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Home telework, travel behavior, and land-use patterns: A path analysis of British single-worker households

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Abstract: This work analyzes the effects of home-based teleworking on the number of trips and weekly miles travelled by mode and purpose for one-worker households in Great Britain using data from the National Travel Survey for the period between 2005 and 2012. Two path analysis models are developed, one considering weekly trips and travel distances by mode and the other weekly trips and travel distances by purpose. Both models consider teleworking frequency in the context of home and workplace land-use characteristics, commuting distance, car ownership levels and weekly trips and travel distances. This framework allows us to explicitly model endogenous relations in the chains of decisions relating these variables. The results suggest that home-based teleworking is a strategy used by people to cope with long and costly commutes. Workers living in less transit accessible areas and with longer commutes tend to work from home more frequently. The main conclusions relating to teleworking frequency point to the fact that it increases weekly miles travelled, particularly by car, while it does not reduce commuting distances travelled. These results suggest that home-based teleworking is not an effective travel demand management strategy, particularly because it seems to increase car use. The overall main result is that teleworkers travel more by more polluting transport modes.

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1 Introduction

Home-based telework[1] rose to prominence in the last two decades of the 20th century mainly as a result of developments in information and communication technologies (ICT). Telework rapidly emerged as a possible travel demand management strategy, aimed at reducing congestion and negative environmental impacts of transportation. The main rationale behind it was that by working at home people would not have to commute to their work locations and thereby travel would be curtailed. In this manner, ICT was seen as substitute for physical travel. Although enthusiastically supported by at least some policymakers, scholars' views on the transportation impacts of home-based teleworking are mixed: some studies point to positive impacts (e.g., Kitamura, Nilles, Conroy, & Fleming, 1991; Pendyala, Goulias, & Kitamura, 1991; Helminen & Ristimaki, 2007), while others consider it ineffective (e.g., Hjorthol & Nossum , 2007; Zhu, 2012; Zhu & Mason, 2014; He & Hu, 2015). The reasons behind these differences might be related to study heterogeneity, i.e., different methodologies, sample sizes (small samples, e.g., Kitamura et al., 1991; Henderson, Koenig, & Mokhtarian, 1996; and larger samples, e.g., Zhu, 2012; Zhu & Mason, 2014; Kim, Choo, & Mokhtarian, 2015), and the use of travel diaries ranging from one to several days, among other factors.

Home-based telework also has implications in terms of land use patterns and the home and workplace location choices of teleworkers, particularly because teleworkers tend to have longer commuting distances than other workers (Wells, Douma, Loimer, Olson, & Pansing, 2001; Mokhtarian, Collantes, & Gertz, 2004; Zhu, 2012, 2013). Regarding this aspect, there is contention about the direction of causality. Does it stem from commuting distance to telework?—meaning that telework is a strategy used by people to reduce commuting burden, or is it another opportunity for households to move to peripheral urban areas, thus contributing to sprawl? These issues guide the present research, which aims to study the effects of home-based telework frequency on weekly travel by mode and purpose. Telework frequency is modelled in the context of home and workplace urban characteristics, commuting distance and the number of trips and miles travelled during a whole week (to account for possible shifts of travel during different weekdays). The data used refers to a sample of single-worker households collected from the National Travel Survey (NTS) in Great Britain, between 2005 and 2012.

This paper is organized as follows. In the next section a literature review is offered. It focuses mainly on the following aspects: impacts of teleworking on travel; relationships between teleworking, land use patterns and location choices; causality between commuting distance, residential and workplace location choices and teleworking; and factors affecting the decision to work from home. Section 3 presents the conceptual framework underlying the empirical analysis, while Section 4 describes the data and variables. Section 5 briefly describes the modeling method, and is followed by the discussion of the results in Section 6. The paper ends with the conclusions and a brief discussion about further research in Section 7.

2 Literature review

2.1 Impacts of home telework on travel

One of the most important streams of research refers to the potential impacts of teleworking on the total amount of travel, and its subsequent effects on the environment. Although ICT in general, and teleworking in particular, can reduce travel costs and time, these savings may be used for engaging in other

[1]The term telework is a synonym of telecommuting. Telework or telecommuting could be either home-based, meaning that people work remotely from home, or center-based where people commute to a telework center and work remotely from there.

activities which might include travel (Mokhtarian, 2009), thus offsetting some of its benefits. Early studies were mainly positive about the potential benefits of teleworking, with several reporting a reduction in the number of trips and miles driven by teleworkers (Hamer, Kroes, & Oosttsroom, 1991; Kitamura et al., 1991; Pendyala, Goulias, & Kitamura, 1991; Nilles, 1991; Mokhtarian, Handy, & Salomon, 1995; Henderson et al., 1996; Choo, Mokhtarian, & Salomon, 2005; Helminen & Ristimaki, 2007). Some studies also reported travel reductions at the level of the household (Nilles, 1991; Mokhtarian et al., 1995). Later studies tended to conclude the opposite, or at least that the gains were not as expressive as was initially thought (Nelson, Safirova, & Walls, 2007; Hjorthol & Nossum, 2007; Zhu, 2012; Zhu & Mason, 2014; He & Hu, 2015; Kim et al., 2015). In addition, some recent studies concluded that households with teleworkers travel more than other households (Zhu & Mason, 2014; Melo & de Abreu e Silva, 2017) and that teleworkers have bigger travel budgets (Zhu, 2012).

There is also evidence that workers who engage in teleworking tend to have smaller activity spaces (Pendyala et al., 1991) because their activities tend to be clustered around home on the days they work from home, contrary to what happens on the other (commuting) days where their activities tend to be oriented towards the employment area (Saxena & Mokhtarian, 1997). Furthermore, because teleworkers tend to live in more suburban areas, usually associated with lower levels of transit supply, there is a higher likelihood that their trips on teleworking days are made by car (Yen, 2000). As a result, teleworking might contribute to decentralizing travel rather than reduce it (Kim et al., 2015). This view is concurrent with the conclusions from studies which found that teleworkers are more frequent car users (Wells et al., 2001; Hjorthol & Nossum, 2007; Zhu & Mason, 2014). Regarding travel purposes teleworkers tend to engage in more business and non-work trips than non-teleworkers (Zhu, 2012; Kim et al., 2015).

2.2 Impacts of home telework on land-use patterns and location choice

Teleworker households tend to be located in the periphery of cities (Kim, Mokhtarian, & Ahn, 2012) and have longer commutes (Wells et al., 2001; Mokhtarian et al., 2004; Zhu, 2012, 2013). Although several authors refer to commuting distance, or time, as one relevant reason to adopt home-based teleworking (Yen, 2000; Mokhtarian & Bagley, 2000; Mokhtarian et al., 2004; Nurul Habib, Sasic, & Zaman, 2012), the latter can allow workers to live further away from their jobs thereby contributing to sprawl and longer commutes (Nilles, 1991; Mokhtarian, 2009). In the long term, this relocation of households to the periphery can reduce the transportation benefits of teleworking (Lund & Mokhtarian, 1994). Other forces might also come into play since teleworking can increase both residential and workplace location flexibility (Tavyaran & Khan, 2003). Teleworking might contribute to the dispersion of employment, leading to the reduction of teleworkers commuting distances, but it could also result in the centralization of urban activities (Rhee, 2008). These possibilities, derived from theoretical urban models, are in some way validated by an empirical study in Seoul where it was found that teleworkers' commuting distance is shorter than for non-teleworkers, which could be explained by the transfer of jobs to the suburbs (Kim et al., 2012).

2.3 Causality between home telework and commuting distance

There is ongoing debate on the direction of causality between home telework and commuting distance. Assuming households minimize commuting and housing costs, one would expect the causal direction to go from teleworking to home location (Tavyaran & Khan, 2003; Zhu, 2013; Zhu & Mason, 2014;), since teleworking can reduce commuting costs and allow people to move to the periphery where housing costs are lower. Nevertheless, several studies focusing on the decision to telework hint at a reverse relationship, proposing that it is the commuting cost, or time, that increase the likelihood to engage in home telework (Yen, 2000; Wells, et al., 2001; Peters, Tijdens, & Wetzels, 2004; Helminen & Ristimaki, 2007; Kim et al., 2012). These conclusions are reinforced by Ory and Mokhtarian (2006), who studied retrospectively 200 state workers in California. They found that people who always teleworked tended to move closer to their workplace, while those who moved further away from their workplace only tended to start teleworking after the move. In addition, teleworking did not appear to be relevant enough to affect home relocation decisions (Ory & Mokhtarian, 2006). Other empirical studies also found that teleworking was not a significant factor in home relocation decisions (Muhammad, Ottens, Ettema, & de Jong, 2007; Ettema, 2010). However, and despite the fact that teleworkers cannot be considered as an uniform group regarding their residential preferences, a positive association between being a teleworker and having suburban living preferences has been found by some studies (Ettema, 2010). Although there is a theoretical rationale to consider that teleworking influences home (and work) location, the empirical studies reviewed here concluded otherwise, that is, teleworking is mainly a strategy to cope with long and costly commutes. Furthermore, since home location can be considered a long term decision, which because of its transaction costs is much more difficult to reverse than the decision to telework (Giuliano, 1989; Golledge & Garling, 2003), it could also be argued that at least in the short term the direction of causality is more likely to run from commuting distance to home telework.

2.4 Other factors influencing the adoption of home telework

Several socioeconomic attributes were found to be associated with telework adoption, namely higher education levels (de Graaff & Rietvelt, 2004; Hjorthol & Nossum, 2007) and higher income (He & Hu, 2015). People working in managerial/professional occupations are also more likely to telework than those working in other activities, namely in sales (Hjorthol & Nossum, 2007; Singh, Paleti, Jenkins, & Bhat, 2013). The results are mixed for gender and age. Whereas Peters et al. (2004) found no differences in the predisposition to telework between men and women, other authors contend that being a man influences the likelihood to engage in telework (Poury & Bhat, 2003; Hjorthol & Nossum, 2007). Regarding age, de Graaff and Rietvelt (2004) found that younger people are more willing to telework, whereas Poury and Bhat (2003) concluded otherwise. These contradictory findings might be related to the types of functions different workers perform and their specific compatibility with telework. Whereas younger people are generally more at ease with ICT, and therefore more apt to telework, older people might hold managerial functions which are also more compatible with teleworking.

Household and location related characteristics also influence the decision to telework. Peters et al. (2004) found that the presence of children in households reduces the propensity to telework, but house size is a relevant positive influence (Yen, 2000). Since bigger living space is usually associated with living in suburban areas, this implies that, besides reinforcing the connection between commuting distance and telework, it may also reinforce the role of built environment characteristics on the decision to telework (Singh et al., 2003). However, Singh et al. (2003) also found a positive relationship between living in more urbanized areas and teleworking. This could be due mainly to better access to ICT devices and infrastructures in more urbanized areas. It could also mean that while teleworkers may be more likely to reside in the suburbs of large urban areas, their sprawl to the countryside is more difficult.

Travel behavior can also influence the decision to telework. People who commute by transit are more likely to engage in telework and are more sensitive to transit attributes (fares, travel times and access/egress times) than their car commuting counterparts (Yen, 2000; Nurul Habib, Sasic & Zaman, 2012). These findings have potential negative effects for transport policy since they could spell reductions in transit patronage and higher mode shares for car. Individual preferences may impact on the decision to adopt home telework. People who perceive commuting as a burden are more inclined to engage in teleworking (Mokhtarian & Salomon, 1997; Mokhtarian & Bagley, 2000). Social influence (Paez & Scott, 2007) and feedback effects from past behavior (Salomon, 1998) were also found to influence telework adoption.

3 Conceptual framework

The main research questions addressed in this work relate to the effects of home-based telework on weekly travel by mode or purpose, and how the land use characteristics of residence and employment areas affect these relationships. To answer these questions, we developed a modelling framework for the relationship between home telework frequency, land use patterns of residence and employment areas, and long- and short-term travel behavior. Long-term relationships include location decisions, commuting distance and car ownership, whereas short-term decisions include the number of weekly trips and the number of weekly distance travelled by mode or purpose. Figure 1 presents the conceptual model, which is described below.

Telework frequency was included in a modelling framework that relates land use patterns both at the residence and employment locations with commuting distance, household car ownership and the amount of weekly travel. The original framework, without home telework, has been applied to different cities in previous studies and resulted in similar outcomes and conclusions (de Abreu e Silva, Golab, & Goulias, 2006; de Abreu e Silva, Morency, & Goulias, 2012), thereby reinforcing its robustness. To the best of our knowledge this is the first time that home telework frequency has been included in a model explicitly incorporating location decisions, and long- and short-term travel behavior decisions.

Building a model that can incorporate both travel purposes and modes creates daunting difficulties (this model would have 18 equations describing travel as compared to the 6 in the case of the present models). Therefore, we opt for the estimation of two separate models, one considering travel by mode and the other travel by purpose. The model focusing on weekly travel by mode (i.e., car, transit, active modes) investigates possible patterns of substitution between different transport modes, particularly between car use, public transport and active travel. It will allow us to examine the influence of teleworking frequency on car use, while at the same time controlling for other relevant determinants of modal choice like land use characteristics and car ownership. If, as Pendyala et al. (1991) and Saxena and Mokhtarian (1997) suggested, the activity spaces of teleworkers tend to be smaller and centered around home in the days they telework, then the trips made in these days could favor the use of modes more adapted to the transport and land use characteristics of residential locations, possibly car and active modes. The model for weekly travel by purpose (i.e., commuting, business, non-work) allows us to examine if the likely reduction in commuting trips due to home-based telework could be offset by the longer one-way commuting distance of teleworkers, and its effects on total weekly commuting distance. Importantly, this model also highlights the possible effects that savings in commuting travel might have on other activities (work and non-work related) that lead to additional travel, as hypothesized by Mokhtarian (2009). These two models can also be used to test the hypothesis that teleworkers have larger travel budgets than non-teleworkers, as advanced by Zhu, (2012).

The conceptual framework considers that the land use characteristics surrounding both the residence and the workplace are endogenous, and thus specified as a function of socioeconomic and demographic attributes of the individuals, their households, and travel behavior decisions, which in turn accounts for self-selection effects due to either specific needs or preferences of the respondents and their households. Both land use characteristics and socioeconomic variables affect commuting distance and car ownership. Frequency of teleworking is considered to be a shorter term travel decision, and therefore was modelled as a function of the longer term travel decisions and socioeconomic attributes. However, since existing literature on the relationship between commuting distance and home telework also suggests that the effect could be reversed (i.e., the possibility of teleworking could influence residential location to more remote areas: e.g., Zhu, 2013; Zhu & Mason, 2014) both specifications were tested, as well as a non-recursive specification where both directions of causality are considered. Finally, the variables representing longer term decisions (home and work location characteristics, commuting distance and car ownership) influence the number of weekly trips and travel distances either by mode or by purpose, which are considered to be short-term decisions. The conceptual framework also considers feedback effects, whereby shorter term travel behavior variables could influence commuting distance or location patterns of individuals.

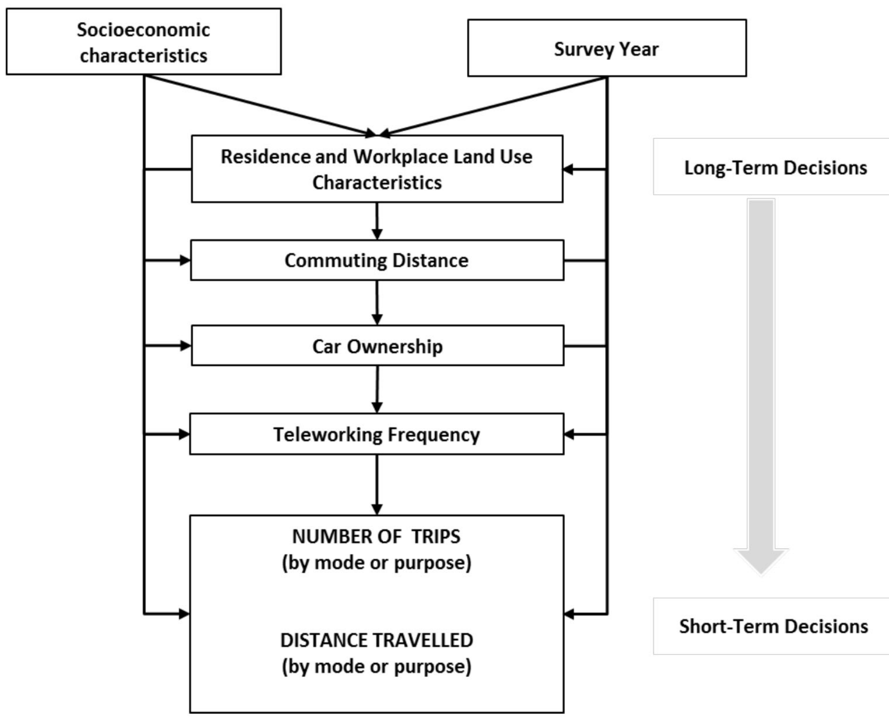

Figure 1: Conceptual model of the relationships between home telework, travel behavior, and land use

4 Data and variables

The data were obtained from Great Britain's National Travel Survey (NTS) for the period between 2005 and 2012. The NTS is a stratified multi-stage random sample face-to-face travel survey of British households and has been carried on a yearly basis since 1988. The survey collects data for trip diaries for each surveyed household during a 7-day period. The sample used in this study comprises workers from single-worker households, who reported working in the same place at least two days a week, are not self-employed in single worker companies and who do not work in agriculture or fisheries. Single-worker households, besides being easier to model, represent 44.7% of the households with workers in the NTS sample, making them a relevant segment. The sample size is 10,516 observations. Table 1 presents the variables used in the empirical analysis, their mean values and standard deviations, or frequencies, and their role in the model (endogenous or exogenous).

Table 1: Descriptive statistics of demographic, socioeconomic, and travel variables

Variable name	Type	Statistic	2005	2006	2007	2008	2009	2010	2011	2012
Endogenous variables										
Travel distance car	Censored	Mean	141,001	135,155	137,691	130,112	124,441	123,921	127,652	124,081
		St. Dev.	151,915	148,561	146,729	155,056	132,494	130,196	138,823	128,732
Travel distance transit	Censored	Mean	33,899	28,603	32,479	34,082	34,862	33,944	29,875	32,447
		St. Dev.	96,756	85,686	107,666	85,178	104,124	91,782	83,783	92,130
Travel distance active modes	Censored	Mean	4,327	4,391	4,240	4,551	4,471	4,581	5,221	4,990
		St. Dev.	9,655	8,737	9,668	10,277	9,961	9,226	12,571	13,111
# Trips car	Censored	Mean	14,858	14,796	14,859	14,105	14,288	14,393	14,231	14,645
		St. Dev.	10,317	10,219	10,125	10,005	9,851	10,209	10,057	9,873
# Trips transit	Censored	Mean	2,472	2,267	2,440	2,662	2,540	2,537	2,256	2,291
		St. Dev.	4,330	4,163	4,332	4,472	4,535	4,491	4,171	4,125
# Trips active modes	Censored	Mean	2,141	2,281	1,980	2,199	2,181	2,208	2,167	2,041
		St. Dev.	3,735	4,225	3,861	4,008	3,894	4,122	3,896	3,650
Commuting travel distance	Censored	Mean	69,073	65,445	68,094	68,136	64,696	63,785	62,254	63,926
		St. Dev.	91,114	85,045	85,479	92,974	92,234	81,688	85,344	79,782
Business trips travel distance	Censored	Mean	19,094	17,585	19,307	15,376	14,879	10,480	14,070	11,671
		St. Dev.	69,753	74,111	93,335	70,501	68,991	47,472	60,098	49,977
Non-work trips travel distance	Censored	Mean	90,978	85,050	86,939	85,145	84,127	88,063	86,316	85,809
		St. Dev.	105,717	104,986	102,712	96,643	98,877	103,720	105,438	108,410
# Commuting trips	Censored	Mean	7,407	7,407	7,635	7,350	7,263	7,056	7,125	7,167
		St. Dev.	3,294	3,378	3,535	3,370	3,371	3,374	3,320	3,280
# Business trips	Censored	Mean	0,881	0,774	0,788	0,646	0,717	0,646	0,708	0,710
		St. Dev.	2,334	2,301	2,419	1,835	2,302	1,913	2,249	2,193
# Non-work trips	Censored	Mean	11,183	11,163	10,856	10,970	11,029	11,435	10,822	11,100
		St. Dev.	8,393	8,333	8,371	8,197	8,018	8,875	8,191	8,207
# Household vehicles	Ordered	Mean	1,068	1,044	1,063	1,024	1,043	1,063	1,032	1,050
		St. Dev.	0,696	0,682	0,684	0,694	0,694	0,714	0,702	0,651
Log Commuting distance	Continuous	Mean	1,679	1,694	1,694	1,701	1,670	1,696	1,654	1,693
		St. Dev.	1,110	1,046	1,039	1,059	1,068	1,022	1,041	1,049
Exogenous variables										
Age	Continuous	Mean	44,181	44,755	44,999	45,052	46,251	46,122	46,374	45,627
		St. Dev.	11,953	12,190	12,691	12,470	12,297	12,487	12,166	12,634
Gender (1=man)	Binary	%	55,47%	54,55%	53,96%	52,32%	49,74%	52,23%	50,00%	50,69%
# Household adults	Censored	Mean	1,596	1,554	1,564	1,569	1,621	1,568	1,578	1,572
		St. Dev.	0,635	0,640	0,621	0,616	0,670	0,666	0,645	0,641
# Household children	Censored	Mean	0,643	0,561	0,532	0,587	0,561	0,536	0,557	0,569
		St. Dev.	1,032	0,990	0,924	0,984	0,979	0,934	0,962	1,006
1 person Household	Binary	%	37,48%	43,15%	41,30%	39,72%	38,10%	41,82%	39,97%	40,78%
Household Income	Continuous	Mean	27,151	26,582	27,947	29,030	29,270	29,738	30,009	30,342
		St. Dev.	18,478	17,813	18,123	19,833	19,188	20,461	20,622	19,111
Manager / Professional	Binary	%	44,17%	45,15%	45,47%	41,96%	41,72%	41,66%	41,67%	42,00%
Self-employed	Binary	%	2,16%	2,22%	1,77%	1,47%	2,04%	1,72%	1,86%	1,95%
Manufacturing worker	Binary	%	17,41%	15,54%	15,63%	16,07%	14,06%	12,69%	13,59%	13,65%
Time in residence	Ordered	Mean	3,553	3,572	3,649	3,660	3,742	3,729	3,826	3,723
		St. Dev.	1,759	1,809	1,781	1,811	1,772	1,770	1,754	1,786
Part-time worker	Binary	%	18,35%	18,73%	20,79%	22,64%	22,90%	23,73%	26,21%	21,61%
College educated	Binary	%	28,78%	28,05%	27,86%	27,43%	26,83%	30,15%	29,45%	31,44%

Table 2 shows there has been an increase in home-based teleworking between 2005 and 2012, particularly for those teleworking three or more times per week, which more than doubled. These figures are in accordance with NTS data for the full sample of workers (i.e., not just the sub-sample of single-worker households considered in this study; see Melo & de Abreu e Silva, 2017). Nevertheless, the vast majority of workers (around 82% in 2012) were not involved in home-based teleworking.

Table 3 shows that the relation between travel and one-way commuting distance and teleworking is not linear. It is possible to devise a general mobility and commuting distance growth tendency as the frequency of teleworking increases. However, for the highest frequency of teleworking there is a decrease in commuting distance and weekly travelled distances for all purposes and modes, with the exception of active modes. The more frequent teleworkers also have a higher number of weekly trips by active modes and business and non-work trips.

Table 2: Summary descriptive statistics of home telework frequency

	Teleworking frequency						
Year	Less than once a year	Once or twice a year	Less than once a month but more than twice a year	Once or twice a month	Less than once a week but more than twice a month	Once or twice a week	3 or more times a week
2005	88.8%	1.7%	1.8%	3.5%	1.6%	2.4%	0.3%
2006	89.1%	1.6%	1.9%	3.3%	0.7%	2.8%	0.6%
2007	88.9%	2.1%	2.3%	3.4%	1.1%	1.8%	0.4%
2008	88.9%	2.0%	2.1%	3.8%	0.7%	2.0%	0.5%
2009	84.8%	3.2%	4.0%	3.6%	1.2%	2.3%	0.9%
2010	85.0%	2.7%	3.2%	3.6%	1.5%	3.6%	0.4%
2011	85.2%	2.9%	3.3%	3.7%	1.1%	3.6%	0.2%
2012	81.9%	4.1%	3.9%	4.5%	1.6%	3.2%	0.7%

Table 3: Travel patterns by home telework frequency

	Teleworking frequency						
Travel variables (mean values)	**Less than once a year**	**Once or twice a year**	**Less than once a month but more than twice a year**	**Once or twice a month**	**Less than once a week but more than twice a month**	**Once or twice a week**	**3 or more times a week**
Travel distance car (miles)	122.020	184.010	179.890	201.550	206.920	183.520	123.670
Travel distance transit (miles)	26.790	59.860	69.650	78.690	60.740	80.560	22.240
Travel distance active modes (miles)s	4.460	5.760	6.040	4.920	6.880	4.120	6.130
# Trips car	14.440	15.340	15.410	15.310	15.220	14.590	13.540
# Trips transit	2.350	3.000	3.080	3.140	2.840	2.750	2.300
# Trips active modes	2.150	2.210	2.280	1.910	2.400	1.790	3.440

Travel variables (mean values)	Teleworking frequency Less than once a year	Once or twice a year	Less than once a month but more than twice a year	Once or twice a month	Less than once a week but more than twice a month	Once or twice a week	3 or more times a week
Commuting travel distance (miles)	60.152	91.413	93.852	107.509	109.399	120.624	50.670
Business trips travel distance (miles)	11.630	36.249	37.529	50.870	45.437	34.943	12.628
Non-work trips travel distance (miles)	81.400	121.876	124.133	126.673	119.576	112.551	88.628
# Commuting trips	7.410	7.270	7.010	6.770	6.600	5.740	5.370
# Business trips	0.630	1.310	1.330	1.560	1.500	1.430	1.740
# Non-work trips	10.910	11.970	12.430	12.020	12.350	11.960	12.170
One-ways commuting distance (miles)	4,932	8,330	8,581	10,332	11,306	11,635	6,170

The variables describing land use features and transport accessibility of residence and work locations were obtained both from the NTS and from external data sources. NTS data for residence and work locations are available at different geographical levels. Data for residential locations are available at the level of Primary Sampling Units (PSU), which corresponds to a postcode sector, but also for more aggregate levels such as wards and unitary authorities (UAs). On the other hand, data for employment locations are available only at the level of unitary authorities. The NTS also collects data on respondents' perceptions about accessibility to public transport (i.e., nearest bus stop, nearest train station) and frequency of services close to their residence. These data were complemented by additional external (i.e., not in NTS) data relating to the number and density of jobs in the employment UAs, as well as the density of roads and train stations in the residence ward. Based on these variables, a principal components factor analysis technique was employed, which resulted in six factors explaining 68.5 % of the total variation. These factors, together with their defining variables and respective scores, are presented in Table 4.

Table 4: Principal components factor analysis of land-use factors (KMO = 0.731)

Land use factor	Most important variables	Loadings
(1) Living in a denser area	Population density (primary sampling unit of residence)	0.832
	Population density (local authority of residence)	0.774
	Bus frequency in the residence area	0.681
	Minor roads density (ward of residence)	0.809
(2) Working in London or other dense urban centers	Working in London central area x number of jobs in the working unitary authority(*)	0.980
	Density of jobs in the working unitary authority	0.980

Land use factor	Most important variables	Loadings
(3) Living in a rail accessible area	Walking time to the closest rail station (residence area)	-0.697
	Rail stations density (residence ward)	0.743
(4) Living in a low transit accessible area	Walking time to the closest bus stop (residence area)	0.721
	Travel time in bus to the closest rail station (residence area)	-0.719
(5) Working in metropolitan suburbs and living in a freeway accessible area	Working in a metropolitan centre outer area x number of jobs in the working unitary authority (*)	0.689
	Motorway density in the residence ward	0.714
6) Working in the countryside	Working in small urban areas(3k-25k inhabitants) x number of jobs in the working unitary authority	-0.671
	Working in rural areas x number of jobs in the working unitary authority	0.777
(*) Interaction effects between the working area and the number of jobs		

From the resulting six factors, three are mainly related with the characteristics of the residence area, two with the employment area, and one is related both with the residence and employment areas. The first factor, named Living in a denser area has high loadings in density variables, bus frequency and minor roads density. The second factor is associated with working in London or other dense job centers. The third and fourth factors are related with the level of accessibility to both rail and bus services in the vicinity of the residence, and capture both zones with high accessibility to rail and zones with low levels of bus accessibility. The fifth factor captures the joint characteristics of living in areas with high accessibility by freeway and working in the suburbs of metropolitan areas. Finally, the sixth factor has strong loadings on the interaction between the number of jobs and working either in rural areas or in small urban areas. It was named Working in the countryside.

5 Methodology

The modelling approach used here is path analysis, which is a special case of Structural Equation Modelling (SEM) when all variables included in the different model equations are observed. The general equation for this method is as follows:

$$y = By + \Gamma x + \zeta \quad (1)$$

where:
y is the vector of the endogenous variables;
B is the matrix containing the coefficients for the equations relating the endogenous variables;
X is the vector of the exogenous variables;
Γ is the matrix containing the coefficients for the equations relating the exogenous with the endogenous variables;
ζ is the vector of the residuals from the structural relationships between y and x.

The fact that this method is able to model simultaneously several endogenous variables and handle direct and indirect relationships makes it particularly adequate to study complex relationships between travel behavior and the urban environment (for more details about SEM see, for example, Kaplan, 2000; Bollen, 1989). The model results include direct (equivalent to regression coefficients), indirect (sum of the effects mediated by other variables) and total effects (sum of the direct and indirect effects). Direct effects give a clear image about the model structure, but the total effects allow for a better interpretation, since due to possible contradictory direct and indirect effects, model interpretation based only in the direct effect might lead to misleading conclusions.

The estimation method used is the Weighted Least Squares (WLS). This method was developed to deal with binary, ordered and censored variables (Golob, 2003), as is the case of our data. Since WLS uses correlation matrices, the resulting coefficients are standardized, facilitating a direct comparison between the magnitudes of the different effects.

6 Results and discussion

6.1 Causality between home telework and commuting distance

As discussed previously, one of the key issues in the study of the relations between teleworking, land use patterns and travel behavior is the direction of causality between teleworking and commuting distance. The modelling method, path analysis, is used to test theoretical relationships, but it cannot establish causal relationships unless the conditions of temporal ordering, correlation and control for other causes are met (Schumaker & Lomax, 2004). In the case of our study it is basically temporal ordering that is missing, since the data comes from eight years of cross-sectional travel surveys. Nevertheless, it is possible to test different model specifications, compare them, and based on the model fit indicators and the arguments laid out in the literature, opt for one specification.

Since both models used share a common part (the only difference in their structure relates to the endogenous variables for the travel modes and travel purposes), three different alternatives were tested for the common component: a) teleworking frequency is a function of commuting distance, b) the reverse relation is considered, and c) a simultaneous bidirectional relationship between commuting distance and teleworking frequency (non-recursive model). To compare these models four goodness-of-fit indicators where considered, namely, the chi-square statistic (and its p-value), the Akaike Information Criterion (AIC), the Consistent Akaike Information Criterion (CAIC), and the Expected Cross Validation Index (ECVI) together with its 90% confidence interval. The model with the lowest values for the three last indicators should be the preferred one (Kaplan, 2000; Schermelleh-Engel, Moosbrugger, & Müller, 2003). The results are presented in Table 5. With the exception of the chi-square statistic (although the implied p-value is almost identical to the one for alternative c), which has the smaller chi-squared statistic), all the fit indicators support the choice of alternative a), that is, teleworking frequency as a function of commuting distance, as the preferred specification. However, the fit indicators are not fully conclusive, since the confidence intervals of ECVI have some overlap. Also, in the case of specification c) the coefficient for the effect of commuting distance on telework is negative and non-significant. From these indicators and the discussion presented earlier we have opted for specifying home telework as a function of commuting distance.

Table 5: Comparison between the different model specifications

Model specification	Chi-square (p-value)	AIC	CAIC	ECVI [90% confidence interval]
a) - Teleworking function of commuting distance	114.841 (0.0143)	452.841	1848.892	0.0431 [0.0408; 0.0462]
b) - Commuting distance function of teleworking	120.844 (0.0053)	458.844	1854.894	0.0437 [0.0413; 0.0469]
c) – bidirectional relationship between commuting distance and teleworking (non-recursive relationship)	113.657 (0.0144)	453.657	1857.868	0.0432 [0.0409; 0.0462]

6.2 Goodness of fit of models by travel mode and travel purpose

Both model specifications (travel modes and travel purposes) present good levels of fit, as can be seen from Table 6 for the following fit indicators: the Chi-square statistic, respective p-value, the RMSEA and the Test of Close Fit (RMSEA<0.05), and both Bayesian fit indicators AIC and CAIC. The ratio between the chi-square and the degrees of freedom, close to 1 for both models, is also indicative of a good fit (Schermelleh-Engel et al., 2003; Jöreskog & Sörbom, 1993). In addition, the RMSEA values indicate a good fit (Schermelleh-Engel et al., 2003) and the values for AIC and CAIC are smaller than the values for both the saturated and independence models, indicating that the estimated models are superior to these.

Table 6: Summary of goodness of fit indicators of the SEM analysis

Goodness of fit indicators	Model travel modes	Model travel purposes
Chi-square	183,487	173,157
# degrees of freedom	181	185
p-value	0,434	0,724
RMSEA	0,0011	0,000
p-value (test of close fit)	1,000	1,000
AIC	633,487	615,157
CAIC	2492,134	2440,762

6.3 Effects on weekly travel due to the exogenous variables

Table 7 and Table 8 report both the standardized direct and total effects of the exogenous variables obtained from the models of weekly travel by mode and by purpose, respectively. Globally, both models are able to capture the effects from socioeconomic characteristics on travel variables as predicted in the literature. Higher household income levels are associated with increased travel by (private and transit) motorized modes and for the different purposes (i.e., commuting, business, non-work). Weekly travelled distances are higher for men for each type of travel mode and purpose, with the exception of non-work related travel, which is higher for women. This suggests that women may spend more time than men travelling for non-work reasons (e.g., shopping, escorting children to school). Car ownership levels are also influenced by the exogenous variables, namely, household income and the number of adults in the household. The results also support the existence of self-selection of residential and working location on individual and household socioeconomic characteristics.

With respect to the factors affecting home telework frequency, the models suggest that younger, male workers with a college degree belonging to smaller households with higher income levels are more likely to engage in telework more frequently. This is in accordance with what has been reported previously (e.g., de Graaff & Rietvelt, 2004; Poury & Bhat, 2003; Hjorthol & Nossum, 2007; He & Hu, 2015). House tenure duration is positively related with telework frequency, supporting the argument that teleworking is in great part a strategy to cope with longer commutes.

Table 7: Direct and total effects on weekly travel by mode attributable to exogenous variables

	Type of Effect	Survey Year	Age	Gender (1=man)	# Household adults	#Household children	1 person Household	Household Income	Manager / Professional	Self-employed	Manufacturing worker	Time in residence	Part time worker	College educated
Travel distance car	Direct	**-0.047**		**0.096**	**0.281**	**-0.464**		**0.175**	**-0.024**			**-0.169**		
	Total	**-0.046**	**0.018**	0.014	**0.296**	**-0.432**	0.000	**0.254**	**-0.054**	**0.123**	**0.099**	**-0.137**	**0.034**	**0.041**
Travel distance transit	Direct				**-0.026**			**0.085**		**0.020**			**0.048**	**0.028**
	Total	**-0.024**	**-0.029**	**0.069**	**-0.103**	**0.006**	**0.000**	**0.229**	**0.046**	**-0.132**	**-0.139**	-0.009	0.030	**0.082**
Travel distance active modes	Direct	**0.019**		**0.015**							**0.017**			
	Total	0.012	-0.003	**0.162**	**-0.083**	**0.002**	**0.000**	**-0.111**	**0.006**	**-0.110**	**-0.001**	**-0.012**	**0.140**	**0.150**
# Trips car	Direct			**-0.118**	**-0.168**	**0.056**					**0.035**			
	Total	**-0.006**	**0.028**	**-0.127**	**0.038**	**0.048**	0.000	**0.090**	**-0.045**	**0.156**	**0.149**	**0.046**	**0.051**	0.005
# Trips transit	Direct	**-0.036**	**0.040**	**-0.038**	**0.104**			**0.138**			**-0.029**		**0.063**	
	Total	**-0.023**	-0.027	**0.033**	**-0.071**	**0.011**	**0.000**	**0.006**	**0.065**	**-0.151**	**-0.180**	-0.012	-0.029	**0.089**
# Trips active modes	Direct	**-0.022**		**0.183**	**-0.023**					**-0.117**			**0.162**	**0.112**
	Total	**-0.004**	0.001	**0.132**	**-0.076**	**0.003**	**0.000**	**-0.179**	**0.007**	**-0.096**	**-0.016**	**-0.012**	**0.144**	**0.162**
Teleworking frequency	Direct	**0.070**			**-0.094**			**0.124**		**0.233**		**0.024**		**0.431**
	Total	**0.066**	**-0.006**	**0.030**	**-0.109**	0.000	**0.000**	**0.215**	**-0.002**	**0.202**	**-0.005**	**0.024**	**0.002**	**0.419**
# Household vehicles	Direct				**0.373**					**0.272**	**0.058**	**0.110**		**0.138**
	Total	**-0.010**	**0.039**	**0.024**	**0.331**	**-0.004**		**0.254**	**-0.028**	**0.232**	**0.114**	**0.078**	**0.071**	**0.052**
Log Commuting distance	Direct	**-0.026**	**-0.045**	**0.208**	**-0.113**			**0.600**		**-0.192**	**-0.054**			**-0.038**
	Total	**-0.033**	**-0.038**	**0.196**	**-0.106**	**-0.007**		**0.606**	**-0.008**	**-0.180**	**-0.032**	-0.004	**0.014**	**-0.049**
Living in a denser area	Direct		**-0.176**	**0.040**	**0.095**			**-0.506**	**0.045**		**-0.166**	**0.118**	**-0.226**	**0.234**
	Total		**-0.176**	**0.040**	**0.095**			**-0.506**	**0.045**		**-0.166**	**0.118**	**-0.226**	**0.234**
Working in London or other dense centers	Direct	**0.031**		**0.038**		**0.029**			**0.126**		**-0.156**		**-0.084**	**0.079**
	Total	**0.025**	**-0.007**	**0.073**	**-0.020**	**0.028**		**0.111**	**0.125**	**-0.033**	**-0.162**	-0.001	**-0.081**	**0.070**
Living in a rail accessible area	Direct				**-0.047**				**0.017**	**0.046**	**-0.018**			**0.071**
	Total				**-0.047**				**0.017**	**0.046**	**-0.018**			**0.071**
Living in a low transit accessible area	Direct	**-0.062**		**-0.076**	**0.049**	**-0.055**		**-0.084**	**0.021**	**0.125**	**0.052**			**0.058**
	Total	**-0.063**	**0.003**	**-0.074**	**0.074**	**-0.055**		**-0.065**	**0.019**	**0.143**	**0.061**	**0.006**	**0.005**	**0.062**
Working in metropolitan suburbs and living in a freeway accessible area	Direct						**0.017**			**-0.039**				
	Total						**0.017**			**-0.039**				
Working in the countryside	Direct	**0.063**								**-0.036**	**-0.026**			
	Total	**0.063**	**0.001**	**0.001**	**0.009**	**0.000**		**0.007**	**-0.001**	**-0.030**	**-0.023**	**0.002**	**0.002**	**0.001**

Note: coefficients significant at 95% presented in bold.

Table 8: Direct and total effects on weekly travel by purpose attributable to exogenous variables

	Type of Effect	Survey Year	Age	Gender (1=man)	# Household adults	#Household children	1 person Household	Household Income	Manager / Professional	Self-employed	Manufacturing worker	Time in residence	Part time worker	College educated
Commuting travel distance	Direct	**-0,020**			**0,457**	**-0,541**						**-0,181**		
	Total	**-0,019**	**0,017**	**0,119**	**0,426**	**-0,542**	**-0,007**	**0,191**	0,001	-0,021	**-0,075**	**-0,184**	**-0,203**	**-0,029**
Business travel distance	Direct	**-0,026**								**0,090**				**0,065**
	Total	**-0,048**	**0,019**	**0,025**	**-0,026**	**-0,002**	**0,004**	**0,132**	**-0,011**	**0,130**	**-0,038**	**0,002**	**-0,043**	**0,138**
Nonworktrips travel distance	Direct			**0,058**			**0,131**	**0,223**				**-0,028**		
	Total	**-0,039**	**-0,031**	**-0,029**	**0,018**	**-0,004**	**0,161**	**0,349**	**-0,020**	**0,023**	**0,107**	-0,010	**0,264**	**0,101**
# Commuting trips	Direct		**0,062**	**0,097**	**0,057**					**0,058**	**-0,119**		**-0,457**	**-0,097**
	Total	**-0,009**	**0,067**	**0,065**	**0,092**	**0,001**	**0,000**	**-0,120**	**0,001**	**0,036**	**-0,114**	**-0,004**	**-0,459**	**-0,176**
# Business trips	Direct	**-0,027**	**0,067**		**-0,018**				**-0,016**	**0,158**	**-0,108**		**-0,187**	**0,147**
	Total	**-0,034**	**0,055**	**-0,029**	**-0,013**	**-0,001**	**0,009**	**0,036**	**-0,022**	**0,161**	**-0,071**	**0,006**	**-0,098**	**0,179**
# Nonwork trips	Direct	**-0,025**		**-0,050**			**0,034**						**-0,070**	
	Total	**-0,027**	**-0,043**	**-0,107**	**0,019**	**-0,005**	**0,034**	**0,130**	**-0,020**	**0,010**	**0,138**	**0,022**	**0,325**	**0,117**
Teleworking frequency	Direct	**0,066**			**-0,094**			**0,121**		**0,249**		**0,024**		**0,430**
	Total	**0,062**	**-0,005**	**0,033**	**-0,110**	0,000	**0,000**	**0,216**	**-0,002**	**0,217**	**-0,005**	**0,024**	**0,002**	**0,418**
# Household vehicles	Direct				**0,375**					**0,251**	**0,057**	**0,114**		**0,143**
	Total	**-0,009**	**0,042**	**0,023**	**0,334**	**-0,004**		**0,249**	**-0,026**	**0,212**	**0,113**	**0,082**	**0,070**	**0,058**
Log Commuting distance	Direct	**-0,024**	**-0,040**	**0,210**	**-0,111**			**0,594**	**0,000**	**-0,191**	**-0,052**			**-0,037**
	Total	**-0,031**	**-0,032**	**0,198**	**-0,105**	**-0,006**		**0,604**	**-0,007**	**-0,180**	**-0,031**	**-0,004**	**0,014**	**-0,049**
Living in a denser area	Direct		**-0,177**	**0,041**	**0,092**			**-0,492**	**0,040**		**-0,164**	**0,117**	**-0,219**	**0,229**
	Total		**-0,177**	**0,041**	**0,092**			**-0,492**	**0,040**		**-0,164**	**0,117**	**-0,219**	**0,229**
Working in London or other dense centers	Direct	**0,027**		**0,041**		**0,030**			**0,122**		**-0,158**		**-0,086**	**0,077**
	Total	**0,022**	**-0,006**	**0,075**	**-0,018**	**0,029**		**0,104**	**0,121**	**-0,031**	**-0,163**	**-0,001**	**-0,084**	**0,068**
Living in a rail accessible area	Direct				**-0,048**				**0,018**	**0,047**	**-0,018**			**0,071**
	Total				**-0,048**				**0,018**	**0,047**	**-0,018**			**0,071**
Living in a low transit accessible area	Direct	**-0,062**		**-0,074**	**0,048**	**-0,051**		**-0,081**	**0,020**	**0,126**	**0,051**			**0,056**
	Total	**-0,063**	**0,003**	**-0,072**	**0,072**	**-0,051**		**-0,064**	**0,018**	**0,141**	**0,059**	**0,006**	**0,005**	**0,060**
Working in metropolitan suburbs and living in a freeway accessible area	Direct						**0,016**			**-0,038**				
	Total						**0,016**			**-0,038**				
Working in the countryside	Direct	**0,063**								**-0,036**	**-0,027**			
	Total	**0,063**	**0,001**	**0,001**	**0,010**	**0,000**		**0,007**	**-0,001**	**-0,030**	**-0,024**	**0,002**	**0,002**	**0,002**

Note: coefficients significant at 95% presented in bold.

6.4 Effects on weekly travel due to the endogenous variables

Table 9 and Table 10 report the main findings for the standardized effects of the endogenous variables obtained from the models of weekly travel by mode and by purpose, respectively. The relationships estimated in the models are shown in Figure 2 and Figure 3, which provide a visual summary of the standardized effects due to the endogenous variables in the form of path diagrams.

Table 9 shows that home teleworking frequency increases the weekly distance travelled for all modes, indicating that teleworking is not an effective travel demand management strategy, quite the contrary. This in turn suggests that home teleworking has a complementarity effect on travel, corroborating the findings of Zhu (2012), who argued that teleworkers had larger travel budgets. Looking at the total effects of teleworking on the weekly distances travelled, the strongest effect is found for active modes followed by car, while the effect for transit modes is substantially weaker. The positive effect on distance travelled by active modes is mainly a consequence of the positive effect of teleworking on the number of trips by active modes. This result is in accordance with findings by Pendyala et al. (1991) and Saxena and Mokhtarian (1997), which point to the fact that teleworkers tend to have a smaller activity space centered around their house in the days they work from home. On the contrary, the effect of teleworking on weekly travel by car suggests that although teleworkers may make fewer car trips, they travel longer distances. These results also indicate that although teleworking frequency increases travel, the stronger determinants of mobility are location patterns, commuting distance and motorization rates. Nevertheless, teleworkers travel more than non-teleworkers with similar location and motorization patterns.

When considering weekly travel by purpose (in Table 10), the results show that home teleworking frequency reduces weekly commuting trip frequency, but increases the number of trips for the other two purposes (i.e., business and non-work). Teleworking frequency also increases the distances travelled for all purposes, although the total effect on non-work distances travelled is not statistically significant. This indicates that teleworkers may engage in more, but shorter, non-work related trips, possibly as a result of reduced trip chaining, which is in accordance with the findings by Pendyala et al. (1991).

The direct effect of teleworking frequency on weekly travelled commuting distance travelled is positive in spite of the negative effect of teleworking on the number of commuting trips. This result suggests there may be a negative offsetting / compensation effect whereby the reduced number of trips is more than offset by longer one-way commute distances. These results, and the fact that commuting distance has a strong negative total effect on commuting trips, and a positive effect on teleworking frequency, show that individuals who live farther from work may have a greater incentive to make fewer weekly commuting trips, for example by working from home, in accordance with the hypothesis that teleworking may be, at least in the short term, a strategy to cope with longer and costlier commutes. Longer commute distances may encourage individuals to adopt home teleworking as a way of saving time and monetary cost associated with commuting to work. The higher housing costs of very large urban areas, as is the case of London, may create an additional pressure on commuters to live farther away from their urban workplaces, in suburban or peri-urban areas where housing is more affordable. Particularly relevant is the fact that workers living in denser areas and in areas with good rail accessibility have a lower probability of working from home more frequently; reinforcing the view that teleworking may be used as a strategy adopted to cope with costlier and longer commutes.

As for the other relationships, Figure 2 and Figure 3 show that there is a clear hierarchy of decisions going from longer term decisions to shorter term ones. Nevertheless, there are some feedback effects from car ownership and commuting distance to land use factors for both the residence and employment locations. Land use characteristics associated with living in more central and denser areas are associated with shorter commutes. Car ownership level is positively influenced by commuting distance, and strongly negatively influenced by land uses associated with more central and denser areas. These results are in line with existing empirical evidence, thereby reinforcing our confidence in the models.

Table 9: Direct and total effects on weekly travel by mode attributable to endogenous variables

	Effects	Travel distance Transit	Travel distance active modes	# Trips car	# Trips transit	# Trips active modes	Teleworking frequency	# Household vehicles	Log Commuting distance	Living in a denser area	Working in London or other dense centers	Living in a rail accessible area	Living in a low transit accessible area	Working in metropolitan suburbs and living in a freeway accessible area
Travel distance car	Direct			**0,668**			**0,091**							
	Total	**-0,098**	-0,010	**0,668**	**-0,072**	-0,010	**0,086**	**0,414**	**0,038**	**-0,128**	**-0,190**	**-0,043**	0,001	**-0,002**
Travel distance transit	Direct				**0,736**				**0,230**					
	Total		**0,105**		**0,736**	**0,101**	**0,050**	**-0,374**	**0,283**	**0,259**	**0,264**	**0,015**	**0,025**	**-0,001**
Travel distance active modes	Direct					**0,960**			**0,101**					
	Total					**0,960**	**0,110**	**-0,196**	**-0,161**	**0,058**	**0,030**	**0,023**	**-0,017**	**-0,002**
# Trips car	Direct	**-0,146**						**0,565**			**-0,181**			
	Total	**-0,146**	-0,015		**-0,108**	-0,015	**-0,007**	**0,620**	**0,036**	**-0,191**	**-0,283**	**-0,058**	**0,003**	**0,000**
# Trips transit	Direct		**0,142**				**0,052**	**-0,483**	**0,126**	**0,232**	**0,327**			
	Total		**0,142**			**0,137**	**0,068**	**-0,510**	**0,074**	**0,364**	**0,376**	**0,039**	0,005	**-0,001**
# Trips active modes	Direct						**0,115**	**-0,203**	**-0,251**					
	Total						**0,115**	**-0,205**	**-0,272**	**0,065**	**0,037**	**0,030**	**-0,027**	**-0,002**
Teleworking frequency	Direct								**0,147**			**-0,041**	**-0,022**	**-0,019**
	Total							-0,001	**0,145**	**-0,005**	**-0,008**	**-0,049**	-0,009	**-0,019**
# Household vehicles	Direct								**0,217**	**-0,265**	**-0,105**	**-0,091**		
	Total							**0,001**	**0,196**	**-0,273**	**-0,116**	**-0,102**	**0,018**	
Log Commuting distance	Direct									**-0,038**	**-0,056**	**-0,059**	**0,091**	
	Total							**0,007**	-0,009	**-0,039**	**-0,056**	**-0,059**	**0,090**	
Working in London or other dense centers	Direct								**0,183**					
	Total							**0,001**	**0,182**	**-0,007**	-0,010	**-0,011**	**0,016**	
Living in a low transit accessible area	Direct							**0,074**						
	Total							**0,075**	**0,015**	**-0,020**	**-0,009**	**-0,008**	**0,001**	
Working in the countryside	Direct							**0,028**						
	Total							**0,028**	**0,005**	**-0,008**	**-0,003**	**-0,003**	**0,000**	

Note: coefficients significant at 95% presented in bold.

Table 10: Direct and total effects on weekly travel by purpose attributable to endogenous variables

	Type of Effect	Business travel distance	# Commuting trips	# Business trips	# Non-work trips	Teleworking frequency	# Household vehicles	Log Commuting distance	Living in a denser area	Working in London or other dense centers	Living in a rail accessible area	Living in a low transit accessible area	Working in metropolitan suburbs and living in a freeway accessible area	Working in metropolitan suburbs and living in a freeway accessible area
Commuting travel distance	Direct		**0,315**		**-0,195**	**0,160**	**0,000**	**0,364**						
	Total		**0,472**		**-0,195**	**0,079**	**-0,047**	**0,309**	0,000	0,010	**-0,018**	**0,026**	**-0,001**	
Business travel distance	Direct			**0,460**				**0,192**						
	Total		**-0,101**	**0,460**	**0,125**	**0,011**	**0,032**	**0,209**	**-0,017**	**-0,027**	**-0,016**	**0,018**	**0,000**	
Nonworktrips travel distance	Direct	0,234			**0,844**	**-0,072**								
	Total	0,234	**-0,701**	**0,108**	**0,873**	0,004	**0,218**	**0,158**	**-0,065**	**-0,122**	**-0,031**	**0,014**	0,000	
# Commuting trips	Direct					**-0,204**		**-0,126**						
	Total					**-0,204**	-0,001	**-0,156**	**0,007**	0,008	**0,018**	**-0,009**	**0,004**	
# Business trips	Direct				**0,272**									
	Total		**-0,219**		**0,272**	**0,024**	**0,068**	**0,039**	**-0,020**	**-0,038**	**-0,010**	**0,003**	**0,000**	
# Nonwork trips	Direct		**-0,803**			**-0,077**	**0,248**			**-0,106**				
	Total		**-0,803**			**0,087**	**0,249**	**0,143**	**-0,073**	**-0,138**	**-0,036**	**0,011**	**-0,002**	
Teleworking frequency	Direct							**0,157**			**-0,041**	**-0,023**	**-0,018**	
	Total						**-0,001**	**0,155**	**-0,006**	**-0,007**	**-0,051**	-0,009	**-0,018**	
# Household vehicles	Direct							**0,209**	**-0,270**	**-0,101**	**-0,095**			
	Total						**0,001**	**0,191**	**-0,278**	**-0,111**	**-0,107**	**0,017**		
Log Commuting distance	Direct								**-0,042**	**-0,049**	**-0,062**	**0,089**		
	Total						**0,006**	-0,007	**-0,043**	**-0,049**	**-0,062**	**0,088**		
Working in London or other dense centers	Direct							**0,173**						
	Total						**0,001**	**0,171**	**-0,007**	-0,008	**-0,011**	**0,015**		
Living in a low transit accessible area	Direct						**0,071**							
	Total						**0,071**	**0,014**	**-0,020**	**-0,008**	**-0,008**	**0,001**		
Working in the countryside	Direct						**0,029**							
	Total						**0,029**	**0,006**	**-0,008**	**-0,003**	**-0,003**	**0,000**		

Note: coefficients significant at 95% presented in bold.

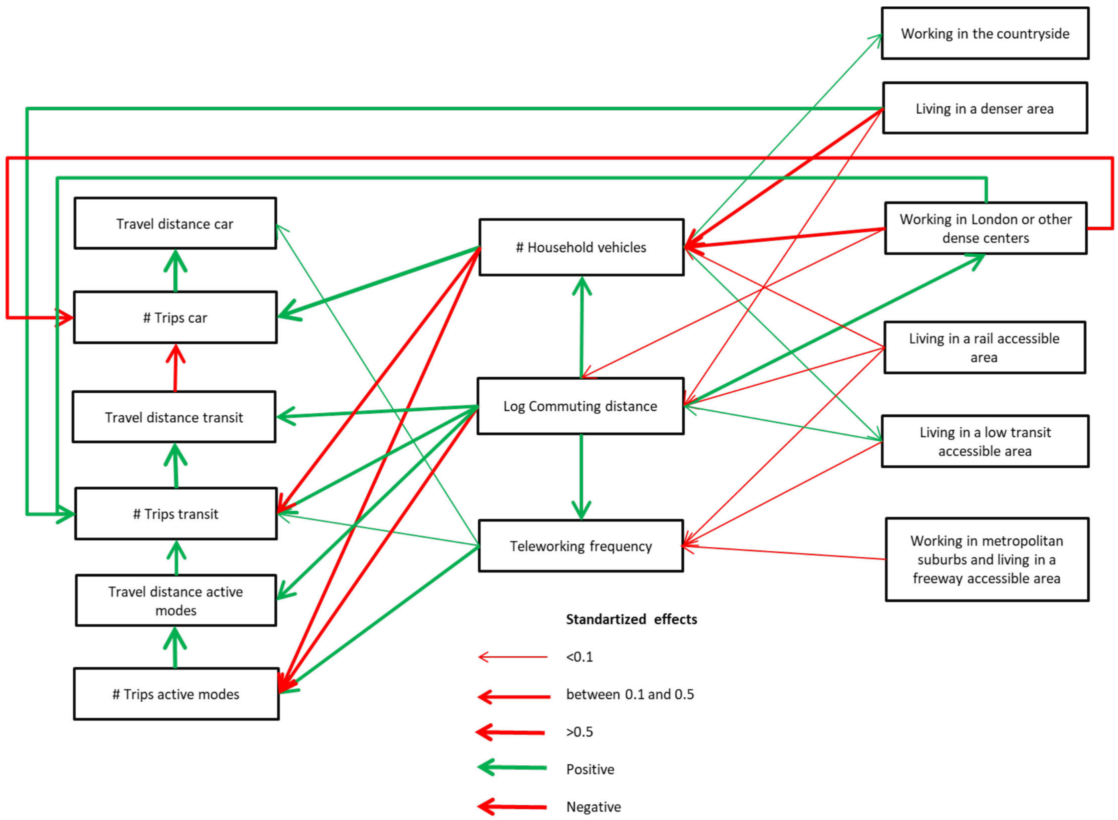

Figure 2: Causal path diagram for weekly travel by mode

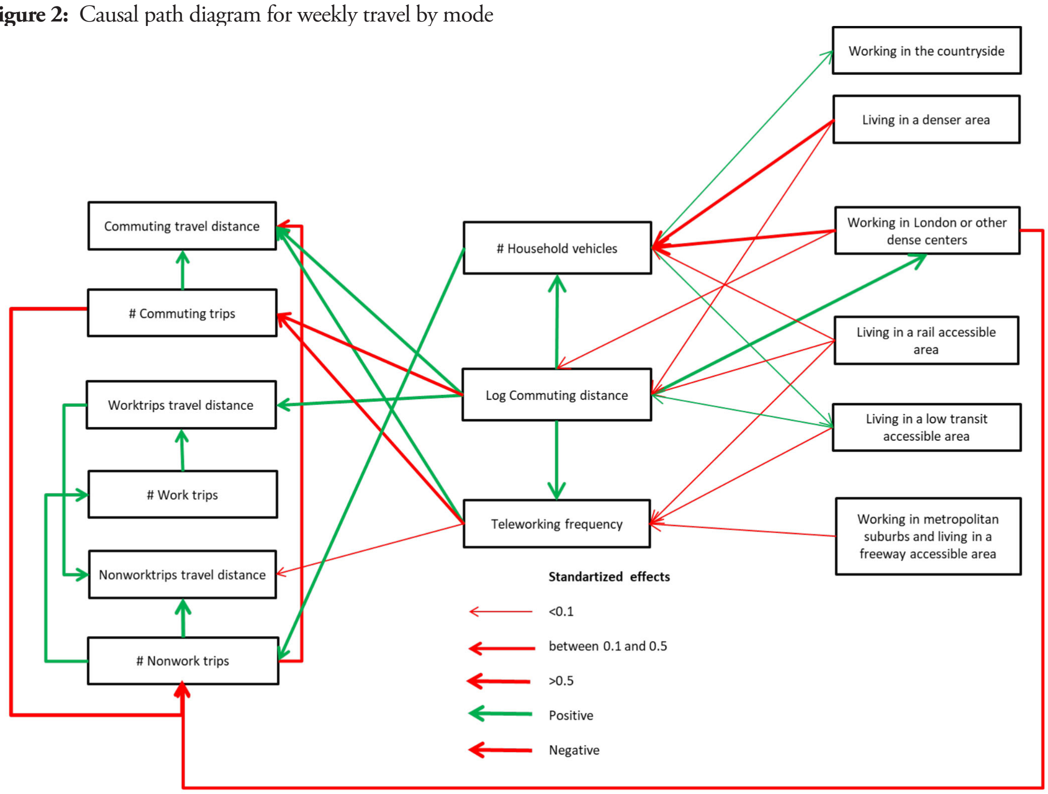

Figure 3: Causal path diagram for weekly travel by purpose

7 Conclusions

This work studied the effects of home-based teleworking on the number of trips and weekly miles travelled by mode and purpose for one-worker households in Great Britain using data from the NTS for the period between 2005 and 2012. To better understand the relationship between home teleworking and travel, a path analysis model based on previous research on the relationships between travel behavior, home and workplace land use characteristics, and long- and short-term travel related decisions was estimated. The use of this modelling approach allowed us to explicitly model endogenous relations in the chain of decisions relating to home and work location, commuting distance, car ownership, teleworking frequency and weekly travel.

The main conclusions relating to home teleworking frequency point to the fact that it increases weekly miles travelled, particularly by car, while it does not reduce commuting weekly miles travelled (in spite of reducing the number of commuting trips). This indicates that the benefits of home teleworking are offset by the longer home-to-work commuting distances of teleworkers. It also suggests that home teleworking is not an effective travel demand management strategy, particularly because it seems to increase car mode share. On the other hand, teleworkers may engage in more non-work related trips centered around their homes, and since they have lower transit accessibility levels at their residence areas, they are likely to resort to either active travel (for shorter trips) or the car, which is available to them (i.e., higher levels of car ownership). The outcome therefore appears to be: travelling more by less sustainable and more polluting transport modes.

The findings also support the hypothesis that home teleworking can be used by individuals as a strategy to cope with long and costly commutes. This is supported both by the reverse causality analysis using competing model specifications, the studies discussed in the literature review (e.g., Mokhtarian & Salomon, 1997; Ory & Mokhtarian, 2006; Helminen & Ristimäki, 2007), and the fact that commuting distance is the result of decisions with respect to both residence and employment locations. These decisions are considered as medium- to long-term decisions, since high transaction costs mean they are difficult to revert instantly. This does not mean that the possibility of working from home might not be considered as one decision variable when households are contemplating relocating, but it is more likely an enabler than one of the main drivers for home relocation.

These results have one potential caveat. Although the distance travelled by mode and commuting distance increase with teleworking frequency (see Table 3), there is a reduction in these indicators for the highest frequency of teleworking. This implies the possibility of very frequent teleworkers travelling less and indicates there may be some non-linear effects in the relationship between telework and travel behavior. Unfortunately, since the number of very frequent teleworkers (i.e., people engaging in teleworking three or more days a week) represents a very small proportion of the dataset (3.6%) it is not possible, even when modelling telework frequency as an ordered variable, for the model to capture this slump and to draw definitive conclusions about its causes.

Finally, it is worth noting that this research only considers a specific group of households, namely single-worker households. Although they do not represent the majority of households, they are nonetheless a relevant group (almost half of the households with workers) of the population and allow testing our modelling approach in a less complex context such as that of two-worker households. Therefore, future research will extend and adapt the path analysis modelling framework developed in this paper to two-worker households and total household travel.

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