficial in addressing time poverty and social exclusion considerations.

Thus far, the discussion has focused on the conceptual and empirical value of jointly considering virtual and physical activity pursuits of different activity purposes. The construction of the latent accessibility variables VALSC and PALSC, and their effects on multiple VAG and PAG outcome variables indicate that choices regarding participation and duration in virtual and physical pursuits are jointly determined as a package. This section is ended by examining if considering VAG and PAG as a package also improves statistical data fit. To do so, an independent heterogeneous data model (IHDM) was estimated, in which the model excluded the VALSC and PALSC constructs, but included the exogenous determinants of these latent constructs as explanatory variables. This is an independent model because of the absence of the unobserved correlation across the VAG and PAG outcomes (which is incorporated through the VALSC and PALSC in the GHDM model).

The GHDM and the IHDM models are not nested, but they may be compared using the composite likelihood information criterion (CLIC) (see Bhat et al., 2016b for details). The model that provides a higher value of CLIC is preferred. Another way to examine the performance of the two models is to compute the equivalent GHDM predictive household-level likelihood value and to compute the log-likelihood value across all respondents at convergence. The corresponding IHDM predictive log-likelihood value may also be computed. Then, one can compute the adjusted likelihood ratio index of each model with respect to the log-likelihood with only the constants. To test the performance of the two models statistically, the non-nested adjusted likelihood ratio test may be used (see Ben-Akiva and Lerman, 1985, page 172). This test determines if the adjusted likelihood ratio (ALR) indices of two non-nested models are significantly different. In particular, the test determines the probability that the difference in the ALR indices could have occurred by chance in the asymptotic limit. A small value of the probability of chance occurrence

indicates that the difference is statistically significant and that the model with the higher value of adjusted likelihood ratio index is to be preferred.

The composite marginal likelihoods of the GHDM and IHDM models came out to be -625,367.5 and -641,144.5. Other measures of fit are provided in Table 8. The GHDM shows a better goodness-of-fit on the basis of the CLIC statistic, the predictive likelihood value and the predictive adjusted likelihood ratio indices. The same result is obtained from the non-nested likelihood ratio statistic; the probability that the adjusted likelihood ratio index difference between the GHDM and the IHDM models could have occurred by chance is literally zero. In summary, the results clearly show that the GHDM model proposed here outperforms the IHDM model in data fit.

Chapter 4: Summary and Conclusion

This paper has proposed a modeling framework to study the effects of information and communication technologies (ICT) on activity and travel behavior based on physical and virtual accessibility. Virtual accessibility and physical accessibility were modeled as two latent variables (VALSC and PALSC) that are functions of observed socio-economic and demographic variables, virtual accessibility measures or VAMs (the proportion of work that can be undertaken at home, occupation type, and internet availability), and physical accessibility measures or PAMs (location-based objective accessibility measures). The latent variables and exogenous covariates were used to explain an array of activity and travel behaviors (number of activity episodes and activity episode duration by activity purpose, vehicle ownership, trip distances, and trip chaining). This paper utilized the generalized heterogeneous data model (GHDM) approach that allows for the joint modeling of multiple outcomes of mixed types, including count, continuous and ordinal variables. The data used was extracted from the 2011 and 2012 National Travel Survey in Great Britain, which collected information on individual sociodemographic characteristics, attitudes, stated frequency of remote purchases and work, as well as seven-day trip diaries.

This study provides several insightful results and observations. First, it identified that young wealthy individuals have the highest levels of virtual accessibility. Physical accessibility is also higher for younger individuals. The main takeaway here is that aging contributes to a decrease in both types of accessibility, suggesting that the older population segment needs special attention concerning accessibility policies. In particular, this segment of the population does not seem likely to benefit substantially from virtual accessibility as an overall accessibility enhancer, so actions to increase their physical accessibility directly or to educate them on how to take advantage of virtual accessibility

seem urgent. Note that although 10 percent of the sample contains individuals aged sixty or older and 35 percent of individuals with fifty or more years of age, the sample only included employed individuals. The accessibility situation of retired individuals may be even more critical and should be evaluated by specific studies.

Second, by focusing on a sample of individuals who are workers at the same time that they are the main food shoppers of their households, and by including interactions between gender, employment status, and presence of children, this study was able to analyze gendered social roles and the potential benefits that virtual accessibility can bring to different individuals. The results point to the busy and time-squeezed schedules of working mothers who seem to undertake major household and childcare responsibilities (the "second shift", as referred to by sociologist Hochschild, 1997), and who could benefit from increased virtual and physical accessibility through welfare policies that enhance spatiotemporal flexibility and encourage social inclusion. More generally, the ability to see the "forest" of activity engagement (without losing the "trees") can lead to more informed equity and welfare policies than when focusing only on the "trees".

Third, and related to the second point, the construction of the latent accessibility variables VALSC and PALSC, and their effects on multiple VAG and PAG outcome variables indicate that choices regarding participation and duration in virtual and physical pursuits of multiple activity purposes are jointly determined as a package. Considering a singular activity purpose for analysis (e.g., only shopping) or considering virtual pursuits to be exogenous in understanding ICT effects on physical pursuits can provide misinformed results. For example, the analysis has clearly shown that ignoring the jointness in decision-making would provide, in the context of this data, the incorrect result that telecommuting, by itself, increases OH discretionary activity episodes, while controlling for the joint package nature of these decisions through the VALSC stochastic

measure indicates that this is simply an artifact of the kind of people who are likely to telecommute as well as pursue a large number of OH discretionary episodes. While the final results may vary based on context (and the segment of the population studied), this study has provided a conceptual and analytic structure to be able to consider the jointness of PAG and VAG outcomes, which will lead to richer and fuller empirical studies in the future. Further, the structure is also able to consider episode planning dimensions (through such instruments as vehicle ownership and episode chaining/trip planning) as co-endogenous package variables in the analysis.

Finally, as an observation, and as with all research studies, there are limitations of the current study that suggest future directions. Most of these limitations are related to data availability. In particular, improved data on virtual accessibility measures or VAMs (data on smartphone ownership, perceptions related to virtual accessibility, and use of real time-information), physical accessibility measures or PAMs (geocoded data of activity locations and residences, which can be used to develop improved BE attributes), and VAG outcomes (diaries of virtual activities, including multi-tasking) are needed to harness the full potential of the proposed framework and to provide a more complete analysis of joint activity participation in both the virtual and physical worlds.

Tables and Figures

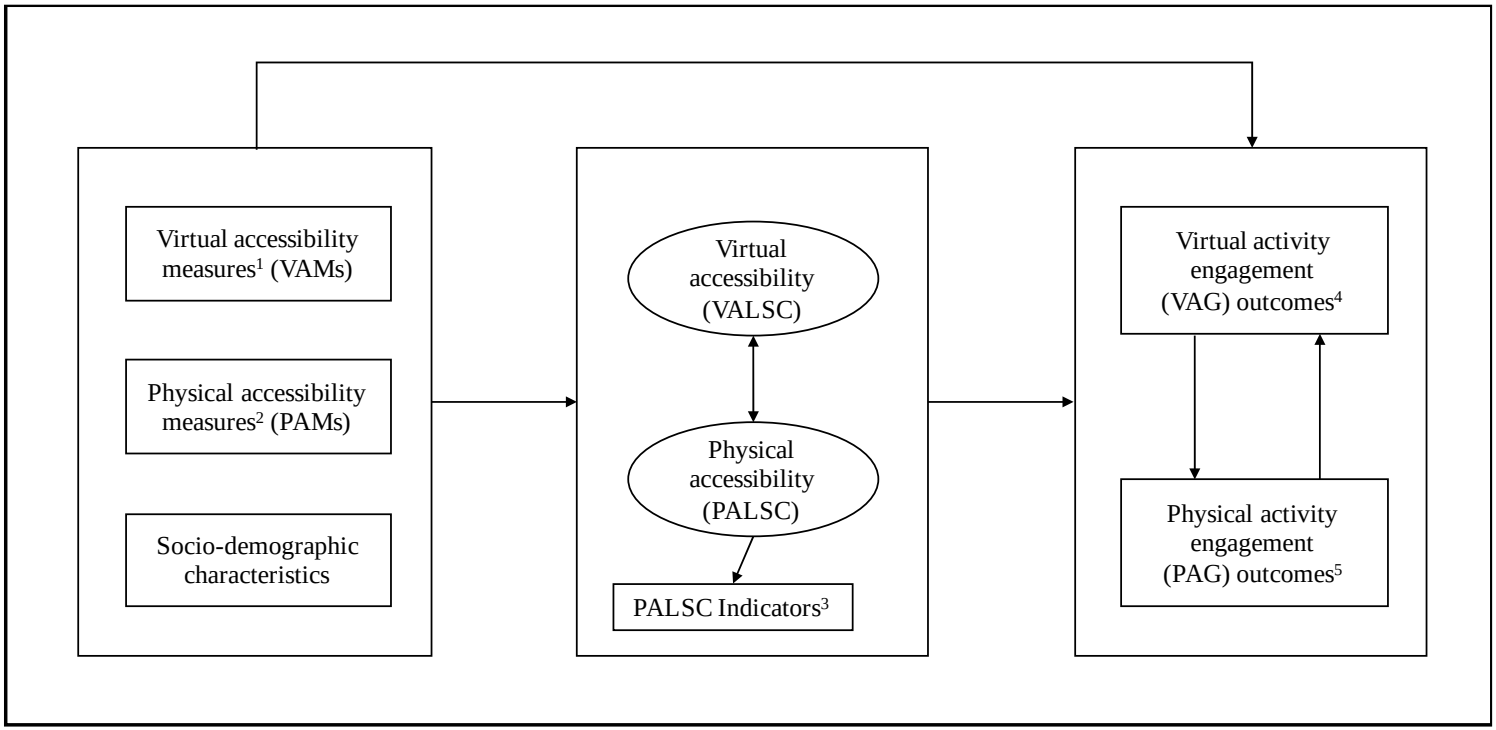

FIGURE 1 Conceptual and Analytic Framework

[1] The Virtual accessibility measures include occupation type, and internet availability.
[2] The Physical accessibility measures include travel time to the nearest hospital, travel time to the nearest shopping center, and travel time to the nearest rail station.
[3] The PALSC indicators include ease of commute without a car, ease of shopping without car, quality of bicycle lanes in the vicinity of the respondent's residence, and quality of roadway pavement in the vicinity of the respondent's residence.
[4] The VAG outcomes include frequency of work from home, whether main food shopping method is online or not, frequency of food delivery, and frequency of goods delivery.
[5]The PAG outcomes include the number and average duration of mandatory activity episodes, maintenance activity episodes, and discretionary activity episodes, the number of vehicles in the household, the average number of activity episodes per tour, and average trip distance per tour.

TABLE 1 Descriptive statistics of VAM and PAM variables

VAM		
Variable	Count	%
Internet Availability		
Yes	3,027	89.8
No	343	10.2
Occupation types		
Managerial and professional occupations	319	9.5
Routine, manual, intermediate occupations	3,051	90.5
PAM		
Variable	Count	%
Travel time to nearest rail station		
6 mins or less	235	7.0
7–13 mins	368	10.9
14–26 mins	888	26.4
27–43 mins	553	16.4
44 mins +	1,326	39.3
Travel time to nearest shopping center		
15 minutes or less	1,821	54.0
16 - 20 minutes	575	17.1
21 - 30 minutes	535	15.9
31 - 40 minutes	147	4.4
41 - 60 minutes	225	6.6
60 minutes +	68	2.0
Travel time to nearest hospital		
15 minutes or less	746	22.1
16 - 20 minutes	484	14.4
21 - 30 minutes	815	24.2
31 - 40 minutes	333	9.9
41 - 60 minutes	745	22.1
60 minutes +	247	7.3

TABLE 2 Socio-demographic characteristics

Variable	Count	%	Variable	Count	%
Gender			**Housing Type**		
Female	2,351	69.8	Detached	760	22.6
Male	1,019	30.2	Semi-detached	1,090	32.3
Age			Townhome	997	29.6
17–29 years old	400	11.9	Apartment/Flat	511	15.1
30–39 years old	786	23.2	Other	12	0.4
40–49 years old	996	29.6	**Household Tenure Status**		
50 - 59 years	849	25.2	Owns/buying	2,400	71.2
60 years +	339	10.1	Rents	948	28.1
Presence of Children			Other	22	0.7
Yes	1,168	34.6	**Residential Location**		
No	2,202	65.4	Metropolitan	956	28.4
Employment Status			Non-metropolitan	2414	71.6
Full Time	2,159	64.1	**Residential Location**		
Part Time	1,211	35.9	Less than £25,000	1,023	30.4
Employment Type			£25,000 to £49,999	1,241	36.8
Self-employed	319	9.5	£50,000 and over	1,106	32.8
Employee	3,051	90.5			

TABLE 3 Descriptive statistics of the indicators of PALSAC

Variable	Count	%
Ease to commute without car		
Very difficult	865	25.7
Quite difficult	501	14.9
Neither easy nor difficult	140	4.2
Fairly easy	581	17.2
Very easy	1,283	38.0
Ease to shop without car		
Very difficult	460	13.6
Quite difficult	615	18.2
Neither easy nor difficult	262	7.8
Fairly easy	946	28.1
Very easy	1,087	32.3
Rating of quality of pavement		
Quite poor	532	15.8
Fairly poor	555	16.5
Neither poor/good	531	15.8
Fairly good	1,528	45.3
Quite good	224	6.6
Rating of quality of bicycle lanes		
Quite poor	1,171	34.7
Fairly poor	460	13.6
Neither poor/good	758	22.5
Fairly good	764	22.7
Quite good	217	6.5

TABLE 4 Virtual Activity Engagement (VAG) and Physical Activity Engagement (PAG) Outcome Variables

VAG outcome variables

Variable	Count	%	Variable	Count	%
Freq. of working at home			**Frequency of food delivery**		
Twice a year or less	2,720	80.7	Less than once per year	2,244	66.6
More than twice a year	219	6.5	Less than once per month	490	14.5
Monthly	159	4.7	Less than once per week	342	10.2
1–2 per week	168	5.0	One or more times per week	294	8.7
3 or more times a week	104	3.1	**Frequency of goods delivery**		
Main food purchase method is online			Twice a year or less	328	9.7
No	3,137	93.1	More than twice a year	641	19.0
Yes	233	6.9	1–2 times per month	963	28.5
			More than twice per month	505	15.0
			One or more times per week	936	27.8

PAG outcome variables

Variables	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Number of mandatory episodes	0	39	3.86	3.18
Number of maintenance episodes (shopping)	0	14	2.09	1.81
Number of discretionary episodes	0	35	3.05	3.18
Average duration of mandatory episodes (minutes)	0	881	306.51	207.18
Average duration of maintenance (shopping) episodes (minutes)	0	460	56.62	58.61
Average duration of discretionary episodes (minutes)	0	920	96.13	99.49
Number of vehicle Ownership	0	7	1.48	0.943
Average number of episodes in a tour (excluding work-based sub-tours)	1	39	1.45	1.23
Average trip distance (kilometers)	0.30	270	9.51	11.68

TABLE 5 Structural Equations Model Results

Virtual Accessibility Latent Stochastic Construct (VALSC)		
Socio-demographic variables	**Coefficient**	**T-stat**
Age (base: 17 to 49 years old)		
50 or more years old	-0.081	-1.94
Household income (base: less than £50,000)		
£50,000 and over	0.289	1.96
Virtual accessibility measures (VAM)	**Coefficient**	**T-stat**
Occupation type (base: routine, manual, intermediate occupations)		
Managerial and professional jobs	1.477	4.30
Internet availability (base: does not have Internet connection at home)		
Has Internet connection at home	1.019	5.98
Physical Accessibility Latent Stochastic Construct (PALSC)		
Socio-demographic variables	**Coefficient**	**T-stat**
Gender and presence of children (base: male and female without children)		
Female with children	-0.117	1.95
Male with children	-0.388	1.96
Age (base: 17 to 29 years old)		
30 to 39 years old	-0.242	-1.99
40 or more years old	-0.408	-2.04
House type (base: detached or semi-detached)		
Townhome	0.254	4.57
Apartment/flat	0.885	2.11
Household tenure status (base: owner/buying or other)		
Renter	0.372	2.80
Physical accessibility measures	**Coefficient**	**T-stat**
Travel time to the nearest hospital (hours)	-0.905	-3.50
Travel time to the nearest shopping center (hours)	-1.216	-6.33
Travel time to the nearest rail station (hours)	-0.721	-4.24
Correlation between VALSC and PALSC	**-0.010**	**-0.075**

TABLE 6 Virtual Accessibility Engagement (VAG) Outcome Variable Results

	Freq. work from home		Main food shopping method is online		Freq. food delivery		Freq. goods delivery	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Constants	-2.880	-22.74	-2.007	-22.87	-0.863	-13.607	1.222	42.01
Thresholds for frequency indicators								
Less than once a month & less than once a week	0.365	12.41	N/A	N/A	0.488	20.10	0.789	29.45
Less than once a week & weekly	0.756	15.21			0.988	25.93	1.973	58.46
Gender (base: male)								
Female	-0.381	-1.99	0.405	6.73				
Gender and presence of children								
Female with children	-0.041	-1.85			0.296	4.19		
Age (base: 17 to 39 years old)								
40 to 49					-0.256	-4.22		
50 or more					-0.256	-4.22		
Employment status (base: full-time)								
Part-time	-0.080	-1.90						
Employment type (base: employee)								
Self-employed	1.244	7.39						
Household income (base: less than £50,000)								
£50,000 and over			0.486	8.77	0.318	5.19	0.285	6.87
Residential location (base: non-metropolitan area)								
Metropolitan area			-0.157	-1.98			0.041	1.86
Latent constructs								
VALSC	0.876	8.31	0.195	13.79	0.196	8.67	0.010	1.80
PALSC	-0.087	-1.81	0.224	10.19				
Recursive Endogenous Effects								
Total work duration (hours) per week (/10)	1.244	7.39			0.017	1.81		
Vehicle ownership (zero vehicles; base is >1)			0.331	6.14	0.229	2.31	0.322	4.53

TABLE 7 Physical Activity Engagement (PAG) Outcome Variable Results

Independent variables	Activity engagement and travel behavior																	
	Number of mandatory activity episodes		Average duration of mandatory activity episodes		Number of maintenance activity episodes		Average duration of maintenance activity episodes		Number of discretionary activity episodes		Average duration of discretionary activity episodes		Number of vehicles in the household		Average number of episodes per tour		Average trip distance	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Constants	1.724	23.46	1.825	13.69	-2.943	-8.88	-1.286	-5.70	0.203	1.56	-1.202	-2.91	-1.689	-9.88	-3.293	-5.35	1.366	3.36
Presence of children in the household (base: no children)																		
Children											0.054	1.78			-0.101	-1.85	-0.252	-1.98
Gender and presence of children (base: male or female without children)																		
Male with children	0.079	1.76							-0.490	-1.99								
Female with children	-0.078	-1.78							-0.114	-1.93								
Age (base: 17 to 49 years old)																		
50 or more					0.283	1.93												
Employment status (base: full-time)																		
Part-time	-0.346	-1.99																
Gender and employment (base: full-time male)																		
Part-time male					0.628	2.71												
Part-time female							0.279	1.87							0.197	1.94		
Full-time female			0.190	1.86														
Employment type (base: employee)																		
Self-employed			-0.494	-1.75											-0.277	-1.84		
Household income (base: less than £25,000)																		
£25,000 to £49,999																		
£50,000 and over											0.399	1.98			-0.150	-2.02		
Household workers (Base: single worker)																		
Multi-worker													0.953	20.14				

TABLE 7 (Continued)

Residential location (base: non-metropolitan area)																		
Metropolitan area	-0.130	-2.14	0.110	2.31	0.784	4.20	0.823	2.89	-0.172	-1.95			-0.046	-1.87				
Latent constructs																		
VALSC	-0.238	-15.75	-0.160	-1.98	-0.605	-4.69	-0.345	-2.50	0.872	14.40	0.424	4.81			-0.566	-7.63	0.676	3.14
PALSC					-2.826	-15.81	-1.127	-9.09	0.145	1.84	0.126	1.92	-0.914	-16.61	-2.304	-30.80		
Recursive endogenous effects																		
Works from home one or more times in a week					-0.452	-1.95											-0.796	3.33
Goods delivered one or more times per week					-0.480	-2.74												
Total work duration per week (/10)					-0.231	-3.52	-0.236	-2.72										

TABLE 8 Data Fit Measures

Summary Statistics	Model	
	GHDM	**IHDM**
Composite Marginal log-likelihood value at convergence	-625,367.5	-641,144.5
Composite Likelihood Information Criterion (CLIC)	-626,698.7	-642,852.1
Log-likelihood at constants	-41,086.0	
Predictive log-likelihood at convergence	-37,068.9	-37,945.2
Number of parameters	118	187
Number of observations	3370	3370
Predictive adjusted likelihood ratio index	0.095	0.071
Non-nested adjusted likelihood ratio test between the GHDM and IHDM	$\Phi[-43.19]<<0.0001$	

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