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Telecommuting, Household Commute and Location Choice

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Abstract

Previous empirical studies have made contributions to the understanding of the impact of telecommuting on individual travel patterns. There has been much less research that has examined the impact of telecommuting on commute travel at the household level. Using data from the 2001 and 2009 US National Household Travel Surveys, this study focuses on one-worker and two-worker households and investigates how telecommuting affects household one-way commute distance and duration. The results show that telecommuting increases the commute distance and duration for both one-worker households and two-worker households. It is also found that, in two-worker households, the telecommuting status of one worker does not increase the commute distance and duration of the other worker. These findings suggest that telecommuting (two-worker) households tend to choose locations involving a longer total one-way commute than non-telecommuting households, and this difference is largely due to the longer commute of their telecommuting members.

1. Introduction

Over the past 30 years, interest among urban planners and urban economists has incorporated discussions of information and communications technology (ICT) and its relationship to urban form. Futurists predicted the dissolution of traditional cities as progress in ICT eliminates the need for face-to-face communications (for example, Webber, 1963, 1968; Toffler, 1981; Naisbitt, 1984, 1995; Pascal, 1987; Negroponte, 1995; Knoke, 1996; Cairncross, 1997). Despite some distance-lubricating effects of modern ICT, cities are not disappearing. Instead, cities are evolving, as various agglomeration benefits (for example, labour market pooling, knowledge spillovers) continue to contribute to sustaining cities (Webber, 1996; Glaeser and Kohlhase, 2004; Storper and Leamer, 2001).

Given that the broad adoption of new ICT has dramatically lowered interaction costs, it appears intuitive that these changes

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should have identifiable and significant implications for travel patterns and perhaps urban form. Empirical work to date has mostly focused on the impact of telecommuting (as a specialised use of ICT) on travel behaviour at the individual level. They have found that telecommuters live further from their jobs than non-telecommuters and have suggested that telecommuting tends to increase the individual worker's one-way commute (for example, Nilles, 1991; Mokhtarian *et al.*, 1995, 1997, 2004; Handy and Mokhtarian, 1995; Mokhtarian, 1998; Salomon, 1998; Gareis, 2003; Choo *et al.*, 2005; Ory and Mokhtarian, 2005, 2006; Jiang, 2008; Zhu, 2011, 2012). Other studies have sought to understand the implications of the emerging work arrangements (i.e. telecommuting, work-at-home) on household residential location choice (for example, Nilles, 1991; Ellen and Hempstead, 2002; Tayyaran *et al.*, 2003; Andrey *et al.*, 2004; Moos *et al.*, 2006; Moos and Skaburskis, 2007, 2008, 2010). Although household residential location could allow inferences on household commuting patterns, research that has directly examined the impact of telecommuting on commute travel at the household level has been sparse.

Each of us has many priorities. We make complex trade-offs as we make choices. In a family, this is even more complex than for a solo individual. Individual choice of location involves commuting as well as an array of access choices. The neo-classical urban economics model assumes that individual workers face a trade-off between housing and commute costs when making their residential location choice (Alonso, 1960, 1964; Mills, 1967, 1972; Muth, 1969). In a family with more than one worker, the choice of location involves more complex trade-offs that take into account more than one commute.

Telecommuting alters commute frequency. Since individual workers are 'footloose', it is logical that telecommuting could change their residential locations and rebalance the consumption of a bundle of goods, such as travel, housing, land and amenity. Yet for households, location choice is often based on the travel needs of more than one family member. If one member is telecommuting or expected to telecommute, the household could choose to move to a residence that is closer to the other working member's workplace to reduce his/her commute. Will telecommuting, on net, increase or decrease the household's total one-way commute? This paper examines the impact of telecommuting on household commuting patterns as a way to shed light on the possible influence of telecommuting on household location choice and perhaps urban form.

Although previous empirical studies have made contributions to the understanding of the impact of telecommuting on individual travel patterns, most of them have not examined how telecommuting alters the commuting patterns of other (non-telecommuting) household members or the total commute of the household. Individual travel patterns are determined by their residential location and the residential location decision is based on the utility of the entire household, not just an individual member. The importance of collective decision-making mechanisms in household behaviour has been recognised since the 1980s in the context of activity-based approaches (for example, Fox, 1995; Srinivasan and Ferreira, 2002; Plaut, 2006; Kato and Matsumoto, 2009; Timmermans and Zhang, 2009; Zhang *et al.*, 2009). The residential location choice of a household is largely dependent on all its workers' commuting costs (distance and time), other things being equal (such as housing price). A one-worker household predominantly considers one member's commute in making residential location decision,

whereas a two-worker or three-worker household's location choice reflects a balance among the commuting costs of all household working members. It is well known that multiple-worker households are now common in the US. Taking into account the weighting factors provided by the US National Household Travel Surveys (NHTS), 42.5 per cent of households in the US had at least two workers in 2001 and, even with the most disruptive economic crisis since the Great Depression, there were still 30.7 per cent households reporting at least two workers in 2009.[1] This drop could also be explained by the continued fall in average household size. Therefore, to reach a better understanding of the impact of telecommuting on travel behaviour and residential location choice, it is important to examine evidence on how telecommuting might change commuting patterns at the household level.

The major contribution of this study is to provide household-level evidence by investigating the impact of telecommuting on household one-way commute trips, using data from the 2001 and 2009 US National Household Travel Surveys (NHTS). Since household one-way commuting measures the relation between residential location and job locations of all household members, this study also aims to provide some insights into the possible influence of telecommuting on location choice. This paper focuses on two types of household: one-worker households and two-worker households. Three specific questions are addressed.

First, what is the impact of telecommuting on one-worker household's commute distance and duration?[2] 'One-worker household commute' is simple nomenclature, standing for the one-way commute of the only working member in a one-worker household. Although a one-worker household only has one worker or commuter, studying one-worker household commute has different meanings and implications than studying an individual worker's commute. A one-worker household simply needs to consider the commute of its only working member in making residential location choice, aside from many other variables (such as housing price). Yet individual workers examined in previous studies include those from not just one-worker households, but also multiworker households. Therefore, the commuting patterns of one-worker households are presumably different from the commuting patterns of individual workers. To provide some evidence on this possible difference, this study also compares the impact of telecommuting on one-worker household commute with the impact on individual worker's commute.

Secondly, what is the impact of telecommuting on two-worker household's total commute distance and duration? 'Two-worker household total commute' stands for the sum of the one-way commute (distance or duration) of the two working members in a two-worker household.

Thirdly, for a two-worker household, what is the impact of one member's telecommuting status on the other worker's (i.e. the non-telecommuting working member's) commute?

In each case, any changes between the two survey years are also of interest. Zhu (2012) has shown that, at the individual level, a worker tends to commute longer (distance and duration) if he/she telecommutes. The three questions to be addressed in this study are important extensions as I analyse the commute travel impact of telecommuting at the household level.

Similar to studies on individual travel behaviour, this research might also suffer a self-selection bias derived from the simultaneous choice of telecommuting and commute distance (or duration), especially when studying one-worker household commute. Therefore, another contribution of

this research is to apply an instrumental variable approach to address this possible endogeneity problem and investigate the causal effect of telecommuting on household commute.

This paper is organised as follows. Section 2 analyses changes in household commute trips from 2001 to 2009 and briefly describes the differences between telecommuting households and non-telecommuting households in terms of their one-way commute distance and duration. Section 3 discusses the methodology used to test for the three questions mentioned. Section 4 describes the NHTS data and section 5 summarises the model results, followed by a discussion of findings in section 6.

2. A Preview: Differences in Commute Trips at the Household Level, 2001–09

2.1 Definitions

Telecommuters are defined as those workers who report telecommuting at least once a week. Infrequent telecommuters and never-telecommuters are all classified as non-telecommuters, because the NHTS data suggest that infrequent telecommuting (for example, once a month) does not have a sizeable effect on an individual's commute trip and residential location choice. Non-telecommuters are workers and thus they also have commute trips. Finally, telecommuting households are defined as households with at least one telecommuter; non-telecommuting households are defined as households without any telecommuters.

2.2 Differences in One-way Commute Trips for Telecommuting vs Non-telecommuting Households, 2001–09

The main purpose of this paper concerns the differences in commuting patterns between telecommuting households and non-telecommuting households. In order to investigate these differences, a table summarising the household-level commute trip data from the 2001 and 2009 US NHTS is first discussed. Table 1 provides summaries for household total commute trips by household size and telecommuting status in 2001 and 2009.

An interesting temporal change can be observed in this table—the one-way commute distance and duration for both telecommuting and non-telecommuting households have increased from 2001 to 2009. Yet the extent of this increase is different for the two groups, with a bigger increase for telecommuting households.

For telecommuting one-worker households, the means of one-way commute distance and duration were 15.3 miles and 24.8 minutes in 2001, 22.8 miles and 32.8 minutes in 2009. For non-telecommuting one-worker households, the means were 12.0 miles and 22.1 minutes in 2001, 13.9 miles and 23.9 minutes in 2009. The percentage increases in one-way commute distance and duration over the eight years were much larger for telecommuting one-worker households compared with the non-telecommuting counterparts.

For telecommuting two-worker households, the means of household total commute distance and duration were 24.5 miles and 37.8 minutes in 2001, 32.2 miles and 48.9 minutes in 2009. For non-telecommuting two-worker households, the means were 19.1 miles and 31.9 minutes in 2001, 23.7 miles and 39.0 minutes in 2009. The percentage increases in total one-way commute distance and duration over the eight years were slightly larger for telecommuting two-worker households compared with the non-telecommuting counterparts.

Most importantly, in both 2001 and 2009 and for both one-worker households

Table 1. Household one-way commute trips by household type and telecommuting status

Year	*Trip type*	*Measure*	*Telecommuting households*			*Non-telecommuting households*		
			Mean	*S.E.*	*N*	*Mean*	*S.E.*	*N*
2001	One-worker household, one-way commute	Distance	15.3	1.2	815	12.0	0.2	16 288
		Duration	24.8	1.0	766	22.1	0.2	16 076
	Two-worker household, total one-way commute	Distance	24.5	1.0	1711	19.1	0.2	24 171
		Duration	37.8	0.8	1711	31.9	0.2	24 171
2009	One-worker household, one-way commute	Distance	22.8	1.2	2039	13.9	0.1	41 608
		Duration	32.8	0.9	1924	23.9	0.1	40 870
	Two-worker household, total one-way commute	Distance	32.2	0.8	2566	23.7	0.2	31 860
		Duration	48.9	0.8	2566	39.0	0.2	31 860

Notes: Based on two-tailed mean-comparison tests (t-test) at the 95 per cent confidence level, means of telecommuting households are statistically significantly larger than those of non-telecommuting households for all comparison pairs. Two-worker households with two telecommuters have been dropped to simplify interpretation and analysis. Therefore, a two-worker telecommuting household comprises one telecommuter and one non-telecommuter.

and two-worker households, telecommuting households consistently reported significantly longer commute distance and duration than non-telecommuting households. In 2001, telecommuting one-worker households' commute was on average 28.2 per cent longer in distance and 12.2 per cent longer in duration than non-telecommuting one-worker households; telecommuting two-worker households' total commute was on average 28.3 per cent longer in distance and 18.4 per cent longer in duration than non-telecommuting two-worker households. In 2009, the average differences between telecommuting and non-telecommuting households had been increased, with 64.7 per cent longer in distance and 37.0 per cent longer in duration for one-worker households, 35.9 per cent longer in distance and 25.3 per cent longer in duration for two-worker households.

Telecommuting households apparently have significantly longer one-way commute trips than non-telecommuting households. As we know, many factors affect household commute trips. Is this longer commute of telecommuting households a direct outcome of their telecommuting status? Or is it because of those unobserved factors (such as place of residence, age, gender, household size, etc.) that are not fully controlled in the previous table? To address these questions, I estimate various models to investigate more fully the impact of telecommuting on household commuting patterns.

3. Research Methodology

3.1 Model Specification and Variables

Travel demand is associated with individual and household activity patterns. Travel demand can therefore be modelled using an activity-based approach (Fox, 1995). Based

on this approach, travel demand has been found to be affected by factors including household socioeconomic status (such as household income, presence of child), household structure and life cycle (Strathman *et al.*, 1994; Srinivasan and Ferreira, 2002), place of residence (Zhu, 2011, 2012) and lifestyle (Nelson and Niles, 2000).

In the empirical tests described here, the dependent variable is the household one-way commute distance and duration. The explanatory variables include individual demographics (for example, age, sex, marital status, education and occupation), household socioeconomic status (for example, household income, presence of child), locational characteristics (for example, place of residence in urbanised area or suburban area, MSA population) and transportation variables (for example, number of vehicles per driver in the household, transportation mode). The variable of interest is a dummy variable added to the transportation factors to indicate whether the household is a telecommuting household. The basic models use ordinary least squares (OLS) estimation methods, but are subject to modifications discussed later. The basic model is specified as the following equation

$$\begin{aligned} &\textit{Household commute distance/duration} \\ &\quad = \mathrm{f}(\textit{individual demographics}, \\ &\textit{household socioeconomic status}, \textit{locational} \\ &\quad \textit{characteristics}, \textit{transportation factors}, \\ &\quad \textit{telecommuting dummy}) \end{aligned}$$

As discussed earlier, this study differentiates itself from previous studies by examining the impact of telecommuting on household commute trips. In order to make sample selection useful and representative, this study selects two major subsets from the NHTS household sample: one-worker households and two-worker households. It is then possible to investigate the impact of telecommuting on the commute of the worker in a one-worker household, on the total commute of a two-worker household and on the commute of the other worker in a two-worker household.

3.2 Studying the Impact of Telecommuting on One-worker Household Commute

For one-worker households, the basic OLS models test for the effects of household members' demographic characteristics, household socioeconomic and locational attributes, and determine the importance of telecommuting on workers' one-way commute distance and duration. However, there may be an endogeneity problem associated with the telecommuting variable when studying one-worker household commute. In other words, there exists a possibility of self-selection bias derived from the simultaneous choice of telecommuting and commute distance (or duration)—on the one hand, a worker chooses to commute longer in response to the option of telecommuting; on the other hand, a longer commute might also encourage the worker to telecommute. This study uses an instrumental variable approach (two-stage least squares, or 2SLS) to address this possible endogeneity problem and to investigate the causal effect of telecommuting on the commute distance and duration of workers in one-worker households.

The instrumental variables used in the 2001 2SLS models are Internet use at home (dummy) and total number of phones available. Because 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). Since 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 the worker's commute distance is indirect at most, only through their impact on the propensity to telecommute. These reasons suggest that these variables are plausible instruments for the telecommuting variable when studying the one-worker household commute.

3.3 Studying the Impact of Telecommuting on Two-worker Household Commute

For two-worker households, two major questions are addressed. How does one member's telecommuting affect the household total commute? How does one member's telecommuting affect the other worker's (i.e. non-telecommuting working member's or non-telecommuter's) commute?[3] Zhu (2012) suggested that, if a worker is telecommuting, he/she tends to experience a longer commute. This can, however, have two possibly counteracting effects on his/her household. One effect might involve choosing a location that is closer to the other working member's (or non-telecommuter's) workplace, thus reducing the other worker's one-way commute. In this case, household total commute may or may not change. Another possible effect is that the household moves to a location with more amenities (for example, environmental amenities such as those typically in suburbs or exurbs, or urban amenities such as entertainment), which could cause the commute of the non-telecommuter to increase as well. In this case, the household total commute may increase. This study tries to disentangle these two effects by analysing not only the two-worker household total commute, but also the non-telecommuter's commute. In this regard, the sample of two-worker households must meet a specific standard: there is zero or one telecommuter in the two-worker household. In measuring the impact of telecommuting on the two-worker household total commute, we are essentially comparing the total commute of two types of two-worker households: households without a telecommuter vs households with one telecommuter. I exclude the two-worker households with two telecommuters, because their presence in the sample would complicate the model and upward bias the estimated impact of telecommuting on household commute.[4]

To analyse the impact of telecommuting on the total commute of a two-worker household, all variables have to be aggregated to the household level, including commute distance and duration. Yet this also means dropping individual characteristics variables such as education and occupation, using average age of the two workers for the age variable, and adding a new set of transportation mode dummy variables to indicate whether either of the two workers uses public transit or other modes in their commute. A new telecommuting dummy variable is also generated to indicate whether the household has one member telecommuting (namely, whether this household is a telecommuting household). The advantage of this aggregation is that the endogeneity problem associated with the telecommuting variable is no longer a serious issue. To provide some corroboration, the Wu–Hausman F–test, the Durbin–Wu–Hausman chi-squared test and the difference-in-Sargan test are conducted and they all suggest that the specified endogenous regressor (i.e. telecommuting household) should be treated as exogenous. Therefore, ordinary least squares (OLS) estimation methods are used when studying the two-worker household total commute.

To analyse the impact of one member's telecommuting status on the other worker's commute in a two-worker household context, it is equivalent to test whether a non-telecommuter of a telecommuting household is statistically different from a worker of a non-telecommuting household, in terms of their one-way commute distance and duration. However, the comparison becomes complicated in this case. If the analysis estimates models for all non-telecommuters (with 'telecommuting household' added to the model as a dummy variable), many of the observations are dependent on each other because they could belong to the same households. If the analysis compares the non-telecommuter's commute of a telecommuting (two-worker) household with the average commute of a non-telecommuting (two-worker) household, variables that describe important individual characteristics such as gender, education and occupation are lost due to averaging. In order to overcome these problems, the approach used here is to divide the workers from all two-worker households by gender and test whether the non-telecommuting male/female worker is affected by the telecommuting status of the other worker in his/her household. I thus select two-gender households (namely, households with one male worker and one female worker) from the previous two-worker household sample. In this way, it is possible to estimate models for male non-telecommuters and female non-telecommuters separately, and determine whether a male (female) non-telecommuter's one-way commute is affected by the telecommuting status of his (her) 'partner'. Presumably, the two workers of most of these two-gender households consist of a husband and a wife. There may also exist a few other cases, such as a boyfriend and a girlfriend, a brother and a sister, or a father and a daughter. To simplify denotation, this study uses 'partner' to denote the other working member in a two-gender household. Theoretically, the 'telecommuting partner' dummy variable is exogenous here, because a worker's long commute possibly encourages his/her own choice of telecommuting, but arguably does not directly affect the telecommuting decision of the 'partner'. In fact, the three statistical tests used previously all suggest that the 'telecommuting partner' variable can be treated as exogenous. Thus only OLS model results are reported here.

4. Data Description

This study uses data from the 2001 and 2009 US NHTS. The NHTS contains information on individual demographics, household socioeconomic status, location of households, detailed information on household member commute trips and telecommuting status, as well as information technology measures such as telephone and Internet usage. Intertemporal comparisons between 2001 and 2009 are made to identify a more accurate assessment of the impact of telecommuting on household commute over time.

In 2001, 8.3 per cent of respondents said that they worked from home instead of travelling to their usual workplace on any day in the past two months.[5] Among them, 3.7 per cent did so infrequently (less than once a week) and 4.6 per cent did so frequently (at least once a week). The remaining 91.7 per cent of respondents said that they did not telecommute in the past two months. In 2009, 4.6 per cent of respondents reported that they telecommuted frequently (four times or more in the past month); 9.5 per cent of respondents telecommuted infrequently (less than four times in the past month); and 85.9 per cent of respondents said they did not have the option to telecommute.[6] Taking into account both frequent and infrequent telecommuters, the

number of telecommuters increased from 8.3 per cent to 14.1 per cent over the 2001–09 period. There are two explanations for this increase. First, the availability of easy ICT access (such as high-speed Internet and smart phone) had improved over the decade, which in turn encouraged telecommuting. Secondly, the 2008 economic recession following the sub-prime mortgage and housing crisis resulted in a disproportionate decrease in employment among non-telecommuters such as construction workers and related hard-hit occupations (Mayer, 2010). Based on our definition of telecommuter (i.e. telecommute at least once a week), 4.6 per cent of the NHTS sample were telecommuters in both 2001 and 2009.

In terms of household composition, the 2001 NHTS household sample consisted of 22.4 per cent with no worker, 32 per cent with one worker, 37.3 per cent with two workers and 8.3 per cent with three or more workers. In 2009, the corresponding household composition was 38.5 per cent, 34.7 per cent, 23.0 per cent and 3.7 per cent respectively.[7] As for telecommuting households, in 2001, 95.5 per cent of all sampled households were not telecommuting households, 4.2 per cent of households reported one telecommuter and 0.2 per cent reported two or more telecommuters. In 2009, 96.5 per cent of households reported no telecommuters, 3.4 per cent reported one telecommuter and 0.1 per cent reported two or more telecommuters. The recent economic recession could explain why fewer households had workers in 2009 than in 2001 and why the percentage of telecommuting households was lower in 2009.

5. Model Results

The results reported in this section are based on analyses of the two major household types in the sample—one-worker households and two-worker households.

5.1 One-worker Households

OLS models. OLS models are first estimated to investigate the role of telecommuting in affecting the commute distance and duration of workers in one-worker households, taking into account their demographics, household socioeconomic characteristics and locational attributes. Models (1) and (2) in Table 2 present OLS results for 2001, while models (5) and (6) report OLS results for 2009.

The OLS models show mixed results for the impact of telecommuting between 2001 and 2009. Although the 2009 OLS models show a statistically significant and positive impact of telecommuting on workers' commute distance and duration, the 2001 OLS models show insignificant impacts. As discussed in the previous section, it is possible that an endogeneity problem is associated with the telecommuting variable. To examine the severity of the endogeneity problem, three statistical tests are conducted: the Wu–Hausman F-test, the Durbin–Wu–Hausman chi-squared test and the difference-in-Sargan test. All tests suggest rejecting the null hypothesis that the specified endogenous regressor (i.e. telecommuting household) can be treated as exogenous. Therefore, two-stage least squares (2SLS) models are estimated in the next section to address the endogeneity problem associated with telecommuting. Prior to that, I want to briefly discuss how workers' demographic characteristics and household socioeconomic status affect the one-worker household commute.

Based on the OLS models, the workers' demographic characteristics are important factors influencing one-worker households' commute distance and duration.

Table 2. One-worker household (one-way) commute distance and duration

Variables	*OLS 2001*		*2SLS 2001*		*OLS 2009*		*2SLS 2009*	
	(1) Distance (log)	*(2) Duration (log)*	*(3) Distance (log)*	*(4) Duration (log)*	*(5) Distance (log)*	*(6) Duration (log)*	*(7) Distance (log)*	*(8) Duration (log)*
Telecommuting household (dummy)	−0.01	0.01	2.07***	1.28***	0.20***	0.17***	3.98***	1.60***
Age	−0.005***	−0.001	−0.007***	−0.002***	−0.007***	−0.003***	−0.009***	−0.003***
Male	0.11***	0.06***	0.08***	0.05***	0.15***	0.09***	0.12***	0.08***
Medical condition	−0.01	0.02	−0.07	−0.02	−0.08***	−0.03	−0.16***	−0.06**
High school graduate or some college	0.06*	−0.004	0.04	−0.03	0.08***	0.03	0.07**	0.02
BA degree	0.10**	0.03	0.03	−0.02	0.04*	−0.00	−0.07	−0.04
Graduate degree	−0.03	−0.05	−0.17***	−0.14***	−0.06**	−0.05**	−0.22***	−0.11***
Sales or service	−0.15***	−0.11***	−0.21***	−0.15***	−0.18***	−0.14***	−0.28***	−0.18***
Clerical or administrative support	−0.10***	−0.03	−0.11***	−0.03	−0.10***	−0.05***	−0.10***	−0.05***
Professional, managerial or technical	−0.04*	−0.01	−0.08***	−0.03	−0.006	0.003	−0.06**	−0.02
Other occupation	−0.14	−0.05	−0.11	−0.02	−0.08*	−0.07*	−0.17**	−0.10**
Household income (log)	0.17***	0.09***	0.14***	0.07***	0.15***	0.07***	0.08***	0.05***
Presence of children	0.08***	0.06***	0.07***	0.06***	0.02*	0.03***	−0.02	0.01
Number of vehicles per driver	0.05***	0.02**	0.05***	0.02*	0.05***	0.02***	0.03***	0.02**
Residence in urbanised area	−0.39***	−0.19***	−0.39***	−0.19***	−0.37***	−0.19***	−0.37***	−0.19***
Residence in rural area	−0.008	0.03	0.10	0.09	−0.04	−0.04	0.05	−0.006
Not in an MSA	−0.02	−0.02	−0.15	−0.09	0.02	0.003	−0.08	−0.04
In an MSA of 250 000–499 999	0.13***	0.11***	0.12***	0.10***	0.14***	0.09***	0.14***	0.09***
In an MSA of 500 000–999 999	0.19***	0.22***	0.19***	0.22***	0.17***	0.14***	0.18***	0.14***
In an MSA or CMSA of 1–2 million	0.28***	0.26***	0.26***	0.25***	0.26***	0.21***	0.24***	0.20***
In an MSA or CMSA over 3 million	0.45***	0.45***	0.42***	0.44***	0.35***	0.35***	0.28***	0.33***
Intercept	0.59***	1.86***	0.92***	2.07***	0.95***	2.20***	1.80***	2.51***
Observations	13766	13853	13142	13227	34995	35339	34995	35339
R^2	0.096	0.081	—	—	0.099	0.074	—	—

Notes: *** p <0.01; ** p <0.05; * p <0.1. For education dummy variables, the reference is 'less than high school'. For occupation variables, the reference is 'manufacturing, construction, maintenance or farming'. For place of residence dummy variables, the reference is 'residence in suburban area'. For MSA size dummy variables, the reference is 'in an MSA of less than 250 000'. In order to eliminate the endogeneity problem associated with transportation mode, the sample is restricted to workers who use personal vehicles for commuting; workers commuting by public transit or other modes are dropped.

Households with younger workers and male workers consistently report a significantly longer one-way commute distance and commute duration in both years. Workers with high school diplomas and bachelor degrees tend to have a longer commute distance than those who have not graduated from high school. In terms of workers' occupation, working in sales or service industries tends to have a shorter one-way commute distance and duration than working in manufacturing, construction or maintenance industries. Similarly, clerical or administrative workers also have a shorter commute than those working in the manufacturing, construction or maintenance industries.

In terms of household socioeconomic status, households with children tend to have a longer one-way commute distance and duration in both 2001 and 2009. Households with higher total income and a larger number of vehicles per driver are also found to have a substantially longer commute distance and duration. Among household locational attributes, households located in urbanised areas tend to have much shorter one-way commute distance and duration than those located in suburbs (an omitted category in the models) or rural areas in both years. As shown by the coefficient estimates for the group of variables that measure the sizes of metropolitan statistical areas (MSAs), a clear pattern can be observed that both commute distance and duration increase with the size of MSA in both 2001 and 2009.

2SLS models. Models (3) and (4) in Table 2 present 2SLS results for 2001, while models (7) and (8) report 2SLS results for 2009. The instrumental variables used in the 2001 2SLS models are Internet use at home (dummy) and total number of phones. The instrumental variable used in the 2009 2SLS models is 'frequently use Internet' (dummy). Since weak or invalid instruments often lead to measurement errors in the endogenous regressor (Bound *et al.*, 1995; Hall *et al.*, 1996; Greene, 1997; Shea, 1997; Staiger and Stock, 1997; Stock, 2010), several tests are conducted on the relevance of these instruments after running the first-stage regressions for both 2001 and 2009. These tests include the Bound–Jaeger–Baker F-statistics, partial R^2 measures, and IV redundancy test. They all suggest that the selected instruments are relevant and the 2SLS results can be accepted.

In both 2001 and 2009, variables in the 2SLS models that describe workers' demographic characteristics, household socioeconomic and locational attributes only differ marginally from those in the OLS models, in terms of their coefficient estimates. However, the coefficient estimates for the telecommuting variable in all the 2SLS models have increased substantially, when compared with the OLS models. For example in model (3), the impact of telecommuting on one-worker household commute distance has become significant and positive, with its coefficient changed from −0.007 (insignificant) in the previous OLS model (model 1) to +2.067 in the 2SLS model (model 3). Overall, the coefficient estimates for telecommuting in 2SLS models suggest that a one-worker household tends to have a significantly longer commute distance and duration if its (only) working member is telecommuting, holding other factors constant.

Since I estimate the same models for 2001 and 2009, it is possible to compare the impact of telecommuting on one-worker household commute over the years. In terms of the impact of telecommuting on commute distance, the 2SLS models show that the coefficient estimates for telecommuting increased from 2.1 in 2001 (model

3) to 4.0 in 2009 (model 7)—roughly twice the effect. In terms of the impact of telecommuting on commute duration, the 2SLS models show that the coefficient estimates for telecommuting changed from 1.3 in 2001 (model 4) to 1.6 in 2009 (model 8). These results indicate that the magnitude of the impact has increased over the years, suggesting that those one-worker households whose only working member is a telecommuter have chosen to live further away from their workplace (in terms of distance as well as duration) over this time-period.

Zhu (2012) estimated the impact of telecommuting on the one-way commute distance and duration of individual workers, who may come from one-worker households as well as from multiworker households. Compared with those estimates, this study shows that telecommuting has even larger effects on household one-way commute distance and duration (for one-worker households). This would be expected because, according to the neo-classical urban economics model, the residential location choice of a household is decided by its workers' commuting costs (distance and time), other things being equal (such as housing price) (Alonso, 1960, 1964; Mills, 1967, 1972; Muth, 1969). A one-worker household predominantly considers one member's commute in making its residential location decision, whereas an individual worker's commute probably reflects the compromise with other workers in a two-worker or three-worker household, whose location choice reflects a balance among the commuting costs of all household working members. Therefore, it is not surprising to find that the effects of telecommuting on the commute distance and duration of one-worker households is larger than on individual workers.

5.2 Two-worker Households

Two-worker households are becoming more common in the US and they represent an interesting and important case for any attempts to describe accurately the impact of telecommuting on household commuting patterns. To simplify interpretation and analysis, two-worker households with two telecommuters are excluded from the sample. As discussed in section 3.3, if one household working member is frequently telecommuting, it could have two possibly opposing effects on household residential location choice. One effect is to choose a location that is closer to the other worker's (or non-telecommuter's) workplace and thus reduces his/her commute; another effect is to move to a location with more amenities (such as environmental amenities that typically exist in suburbs or exurbs), which could result in the commute of the other worker to increase as well. This study attempts to disentangle these two effects by analysing not just the two-worker household's total commute, but also the non-telecommuter's commute.

Two-worker Household Total Commute. As discussed previously, the telecommuting dummy variable here indicates whether the household has one member telecommuting—namely, whether this household is a 'telecommuting household'. The simultaneity problem between the telecommuting dummy variable and dependent variables (household total commute distance and duration) is arguably weakened. As suggested by the Wu–Hausman F-test, the Durbin–Wu–Hausman chi-squared test and the Difference-in-Sargan test, the 'telecommuting household' variable can be treated as exogenous when studying two-worker household total commute. Therefore,

Table 3. Two-worker household total (one-way) commute distance and duration

Variables	*OLS 2001*		*OLS 2009*	
	(1)	*(2)*	*(3)*	*(4)*
	Distance (log)	*Duration (log)*	*Distance (log)*	*Duration (log)*
Telecommuting household (dummy)	0.12***	0.14***	0.21***	0.17***
Household income (log)	0.38***	0.25***	0.30***	0.17***
Average age	−0.01***	−0.007***	−0.01***	−0.01***
Presence of children	−0.02	−0.04**	−0.04***	−0.06***
Number of vehicles per driver	0.13***	−0.03*	0.12***	0.006
Residence in urbanised area	−0.38***	−0.13***	−0.40***	−0.19***
Residence in rural area	0.16**	0.07	−0.09*	−0.16***
Not in an MSA	−0.26***	−0.12	0.04	0.06
In an MSA of 250 000–499 999	0.12***	0.13***	0.20***	0.15***
In an MSA of 500 000–999 999	0.18***	0.22***	0.22***	0.17***
In an MSA or CMSA of 1–2 million	0.23***	0.21***	0.25***	0.17***
In an MSA or CMSA of 3 million or more	0.26***	0.37***	0.30***	0.32***
Intercept	−1.26***	0.63***	−0.004	2.03***
Observations	24 111	24 111	33 018	33 018
R^2	0.075	0.040	0.075	0.041

Notes: *** p<0.01; ** p<0.05; * p<0.1. For place of residence dummy variables, the reference is 'residence in suburban area'. For MSA size dummy variables, the reference is 'in an MSA of less than 250 000'.

only OLS models are estimated. Table 3 presents the OLS results for the two-worker household total commute distance and duration. All coefficient estimates for variables that describe household socioeconomic and locational attributes are consistent with those described in previous sections.

The primary interest here concerns the dummy variable indicating whether there is a telecommuter in the two-worker household. It is found that the total commute distance and duration of a two-worker household are significantly longer if the household has one member telecommuting. In 2001, a telecommuting two-worker household on average had a 12.4 per cent longer total commute distance and a 14.8 per cent longer total commute duration than a non-telecommuting two-worker household, holding other factors constant. In 2009, these numbers increased to 23.9 per cent and 18.3 per cent respectively.[8] Temporal comparisons of these numbers indicate that the effects of one member's telecommuting on the household total commute distance and duration had significantly increased over the 2001–09 period.

Non-telecommuters' commute in two-worker households. Table 4 presents the results for the commute of non-telecommuters (by gender) in two-worker households. As discussed in section 3.3, only two-gender households—namely, households with one male worker and one female worker—are selected from the previous two-worker household sample. All coefficient estimates for variables that describe individual and household socioeconomic characteristics and household locational attributes are consistent with previous estimates. A comparison of these coefficient estimates between male and female non-telecommuters for both 2001

Table 4. Non-telecommuters' (one-way) commute in two-worker households

Variables	*2001*				*2009*			
	Female		*Male*		*Female*		*Male*	
	(1) Distance (log)	*(2) Duration (log)*	*(3) Distance (log)*	*(4) Duration (log)*	*(5) Distance (log)*	*(6) Duration (log)*	*(7) Distance (log)*	*(8) Duration (log)*
Telecommuting 'partner'	0.01	−0.01	−0.003	−0.002	0.03	0.02	0.02	0.03
Age	−0.007***	−0.002***	−0.004***	0.00	−0.007***	−0.004***	−0.005***	−0.002***
Medical condition	0.03	0.05	−0.04	−0.04	−0.01	0.02	0.02	0.04
High school or some college	0.17***	0.08**	0.06*	0.006	0.07*	−0.02	0.03	0.00
BA degree	0.20***	0.11***	0.06	0.008	0.07	−0.007	−0.01	−0.02
Graduate degree	0.19***	0.12***	−0.04	−0.05	0.06	−0.004	−0.12***	−0.08***
Sales or service	−0.20***	−0.17***	−0.11***	−0.07***	−0.20***	−0.18***	−0.16***	−0.12***
Clerical or administrative support	−0.13***	−0.08***	−0.05	0.01	−0.07**	−0.06**	−0.04	−0.02
Professional, managerial or technical	−0.03	−0.02	0.001	0.02	−0.004	−0.02	−0.03*	−0.01
Other occupation	−0.16	−0.02	−0.05	−0.06	−0.16**	−0.18***	−0.14	−0.11*
Household income (log)	0.15***	0.07***	0.16***	0.07***	0.12***	0.08***	0.19***	0.11***
Presence of children	−0.06***	−0.04***	0.05***	0.05***	−0.06***	−0.05***	0.04***	0.02*
Number of vehicles per driver	0.10***	0.05***	0.12***	0.06***	0.10***	0.06***	0.10***	0.05***
Residence in urbanised area	−0.45***	−0.21***	−0.40***	−0.20***	−0.39***	−0.19***	−0.38***	−0.21***
Residence in rural area	−0.09	−0.08	0.01	0.002	−0.06	−0.08**	−0.12**	−0.09**
Not in an MSA	−0.001	0.06	−0.07	−0.02	0.006	−0.002	0.10**	0.05
In an MSA of 250 000–499 999	0.15***	0.15***	0.15***	0.13***	0.16***	0.13***	0.20***	0.16***
In an MSA of 500 000–999 999	0.28***	0.30***	0.22***	0.25***	0.20***	0.16***	0.28***	0.22***
In an MSA or CMSA of 1–2 million	0.28***	0.27***	0.34***	0.31***	0.28***	0.24***	0.34***	0.28***
In an MSA or CMSA of 3 million or more	0.41***	0.44***	0.53***	0.53***	0.31***	0.33***	0.48***	0.45***
Intercept	0.74***	2.01***	0.65***	1.99***	1.16***	2.19***	0.46***	1.81***
Observations	13451	13527	14659	14709	21990	22168	21266	21367
R^2	0.096	0.079	0.081	0.080	0.076	0.063	0.080	0.072

Notes: *** p <0.01, ** p <0.05, * p <0.1. For education dummy variables, the reference is 'less than high school'. For occupation variables, the reference is 'manufacturing, construction, maintenance, or farming'. For place of residence dummy variables, the reference is 'residence in suburban area'. For MSA size dummy variables, the reference is 'in an MSA of less than 250 000'. In order to eliminate the endogeneity problem associated with transportation mode, the sample is restricted to workers who use personal vehicles for commuting; workers commuting by public transit or other modes are dropped. All models in this table only include non-telecommuters. I compare non-telecommuters from telecommuting households with non-telecommuters from non-telecommuting households by gender. Therefore, the telecommuting dummy variable used in all models is whether the 'partner' is telecommuting.

and 2009 reveals that the commute impact of most of these variables does not differ significantly between the two gender groups. The only significant differences between male and female non-telecommuters are the coefficient estimates for the 'presence of children' variable. While two-worker households with children tend to have a shorter total commute (as shown in Table 3), it appears that the presence of children has placed a disproportionally negative impact on female non-telecommuters. As a result, female non-telecommuters are found to have a shorter commute due to the presence of children, whereas male non-telecommuters would commute longer if they have children. This corroborates the idea that households with children face more complex trade-offs.

Similarly, the major interests here are also the coefficient estimates for the telecommuting dummy variable, which in this case indicates whether the male/female non-telecommuter's 'partner' telecommutes. For both gender groups, the non-telecommuter's commute distance and duration are not statistically significantly affected by whether his/her 'partner' is telecommuting. In other words, one household member's telecommuting is not affecting the other (non-telecommuting) member's commute distance or duration. This result holds true for both male and female non-telecommuters and for both 2001 and 2009.

Combining the results from the two-worker household total commute (Table 3) and the non-telecommuters' commute (Table 4), it appears that, in a two-worker household, one worker's commute distance and duration, regardless of gender, remains unaffected by whether the other worker is telecommuting or not and that the longer total commute of a telecommuting household is largely due to the increase in its telecommuter's commute. These findings indicate that the presence of a telecommuter in a two-worker household does not necessarily make the household choose a residential location closer to the non-telecommuter's workplace. Whether this implies that the household is more inclined to move to a more distant location with cheaper land and more environmental amenities (such as suburbs or exurbs) will require further well-designed tests.

6. Conclusions

Through a series of empirical analyses that address possible self-selection bias, this study investigates how telecommuting affects commuting patterns at the household level and also sheds some light on the possible influence of telecommuting on household location choice. The results of these analyses suggest that telecommuting has been a consistently important factor in shaping household commuting patterns over the 2001–09 period and that telecommuting tends to increase the household total one-way commute. As expected, these effects are overall more important in 2009 than in 2001.

Using instrumental variables to address the endogeneity problem associated with telecommuting, the 2SLS models provide more plausible results than OLS models when studying one-worker households. The results suggest that telecommuting one-worker households tend to choose locations involving longer commute trips than non-telecommuting one-worker households. And the size of the impact of telecommuting has significantly increased over the 2001–09 period. It is also found that the impact of telecommuting on the commute of one-worker households is much larger than on the commute of individual workers (who may come from one-worker households as well as multiworker

households). This is probably because a one-worker household simply considers one member's commute in making its residential location decision. As for two-worker households, although the results show that one household member's telecommuting does not affect the other (non-telecommuting) member's commute distance and duration, the evidence supports the idea that the total commute distance and duration of a two-worker household will be significantly longer if this household has one member telecommuting. These findings suggest that the presence of a telecommuter in a two-worker household does not necessarily induce the household to choose a residential location closer to the non-telecommuter's workplace. Whether longer household total commute implies that those telecommuting two-worker households are more likely to move to more distant locations with cheaper land and more environmental amenities (such as suburbs or exurbs) will require further well-designed tests. However, the findings about the positive impact of telecommuting on household total commute (for both one-worker households and two-worker households) at least suggest that telecommuting considerably increases the one-way commute distance and duration for the majority of US households.

Compared with investigations on individual travel patterns, the analyses on household commute in this research provide useful insights on how telecommuting might affect travel behaviour and location choices simultaneously, as these decisions are often made in complex household arrangements, especially those with more than one worker. With the capability to substantially reduce interaction costs, telecommuting could provide households with an opportunity to rebalance their consumption of various goods (for example, travel, housing, land, amenities, etc.) through making their location decisions. This will, in the long run, change urban form if telecommuting moves into the mainstream.

Note that the distance between residential location and job location, measured by one-way commute distance, cannot fully depict the residential spatial pattern of an MSA—for example, are telecommuting households more likely to live in the suburban areas of an MSA, or do they live further away from the traditional centre than their counterparts? Since jobs are experiencing suburbanisation as well and are no longer necessarily located in the centre, living further away from jobs does not mean living further way from the city centre. Households may likewise choose to move towards urban amenities—away from suburban jobs—or to better school districts. Future research that examines whether telecommuting households are more likely to live in suburban areas would be an interesting next step. Nonetheless, the findings of this study are an initial step towards addressing the bigger questions about how telecommuting may change the urban landscape or, more generally, how progress in ICT may determine the fate of our future cities.

Currently, most states are struggling with insufficient funding for transportation infrastructures and the federal highway trust fund has already been relying on the infusion of general fund revenues (Zhu and Brown, 2013). Planners and policy-makers need to be cautious about the full consequences of implementing policies that encourage telecommuting. Although telecommuting can reduce the frequency of commuting trips, workers are 'footloose' and they could choose to live further away from jobs if provided with the telecommuting option (Zhu, 2012). This is still true even when the complex household arrangements (such as two workers in one household) are taken into account, as shown in this research. Although it is not the focus of this

paper, it would be interesting in future research to take into account the frequency of telecommuting in a week or a month so that we can estimate the impact of telecommuting on the household weekly or monthly total commute. This will enable us to have a more holistic view on the on-going discussion about whether telecommuting and travel are complements or substitutes. Yet given several issues associated with the current NHTS questionnaire, it is hard to get accurate estimates on this. Hopefully, the NHTS questionnaire will change in the future so that such endeavours can be possible.

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Notes

1. For unweighted household sample composition in the 2001 and 2009 NHTS, refer to the Data Description section.
2. From now on, the paper only uses 'household commute' for simplicity. It refers to 'one-way household commute' throughout the paper.
3. There are only a few two-worker households with both workers telecommuting. For reasons discussed later, this study excludes those two-worker households with two telecommuters. Therefore, if one worker is telecommuting, the other worker must be a non-telecommuter.
4. The reason it will incur an upward bias is that telecommuting has a positive effect on the individual commute (Zhu, 2012). If two-telecommuter households are included in the two-worker household sample, the positive effect of telecommuting on household total commute is expected to be larger than only including one-telecommuter two-worker households.
5. The percentage calculation is based on those respondents who answered the question of whether they worked from home instead of travelling to their usual workplace on any day in the past two months.
6. The questions on telecommuting are slightly different between the 2001 NHTS and the 2009 NHTS. However, in both surveys, respondents who only work at home (home-based businesses, for example) are skipped on these questions about telecommuting as well as the questions about commute distance and duration. Therefore, my sample only includes those workers who have a workplace.
7. All these percentages are unweighted percentages based on raw NHTS data.
8. The percentage change in Y (from Y_0 to Y_1), for a discrete change in the 'telecommuting household' dummy variable (from 0 to 1), is calculated as

$$100(Y_1 - Y_0)/Y_0 = 100^*(exp\{b\} - 1).$$

Therefore, the percentage changes are slightly larger than the coefficient estimates for 'telecommuting household' in Table 3.

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