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ORIGINAL PAPER

Two traditional questions on the relationships between telecommuting, job and residential location, and household travel: revisited using a path analysis

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Abstract This study aims to provide empirical evidence for two traditional research questions in the field of telecommuting studies: (1) Does telecommuting promotes dispersion of urban space? (2) Does telecommuting substitute for household travel? Although these causality issues have received great deal of attention, no multivariate analysis approaches exist. Using the 2006 household travel survey data from the Seoul Metropolitan Area, this study adopts a path analysis to discover the complex relationships between telecommuting, residential/job locations, and household travel. First, the path analysis shows that rather than telecommuting serving as the determinant of location choice, job locations determine the choice to telecommute. Hence, secondary impacts of telecommuting on travel may not occur with location changes as the medium. Second, the analysis also shows that the household head's telecommuting has a positive influence on his/her non-commuting travel in both the person kilometers traveled (PKT) and vehicle kilometers traveled (VKT) models and on household members' travel in VKT models. Moreover, the VKT model suggests that the household head's non-commuting travel has a negative impact on the household members' travel. These results indicate that although telecommuting reduces commute travel, this may be offset by other travel demand within the household, owing to exhaustion of the limited travel budget. Thus, planners and policymakers must consider these impacts when evaluating the benefits and costs of telecommuting as an urban management policy.

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1 Introduction

The high social expectations of telecommuting have led to numerous studies across a number of planning research fields. The studies on the impacts of telecommuting generally fall into two main research questions, respectively, associated with urban and transportation planning: (1) whether or not telecommuting promotes urban dissolution [so-called telesprawl, (Nilles 1991)], and (2) whether or not telecommuting substitutes for household travel. If telecommuting encourages residential relocation to outlying areas, the overall effects of telecommuting on travel will be the sum of the direct effects and the indirect effects with the residential location as the medium. Thus, these two issues are interrelated, as are urban and transportation studies.

To address the first question, we need to verify whether telecommuting precedes outlying living or vice versa. However, conflicting arguments exist between theoretical studies (numerical simulations), which support the telesprawl idea (Lund and Mokhtarian 1994; Rhee 2009) and empirical studies, which repute the idea (Ellen and Hempstead 2002; Moos and Skaburskis 2007, 2010). Similarly, previous studies have failed to take into account telecommuters' job location (Ellen and Hempstead 2002; Moos and Skaburskis 2010), even though residential location choice is highly relevant to their job location (van Ommeren et al. 2000).

Regarding the second question, we need to examine the impacts of telecommuting on both workers' own travel and those of household members. In addition, to measure the secondary effects of telecommuting, we need to explore how the changes in travel behavior of each household member caused by telecommuting affect one another, as one's travel can change others' travel when this aspect of the household budget is constant. However, existing empirical studies show conflicting findings according to their methodological approaches. Quasi-experimental studies that use data from a few small-sample pilot projects generally argue that telecommuting substitutes household travel (Lari 2012; Mokhtarian et al. 2004; Pendyala et al. 1991); conversely, econometric studies using general travel survey data from a large sample size covering metropolitan areas suggest that they complement each other (Kim and Ahn 2010; Kim et al. 2015; Zhu 2012). Moreover, both types of studies mainly paid attention to the telecommuter's travel, without sufficiently examining interactions within household members and across travel purposes.

Finally, in order to judge whether or not telecommuting can substitute household travel, the secondary effects of residential relocation on travel also need to be investigated. Even though theoretical studies predict that changes in residential location owing to the opportunity to telecommute may lead to additional other travel (Lund and Mokhtarian 1994), no empirical study exists that proves this secondary effect. As such, there is still no clear conclusion regarding the causal relationships between telecommuting and residential/job locations.

The two research questions above are interrelated and highly relevant to issues of causality; thus, it is necessary to establish a model that simultaneously considers these aspects, as Zhu (2012) and Kim et al. (2015) argued. Against this backdrop, by applying path analysis to data from the 2006 household travel survey (HTS) data of Seoul Metropolitan Area (SMA), this study aims to examine (1) the causal relationships between telecommuting and residential/job locations as well as the secondary effects of residential relocation, and (2) the impacts of the household head's telecommuting on his/her own travel and household members' travel as well as the interactions between them to expand the understanding of the aforementioned two traditional discussions. By applying this new approach, this study also aims to reconfirm the findings of two companion papers (Kim et al. 2012, 2015).[1] Although this cross-sectional approach cannot confirmatively assign the causality issues, the series of path analyses based on the previous literatures can contribute to a basic understanding of the complex causal relationships between key variables.

2 Literature review

2.1 The relationship between telecommuting and residential location

Discussions on the relationship between telecommuting and residential location originate in futurologists' concerns about urban dissolution (Mitchell 1995; Webber 1968). They argued that the development of *information and communications technology* (ICT) would lead to death of distance, thereby eliminating the need for urban existence (McLuhan 1967).

Futurologists have more recently presented a similar view regarding the impact of *telecommuting* (a by-product of ICT development) on urban space. They have argued that telecommuting would weaken the need for the separation between residential and job locations, which have been sustained since the Industrial Revolution, with result that urban space would rapidly be dissolved (Janelle 1995; McLuhan 1995; Mitchell 1995). In other words, inner city areas would gradually lose their historical authority, while the suburbs would be transformed into "24-hour electronic neighborhoods" filled with energy and vitality, even during traditional daytime working hours (Mitchell 1999). Consequently, this would lead to "telesprawl," in which the telecommuters' residential locations would spread out into the suburbs, with less need for accessibility to the central business district.

This foresight has been supported by neoclassical urban economics theorists (Alonso 1964; Fujita 1989). According to their classical utility maximization theory and budget-constraint assumptions, households' residential location choice was determined by the trade-off between the consideration of job accessibility (commuting costs) and housing space (housing costs), and the sum of these choices determined the urban form. In short, if commuting costs are reduced by telecommuting, the housing options for residential location will increase, thereby encouraging relocation toward outlying areas. Based on this theory, numerical simulations were conducted on virtual urban models with the assumption that there would be telecommuting, which gen-

[1] These papers are based on the same survey data and geographical boundaries with this paper. But, the specific data set and methodologies applied are different from one another according to their different research questions.

erally showed that model cities in the long term were more spread out compared to reference models (Lund and Mokhtarian 1994; Rhee 2009; Shen 2000). Furthermore, Tayyaran and Khan (2007) have analyzed the preferred residential locations of office workers in Ottawa, Canada, and found that telecommuting was a highly significant factor in choosing a suburban residential location, which would generate a dispersion of land development patterns.

Conversely, the findings of most empirical studies have shown that telecommuting has not necessarily encouraged residential dispersion. Several studies have shown that telecommuters tend to live farther away from their workplaces compared to regular commuters and that telecommuting improves flexibility in choosing a residential location (Mokhtarian et al. 1995, 2004; Muhammad et al. 2007; Nilles 1991; Ory and Mokhtarian 2006; Zhu 2013). However, these results should not be considered as conclusive evidence that residential areas have dispersed, because long-distance commuting does not necessarily mean living in a suburban location in the contemporary multipolar urban structure (Kim et al. 2012). In addition, some studies have rejected the telesprawl hypothesis. Firstly, Nilles (1991) analyzed the patterns of residential relocations over a 2-year period (1988–1990) during the well-known State of California Telecommuting Pilot Project, which involved more than 150 participants. Results showed that the average commuting distance of telecommuters was longer than for non-telecommuters, and this gap increased during the time of the pilot project; however, the average relocation distance of telecommuting households did not show a significant difference from that of the control group.

Cross-sectional analyses using large samples have yielded similar results. Ellen and Hempstead (2002) discovered that there was no significant relationship between telecommuting and suburban location; rather, self-employed telecommuters tended to be located near the urban center. Moos and Skaburskis (2007) also showed that the residential location patterns of telecommuters followed Hoyt's sectoral form, being mostly concentrated in central (and high-income) urban areas. Muhammad et al. (2007) argued the impact of telecommuting on location choice might vary according to the life-cycle stage of households, most important factor in the location choice.

Studies focusing on the SMA also showed consistent results. Using 2005 census data in Korea, Kim and Ahn (2011) suggested that over a 5-year period, telecommuter households had a lower rate of residential relocation than did commuting households, and the direction for residential relocation was more center-oriented. Kim et al. (2012) also argued that although the residential location of telecommuters was more suburb-oriented, this tendency was primarily due to the fact that jobs allowing telecommuting were concentrated in the suburban center, thereby determining telecommuters' residential location.

Moreover, some studies have argued that telecommuting does not cause residential suburbanization, but rather that outlying residential location causes the decision to telecommute. Ory and Mokhtarian (2006) analyzed the 10-year residential relocation history of 216 workers in California and concluded that workers who moved farther away from their workplaces or were living in the suburbs chose telecommuting as a means to avoid a long commute. Moos and Skaburskis (2010) also argued that telecommuters' residential location preceded the decision to telecommute although they were more likely to live in peripheral areas.

These arguments have been supported by the evidence that the location-dependent factors—such as commuting distance and quality of physical and ICT environment—have been closely related to worker's telecommuting choice and frequency (Helminen and Ristimaki 2007; Nagurney et al. 2003; Sener and Bhat 2011; Tang et al. 2008; Zhou et al. 2009). This implies that the relationship between telecommuting and residential location is not a one-way influential relationship; rather, it goes in both directions.

As discussed so far, significant limitations remain in accepting either argument regarding the causal relations between telecommuting and residential location, requiring further empirical studies. In particular, previous studies have rarely considered telecommuter's job location, affecting residential location. Because the industries, businesses, occupations, and job types in which telecommuting is possible are still limited, the distribution of jobs allowing telecommuting may be distinctive from traditional jobs. Thus, this paper considers the job location of telecommuters, as argued by Ellen and Hempstead (2002) and Kim et al. (2012).

2.2 The relationship between telecommuting and household travel

Futurologists and policymakers optimistically anticipated that telecommuting would not only reduce travel demand but would also alleviate congestion during peak hours, reducing transportation energy consumption and decreasing air pollution (Mokhtarian 1991; Mokhtarian et al. 1995; Salomon 1986). However, this prospect was initially quite radical (Graham 1997), and the effect of telecommuting has not been as great as expected (Mokhtarian 1998). In this context, the key issue is whether telecommuting can substitute for travel, or whether it instead generates more travel.

Most studies that have focused on telecommuting pilot projects have applied a quasi-experimental approach and concluded that telecommuting substitutes for travel. Koenig et al. (1996), Mokhtarian et al. (2004), Nilles (1991, 1996), and Pendyala et al. (1991) all researched the State of California Telecommuting Pilot Project, and further studies have been done on telecommuters in other US and European cities (Glogger et al. 2008; Hamer et al. 1991; Hopkinson et al. 2002; James 2004; Lari 2012). These studies share the common result that telecommuting partially substitutes for *commuting*. In particular, Mokhtarian et al. (2004) and Nilles (1991) stated that although the commuting distance might increase due to the change in the residential location, the frequency of telecommuting was enough to offset this increase; as a result, the total commuting distance decreased.

Moreover, these studies revealed the additional reduction effect on telecommuters' non-commuting travel and their household members' travel. First, the distance, time, and frequency of work-related but non-commuting travel for telecommuters, as well as non-work travel decreased after telecommuting was adopted (Mokhtarian et al. 2004; De Graaff 2004; Hamer et al. 1991). Mokhtarian et al. (1995) and Pendyala et al. (1991) stated that travel destinations were concentrated nearby to their residential location. This effect was also found on non-telecommuting days and in the travel of household members; for example, Pendyala et al. (1991) argued that telecommuters and their household members typically sought close travel destinations from their home. Hamer et al. (1991), Lari (2012), and Pendyala et al. (1991) also proved that the travel of both telecommuters and their household members decreased during peak hours. Finally, in terms of changes in travel mode, telecommuters' VKT and frequency decreased (Hamer et al. 1991; Pendyala et al. 1991).

Later studies that have used large-scale, cross-sectional travel survey data, however, have shown contrary findings. Kim and Ahn (2010) focused on the SMA in Korea and revealed a positive association between telecommuting and daily PKT by travel purpose (excluding commuting), asserting that this relationship is more apparent in the case of household members. Zhu (2012) argued that even though demand for commuting may decrease somewhat (owing to telecommuting), the demand for other travel would supplement it due to a constant travel budget. Moreover, Zhu (2012) argued that because telecommuters had longer commuting distances, telecommuting and travel had a complementary rather than substitutionary relationship.

Some studies using large-scale, cross-sectional travel survey data adopted multivariate analysis approaches to analyze the intra-household interactions caused by telecommuting. Using a path analysis, Golob (1996) suggested that because the *time budget* for private car travel was constant within a household, if a worker used the household's car less often, other members would use that car more. Kim et al. (2015) applied seemingly unrelated regression to consider interrelatedness between all travel types that might occur within a household, and showed that if household head telecommuted, the non-work travel for him/her, as well as for other household members, might increase. In contrast, Zhu (2013) revealed that telecommuting of one worker did not increase the commuting distance of the other worker.

In short, whereas it is uncontroversial to state that telecommuting may either partially or wholly substitute for commuting, conflicting opinions exist on its effect on telecommuters' non-commuting travel and household members' travel. These conflicting opinions mostly stem from distinctive data and methodology they applied: quasi-experiments based on few pilot projects or regression approaches using large-scale travel survey data. Firstly, both approaches vary in terms of how they use a control group. Whereas the former only controlled for the employment type of the worker (i.e., telecommuter or general commuter) by conducting a simple comparison analysis, the latter controlled for much more factors that influence household travel, including the employment type, by applying a multiple regression approach. In contrast, whereas some of the former applied a before-and-after control group design, the latter usually covered a one-off survey. Hence, the latter is limited in that it cannot provide any implication on causality issues. Secondly, both have difference in their generalizability. The former usually adopted a data from a few pilot projects with small sample size and limited study areas, thus limiting the generalizability of their findings (Kim et al. 2015). On the other hand, the latter used a large-scale travel survey data covering metropolitan areas; therefore, they are free of generalization problems. Lastly, both used different definitions on a telecommuter. While the former studied the *real* telecommuting participants, the latter mainly focused on the *likely* telecommuters based on their data and operational definition. In fact, the former has higher accuracy in defining a telecommuter. Yet, due to its biased respondents (normally, public servants) who exactly understood the main purpose of telecommuting pilot programs, it may lead intentional falsification (underreporting) problems (Mokhtarian et al. 1995).

The fact that both types of empirical approaches suggested in Sect. 2.1. do not show conflicting results each other also supports this possibility.

Both approaches have strengths and weaknesses, and we cannot conclude which is more proper because previous studies have never used perfect data that have both strengths. The crucial point to note here is that this paper only applies the *latter* approach. Accordingly, this paper intends to provide new evidence to the body of the literature that mainly uses the latter approach, and overcome their limitations on the causality issues while using cross-sectional data. Although several studies have applied a multivariate analysis approach to overcome this limitation, they have failed to examine any direct endogenous interactions between household members' travel.

Against this backdrop, this study applies a path analysis to demonstrate more compelling solutions to the remaining research questions and to minimize the aforementioned methodological limitations. We seek to provide persuasive empirical grounds for understanding the causal relationships between telecommuting and residential location, as well as intra-household interactions in household travel arising from telecommuting. Section 3 explains the specific research methodologies related to the path analysis.

3 Empirical setting

3.1 Data and study area

Consistent with the Kim et al. (2012), this paper uses the 2006 SMA HTS data, which were gathered from a self-administered survey of a random sample of 1 % of all households living in the SMA and its influence areas. Within the sample, we focus on 15,458 households (including 385 telecommuter households) that have household head engaged as a white-collar worker. These large sample data covering a major metropolitan area makes it possible to (at least partially) overcome the limitations of previous studies.

Generally, the SMA refers to the broad area covering Seoul Metropolitan City, Incheon Metropolitan City, and Gyeonggi Province; however, the HTS also covers the influence areas of the SMA, which includes some parts of Gangwon, Chungbuk, and Chungnam provinces (Kim et al. 2015). Therefore, for convenience, this study refers to the SMA and its influence areas as "the SMA." The SMA, which occupies only 22 % of the country's total area, accommodates 23.5 million residents as of 2010 and is the largest metropolitan area by population in the country and the world's fourth largest metropolitan areas (Demographia 2012). In addition, compared to the previous study areas, the SMA has quite higher housing cost and lower commuting cost (Kim et al. 2012). As shown in James (2004), this distinctive urban context may lead to different telecommuting impacts from the previous study areas.

3.2 Conceptual frameworks of path models

To obtain answers to the aforementioned research questions, two path models with binary (telecommuting variable), continuous (location variables), and censored (travel variables) endogenous variables are applied. Despite our cross-sectional data, the path analysis and the series of hypothetical modeling processes contribute to an understanding of the causal relationships between these variables in real situations, because it was developed to structuralize and verify hypothetical causal relationships (Wolfle 2003). The conceptual frameworks of the path models, applied in Sects. 4 and 5, are as follows.

Model 1: Relationships between telecommuting, residential location, and job location The first path model (Sect. 4) aims to promote the basic knowledge on the causal relationships between telecommuting, residential location, and job location variables. In this model, the household travel variable (PKT or VKT excluding household head's commuting per household member on the survey day) is applied as an ultimate dependent variable,[2] with the three key variables applied differently. If we do not consider reciprocal paths among them,[3] six sequential combinations will be possible. However, to improve the simplicity and fit of the models, the structure was simplified to assume that two out of the three variables were simultaneously determined in advance in comparison with the other variable. As such, the hypothetical relationships were reduced into the following two models: theoretical and rival.

1. Theoretical hypothesis model (THM): This model tests the relationships argued by previous empirical studies (Kim et al. 2012; Moos and Skaburskis 2010; Ory and Mokhtarian 2006). It assumes that jobs allowing for telecommuting tend to be located in outlying areas; thus, employees living in those areas are more likely to choose telecommuting, rather than telecommuting affecting household's locational choices. Although the sequential order of the job and residential locations should also be investigated, we assume that those exogenous variables are simultaneously predetermined.
2. Rival hypothesis model (RHM): The second model tests the rival hypothesis suggested by early futurologists and theorists. It assumes that the household head's telecommuting and job location were exogenous variables simultaneously determined in advance and that they are determinants of the household's residential location.

A further alternative model that assumes household head's telecommuting and residential location are determined prior to his/her job location is also possible. However, this paper excludes this alternative because this assumption goes against the traditional urban economics theory, which argues that job location precedes residential location.[4]

Model 2: Relationships between household head's telecommuting, household head's travel, and household members' travel The second path model (Sect. 5) aims to determine the impact of the household head's telecommuting on the household head's

[2] We also tested simpler models that excluded the travel variables, but we decided to apply the current structure as the models were saturated.

[3] Due to analytical errors, we did not considered reciprocal paths in Sect. 4. However, such analytical errors were not found in Sect. 5.

[4] We also analyzed this alternative model, but its goodness of fit was found to be remarkably lower than that of the other models.

non-commuting travel as well as household members' travel, and the interactions between them. Like a Model 1, Model 2 also includes two sub-models: PKT and VKT models. While PKT represents the total travel demand for daily life regardless of its travel mode, VKT highly depends on the vehicle ownership and household travel budget. Accordingly, by comparing the results of both models, we can understand how and why reduced commute travel demand (i.e., telecommuting) changes other household travel behaviors.

Next, whereas Model 1 applies household PKT or VKT excluding household head's commuting per person as an endogenous variable representing the level of household travel, Model 2 splits that into household head's non-commuting travel and household members' total travel (not divided by the number of household members).[5] Because both variables may have influenced each other, the model includes a reciprocal path between them as well as a covariance of error terms. In contrast, because mandatory travel including commuting is seldom influenced by other travel, this model assumes that the household head's telecommuting (commuting) is not influenced by the other travel variables.

Finally, the specific relationships among the aforementioned three key variables (telecommuting and residential/job location) are established based on the results of the analysis in Sect. 4. Table 1 illustrates a conceptual framework of each path model.

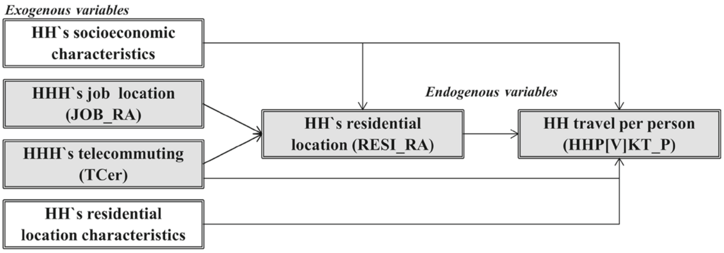
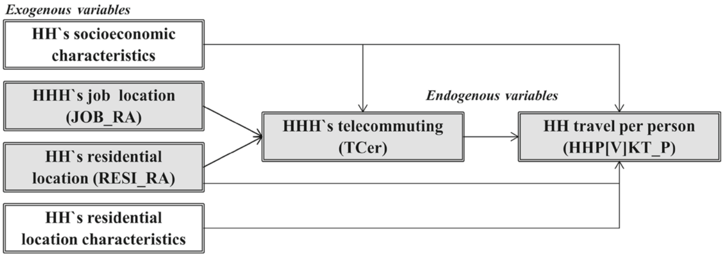
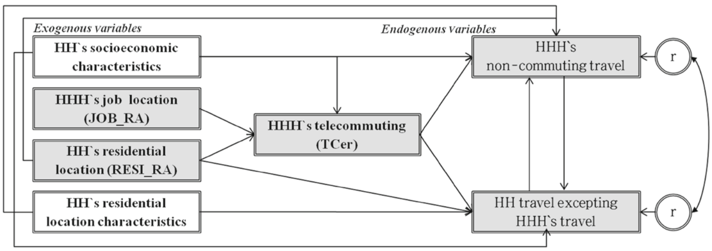
3.3 Measurement

Aside from the aforementioned travel variables, both path models apply various endogenous and exogenous variables. First, the household head's telecommuting variable is applied as a key variable of interest, where the operational definition of a telecommuter is a white-collar worker who chose 'telecommuter' from the four options of employment type (telecommuter; full-time office worker; part-time office worker; and other). Next, the models apply the Hansen-type regional job accessibility (RA) measure to quantify residential and job location (Hansen 1959). The RA of a given area is calculated by the sum of employment within the commutable areas in the SMA, taking into account the distance decay coefficient, as shown in Equation (1). Therefore, using this measure, we can quantify the level of centrality of job and residential locations in a metropolitan area (i.e., locational preference). In general, residential locations with high RA represent neighborhoods that have more job opportunities within a short distance, thereby leading to shorter commuting distance. We also include job and population density variables that represent locational characteristics. Using natural logarithms, the distributions of these three continuous variables are brought closer to normality (Kim et al. 2015).

In addition, to control for the spatial heterogeneity, three job location dummy variables—Seoul, Incheon, and Gyeonggi-do—are used, with Gangwon and Chungcheong provinces as the reference group. Finally, this study applies socioeconomic variables formed from the HTS data as control variables. Table 2 illustrates

[5] Household members' travel variable is not divided by the number of household members in order to reconcile one unit of the two travel-related endogenous variables.

Table 1 Conceptual framework of the path models

Type of model	Conceptual framework
Model 1: theoretical hypothesis model	
Model 1: rival hypothesis model	
Model 2	

HH household, *HHH* household head

the definitions and descriptive statistics of all variables.

$$\mathrm{RA}_i = \sum_j \mathrm{E}_j \times \mathrm{e}^{(\beta \mathrm{d}_{ij})}, \tag{1}$$

where RA_i regional job accessibility in region i, E_j total employees of region j, β distance resistance coefficient $= -0.280$ (Kim 2009), d_{ij} distance between region i and j.

4 Relationships between telecommuting and residential/job locations

Table 3 shows the goodness of fit of the both theoretical and rival models in which the relationships between the key variables are set differently, while controlling for the influence of socioeconomic and residential location characteristics of the household. As shown, the goodness of fit for all indicators is far higher in the THM than in the

Table 2 Definitions and descriptive statistics of variables

Variables and definitions	Unit	Min	Max	Mean	SD
TCer (household head is a telecommuter = 1, otherwise = 0)		0.000	1.000	0.025	0.156
Travel-related variables					
HHPKT_P (household PKT excepting HHH's commuting per person)	km	0.000	136.808	4.720	6.621
HHVKT_P (household VKT excepting HHH's commuting per person)	km	0.000	136.808	1.335	4.080
NCPKT (HHH's non-commuting PKT)	km	0.000	159.191	3.199	10.818
NCVKT (HHH's non-commuting VKT)	km	0.000	155.314	2.313	9.468
HHPKT (household PKT excepting HHH's travel)	km	0.000	313.668	13.639	18.466
HHVKT (household VKT excepting HHH's travel)	km	0.000	170.659	2.176	7.683
HHH's job location					
JOB_RA (natural log of regional job accessibility of job location)		5.217	13.564	12.168	1.281
Seoul (reference: Gangwon and Chungcheong provinces)		0.000	1.000	0.504	0.500
Incheon (reference: Gangwon and Chungcheong provinces)		0.000	1.000	0.085	0.279
Gyeonggi (reference: Gangwon and Chungcheong provinces)		0.000	1.000	0.330	0.470
Residential location characteristics					
POP_DEN (natural log of total population per km^2)		0.000	11.236	9.336	1.378
JOB_DEN (natural log of total jobs per km^2)		0.391	10.922	7.798	1.347
RESI_RA (natural log of regional job accessibility of residential location)		5.217	13.544	12.019	1.068
Individual characteristics of HHH					
Age		20.000	86.000	44.293	8.440
Female (female = 1, male = 0)		0.000	1.000	0.054	0.227
License (have driver's license = 1, otherwise = 0)		0.000	1.000	0.943	0.232
JOB (administrative/mgmt./other office work = 1, professional/technical = 0)		0.000	1.000	0.518	0.500
6 days (reference: irregular working days)		0.000	1.000	0.355	0.478
5 days (reference: irregular working days)		0.000	1.000	0.534	0.499
Household characteristics					
Apartment (reference: other housing type)		0.000	1.000	0.633	0.482
Detached house (reference: other housing type)		0.000	1.000	0.124	0.330
Owner-occupation		0.000	1.000	0.703	0.457

Table 2 continued

Variables and definitions	Unit	Min	Max	Mean	SD
Monthly household income					
$2000–$3000 (reference: $2000 or less)		0.000	1.000	0.289	0.453
$3000–$5000 (reference: $2000 or less)		0.000	1.000	0.383	0.486
$5000 or more (reference: $2000 or less)		0.000	1.000	0.113	0.317
Cars (number of privates cars per driver's license user)		0.000	3.000	0.584	0.376
Members (number of household members)		1.000	9.000	3.560	1.052
Presence of additional employee except HHH					
PT (professional/technical)		0.000	1.000	0.117	0.321
AMO (administrative/mgmt./other office work)		0.000	1.000	0.109	0.312
Sales		0.000	1.000	0.034	0.182
Service		0.000	1.000	0.042	0.201
FF (farming/fishing)		0.000	1.000	0.004	0.063
BLUE (transport/production/labor)		0.000	1.000	0.018	0.132

$N = 15{,}458$ households, For the purposes of this study, we define "white-collar information workers" to mean professional/technical or administrative/management/other office workers. We assume that USD 1 equals KRW 1000. Dagagu and Dasede are among the dominant housing types in Korea. They are detached homes (two or three stories), but usually shared by multiple families

HH household, *HHH* household head. *Source*: Authors' calculations using data from the 2006 SMA HTS

Table 3 Goodness of fit of the models

Type	Measures	Optimum standard[a]	PKT model		VKT model	
			THM[b]	RHM[b]	THM	RHM
χ^2 statistics	χ^2		38.297	3767.532	17.506	3723.348
	Q (χ^2/df)	5 or less	3.191	313.961	1.459	310.279
	p value of χ^2	Larger than 0.05	.001	.000	.132	.000
Absolute fit	RMSEA	Less than 0.05	.012	.142	.005	.141
Incremental fit	TLI	Larger than 0.9	.897	−1.067	.969	−1.131
	CFI	Larger than 0.9	.977	.549	.993	.535
Parsimonious fit	PCFI	The larger the better	.213	.120	.217	.117

[a] Cao (2006), Lee and Lim (2008) and Moon (2009)

[b] *THM* theoretical hypothesis model, *RHM* rival hypothesis model

RHM. This result does not mean that the THM is correct and the other is wrong; however, it at least demonstrates that the THM better explains our data (i.e., the real world observed on the survey day). In other words, it is likely that the majority of workers telecommute because of their residential/job locations even though some of them decide their locations based on their desire to telecommute. Thus, we can tentatively conclude that telecommuting may not cause residential relocation to peripheral areas and secondary effects on travel demand in the SMA. We interpret the results of this analysis by focusing on the THM.[6]

[6] The full results of the RHMs are available from authors upon request.

Tables 4 and 5 show the results of the THMs, which set the ultimate dependent variables as household PKT and VKT excluding household head's commuting per person, respectively. While the RA of residential location is not significantly associated with the household head's telecommuting, the RA of household head's job location has a negative influence on the choice to telecommute at the 0.05 probability level. This result indicates that employees working in companies located in the suburbs are more likely to choose telecommuting, or that companies located in the suburbs are more likely to implement a telecommuting system. Results also show that jobs located in Seoul, Incheon, and Gyeonggi-do tend to have a higher probability of telecommuting compared to those on the outskirts of the SMA (i.e., Gangwon and Chungcheong provinces). Both confirm the research findings by Kim et al. (2012), which argued that whereas jobs allowing telecommuting are concentrated in secondary rather than primary centers, they tend to be metropolis-oriented in the macroscopic aspect. Therefore, the significant association between telecommuting and suburban living may have been influenced by the suburban-oriented locational preference of the firms that allow telecommuting.

As expected, the household head's telecommuting is positively associated with PKT and VKT per household member, which is discussed in more detail in Sect. 5. In addition, the residential location RA and population density variables both have a negative influence on both travel variables. This result coincides with previous travel behavior studies in Korea (Kim 2009).

The impacts of the other control variables are as follows. First, for the telecommuting choice probability model, the result shows that older household heads engaged in administrative, management, and other office works offering irregular working days (compared to professional and technical jobs with regular working days) are more likely to choose telecommuting. In addition, the probability of telecommuting is higher in a household living in a Dagagu/Dasede house than in an apartment, and even higher in a single-family detached house. In contrast, the probability decreases if a household has more members and a higher income.

Next, for the travel distance models, the results show that a household with high income, with multiple earners, or living in an apartment tends to show greater PKT and VKT per member. Moreover, the PKT per member is greater if the household head is female or the household has more members, while the VKT per member is greater if the household head has a driver's license or the household has more vehicles.

5 Relationships between household head's telecommuting, household head's travel, and household members' travel

Tables 6 and 7[7] show results of the path models that address the second research question, and their adequate goodness of fit. The results of this analysis, including those with the control variables, generally coincide with the results of previous analysis in Sect. 4; therefore, specific interpretation is omitted here, leaving us only to interpret

[7] In Sect. 5, the travel-related variables were rescaled in 10 km units for minimizing iterations (Muthén and Muthén 2007).

Table 4 Path model of TCer and HHPKT_P (theoretical hypothesis model)

	Endogenous variables							
	TCer				HHPKT_P			
	B	*β*	*t*	*p*	*B*	*β*	*t*	*p*
TCer					0.824	0.121	6.678	0.000***
JOB_RA	−0.117	−0.137	−2.913	0.004**				
Seoul	1.042	0.478	5.350	0.000***				
Incheon	0.925	0.237	4.918	0.000***				
Gyeonggi	0.888	0.383	5.442	0.000***				
RESI_RA	−0.060	−0.059	−1.313	0.189	−0.292	−0.042	−2.838	0.005**
POP_DEN					−0.635	−0.118	−7.610	0.000***
JOB_DEN					−0.088	−0.016	−0.970	0.332
Age	0.017	0.132	5.784	0.000***	0.133	0.151	18.137	0.000***
Female	0.091	0.019	0.858	0.391	0.540	0.016	2.235	0.025*
License	−0.009	−0.002	−0.097	0.923	0.435	0.014	1.605	0.108
JOB	−0.256	−0.117	−4.850	0.000***	0.097	0.007	0.711	0.477
6 days	−0.353	−0.155	−5.541	0.000***	0.107	0.007	0.524	0.600
5 days	−0.527	−0.241	−7.556	0.000***	−0.223	−0.015	−1.033	0.301
Apartment	−0.239	−0.106	−3.909	0.000***	0.505	0.033	3.094	0.002**

Table 4 continued

	Endogenous variables							
	TCer				HHPKT_P			
	B	*β*	*t*	*p*	*B*	*β*	*t*	*p*
Detached house	0.208	0.063	2.953	0.003**	−0.089	−0.004	−0.413	0.679
Owner-occupation	0.001	0.000	0.018	0.985	0.426	0.026	2.888	0.004**
\$2000–\$3000	−0.047	−0.020	−0.748	0.454	0.899	0.055	5.140	0.000***
\$3000–\$5000	−0.124	−0.055	−1.966	0.049*	1.499	0.098	8.643	0.000***
\$5000 or more	−0.193	−0.056	−1.966	0.049*	2.292	0.098	9.239	0.000***
Cars	0.038	0.013	0.586	0.558	−0.457	−0.023	−2.636	0.008**
Members	−0.050	−0.048	−2.032	0.042*	0.369	0.052	5.814	0.000***
PT					2.091	0.090	10.678	0.000***
AMO					2.579	0.108	12.952	0.000***
Sales					1.924	0.047	5.658	0.000***
Service					1.150	0.031	3.411	0.001**
FF					0.306	0.003	0.407	0.684
BLUE					1.178	0.021	2.482	0.013*
Squared Multiple Correlations	0.158				0.119			
Number of observations	15,458				15,458			
Number of observation at lower bound ("0")	15,073				2208			
Number of other observation	385				13,250			

* $p < .05$; ** $p < .01$; *** $p < .001$

Table 5 Path model of TCer and HHVKT_P (theoretical hypothesis model)

	Endogenous variables							
	TCer				HHVKT_P			
	B	*β*	*t*	*p*	*B*	*β*	*t*	*p*
TCer					1.393	0.153	6.293	0.000***
JOB_RA	−0.091	−0.107	−2.251	0.024*				
Seoul	0.887	0.408	4.540	0.000***				
Incheon	0.875	0.224	4.663	0.000***				
Gyeonggi	0.828	0.358	5.048	0.000***				
RESI_RA	−0.060	−0.059	−1.301	0.190	−0.472	−0.051	−2.551	0.011*
POP_DEN					−0.721	−0.100	−5.140	0.000***
JOB_DEN					0.116	0.016	0.761	0.447
Age	0.017	0.133	5.784	0.000***	0.007	0.006	0.507	0.612
Female	0.095	0.020	0.899	0.369	−0.308	−0.007	−0.660	0.509
License	−0.007	−0.001	−0.073	0.942	2.017	0.047	3.609	0.000***
JOB	−0.256	−0.118	−4.851	0.000***	0.114	0.006	0.503	0.615
6 days	−0.353	−0.155	−5.540	0.000***	−0.109	−0.005	−0.303	0.762
5 days	−0.527	−0.242	−7.558	0.000***	−0.650	−0.033	−1.715	0.086
Apartment	−0.239	−0.106	−3.908	0.000***	1.282	0.062	4.677	0.000***

Table 5 continued

	Endogenous variables							
	TCer				HHVKT_P			
	B	*β*	*t*	*p*	*B*	*β*	*t*	*p*
Detached house	0.209	0.063	2.961	0.003**	0.497	0.017	1.352	0.176
Owner-occupation	0.002	0.001	0.028	0.977	0.246	0.011	0.994	0.320
\$2000–\$3000	−0.047	−0.020	−0.752	0.452	1.312	0.060	4.337	0.000***
\$3000–\$5000	−0.123	−0.055	−1.960	0.050	3.003	0.148	9.997	0.000***
\$5000 or more	−0.193	−0.056	−1.963	0.050	5.876	0.188	14.288	0.000***
Cars	0.039	0.013	0.595	0.550	3.308	0.126	10.948	0.000***
Members	−0.050	−0.048	−2.031	0.042*	−0.041	−0.004	−0.371	0.711
PT					3.436	0.112	10.894	0.000***
AMO					2.227	0.070	6.901	0.000***
Sales					2.435	0.045	4.581	0.000***
Service					1.776	0.036	3.308	0.001**
FF					0.800	0.005	0.558	0.577
BLUE					0.460	0.006	0.594	0.552
Squared Multiple Correlations	0.155				0.124			
Number of observations	15,458				15,458			
Number of observation at lower bound ("0")	15,073				11,142			
Number of other observation	385				4316			

* $p < .05$; ** $p < .01$; *** $p < .001$

Table 6 Path model of TCer, NCPKT, and HHPKT

	Endogenous variables								
	TCer			NCPKT			HHPKT		
	B	*β*	*p*	*B*	*β*	*p*	*B*	*β*	*p*
TCer				0.701	0.238	0.000***	0.149	0.074	0.091
NCPKT							−0.136	−0.199	0.190
HHPKT				−0.003	−0.002	0.958			
JOB_RA	−0.115	−0.136	0.003**						
Seoul	0.906	0.417	0.000***						
Incheon	0.778	0.200	0.000***						
Gyeonggi	0.796	0.344	0.000***						
RESI_RA	−0.060	−0.059	0.190	0.041	0.014	0.560	−0.083	−0.041	0.003**
POP_DEN				−0.137	−0.059	0.007**	−0.207	−0.131	0.000***
JOB_DEN				0.035	0.015	0.509	−0.037	−0.023	0.141
Age	0.017	0.133	0.000***	−0.005	−0.014	0.387	0.058	0.224	0.000***
Female	0.093	0.019	0.380	0.350	0.025	0.053	0.285	0.030	0.002**
License	−0.009	−0.002	0.925	0.354	0.026	0.039*	0.167	0.018	0.057
JOB	−0.256	−0.118	0.000***	0.121	0.019	0.115			
6 days	−0.341	−0.150	0.000***	−0.438	−0.065	0.000***			
5 days	−0.538	−0.247	0.000***	−0.639	−0.100	0.000***			
Apartment	−0.238	−0.105	0.000***	0.156	0.024	0.129	0.191	0.042	0.000***

Table 6 continued

	Endogenous variables								
	TCer			NCPKT			HHPKT		
	B	*β*	*p*	*B*	*β*	*p*	*B*	*β*	*p*
Detached house	0.207	0.063	0.003**	0.073	0.008	0.584	0.047	0.007	0.430
Owner-occupation	0.002	0.001	0.966	−0.114	−0.016	0.212	0.125	0.026	0.007**
$2000–$3000	−0.048	−0.020	0.448	0.122	0.017	0.276	0.277	0.058	0.000***
$3000–$5000	−0.125	−0.056	0.047*	0.420	0.064	0.000***	0.465	0.104	0.000***
$5000 or more	−0.194	−0.057	0.049*	0.854	0.085	0.000***	0.710	0.103	0.000***
Cars	0.040	0.014	0.539	0.133	0.016	0.222	−0.225	−0.039	0.000***
Members	−0.034	−0.033	0.155				0.629	0.304	0.000***
PT							0.730	0.108	0.000***
AMO							0.966	0.138	0.000***
Sales							0.634	0.053	0.000***
Service							0.536	0.049	0.000***
FF							0.468	0.013	0.001**
BLUE							0.569	0.035	0.000***
Squared Multiple Correlations	0.155			0.068			0.183		
Number of observations	15,458			15,458			15,458		
Number of observation at lower bound (“0”)	15,073			12,259			2626		
Number of other observation	385			3199			12,832		

* $p < .05$; ** $p < .01$; *** $p < .001$; $\chi^2 = 41.386$, $Q(\chi^2/df) = 1.724$, p value of $\chi^2 = 0.015$, RMSEA = 0.007, TLI = 0.998, CFI = 0.999

Table 7 Path model of TCer, NCVKT, and HHVKT

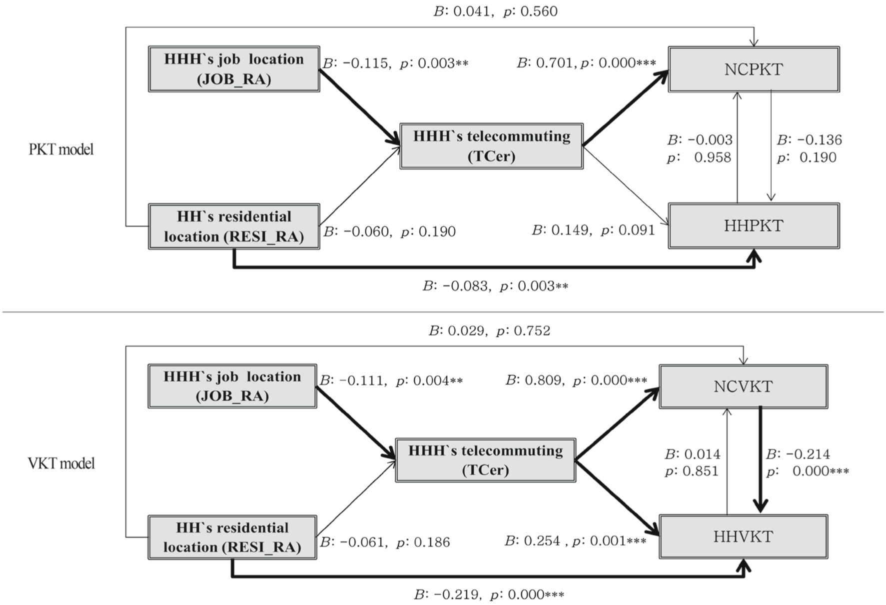
	Endogenous variables								
	TCer			NCVKT			HHVKT		
	B	*β*	*p*	*B*	*β*	*p*	*B*	*β*	*p*
TCer				0.809	0.235	0.000***	0.254	0.105	0.001**
NCVKT							−0.214	−0.305	0.000***
HHVKT				0.014	0.010	0.851			
JOB_RA	−0.111	−0.131	0.004**						
Seoul	0.812	0.372	0.000***						
Incheon	0.836	0.214	0.000***						
Gyeonggi	0.795	0.343	0.000***						
RESI_RA	−0.061	−0.059	0.186	0.029	0.008	0.752	−0.219	−0.089	0.000***
POP_DEN				−0.128	−0.047	0.059	−0.228	−0.119	0.000***
JOB_DEN				−0.006	−0.002	0.931	0.033	0.017	0.478
Age	0.019	0.150	0.000***	−0.028	−0.062	0.000***			
Female	0.112	0.023	0.290	−0.598	−0.036	0.017*			
License	0.018	0.004	0.848	2.739	0.169	0.000***			
JOB	−0.249	−0.114	0.000***	0.084	0.011	0.393			
6 days	−0.346	−0.152	0.000***	−0.263	−0.034	0.087			
5 days	−0.524	−0.240	0.000***	−0.803	−0.107	0.000***			
Apartment	−0.237	−0.105	0.000***	0.260	0.033	0.053	0.544	0.100	0.000***

Table 7 continued

	Endogenous variables								
	TCer			NCVKT			HHVKT		
	B	*β*	*p*	*B*	*β*	*p*	*B*	*β*	*p*
Detached house	0.208	0.063	0.003**	0.052	0.005	0.768	0.258	0.032	0.024*
Owner-occupation	0.001	0.000	0.990	−0.050	−0.006	0.670	0.160	0.028	0.042*
\$2000–\$3000	−0.048	−0.020	0.448	0.340	0.041	0.023*	0.500	0.086	0.000***
\$3000–\$5000	−0.126	−0.056	0.045*	0.760	0.098	0.000***	1.127	0.208	0.000***
\$5000 or more	−0.194	−0.056	0.048*	1.398	0.118	0.000***	2.155	0.259	0.000***
Cars	0.040	0.014	0.535	0.849	0.085	0.000***	1.049	0.150	0.000***
Members	−0.025	−0.024	0.282				0.248	0.099	0.000***
PT							1.451	0.177	0.000***
AMO							1.060	0.125	0.000***
Sales							0.741	0.051	0.000***
Service							0.794	0.061	0.000***
FF							0.232	0.006	0.472
BLUE							0.500	0.025	0.012*
Squared Multiple Correlations	0.160			0.124			0.063		
Number of observations	15,458			15,458			15,458		
Number of observation at lower bound (“0”)	15,073			13,336			12,790		
Number of other observation	385			2122			2668		

$^*p < .05$; $^{**}p < .01$; $^{***}p < .001$; $\chi^2 = 63.530$, $Q(\chi^2/df) = 2.353$, p value of $\chi^2 = 0.000$, RMSEA = 0.009, TLI = 0.981, CFI = 0.994

Table 8 Summary of nonstandardized coefficients of key variables



the summarized results, focusing on the relationships among the key variables. Table 8 summarizes the key results of the analyses in these two models, in which the household head's non-commuting travel and household members' travel were set as the ultimate dependent variables.

First, the PKT model shows that the household head's telecommuting has a positive influence on his/her non-commuting travel distance. This result coincides with those from previous studies that used large-scale travel survey data (Kim et al. 2015; Zhu 2012), and which indicated that the travel budget for commuting had switched to travel for other purposes, owing to the compensatory travel mechanism. It is also consistent with Nilles (1996), who revealed that travel ordinarily taken by other household members, such as driving children to school, are taken by telecommuters on telecommuting days. Meanwhile, although it is statistically insignificant at the 0.05 probability level, the relationship between the household head's telecommuting and their household members' travel distance is also positive ($p = 0.091$). The relationship between both variables should be addressed again with the results of the VKT model.

In addition, this result shows that the reciprocal paths between both travel variables are also statistically insignificant at the 0.05 probability level. Accordingly, the indirect (secondary) effects of household head's telecommuting on household members' travel with his/her travel as the medium or vice versa are also insignificant.

The VKT model shows that the head's telecommuting has a positive influence on his/her non-commuting VKT as well as household members' VKT, partially in contrast to the PKT model. This reconfirms the result that the household vehicle, which is generally used for household head's commuting, can be used for his/her other trips and by other household members on telecommuting days (Kim et al. 2015).

In contrast to the PKT model, the VKT model shows that the household head's non-commuting VKT has a negative influence on household members' VKT, but the opposite path was statistically insignificant. This result means that competitions between household members for vehicle usage can occur owing to the limited travel budget for private vehicles (in terms of the number of vehicles, available hours, and operating expenses). This result reconfirms the time-budget effect on vehicle travel suggested in Golob (1996). Thus, the household head's non-commuting and household members' travel were in a substitutionary relationship in terms of vehicle travel.

According to the results above, the indirect effect of the household head's telecommuting on household members' VKT, using his/her non-commuting VKT as the medium, was negative (indirect effect: $B = -0.173$, $p = 0.000$). However, as the value was smaller than the direct effect, the total effect of household head's telecommuting on household members' VKT appears to be positive (total effect: $B = 0.080$, $p = 0.223$).

As shown, the household head's telecommuting positively influences not only his/her non-commuting travel but also the household members' travel in general. However, whereas non-vehicle travel with relatively flexible budget constraints does not show any inter-dependent relationship between the household head's non-commuting and household members' travel, vehicle travel with strict budget constraints shows a substitutionary relationship within the competition among household members. Thus, although the vehicle travel inducing effect may have been kept below a certain level due to limited vehicle resources, the vehicle travel reduced by telecommuting can be substantially offset by other travel within a household, given a strong mechanism for making the most of limited resources. These results lead us to the conclusion that telecommuting and household travel are complementary rather than substitutional.

6 Conclusion

This study employed a path analysis to address two research questions that are relevant to the causal relationships between telecommuting, residential and job location, and household travel. Even though the path analysis does not necessarily guarantee to confirm the causal relationships of them, this new approach can provide additional evidence to the body of the literature. The key findings and implications are summarized as follows.

Regarding the first research question—Does telecommuting promote dispersion of urban space?—the path analysis better explains that rather than telecommuting determining location choice, residential and job locations determine the choice to telecommute, consistent with Kim et al. (2012). This result, therefore, reconfirms the fact that no secondary impacts of telecommuting on travel generation occur with location changes as the medium. We may infer this relationship because jobs that allow telecommuting are often more suburb-oriented than traditional jobs; thus, households located in the suburbs are more likely to choose telecommuting (Kim et al. 2012). As a result, we can conclude that telecommuting does not promote urban dissolution in the short term.

Nonetheless, in the long-term perspective, the Korean government's active telecommuting-promotion policy—aiming for 45 % prevalence by 2020—may also lead to urban dispersion via suburbanization of employment, a different process of residential suburbanization. This policy may lead to spatial changes in the distribution of daytime population (i.e., workplaces), as more people engage in activities in suburban areas. This dispersion of daily life realm may lead to unplanned and dispersive developments in the suburbs. Moreover, the growth of the suburbs may lead to changes in spatial structures like Edge City (Garreau 1991) in the short run as job locations become suburbanized; however, a long-term effect would be the gradual and scattered diffusion of the metropolitan area, accompanied by issues seen in Edgeless City (Lang 2003). Consequently, this phenomenon will simply be a rerun of urban sprawl by resulting in wasteful travel behaviors, owing to a lack of infrastructure in the suburban areas. Thus, the government's active telecommuting-promotion policy must be accompanied by appropriate measures (such as urban growth management) to cope with the changes in spatial structures.

Regarding the second research question—Does telecommuting substitute for household travel?—the results of path analysis show that the household head's telecommuting has a positive influence on his/her non-commuting travel in both the PKT and VKT models and on household members' travel in VKT models. This result implies that the travel budget for household head's commuting is converted to travel for other purposes or other members owing to the compensatory travel mechanism. In addition, the VKT model shows that household head's non-commuting travel has negative impact on household members' travel. This indicates that a limited travel budget for private vehicles leads to competition among household members to use them; hence, the household head's non-commuting travel and household members' travel are in a substitutionary relationship in terms of vehicle travel. These results reveal that even though telecommuting reduces commuting demand, it may be offset by other travel demand within the household. Although we cannot exactly estimate the overall impact of telecommuting on household travel based on the empirical setting of this paper,[8] at least, we can argue that the benefits of telecommuting are significantly less than anticipated. As a result, telecommuting complements travel rather than substitutes it.

This means that although Korea's telecommuting-promotion policy may be effective for spatiotemporal dispersion of travel, it has clear limitations as a travel demand management strategy that aims to completely eliminate work-based travel (Kim et al. 2015). Likewise, it may be effective in relieving traffic congestion and concentration of air pollution, but it may not have a great effect on reducing overall traffic energy consumption or greenhouse gas emissions. Therefore, planners and policymakers must consider this counteracting effect when predicting the travel-reduction

[8] The empirical setting of this paper focuses on the intra-household interactions in travel rather than overall impact of telecommuting. To draw a more precise estimate of the overall impact, household-level analyses should be performed (Kim et al. 2015). Because this approach needs comprehensive changes in the empirical setting, this issue will be addressed through future research.

effect of telecommuting, or when determining the degree to which telecommuting ought to be promoted in order to accomplish other environmental policy goals.

Using path analysis, this study comprehensively examined two lingering research questions in the field of telecommuting studies and provided empirical grounds for determining the causal relationships among telecommuting, residential and job location, and household travel. Although a path analysis was developed to structuralize the hypothetical causal relationships and verify them (Wolfle 2003), fundamental limitations remain in concluding the causality because the data used in this study are cross-sectional. Therefore, the findings of this study need to be considered as one aspect of the empirical evidence for understanding the causal relationships among the variables, and it has to be constantly tested through future research.

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References

Alonso W (1964) Location and land use: toward a general theory of land rent. Harvard University Press, Cambridge

Cao X (2006) The causal relationship between the built environment and personal travel choice: evidence from Northern California. Dissertation, Civil and Environmental Engineering, University of California at Davis

De Graaff T (2004) On the substitution and complementarity between telework and travel: a review and application. http://dare.ubvu.vu.nl/bitstream/1871/8927/1/20040016.pdf. Accessed 13 June 2011

Demographia (2012) Demographia world urban areas (built-up urban areas or world agglomerations) 10th annual edition. http://www.demographia.com/db-worldua.pdf. Accessed 24 November 2014

Ellen IG, Hempstead K (2002) Telecommuting and the demand for urban living: a preliminary look at white-collar workers. Urban Stud 39:749–766

Fujita M (1989) Urban economic theory: land use and city size. Cambridge University Press, New York

Garreau J (1991) Edge city: life on the new Frontier. Doubleday, New York

Glogger AF, Zängler TW, Karg G (2008) The impact of telecommuting on households' travel behaviour, expenditures and emissions. In: Jensen-Butler C, Sloth B, Larsen MM et al (eds) Road pricing, the economy and the environment. Springer, Berlin, pp 411–425

Golob TF (1996) A model of household demand for activity participation and mobility. University of California, Irvine

Graham S (1997) Telecommunications and the future of cities: debunking the myths. Cities 14:21–29

Hamer R, Kroes E, Vanooststroom H (1991) Teleworking in the Netherlands: an evaluation of changes in travel behavior. Transportation 18:365–382

Hansen WG (1959) How accessibility shapes land use. J Am Inst Plan 25:73–76

Helminen V, Ristimaki M (2007) Relationships between commuting distance, frequency and telework in Finland. J Transp Geogr 15:331–342

Hopkinson P, James, P, Maruyama T (2002) Teleworking AT BT—the economic, environmental and social impacts of its workabout scheme http://www.slideshare.net/KennyBHS/teleworking-at-bt. Accessed 13 June 2011

James P (2004) Is teleworking sustainable? An analysis of its economic, environmental and social impacts. European Communities, Peterborough

Janelle DG (1995) Metropolitan expansion, telecommuting, and transportation. In: Hanson S, Giuliano G (eds) The geography of urban transportation, 2nd edn. The Guilford Press, New York, pp 407–434

Kim H (2009) Effects of compact city planning elements on travel behavior of different income levels. Dissertation, Civil and Environmental Engineering, Seoul National University (**in Korean**)

Kim S-N, Ahn K (2010) Estimating the travel-related impacts of home-based telecommuting. J Korea Plan Assoc 45:147–164 (**in Korean**)

Kim S-N, Ahn K (2011) The relationships between home-based telecommuting and residential location. J Korea Plan Assoc 46:37–55 (**in Korean**)

Kim S-N, Mokhtarian PL, Ahn K (2012) The Seoul of Alonso: new perspectives on telecommuting and residential location from South Korea. Urban Geogr 33:1163–1191

Kim S-N, Choo S, Mokhtarian P (2015) Home-based telecommuting and intra-household interactions in work and non-work travel: a seemingly unrelated censored regression approach. Transp Res Part A Policy Pract 80:197–214

Koenig BE, Henderson DK, Mokhtarian PL (1996) The travel and emissions impacts of telecommuting for the State of California Telecommuting Pilot Project. Transportation Research Part C: Emerging Technologies 4:13–32

Lang R (2003) Edgeless cities: Exploring the elusive metropolis. Brookings Institution Press, D.C

Lari A (2012) Telework/Workforce Flexibility to Reduce Congestion and Environmental Degradation? Procedia-Social and Behavioral Sciences 48:712–721

Lee H, Lim J (2008) Structural Equation Modeling and AMOS 7. Bupmoonsa, Paju (**in Korean**)

Lund JR, Mokhtarian PL (1994) Telecommuting and residential location: theory and implications for commute travel in monocentric metropolis. Transp Res Rec 1463:10–14

McLuhan M (1967) The city has no existence beyond being a cultural ghost for tourists. http://shirleyshor.com/text/city_of_bits.htm. Accessed 29 April 2010

McLuhan M (1995) Understanding Media: The Extensions of Man. Routledge, Cambridge

Mitchell WJ (1995) City of Bits: Space, Place, and the Infobahn. MIT Press, Cambridge

Mitchell WJ (1999) E-topia: Urban life, Jim - but not as we know it. MIT Press, Cambridge

Mokhtarian PL (1991) Telecommuting and travel: state of the practice, state of the art. Transportation 18:319–342

Mokhtarian PL (1998) A synthetic approach to estimating the impacts of telecommuting on travel. Urban Studies 35:215–241

Mokhtarian PL, Collantes GO, Gertz C (2004) Telecommuting, residential location, and commute-distance traveled: Evidence from State of California employees. Environment and Planning A 36:1877–1897

Mokhtarian PL, Handy SL, Salomon I (1995) Methodological Issues in the Estimation of the Travel, Energy, and Air-Quality Impacts of Telecommuting. Transportation Research Part A: Policy and Practice 29:283–302

Moon S (2009) Basic Concepts and Applications of Structural Equation Modeling with AMOS 17. Hakjisa, Seoul [in Korean]

Moos M, Skaburskis A (2007) The characteristics and location of home workers in Montreal, Toronto and Vancouver. Urban Studies 44:1781–1808

Moos M, Skaburskis A (2010) Workplace restructuring and urban form: the changing national settlement patterns of the Canadian workforce. Journal of Urban Affairs 32:25–53

Muhammad S, Ottens HFL, Ettema D et al (2007) Telecommuting and residential locational preferences: A case study of the Netherlands. J Housing Built Environ 22:339–358

Muthén LK, Muthén BO (2007) Mplus User‘s Guide, 5th edn. Muthén & Muthén, Los Angeles

Nagurney A, Dong J, Mokhtarian PL (2003) A space-time network for telecommuting versus commuting decision-making. Papers in Regional Science 82:451–473

Nilles J (1991) Telecommuting and urban sprawl: mitigator or inciter? Transportation 18:411–432

Nilles J (1996) What does telework really do to us? World Transport Policy and Practice 2:15–23

Ory DT, Mokhtarian PL (2006) Which came first, the telecommuting or the residential relocation? An empirical analysis of causality. Urban Geography 27:590–609

Pendyala RM, Goulias KG, Kitamura R (1991) Impact of telecommuting on spatial and temporal patterns of household travel. Transportation 18:383–409

Rhee H (2009) Telecommuting and urban sprawl. Transportation Research Part D: Transport and Environment 14:453–460

Salomon I (1986) Telecommunications and travel relationships: A review. Transportation Research Part A: General 20:223–238

Sener IN, Bhat CR (2011) A copula-based sample selection model of telecommuting choice and frequency. Environment and Planning A 43:126–145

Shen Q (2000) New telecommunications and residential location flexibility. Environment and Planning A 32:1445–1463

Tang W, Mokhtarian PL, Handy SL (2008) The role of neighborhood characteristics in the adoption and frequency of working at home: empirical evidence from Northern California.http://escholarship.org/uc/item/13x2q3rb;jsessionid=845EA468EDB1D949EC5508A331385C83. Accessed 28 February 2011

Tayyaran M, Khan A (2007) Telecommuting and residential location decisions: Combined stated and revealed preferences model. Can J Civ Eng 34:1324–1333

van Ommeren J, Rietveld P, Nijkamp P (2000) Job mobility, residential mobility and commuting: A theoretical analysis using search theory. The Annals of Regional Science 34:213–232

Webber MM (1968) The post-city age. Daedalus 97:1091–1110

Wolfle LM (2003) The introduction of path analysis to the social sciences, and some emergent themes: an annotated bibliography. Struct Equa Model Multidiscip J 10:1–34

Zhou LR, Su Q, Winters PL (2009) Telecommuting as a component of commute trip reduction program trend and determinants analyses. Transp Res Rec 2135:151–159

Zhu P (2012) Are telecommuting and personal travel complements or substitutes? Ann Region Sci 48:619–639

Zhu P (2013) Telecommuting, household commute and location choice. Urban Stud 50:2441–2459