# Metropolitan Size and the Impacts of Telecommuting on Personal Travel

Pengyu Zhu
The University of Hong Kong
Pengyuzhu2002@yahoo.com

Liping Wang
Zhejiang Unviersity

Yanpeng Jiang
The University of Hong Kong

Jiangping Zhou
The University of Hong Kong

**Abstract**

Telecommuting has been proposed by policy makers as a strategy to reduce travel and emissions. In studying the metropolitan size impact of telecommuting on personal travel, this paper addresses two questions: 1) whether telecommuting is consistently a substitute or complement to travel across different MSA sizes; and 2) whether the impact of telecommuting is higher in larger MSAs where telecommuting programs and policies have been more widely adopted. Data from the 2001 and 2009 National Household Travel Surveys are used. Through a series of tests that address two possible empirical biases, we find that telecommuting consistently had a complementary effect on one-way commute trips, daily total work trips and daily total non-work trips across different MSA sizes in both 2001 and 2009. The findings suggest that policies that promote telecommuting may indeed increase, rather than decrease, people's travel demand, regardless of the size of the MSA. This seems to contradict what telecommuting policies are designed for. In addition, model results show that the complementary impact of telecommuting on daily travel is lower in larger MSAs, in terms of both daily total work trips and daily total non-work trips.

**Key Words**: Telecommuting, Personal Travel, Complement, Substitute, Commute, Non-work Trips

## 1. Introduction

Information and communication technologies (ICT) have been continuously changing our travel behavior (Bris et al, 2017; Cao, 2009; Cao et al, 2010, 2012; Cao and Mokhtarian, 2005; Choo and Mokhtarian 2007; Mokhtarian, 1998; Mokhtarian et al, 1995, 1997, 2004). As a specialized part of ICT usage, telecommuting is the practice of working from home instead of going to the regular work place every day. Employees may also work at a "telecommuting center" that is close to home and provides office space and basic support services such as Internet access. The idea of telecommuting was first proposed in the 1960s as a strategy to reduce automobile travel and traffic congestion, and thus reduce energy use and improve air quality (NAE, 1969; Nilles, et al, 1976). According to Census figures, as of 2010, around 13.4 million people, or 9.5 percent of the U.S. workforce, worked at home at least one day per week, a substantial increase from 9.2 million people, or 7 percent, in 1997 (Mateyka et al., 2012).[1]

Earlier empirical studies have supported the view that there are traffic benefits associated with telecommuting. Analyzing trip records obtained from 219 respondents, of which 73 are telecommuters, Kitamura et al (1991) concluded that telecommuting is a viable trip reduction measure because it leads to a substantial reduction in trip generation, VMT, peak-period trips, automobile use and freeway travel on telecommuting days, and it does not increase non-work trips. Other empirical research in the 1990s (e.g. Hamer et al., 1991; Mokhtarian et al., 1995; Henderson and Mokhtarian, 1996; Mokhtarian et al.,

[1] The numbers calculated from census include both telecommuters (i.e. those have regular workplaces) and home-based workers (i.e. those work exclusively from home). The margin of error is provided in Table 1 of the referenced article.

1997; Mokhtarian, 1998; Balepur et al, 1998; Salomon, 1998) also concluded that telecommuters travel slightly less than non-telecommuters. Certainly, most of these articles have cautioned about the possible complementary or "generation" effects of telecommuting. For example, Mokhtarian et al. (1995) emphasized that the substitution effect was smaller than expected and that we could not extrapolate the findings from early adopters. Mokhtarian (1998) suggested that the trip generation effects of telecommuting could "increase over time to the extent that the net reduction in travel shrinks."

Nevertheless, these earlier studies in the 1990s provided empirical grounds for policy makers to propose more telecommuting programs in the U.S. In 1999, the 106th Congress passed the National Telecommuting and Air Quality Act, which established pilot programs in five large Metropolitan Statistical Areas (MSAs), including Washington D.C., Los Angeles, Philadelphia, Houston, and Denver, as a basis for developing a market-based emission-credit-trading program aimed at encouraging the use of telecommuting so as to reduce vehicle miles traveled (VMT) and emissions of air pollutants. Through creating emission credits from the use of telecommuting by some firms and selling the credits to firms that seek the reductions in order to comply with air quality regulations, the proponents argued this program could serve as an economic incentive to promote telecommuting and in turn reduce VMT and improve air quality. Since then, telecommuting programs have been adopted by some employers as part of their trip reduction programs. And policies that encourage such programs have been put in place at the local, regional, state, and federal levels. State Departments of

Transportation and Metropolitan Planning Organizations (MPOs) can use funding from the federal Congestion Mitigation and Air Quality (CMAQ) program to support telecommuting programs. For instance, in 2001, Portland Metropolitan Planning Organization used funding from the federal CMAQ program to provide the Oregon Office of Energy with a grant to support its telework outreach and services in the Portland metropolitan area (Community Planning Workshop, 2003). The Houston-Galveston Area Council also uses federal funds to offer grants to employers who begin or expand telecommuting programs as part of the Commute Solutions program.[2]

Although some empirical research after the passage of the 1999 National Telecommuting and Air Quality Act continued to show supporting evidences for telecommuting programs in the U.S. (e.g. Gareis 2003; Mokhtarian et al. 2004; Choo, Mokhtarian and Salomon 2005; Ory and Mokhtarian 2005, 2006; Jiang 2008), more and more recent international research started to caution policymakers that previous estimates of the travel impact of telecommuting might be overly optimistic (e.g. Kim 2016, 2017; Kim, Choo and Mokhtarian 2015; Nelson et al 2007; Tal, 2008; Zhu, 2012). For instance, Zhu (2012) raised concerns about the small sample sizes used in previous research. Instead, he used National Household Travel Survey (NHTS) and found that telecommuting had a complementary effect, rather than substitution effect, on personal travel in both 2001 and 2009. This draws into question the use of telecommuting as a policy to reduce travel demand.

[2] For more details, please refer to http://www.commutesolutionshouston.org/commuters/telework.htm

Note that the effectiveness of telecommuting programs or policies is based on the assumption that the use of telecommuting can reduce travel demand. However, it is possible that the opportunity to telecommute prompts workers to live farther away from workplace, thus offsetting some of the work trip reductions on telecommuting days with longer commuting trips on non-telecommuting days (Mokhtarian, 1998; Tal, 2008; Zhu, 2012). Second, the time saved not commuting on telecommuting days can be redistributed to travel for other purposes. For example, Balepur et al. (1998) observed that telecommuters made more trips returning home, eating meal, shopping, and social/recreational trips on telecommuting days. Zhu (2012) also found that telecommuters had longer daily shopping trips, family/personal business trips, and social/recreational trips than non-telecommuters. Third, it is possible that telecommuting might replace trips using transit or carpooling, rather than driving alone. Balepur et al. (1998) observed a significant shift from other modes to driving alone on telecommuting days, even though commute mode split on non-telecommuting days is not affected by telecommuting.

As the complementary effect of telecommuting has been highlighted in many research, the novelty of this paper is to further examine this effect across different MSA sizes. To date, previous empirical findings have been based on either individual MSA studies (e.g. He and Hu 2015; Mokhtarian et al, 1997, 2004; Kim 2016, 2017; Kim, Choo and Mokhtarian 2015) or national studies (e.g. Choo, Mokhtarian and Salomon 2005; Helminen and Ristimaki, 2007; Muhammad et al 2007; Zhu, 2012, 2013). And national studies have so far only focused on the national average impact of telecommuting on personal travel. They did not examine how this impact might vary across different MSA sizes, even though MSA sizes and density were often controlled in their models.[3] This paper aims to provide spatially disaggregated evidences to examine possible MSA size differences in the impact of telecommuting on personal travel.

Indeed, there are at least two reasons why investigating the MSA size differences of this impact is particularly interesting. First, studies using national samples (e.g. Choo, Mokhtarian and Salomon 2005; Zhu, 2012) basically investigated the national average impact of telecommuting on travel. But large-MSA travelers may make different travel choices (e.g. less proximity between home and workplace) than those in small MSAs, because they are facing different trade-offs between transportation costs and housing costs. Because of this, people in larger MSAs are more likely to use telecommuting to counteract their longer one-way commute so that their weekly/monthly commute does not increase much. In fact, our analyses of the NHTS data have found the percentage of telecommuters among workers in large MSAs is significantly larger than that in small MSAs.

Will earlier findings hold if we subdivide the national sample into groups based on MSA sizes? Could it be possible that telecommuting reduces travel in smaller MSAs but increases travel in larger MSAs? In other words, is telecommuting consistently a complement to person travel across different MSA sizes?

Second, telecommuting is a more popular practice in large MSAs where

[3] For these models, geographic variables such as MSA sizes and density were often included as control variables. Their coefficient estimates simply suggest how MSA sizes and density would affect travel behavior (e.g. commute distance, daily VMT). This is different from the purpose of this research--that is, how the impact of telecommuting on travel behavior varies across different MSA sizes.

telecommuting programs and policies have been more widely adopted. If the impact of telecommuting on personal travel in large MSAs is higher than in small MSAs, previous research that estimated the national average effects of telecommuting on travel might have underestimated the true impact of telecommuting in large MSAs, where telecommuting is more commonly practiced and relevant policies conceivably have more influences. So the logical question would be: Is the travel impact of telecommuting greater in larger MSAs?

The purpose of this paper is to focus on the possible MSA size effects and to identify the different impact of telecommuting on personal travel in different MSA sizes. All MSAs are classified into three groups based on population size in each year as provided by NHTS: small MSAs with a population less than 1 million, medium MSAs with a population greater than 1 million but less than 3 millions, and large MSAs (or CMSAs) with a population over 3 millions.[4] Two specific questions are addressed:

(1) Is telecommuting consistently a complement (or substitute) to personal travel across different MSA sizes?

(2) Is the impact of telecommuting on personal travel higher in larger MSAs than in smaller MSAs over the two survey years?

For both questions, personal travel is measured by one-way commute distance and duration, as well as daily work and non-work trip distance, duration and frequency. Comparisons between the 2001 and 2009 NHTS data are also made to explore the impact of telecommuting over time.

---

[4] According to NHTS, in 2001, there were 30460 households sampled from small MSAs, 8371 households from medium MSAs and 17179 households from large MSAs; in 2009, there were 45884 households sampled from small MSAs, 32508 households from medium MSAs and 40975 households from large MSAs.

One big challenge in addressing these research questions lies fundamentally in the NHTS data, which does not provide sufficient information about telecommuters' different travel behavior in telecommuting versus non-telecommuting days. Because the data was collected through a one-day travel diary, the randomly assigned date of the diary could be either a commuting day or a telecommuting day for telecommuters. If it was a commuting day, the recorded distance and duration of daily total work trips would be significant overestimations for telecommuters, because the data does not account for the fact that each telecommuter (as defined later) has at least one day each week when the regular journey to work is not made. On the other hand, if the diary data were collected on a telecommuting day, the recorded work trip distance and time (presumably zero) would be serious underestimations because telecommuters still travel to their regular job locations multiple days per week. To address this data limitation, this research uses left-censored Tobit models to include observations with zero work trip distance and duration and ensures trip diary data collected on a telecommuting day (i.e. when those telecommuters do not commute to work) are not dropped in the analyses. Note that the Tobit model (left-censored at zero) is a non-linear model that takes into account the probability of having zero work trip distance/duration. In this regard, this model is better than a linear model that could lead to biased estimates given the data structure.

The second empirical challenge, which has plagued much of the research on telecommuting and travel behavior, is the possible endogeneity issue derived from the simultaneous choice of telecommuting and commute distance (or duration)—a worker might choose longer commute in response to telecommuting; at the same time, longer commute might also prompt the worker to be more likely to telecommute. Previous empirical studies have used Structure Equation Models and Instrumental Variable approaches to address the simultaneity between telecommunication/telecommuting and travel demand (e.g. Choo and Mokhtarian 2007; He and Hu 2015; Zhu 2012, 2013). Following Zhu (2012, 2013), this study uses an Instrumental Variable approach to address this possible endogeneity problem and investigate the causal effect of telecommuting on travel distance/duration.

## 2. A Preview: Telecommuter and Non-telecommuter Travel Patterns by MSA Size

### 2.1 Data and Definitions

The dataset used for this research are the 2001 and 2009 National Household Travel Surveys (NHTS). The NHTS is a large-sample national data set that includes information on personal and household characteristics, socioeconomic status, locations of residence, detailed travel information such as one-way commute trips, various daily work trips and non-work trips, and the status of telecommuting. The NHTS day-trip dataset is used to calculate the daily total work and daily total non-work trip distance, duration and frequency for each worker in the sample.

Telecommuters are defined as those workers who report telecommuting (work at home instead of going to usual workplace) at least once a week[5]. Respondents who only work at home (home-based businesses, for example) are not considered as telecommuters.

[5] The NHTS survey questions on telecommuting were only slightly different between 2001 and 2009. And in both surveys, respondents who only work at home (e.g. home-based businesses) are skipped in the questions on telecommuting as well as the questions on one-way commute distance and duration. Therefore, the sample in this paper only includes those workers who have a workplace away from home.

The infrequent telecommuters and those never telecommuting are all classified as non-telecommuters, because infrequent telecommuting (e.g. once a month) would arguably have very limited effect on the respondent's residential location choice and thus on his/her commute trips or daily (work and non-work) trips. Both telecommuters and non-telecommuters could have work trips and non-work trips.

For the differences in travel patterns between telecommuters and non-telecommuters, we first focus on their one-way commute trips, which were provided by NHTS to measure the distance and (travel) time between workers' home and their workplaces. One-way commute trip distance and time are fixed measures and do not change even if a telecommuter recorded his/her trip diary on the day he/she telecommuted. We are also interested in the differences between telecommuters and non-telecommuters in terms of their daily total work trips (which include all daily "to/from work" trips and "work related business" trips) and daily total non-work trips (which include shopping trips, other family/personal business trips, school/church trips, medical/dental trips, visit friends/relatives trips, and other social/recreational trips).

**2.2 Telecommuter and Non-telecommuter Travel Patterns by MSA Size**

The main purpose of this paper concerns the differences in travel patterns between telecommuters and non-telecommuters and, more importantly, how these differences vary across different MSA sizes. In order to investigate these differences, a table summarizing the one-way commute trip data from 2001 and 2009 NHTS is first examined. Table 1 provides summaries for personal one-way commute trips, grouped by telecommuting status and MSA size.

<Table 1 about here>

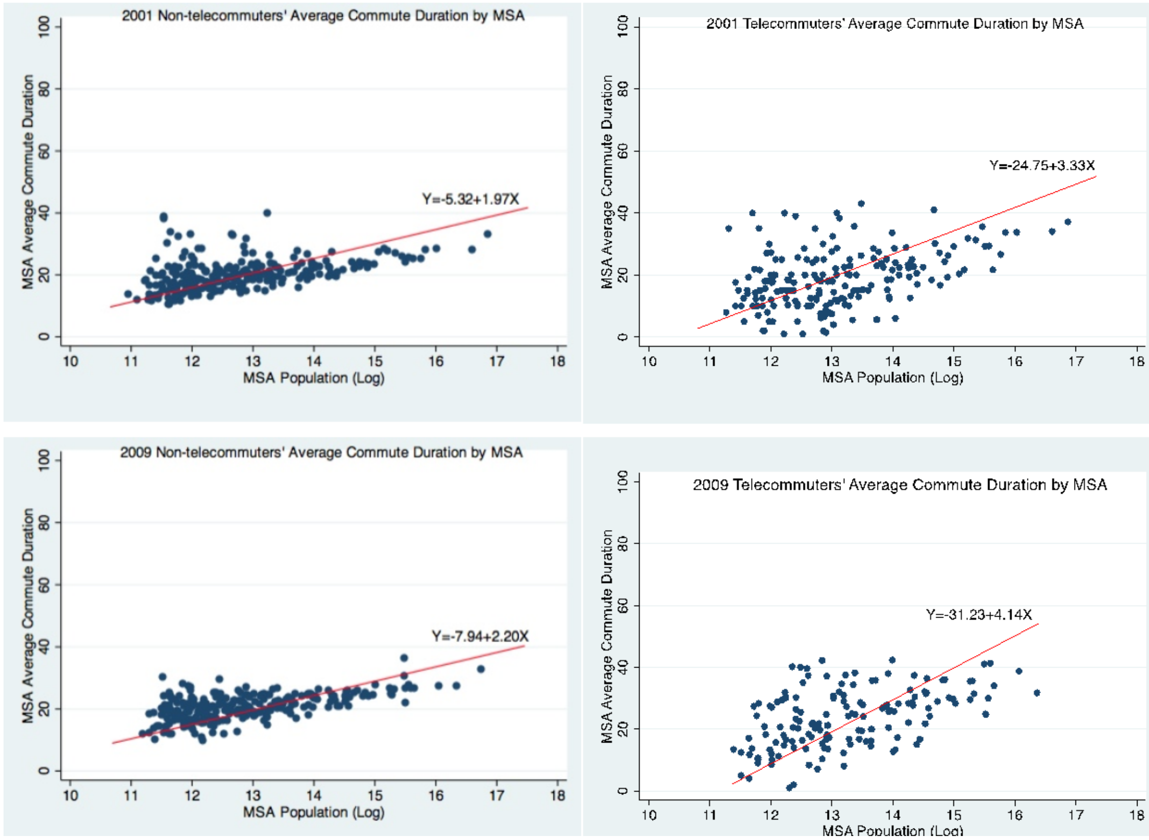
For one-way commute trips, the differences between telecommuters and non-telecommuters have been growing over the 2001-2009 period for the three MSA size groups, in terms of both distance and duration. In 2001, most telecommuters were able to bear greater time costs than non-telecommuters--significantly so for large metros (with a telecommuters/non-telecommuter ratio of 1.15). In terms of one-way commute distance, telecommuters, on average, had significantly[6] longer commute than non-telecommuters across all three MSA sizes in 2001, with a ratio of 1.15 in small MSAs, 1.41 in medium MSAs, and 1.30 in large MSAs. In 2009, telecommuters were able to accept significantly greater time costs than non-telecommuters in all three metro sizes and the ratios had increased and converged to about 1.29 for all three metro sizes. Meanwhile, telecommuters' one-way commute distance had also increased by a larger extent than non-telecommuters in all three metro sizes, with a telecommuters/non-telecommuter ratio of 1.71 in small MSAs in 2009, 1.47 in medium MSAs, and 1.47 in large MSA. Apparently, telecommuters on average chose longer one-way commute distance and duration than non-telecommuters across all three MSA sizes in both years. However, the telecommuters/non-telecommuter ratios do not support that the impact of telecommuting on one-way commute is higher in larger MSAs. In Section 4, we will control for other individual and household characteristics to see whether these results will change.

Next, we create several scatter plots in Figure 1 to demonstrate the relations among MSA average commute duration, telecommuting status and MSA population size, based

[6] Statistical significance are based on two-tailed mean-comparison tests (t-test) at the 95% confidence level

on data from the 2001 and 2009 NHTS. The straight line in each graph represents the simple regression of MSA average commute duration (for telecommuters and non-telecommuters separately) on MSA population (log). For both years, the comparisons between the left and the right graphs shows that telecommuters' MSA-level average commute duration increased with the MSA size at a much faster rate than non-telecommuters (as indicated by the larger slope for telecommuters compared with non-telecommuters). As a result, the gap between telecommuters and non-telecommuters became larger as the MSA grew bigger. From these scatter plots and simple regressions, we speculate that the impact of telecommuting on commute trip (duration) might be higher in larger MSAs. But to what extent the choice of telecommuting itself accounts for this difference (after controlling for other factors) requires more detailed tests.

Figure 1 Scatter Plot for MSA Average One-way Commute Duration (by Telecommuting Status) and MSA Size




## 3. Research Methodology

In order to understand the MSA size differences in the impact of telecommuting on personal travel, the national sample is first confined to those workers who resided within an MSA and then stratified into three classes based on the residing MSA population size: small MSAs (less than 1 million), medium MSAs (1-3 millions), large MSAs (over 3 millions).[7] This study compares the one-way commute distance and duration between telecommuters and non-telecommuters in all three MSA sizes. It also investigates how the status of telecommuting affects workers' daily total work trips and daily total

[7] Our current grouping is commonly used by many other empirical studies to define small (<1 million), medium (1-3 million), and large (>3 million) MSAs in the U.S. During our analyses, we have also tested other groupings, such as {<0.5 million, 0.5-3 million, >3 million} and {<1 million, 1-2 million, >2 million}. The coefficient estimates are slightly different, but they do not change our conclusions in any significant ways.

non-work trips (in terms of distance, duration and frequency) across different MSA sizes.

### 3.1 Baseline model specification and variables

Based on activity-based approaches (e.g. Fox, 1995; Nelson and Niles, 2000; Strathman, Dueker and Davis, 1994; Srinivasan and Ferreira, 2002; Zhu 2012, 2013), our baseline model attributes travel demand to individual demographics (e.g. age, sex, marital status, education, and occupation), household socioeconomic status (e.g. household income, presence of child, number of vehicles per driver in the household), and locational characteristics (e.g. place of residence in urbanized area or suburban area, percent renter-occupied homes at the block group level, population density at the block group level, MSA population). The variable of interest is a dummy variable that measures whether the worker is a telecommuter.

### 3.2 Addressing potential bias associated with one-way commute trip

As indicated earlier, this baseline model suffers a potential bias when analyzing the impact of telecommuting on one-way commute trip. The worker's choice to telecommute is potentially endogenous to the commute distance and duration. It is possible that a worker chooses to commute longer because he/she can telecommute, or the other way around, that longer commute gives the worker incentives to telecommute to avoid such lengthy commutes. Indeed, this endogeneity issue derived from the simultaneous choice of telecommuting and commute distance (or duration) could cause substantial biases in the estimations of the travel impact of telecommuting. This study applies an Instrumental Variable approach as an adjustment to the baseline model to address this possible endogeneity issue and investigate the causal effect of telecommuting on one-way commute distance and duration.

The instrumental variables used in the 2001 2SLS models are "internet use at home" (dummy) and "total number of phones available". Since the 2009 NHTS included a slightly changed questionnaire on internet usage, the instrumental variable used in the 2009 2SLS models is "frequently use internet" (dummy). Because the arrangement of telecommuting usually depends on electronic communications of some form, such as telephones, e-mail, and video-conferencing, these selected instrumental variables plausibly affect a worker's likelihood of telecommuting, but do not *directly* affect his/her commute distance or duration. The potential impact of these instrumental variables on commute distance is indirect at most, only through their impact on the propensity to telecommute. These reasons suggest these variables are viable as instruments for the telecommuting variable.

The choice of commute mode is also endogenous to the commute distance/duration. Commute mode affects commute distance and especially duration, but commute distance/duration could also alter a person's choice on commute mode. Since workers commuting by public transit or other modes (walking, bicycling) only accounted for a small percentage of all workers in both 2001 and 2009[8], the final sample in this section is restricted to be workers commuting by privately owned vehicles (POV) only.

### 3.3 Addressing potential bias associated with daily total work trips

When analyzing the impact of telecommuting on worker's daily total work trip (distance, duration and frequency), the worker's choice to telecommute is still potentially

[8] In 2001, workers commuted by POV, public transit, and other modes were 92.4%, 4.0%, and 3.7%, respectively. In 2009, the shares were 94.0% commuted by POV, 2.5% by public transit, and 3.5% by other modes.

endogenous, because the largest and most routine portion of most people's daily work trips is the commuting trip. The second bias is related to the fact that the randomly assigned date for the trip diary could be either a commuting day or a telecommuting day for telecommuters, as we discussed earlier. If we exclude those cases with zero total work trip distance or duration, we omitted the very people for whom telecommuting has the greatest impact. Therefore, we apply Instrumental Variable Tobit model (left-censored at 0) to not only include those cases with zero work travel but also address the endogeneity issue. Same instrumental variables are used as in previous session. In addition, we limit our sample in this session to workers whose trip diaries were recorded for a weekday, because many of them do not have work trips during weekends.

Using Tobit regression model to address censored data problem has been used in other travel behavior studies. For example, Kim et al. (2015) also used Tobit model to take into account the fact that Personal Kilometer Traveled (PKT) and Vehicle Kilometer Traveled (VKT) for different travel purposes would equal to zero if respondents do not travel for those specific purposes on the trip diary day. While Kim et al. (2015) used seemingly unrelated censored regression models to successfully control for the interdependence of travel demand between household members and that across travel purposes, it did not sufficiently address the endogeneity issue.[9] The distinctiveness of our methodology is that our Instrumental Variable Tobit model can simultaneously address the censored data problem and the endogeneity issue.

### 3.4 Addressing potential bias associated with daily total non-work trips

[9] Their argument was that the commute PKT in their models measured the actual commute distance traveled on the survey day and was different from those determined by locations of residence and workplace. Thus, they argued that the commute PKT is not suffering from endogeneity bias and hence justified its inclusion as one of the dependent variables.

When studying the impact of telecommuting on worker's daily total non-work trips, there is arguably no endogeneity problem associated with the telecommuting variable. In general, telecommuting needs a formal agreement between employers and employees. Theoretically, non-work trip distance, duration and frequency do not directly affect a worker's likelihood to telecommute because the amount of non-work trips does not justify the needs for telecommuting. In fact, for the daily total non-work trip models (for both 2001 and 2009), the Durbin-Wu-Hausman chi-square test and the difference-in-Sargan test were conducted and they both suggested that the specified endogenous regressor (telecommuting) should be treated as exogenous. However, the second bias would still exist when studying daily total non-work trips. Therefore, we apply left-censored Tobit models that include those cases with zero non-work travel to more accurately estimate the impact of telecommuting on daily total non-work trips (in terms of distance, duration and frequency). In addition, a dummy variable is added to indicate whether the recorded trip day is a weekend.

## 4. Model Results

### 4.1 Worker's One-way Commute Distance and Duration

2SLS models are first estimated to address the endogeneity bias and examine the impact of telecommuting on workers' one-way commute distance and duration, taking into account their demographics, household socioeconomic status, and locational attributes. Table 2 presents 2SLS results for 2001, with Models (1) and (2) presenting the group of small MSAs, Models (3) and (4) presenting the group of medium MSAs, Models (5) and (6) presenting the group of large MSAs. Correspondingly, Table 3 reports 2SLS results for 2009.

<Tables 2 and 3 about here>

Of interest to this study is the different role of telecommuting in affecting workers' one-way commute trips across different MSA sizes. In 2001, telecommuting had significant positive impact on workers' one-way commute distance in small and medium MSAs; in 2009, telecommuting had significant and positive impact for all three MSA sizes. These results suggest that telecommuting was a complement to one-way commute trips across different MSA sizes in both years. Everything else being equal, telecommuters tend to commute longer distances on days they do go to work.

Since we estimate the same models for 2001 and 2009, it is possible to compare the impact of telecommuting on workers' one-way commute distance and duration over the years by MSA sizes. In 2001, the impact of telecommuting on commute distance was substantially higher in small MSAs than in medium MSAs,[10] while this impact in large MSAs was insignificant.[11] Over the 2001-2009 period, the impact of telecommuting on one-way commute distance in small, medium and large MSAs had all increased substantially, and the impact on commute duration had also increased significantly in large MSAs. As a result, in 2009, the impact of telecommuting on commute distance was the largest in small MSAs, followed by medium and large MSAs.[12] It is also noteworthy

---

[10] To compare the coefficient estimates from two subsamples (i.e. small MSAs vs. medium MSAs in this case), we applied the procedures as suggested in Wooldridge (2000, pp. 243-246 and pp. 449-450). Specifically, we adopted a fully interacted model that uses interaction terms to "pool" the subsamples and convert the separate models/equations into one giant equation. For the rest of our discussions, we apply the same technique to compare the magnitude of the impact across different MSA categories (i.e. small vs. medium vs. large).

[11] For the purpose of discussion, if the impact is statistically insignificant, we treat it as having 0 impact.

[12] The impact of telecommuting on commute distance in large MSAs was not statistically different from that in

that this impact in large MSAs had experienced the most substantial increase over time, as it was insignificant in 2001. It suggests those telecommuters in larger MSAs have chosen to live further away from their places of work over this time period, at a faster pace than those telecommuters in smaller MSAs.

Among workers' demographic characteristics, the 2SLS model results are consistent across all three MSA sizes in both 2001 and 2009. Male workers consistently reported significantly longer one-way commute in all MSA sizes for both years, whereas younger workers and those who had medical conditions generally reported shorted commute. Workers with higher education consistently had longer commute distances and durations in all MSA sizes. In terms of worker's occupation, it seems that, across different MSA sizes, people working in the Sales or Service occupations tended to have shorter one-way commute distance and duration than those working in the manufacturing, construction, or maintenance occupations. Clerical or Administrative workers in both small and large MSAs experienced shorter commutes than those working in the manufacturing, construction, or maintenance occupations. Similarly, professional, managerial or technical workers in small MSAs also had shorter commutes than manufacturing, construction, or maintenance workers.

Among household socioeconomic attributes, workers from households with children tended to have longer one-way commutes in small and medium MSAs in 2009. Longer commutes were also found to be consistently associated with higher household total income and greater number of vehicles per driver across all MSA sizes in both years.

---

medium MSAs in 2009, based on our test of equality of coefficient estimates.

Among household location characteristics, workers residing in the suburbs (omitted category in the models) consistently experienced longer one-way commute distance and duration than those living in urbanized areas in both years, regardless of the size of MSAs. If the worker resided in a neighborhood (measured as block groups in NHTS) with higher percentage of renters versus homeowners, he/she would have shorter commutes across all three MSA sizes. If the worker resided in a neighborhood with higher population density, his/her commute distance and duration also tend to be shorter. These findings suggest the benefits of mixed housing and high density in terms of reducing commute, which corroborate many other empirical studies (e.g. Zhu, et. al. 2013).

To provide some corroboration to our 2SLS model results, we have conducted several important tests. First, the Wu-Hausman F test, Durbin-Wu-Hausman chi-sq test, and the C or “difference-in-Sargan" test all suggested rejecting the null hypothesis that the specified endogenous regressor (telecommuting in this case) can be treated as exogenous. These tests confirm the existence of endogeneity bias and justify the use of 2SLS models.

Second, to address weak or invalid instruments that often lead to measurement errors in the endogenous regressor (Bound et al. 1995; Hall et al. 1996; Greene 1997; Staiger and Stock 1997), we have also tested the relevance of these instruments after running the first stage regressions for both 2001 and 2009. The results of the first stage regressions are presented in Appendix 1. The simple t-statistic and F-statistic from the first stage regression show that these instruments are statistically significant for all MSA sizes. As suggested in Stock (2010), the F-statistic is a simple yet sufficient tool to infer the weakness of instruments. Our F-statistics are all greater than 10, suggesting that the instruments are sufficiently strong and the usual 2SLS output can be accepted. In addition, IV redundancy test (LM test of redundancy of specified instruments), the Bound-Jaeger-Baker F statistics (see Bound et al., 1995), and “partial $R^2$” measures (see Shea 1997) all suggest that the selected instruments are relevant for all models (any MSA sizes and any year).

Third, we used limited information maximum likelihood (LIML) estimation method in a two-stage context. LIML estimation method usually has better performance than 2SLS when instruments are weak (Stock 2010). The results of LIML are very similar to 2SLS for all MSA sizes and for both years. All these tests and robustness checks suggest that the 2SLS models are able to address the possible endogeneity bias and provide more plausible coefficient estimates for the instrumented telecommuting variable.

**4.2 Worker’s Daily Total Work Trips**

Previous analyses provide a good understanding on how telecommuting affects workers’ one-way commute distance and duration. However, telecommuters sometimes work at home and thus do not have commuting trips. To take into account telecommuters’ different travel behaviors in telecommuting days and commuting days, we further investigate workers’ daily total work trips, using the randomly assigned one-day trip diary from the national sample. As discussed earlier, the IV Tobit models applied in this session have two advantages: 1) take into account the fact that the randomly assigned date for the trip diary could be either a commuting day or a telecommuting day for telecommuters; 2) address the endogeneity bias associated with telecommuting variable. Tables 4 and 5 present the IV Tobit regression results on how the status of telecommuting affects worker's daily total work trip distance, duration, and frequency across different MSA sizes in 2001 and 2009.

<Tables 4 and 5 about here>

For all models, the effects of various control variables on daily total work trip distance, duration and frequency are consistent with our expectations. Across all three MSA sizes, older workers had longer (in terms of total trip duration) and more frequent daily work trips in 2001; male workers and highly educated workers generally had longer (in terms of total trip distance as well as duration) and more frequent daily work trips; medical condition consistently reduced daily total work trip distance, duration and frequency in both years. In all MSA sizes, residents in urbanized areas consistently had shorter (in terms of total distance and duration) daily work trips than suburban residents but the frequency was not statistically different. Workers in neighborhoods with higher population density tended to have shorter total work trips.

The variable of interest—the telecommuting dummy variable—had positive impact on daily total work trip distance for almost all three MSA sizes in both 2001 and 2009.[13] The positive impact on daily total work trip duration and frequency was also mostly significant across three MSA sizes in 2009. These results indicate that, across all MSA sizes and over time, telecommuters generally had more frequent and longer daily work trips than non-telecommuters, after controlling for other factors (such as age, gender,

[13] The impact was insignificant in medium MSAs in 2001.

place of residence, etc.). This is not surprising because telecommuters are more flexible with their time and more likely to schedule other work-related trips than non-telecommuters. The reason might also be that workers with a telecommuting option choose to live in locations that are relatively farther away from their various work trip destinations (e.g. workplace, clients, business partners, etc.).

Note that the complementary impact of telecommuting on daily total work trip distance, duration and frequency had substantially increased over the 2001-2009 period. In 2001, telecommuting had the highest impact on daily total work trip distance in small MSAs, and its impact on duration was insignificant in any of the three MSA sizes. By 2009, the impact on distance, duration and frequency all substantially increased and became statistically significant across almost all MSA sizes. However, large MSAs did not experience the highest rate of increase in terms of the impact. For example, the effect of telecommuting on daily work trip distance increased 49.0% from 2001 to 2009 for large MSAs, whereas this effect increased 82.1% for small MSAs over the same period of time. As a result, the impact of telecommuting on daily total work trip distance, duration and frequency remained the lowest in large MSAs in 2009. These findings suggest that the complementary impact of telecommuting on daily total work trips is actually lower in larger MSAs.

In previous section, we found that the impact of telecommuting on one-way commute trips increases at a faster rate in larger MSAs than in smaller MSAs over time and it becomes highest in large MSAs by 2009. One-way commute trip is a simple measure of the distance between the work’s home and workplace. It does not take into account the fact that the commuting trips might be forgone for a telecommuter in a telecommuting day. In this section, we analyze workers' daily total work trips, which include those telecommuters who recorded their trip diary in their telecommuting days and thus had 0 commuting trips. Interestingly, we found no evidence to suggest that the complementary impact of telecommuting on daily total work trips was higher in larger MSAs in either 2001 or 2009, nor did it grow at a faster rate in larger MSAs over time. One possible explanation is that, for telecommuters, the commuting trip savings during those telecommuting days might be more sizable in larger MSAs than in smaller MSAs. Although the difference in one-way commute trips between telecommuters and non-telecommuters is bigger in larger MSAs, this bigger difference could be counteracted more by the slightly higher telecommuting frequency in larger MSAs where telecommuting policies are more popular. Future data that provides the telecommuting frequency in different MSA sizes would be very useful to test this explanation. Another explanation could be that, in smaller MSAs, businesses (and their clients) are closer to each other and telecommuters are more likely to conduct work-related business trips in those telecommuting days, compared with in larger MSAs.

### 4.3 Worker's Daily Total Non-work Trips

Non-work trips are another important element of workers' daily personal travel. To provide a more comprehensive understanding of how telecommuting affects personal travel, this section investigates how the impact on worker's daily total non-work trips differs across three different MSA sizes. As discussed earlier, we apply left-censored Tobit models which include those cases with 0 non-work travel. Tables 6 and 7 present the Tobit model results for worker’s non-work trips in 2001 and 2009.

< Tables 6 and 7 about here>

All coefficient estimates of the control variables are consistent with expectations. Across all three MSA sizes, female workers, highly educated workers or workers from higher income consistently had longer (in terms of both trip distance and duration) and more frequent non-work trips in both 2001 and 2009. Compared with suburban residents, those living in an urbanized area involved shorter non-work trip distance but longer duration and higher frequency for most MSA sizes in both years. “Weekend” had a significant and positive effect on non-work trip distance, duration and frequency across all MSA sizes.

The variable of interest—the telecommuting dummy variable—consistently had positive impact on worker’s daily total non-work trip distance, duration and frequency across all MSA sizes in both 2001 and 2009. These results indicate that, across all MSA sizes and over time, telecommuters consistently experienced longer and more frequent daily non-work trips than non-telecommuters, after holding constant other factors. This finding suggests that telecommuters are more likely to choose to live in locations that are also relatively farther away from various non-work trip destinations (e.g. grocery stores, shopping malls, medical services, schools, churches, etc.). It also suggests that telecommuters are more flexible with their time than non-telecommuters, and that they tend to conduct more and longer non-work trips if they are able to work at home. These results are in line with the findings of many other empirical studies (e.g. He and Hu 2015; Kim, Choo and Mokhtarian 2015; Zhu 2012).

In 2001, the complementary effects of telecommuting on daily total non-work trip distance and duration were significantly higher in medium MSAs compared to large MSAs or small MSAs.[14] Over the 2001-2009 period, the complementary impact of telecommuting on daily total non-work trip distance, duration and frequency was significantly decreased in medium MSAs but only slightly attenuated in large MSAs. As a result, the impact of telecommuting on daily total non-work trips converged a little bit across three MSA sizes in 2009. However, in 2009, the impact of telecommuting on non-work trip distance in medium MSAs was still substantially higher than in large MSAs. These findings suggest that, similar to daily work trips, the complementary impact of telecommuting on daily total non-work trips is also lower in larger MSAs. We suspect this is because things are closer to each other in smaller MSAs, which potentially encourages telecommuters to conduct more non-work trips in those telecommuting days, compared with in larger MSAs.

## 5. Conclusions

This paper studies the MSA size differences in the impact of telecommuting on personal travel. It is primarily devoted to test 1) whether telecommuting is consistently a complement to personal travel across different MSA sizes and 2) whether the impact of telecommuting is higher in larger MSAs where telecommuting programs and policies are more widely adopted. The models we applied address two empirical challenges: 1) solving endogeneity issues associated with the telecommuting variable when studying

[14] We compared coefficient estimates from different subsamples using the technique as explained in previous footnote 10.

one-way commute trips and daily total work trips; 2) taking into account telecommuters' different travel behaviors in telecommuting days and commuting days when studying workers' daily work and non-work trips.

We found, across all different MSA sizes, telecommuting consistently had a significant and complementary impact on worker's one-way commute trips, daily total work trips and daily total non-work trips in both 2001 and 2009. No matter the size of the MSA in which they live, telecommuters tend to choose lifestyles involving longer one-way commute, longer daily total work trips and longer daily total non-work trips than non-telecommuters, other thing being equal (such as place of residence, age, gender, etc.). This is not surprising as telecommuting enables these workers to be more footloose and to live in locations that are relatively farther away from many work and non-work destinations, including their jobs, clients, business partners, grocery stores, shopping malls, medical services, schools, churches, etc. More importantly, the facts that telecommuters have been found to have longer daily total work trips and longer daily total non-work trips than non-telecommuters across all MSA sizes indicate that telecommuters, despite the geographic context they reside in, generally have a larger "travel budget" than their counterparts. In this regard, policies that promote telecommuting may indeed increase, rather than decrease, people's travel demand, regardless of the size of the MSA. This seems to contradict to what telecommuting policies are designed for.

We also found that the complementary impact of telecommuting on one-way commute distance and duration grows faster in larger MSAs than in smaller MSAs over the 2001-2009 period, suggesting telecommuters in larger MSAs have been chosing to live further away from their workplace at a pace that is faster than telecommuters in smaller MSAs. But there seems to be no evidence to support that the complementary impact of telecommuting on daily total work trips had the same trend (i.e. faster rate of increase in larger MSAs than in smaller MSAs). Note that our daily work trip models included telecommuters in their telecommuting days, telecommuters in their non-telecommuting days, and non-telecommuters in any workdays. Taking into account the commuting trip savings of telecommuters in their telecommuting days, the complementary impact of telecommuting on daily total work trips was lower in larger MSAs than in smaller MSAs in both 2001 and 2009, and it grew at a slower rate in larger MSAs compared to smaller MSAs over time. It appears that, in larger MSAs where telecommuting has been more widely adopted, the much longer one-way commute distance of telecommuters versus non-telecommuters was more counteracted by the higher frequency of telecommuting. This cautions us that, in order to make telecommuting policies effective (from the perspective of reducing travel demand), we need to make sure the benefit of reduced commuting frequency exceeds the cost of increased one-way commute distance from the re-location of telecommuters. In this sense, planning is an essential tool to enhance the amenities and attractiveness of inner city residential locations so that telecommuters do not necessarily choose to relocate to more remote locations when they become more footloose.

Similar to daily total work trips, the complimentary impact of telecommuting on daily total non-work trips was also lower in large MSAs than in medium MSAs. Our explanation is that, in smaller MSAs, things are closer to each other and telecommuters are thus incentivized to conduct more work-related business trips as well as more non-work trips in those telecommuting days. To better test this explanation, we need to investigate MSAs with different density, or more accurately, different spatial structure. Maybe the magnitude of the impact of telecommuting is more affected by the spatial structure of the MSA, rather than its population size. Future research could examine how the spatial structures of MSAs may influence the magnitude of the impact of telecommuting on personal travel, through a comparison of two types of MSAs with different spatial structure: more “dispersed” MSAs such as Los Angeles versus more “compact” MSAs such as New York. According to Lee (2006), New York had 21.2 percent of employment located in its main center in 2000, 7.7 percent of employment located in its 24 sub-centers, and 71.1 percent of employment in dispersed locations. Correspondingly, Los Angeles only had 12.2 percent of employment located in its CBD in 2000, 21.2 percent in its 36 sub-centers, and 66.6 percent in dispersed locations. It would be interesting to test whether a more decentralized spatial structure would be associated with a smaller impact of telecommuting on personal travel in future research.

Last but not least, although our findings corroborate that telecommuting has a complementary effect on travel demand across all MSA sizes, it is still premature to claim that policies proposing telecommuting as part of the travel demand management (TDM) programs to reduce travel would completely fail. Along the substitution and complementary effects, attentions have moved to modification effects--mainly, the way telecommuting changes and modifies travel patterns. Research have suggested a shifting from motorized to non-motorized travel modes due to telecommuting (Mokhtarian 1991; Lachapelle and Tanguay, working paper). In addition, telecommuting could potentially relieve peak-hour congestion, since telecommuters could change the timing of their commuting trips even if they do commute (Mokhtarian et al., 1995; Olszewski and Mokhtarian, 1994, 1998; Pendyala et al., 1991). Finally, telecommuting could result in better trip chaining where telecommuters intentionally combine multiple activities on a single trip because of their flexible schedule (Mokhtarian, 1991; Mokhtarian et al., 2004). The societal, environmental and economic effects of these modifications are substantial and deserve more attention in future research.

## References


Anas, A. 2011. Discovering the efficiency of urban sprawl. In *Handbook of Urban Economics and Planning*, eds. N. Brooks, K. Donaghy, and G. Knaap, Chapter 4. Oxford: Oxford University Press.

Balepur, P., K. Varma, and P. Mokhtarian. 1998. Transportation impacts of center-based telecommuting: Interim findings from the Neighborhood Tele-centers Project. *Transportation*, 25(3):287–306.

Bound J, Jaeger DA, Baker RM (1995) Problems with instrumental variables estimation when the correlation between the instruments and the endogenous explanatory variable is weak. *Journal of the American Statistical Association 90*(430):443-450

Bris, M., Pawlak, J. and Polak, J.W. (2017) How is ICT use linked to household transport expenditure? A cross-national macro analysis of the influence of home broadband access. *Journal of Transport Geography*, 60:231-242.

Brückner, M. (2011) An Instrumental Variables Approach to Estimating Tax Revenue Elasticities: Evidence from Sub-Saharan Africa. Extracted on May 28 from http://www.economics.adelaide.edu.au/research/papers/doc/wp2011-09.pdf

Cairncross F (1997) *The death of distance: How the communications revolution will change our lives?* Harvard Business School Press, Boston

Cao, X. (2009) E-shopping, spatial attributes, and personal travel: a review of empirical studies. *Transportation Research Record Journal of Transportation Research Board* 2135, 160–169

Cao, X., Douma, F., Cleaveland, F. (2010) The influence of e-shopping on shopping travel: evidence from Twin Cities. *Transportation Research Record Journal of Transportation Research Board* 2157, 147–154

Cao, X., Mokhtarian, P. (2005) The Intended and Actual Adoption of Online Purchasing: A Brief Review of Recent Literature. Institute of Transportation Studies, University of California, Davis

Cao, X., Xu, Z., Douma, F. (2012) The interactions between e-shopping and traditional in-store shopping: an application of structural equations model. *Transportation* 39(5): 957–974.

Choo, S. and Mokhtarian, P. L. (2007). Telecommunications and travel demand and supply: Aggregate structural equation models for the US. *Transportation Research Part A*, 41:4–18

Choo S, Mokhtarian PL, Salomon I (2005) Does telecommuting reduce vehicle-miles traveled? An aggregate time series analysis for the U.S. *Transportation* 32(1):37-64

Community Planning Workshop (2003). Oregon Office of Energy's telework program evaluation. Extracted on August 08, 2010 from https://scholarsbank.uoregon.edu/xmlui/handle/1794/10687

Evans, W.N. and Garthwaite, C. (2010) Estimating Heterogeneity in the Benefits of Medical Treatment Intensity. Extracted on May 28 from http://www.kellogg.northwestern.edu/faculty/garthwaite/htm/paper_draft_heterogeneity.pdf

Evans, W.N., Garthwaite, C. and Wei, H. (2008) "The Impact of Early Discharge Laws on the Health of Newborns," *Journal of Health Economics* 27(4): 843-870.

Fox M (1995) Transport planning and the human activity approach. *Journal of Transport Geography* 3(2):105-116

Gareis K (2003) Home-based versus mobile telework: The interrelationships between different types of telework. In: Jackson P, Rapp B (ed) *Organisation and work beyond 2000*. Springer-Verlag, Berlin, pp 171-185

Glaeser, E.L. (1998). Are cities dying? *Journal of Economic Perspectives*, 12(2):139-160.

Glaeser, E.L. and Kahn, M. (2001). Decentralized employment and the transformation of the American city. *Brookings-Wharton Papers on Urban Affair,* 2(1):64.

Glaeser E.L. and Kohlhase, J.E. (2004) Cities, regions and the decline of transport costs. *Papers in Regional Science 83*(1):197-228

Glaeser, E.L. (2011) *Triumph of the City*. Penguin Books, New York.

Graham S, Marvin S (2000) Urban planning and the technological future of cities. In: Wheeler JO, Aoyama Y, Warf B (ed) *Cities in the telecommunication age*. Routledge, New York, pp 71-96

Greene WH (1997) *Econometric Analysis, 3rd edition*. Prentice Hall, Upper Saddle River, NJ

Hall AR, Rudebusch GD, Wilcox DW (1996) Judging instrument relevance in instrumental variables estimation. *International Economic Review* 37(2):283-298

Hamer R, Kroes E, Ooststroom H (1991) Teleworking in the Netherlands: an evaluation of changes in travel behavior. *Transportation* 18(4) 365-382

Handy SL, Mokhtarian PL (1995) Planning for telecommuting: Measurement and policy issues. *Journal of the American Planning Association 61*(1):99-111

Heckman JJ, MaCurdy TE (1985) A Simultaneous Equations Linear Probability Model. *Canadian Journal of Economics* 18(1):28-37

Helminen, V. and Ristimäki, M. (2007) Relationships between commuting distance, frequency and telework in Finland. *Journal of Transport Geography.* 15(5):331–342.

Janelle DG (1986) Metropolitan expansion and the communications– transportation trade-off. In: Hanson S (ed) *The geography of urban transportation*. The Guilford Press, New York, pp 357-385

Jiang Y (2008) *Two empirical essays in environmental and urban economics*. Ph.D. Dissertation, University of Maryland

Kim, S.-N. (2016). Two traditional questions on the relationships between telecommuting, job and residential location, and household travel: revisited using a path analysis. *The Annals of Regional Science*, 56(2), 537-563.

Kim, S.-N. (2017). Is Telecommuting Sustainable? An Alternative Approach to Estimating the Impact of Home-based Telecommuting on Household Travel. *International Journal of Sustainable Transportation*, 11(2), 72-85.

Kim, S.-N., Choo, S., & Mokhtarian, P. L. (2015). Home-based telecommuting and intra-household interactions in work and non-work travel: A seemingly unrelated censored regression approach. *Transportation Research Part A: Policy and Practice,* 80, 197-214.

Knoke W (1996) *Bold new world: The essential road map to the twenty-first century.* Kodansha International, New York

Lachapelle, U., Tanguay, G.A., and Neumark-Gaudet, Lea. (working paper) Downloaded on May 13, 2017 from https://www.researchgate.net/publication/316458929_Telecommuting_and_sustainable_travel_Reduction_of_overall_travel_time_increases_in_non-motorized_travel_and_congestion_relief

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

Leamer EE, Storper M (2001) The economic geography of the internet age. *Journal of International Business Studies 32*(4):641-666

Lee, B. (2006). Urban Spatial Structure and Commuting in US Metropolitan Areas. Conference Paper. Western Regional Science Association 45th Annual Meeting.

Lopez, R. and Hynes, H. P. (2003). Sprawl in the 1990s: Measurement, distribution, and trends. *Urban Affairs Review*, 38(3), 325–355.

Mateyka, P.J., Rapino, M.A. and Landivar, L.C. (2012). Home-based workers in the United States: 2010. *Current Population Reports*, 70-132.

Mitchell WJ (2000) *E-topia: "Urban life, Jim—but not as we know it"*. MIT Press, Cambridge, MA

Mokhtarian PL (1998) A synthetic approach to estimating the impacts of telecommuting on travel. *Urban Studies 35*(2):215-41

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*(10):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 A 29*(4):283-302

Mokhtarian PL, Ho CI, Hung SW, Lam TB, Raney EA, Redmond LS et al (1997) *Residential area-based offices project: Final report on the evaluation of impacts.* No. Research Report UCD-ITS-RR-97-17). Institute of Transportation Studies, University of California, Davis

Muhammad, S., Ottens, H.F.L., Ettema, D., Jong, T., 2007. Telecommuting and residential locational preferences: a case study of the Netherlands. *Journal of Housing and Built Environment.* 22 (4), 339–358.

NAE (1969) *Telecommunications for enhanced metropolitan function and form: report to the director of Telecommunications Management*. National Academy of Engineering

Naisbitt J (1984) *Megatrends: Ten new directions transforming our lives.* Warner, New York

Naisbitt R (1995) *The global paradox.* Avon Books, New York

Negroponte N (1995) *Being digital.* Vintage Books, New York

Nelson D, Niles J (2000) Observations on the causes of nonwork travel growth. *Transportation Research Board Paper*. No. 00-1232, 79th Annual Meeting, January 9-13

Nelson, P., Safirova, E. and Walls, M. (2007). Telecommuting and environmental policy: Lessons from the ecommute program. *Transportation Research Part D* 12(3): 195-207.

Niles JS (1994) *Beyond telecommuting: A new paradigm for the effect of telecommunications on travel.* Prepared for the US Department of Energy, Offices of Energy Research and Scientific Computing, Washington, DC 20585, Report No. DOE/ER-0626), September

Nilles, JM, et al., Telecommuting - Alternative to Urban Transportation Congestion. *Ieee Transactions on Systems Man and Cybernetics*, Vol. 6(2), 1976, pp. 77-84.

Ory DT, Mokhtarian PL (2005) *The impact of telecommuting on the commute time, distance, and speed of state of California workers.* Extracted from http://repositories.cdlib.org/itsdavis/UCD-ITS-RR-05-23 on April 02, 2009

Ory DT, Mokhtarian PL (2006) Which came first, the telecommuting or the residential relocation? An empirical analysis of causality. *Urban Geography* 27(7):590-609

Pagan AR, Hall D (1983) Diagnostic tests as residual analysis. *Econometric Reviews* 2:159-218

Papke, L.E. (2004). Choice and Other Determinants of Employee Contributions to Defined Contribution Plans. Extracted on May 28 from https://www.msu.edu/~ec/faculty/papke/SSBulletin.vr3.pdf

Pascal A (1987) The vanishing city. *Urban Studies 24*:597–603

Rietveld, P. (2011). Telework and the transition to lower energy use in transport: On the relevance of rebound effects. *Environmental Innovation and Societal Transitions* 1(1): 146-151.

Salomon I (1986) Telecommunications and travel: A review. *Transport Research A* 20:223–238

Salomon, I (1998) Technological change and social forecasting: the case of telecommuting as a travel substitute. *Transportation Research Part C-Emerging Technologies*, 6(1-2):17-45.

Shea J (1997) Instrument relevance in multivariate linear models: A simple measure. *The Review of Economics and Statistics* 79:348-352

Sinai T, Waldfogel J (2004) Geography and the internet: Is the internet a substitute or a complement for cities? *Journal of Urban Economics 56*(1):1-24

Staiger D, Stock JH (1997) Instrumental variables regression with weak instruments. *Econometrica* 65(3):557-586

Stock JH (2010) The other transformation in econometric practice: robust tools for inference. *Journal of Economic Perspectives* 24(2):83-94

Storper M, Manville M (2006) Behaviour, preferences and cities: Urban theory and urban resurgence. *Urban Studies 43*(8):1247-1274

Strathman JG, Dueker KJ, Davis JS (1994) Effects of household structure and selected travel characteristics on trip chaining. *Transportation 21*:23-45

Toffler A (1981) *The third wave.* William Morrow, New York

Webber, M.M. (1963) Order in diversity: Community without propinquity. In: Wingo L (ed) *Cities and space: The future use of urban land*. Johns Hopkins Press, Baltimore, MD, pp 25–54

Webber, M.M. (1996) Tenacious cities. *Proceedings of the NCGIA-Sponsored Research Conference on Spatial Technologies, Geographic Information, and the City*, 214–218

Webber MM (1968) The post-city age. *Daedalus 97(4)*:1091–1110

Wooldridge, J.M. (2000) *Introductory Econometrics: A Modern Approach*. Cincinnati, OH: South-Western

Wooldridge, J.M. (2002) *Econometric Analysis of Cross Section and Panel Data.* Cambridge, MIT Press. pp 623-625.

Zhu, P. (2011) *Telecommuting, travel behavior and residential location choice: Can telecommuting be an effective policy to reduce travel demand?* Ph.D. Dissertation, University of Southern California

Zhu, P. (2012) Are telecommuting and personal travel complements or substitutes? *Annals of Regional Science* 48(2): 619-639

Zhu, Pengyu (2013). Telecommuting, Household Commute and Location Choice. *Urban Studies*. 50(12), 2441–2459.

Zhu, Pengyu, Hongwei Dong and Cifang Wu* (2013). Do residents of smart growth neighborhoods in Los Angeles travel "smarter"? *Transportation Research Record: Journal of the Transportation Research Board*. 2397: 61-71.