The impact of teleworking on English travel

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Abstract

The global pandemic has revived debates about the contribution of teleworking to reducing travel, air pollution, energy use and carbon emissions. However, previous research suggests that the availability of teleworking may encourage people to move farther from their place of work, creating the risk that the benefits of fewer commutes will be offset by longer commutes. In addition, teleworking may encourage additional non-work travel by the teleworker, and/or influence the travel behaviour of other household members. These complex interactions make the overall impacts of teleworking difficult to predict.

In this context, we use data from the English National Travel Survey to estimate the impact of teleworking on the travel patterns of workers over the period 2005 to 2019. We compare the weekly distance travelled by teleworkers and non-teleworkers, and examine how this varies with frequency of teleworking. We estimate the impact of teleworking on the weekly distance travelled by purpose (work, non-work and total) and by mode (car, public transport and active) for both one-worker and two-worker households, while controlling for a range of socio-economic and demographic variables.

Our preliminary results provide little support for the claim that teleworking reduces travel. Indeed, after controlling for a range of variables, we find that the majority of English teleworkers travel *farther* each week than non-teleworkers. This results from a combination of greater distances between home and workplace and additional non-work travel. There appears to be a 'tipping point' however: if people telework three or more times a week, their weekly commuting distance may be *less* than that of non-teleworkers. We discuss the factors contributing to these results and indicate priorities for further research.

Introduction

Teleworking (working from home or remotely using information technology) has the potential to reduce commuter travel and the associated congestion, air pollution, energy use and carbon emissions. However, the availability of teleworking may encourage people to move to suburban or rural locations that are further from their place of work [1], and/or encourage additional non-work travel by the telecommuter [2]. In addition, teleworking may influence the travel patterns of other household members – for example, by 'freeing-up' the household car for other uses [3], or by encouraging relocation closer to a partner's place of work. These complex interactions create uncertainty about the overall impact of teleworking, and the empirical literature provides contradictory results [4].

Despite the availability of high quality travel surveys, there are relatively few studies of the impact of teleworking on travel patterns in England. One of the most rigorous studies is by Melo, *et al.* [5], who found that teleworking was associated with *more* rather than less commuter travel – largely as a consequence of teleworkers living farther from their workplace than non-teleworkers. In a follow-up study, de Abreu e Silva, *et al.* [6] found that teleworking was associated with more *total* travel – due to both longer commute distances and additional non-work travel on teleworking days. However, their results were only significant for households with one worker.

Both of these studies use pooled, cross-sectional data from the English National Travel Survey (NTS) [7] over the period 2005 to 2012. The present study takes a similar approach to Melo, *et al.* [5], but extends the dataset to 2019. This time period captures the increase in teleworking over the last few years, but excludes the 2020 global pandemic. We also extend Melo *et al*'s analysis to include the impacts on non-work travel, and on travel by different modes. Our research questions are:

- How does the frequency of teleworking affect an individuals' weekly travel for commuting and other purposes?
- How does the frequency of teleworking by one individual affect the weekly travel of their partner?

This work is ongoing, and we only present preliminary results in what follows. We plan to extend this work in a number of ways, including estimating structural equation models to accommodate the endogeneity of teleworking and commute distance.

Literature Review

Hook *et al* [4] reviewed 39 studies of teleworking and found that 26 of these estimated net reductions in traffic, travel, energy use and/or carbon emissions. However, many of these studies focused solely upon commuting travel, examined small-scale pilots whose results were difficult to generalise, and/or had significant methodological limitations. The more rigorous studies, using comprehensive data from national travel surveys and including both commuting and non-work travel, typically found smaller savings. Indeed several studies suggested that teleworking was associated with a net *increase* in travel – as previously observed by Mokhtarian:

> … Although direct, short-term studies focusing on a single application (such as teleworking) have often found substitution effects, such studies are likely to miss the more subtle, indirect, and longer-term complementarity effects that are typically observed in more comprehensive analyses. [8]

The literature proposes several mechanisms through which the environmental benefits of teleworking may be eroded, including: a) dispersion of residential location and longer commutes; b) induced non-work travel; and c) intra-household dynamics. We summarise the evidence for each in turn.

DISPERSION OF RESIDENTIAL LOCATION AND LONGER COMMUTES

Many studies suggest that the gains from eliminating commutes on teleworking days may be partly or wholly offset by longer commutes on non-teleworking days [9,10]. For example, controlling for a range of variables, Helminen and Ristimäki [11] find that Finnish teleworkers have a 3.7 km longer commute than non-teleworkers, while Melo et al. [5] find that UK teleworkers commute 8–11 miles further each week than non-teleworkers. Several studies find that telecommuters tend to live further away from their workplaces than regular commuters – perhaps because the availability of teleworking reduces commuting costs relative to housing costs and thereby expands the choice of residential location [12–16]. However, not all studies reach this conclusion: for example, Ellen and Hempstead [17] find that US telecommuters are more likely to live in urban centres, while both Muhammed et al. [12] and Ettema [12] find that teleworking has little influence on the residential choices of Dutch households [12,18].

Even if teleworkers do live further from their workplace, the majority of studies do not establish the direction of causality. That is, do people telework to avoid a long commute, or do they choose to live further away from the workplace because their job enables them to telework? Commute distance and the adoption of teleworking are endogenous variables, which creates the risk of bias. Employment location may also be endogenous, although it is commonly assumed that this precedes the choice of residential location. To reduce the risk of bias, Zhu [19] uses the frequency of internet use as an instrument for teleworking since this should be correlated with the latter while not affecting commuting distance. He finds that teleworking has a positive influence on one-way commute distance that has increased over time. In 2009, US teleworkers' work trips were 43 % longer those of non-teleworkers, compared to 34 % in 2001.

Instrumental variables are one approach to accommodating endogeneity, but most datasets lack suitable instruments. An alternative approach is to use panel data (where available), since this allows the changes in teleworking and commuting distance to be identified whilst controlling for time-invariant fixed effects. Using seven waves of the Dutch Labour Supply Panel, de Vos et al. [1] estimate that teleworkers have 5 % longer commuting duration, with every additional day of teleworking being associated with a 3.5 % longer duration commute. In a more recent study using a different dataset, de Vos et al. [20] obtain larger estimates of 12 % and 16 % respectively. Both studies use commuting duration rather than commuting distance as the dependent variable, but these should be correlated [21].

The influence of teleworking on residential location may only be evident in the longer term, and may be sensitive to contextual factors, such as the difference in property prices between urban, suburban and rural regions; the distribution of employment opportunities; and the financial and temporal cost of the commuting journey (e.g. the availability of high-speed rail). Many studies are from North America, but their results may not translate to other contexts with different land use patterns and transportation systems. For example, Zhu [14,19] only considered commuting by car, whereas a large proportion of European commuters travel by rail. In addition, the availability of teleworking may encourage individuals to move closer to their (non-teleworking) partner's workplace - making it difficult to predict the net impact of teleworking on the commuting travel of both workers combined.

INDUCED NON-WORK TRAVEL

Several studies find that teleworkers travel more than non-teleworkers on days when they are working at home. For example, Zhu [19] finds that US teleworkers take 10.8 % more non-work trips per day than non-teleworkers and that these are, on average, 15.7 % longer. Zhu [19] finds that teleworking has a causal, positive impact on non-work travel, while Kim [22] finds the same pattern in South Korea. Budnitz [2] finds that English teleworkers take more non-work trips than non-teleworkers, but she does not study travel distance.

The reasons for additional non-work travel require further research. Zhu [19] suggests that non-commuting workers are

less able to 'daisy chain' (or 'link') trips together in an efficient way, and thus have to make specific trips for non-work activities. Teleworkers may also replace commuting trips with other forms of non-work travel, such as leisure or shopping [23]. These trips could be due to boredom, or teleworkers could take advantage of their free time to travel more or to engage in more social activities [24]. Such effects are consistent with the broader evidence on the stability of daily travel time budgets in widely different contexts – at slightly over one hour a day [25,26].

The evidence for a definitive, non-work travel rebound is inconclusive, however. For example, in their analysis of a teleworking pilot in California, Mokhtarian and Varma [27] find no evidence of increased non-work travel on teleworking days. Similarly, while 15 of the 39 studies reviewed by Hook et al [4] include non-work travel, only five find complementary effects. Moreover, while teleworking may induce more non-work trips, the impact on non-work travel distance will depend upon the proximity of the home to schools, retail outlets and other destinations [2].

INTRA-HOUSEHOLD DYNAMICS AND NON-WORK TRAVEL

The environmental benefits of teleworking may be further eroded by intra-household travel dynamics – where the travel behaviour of other household members is affected by one or more members' teleworking. The evidence is particularly weak in this area, since most studies focus solely upon travel by the teleworker. Exceptions include Melo *et al.* [5] who find that teleworking has no significant impact on the commuter travel of the teleworker's partner, and de Abreu e Silva and Melo [28], who find no significant impact on the total travel of the teleworker and partner combined. In the latter case, it is possible that some of the additional non-work trips by the teleworker substitute for trips that would otherwise be undertaken by their partner.

Using cross-sectional data for Seoul, Kim, *et al.* [3] find that teleworkers' non-work travel is greater than that of non-teleworkers, as was the non-work travel of other members of their household. While teleworkers commuted 7.8 km/day less than non-teleworkers, they travel 24.2 km/day more for other purposes and other household members travelled 1.5 km/day more. These differences were only significant in households with less than one vehicle per employed member, suggesting that teleworking may allow other household members to use the car.

Overall, the evidence for the environmental benefits of teleworking appears to be weak. The indirect effects on residential location, non-work travel and the travel patterns of other household members can erode the benefits of fewer commutes. However, these impacts are context specific, and the intra-household dynamics in particular remain under-researched. The following analysis seeks to improve the evidence for the UK, and to measure how the benefits of avoided commutes may be offset by one or more of the above effects.

Data

Our data source is the National Travel Survey (NTS) for England for the period 2005 to 2019 [7]. The NTS is an annual survey of the travel patterns of a stratified, two-stage, random probability sample of ~13k English households [29]. We confine attention to English households since the NTS excluded Scotland and Wales after 2013. We also exclude surveys prior to 2005, since these omit important explanatory variables such as higher education

The NTS has few rivals in terms of the range and quality of data on travel patterns. Survey respondents fill out detailed travel diaries over a seven-day period, recording the purpose of each trip, the mode of transport used, the trip distance and duration, and other relevant information. The NTS supplements the travel diaries with socio-economic and demographic information collected through face-to-face interviews. The seven-day travel diary offers significant advantages over the one-day diaries used in many national travel surveys (e.g. US and Sweden) [16,30]. To minimise bias, participants complete the diary for different weeks and start days throughout the year.

Our full dataset contains information on ~3.6 million trips by ~269k individuals over the period 2005–19. From this we construct two samples: for one-worker and two-worker households respectively. The first includes households with single adults in employment, and households where only one partner is employed. The second includes households with two or more adults, where both the 'household reference person' and their partner are employed. We exclude holiday and business trips by the reference person and their partner, but include travel for all other purposes. We also exclude travel by other household members, such as adult children and grandparents.

In constructing these samples, we exclude workers in the primary sector (agriculture, fishing, forestry, mining), since 'working from home' in agriculture does not correspond to teleworking as commonly understood. We also exclude the small number of individuals (1,253) where both partners telework, and the larger number (3,164) who have missing values for key sociodemographic variables (e.g. occupation, sector, renting, residence length). We also exclude a very large group of individuals (25,945) who report no commuting travel at all in the survey week. Of these, 8 % claim to work from home less than once a week and 78 % to work from home less than once a year or never. Hence, while full-week teleworking may explain a proportion of these 'zero weekly commutes', the explanation for the majority is unclear. We follow Melo, *et al.* [5] and others in excluding this group from our sample, but the results may be sensitive to this choice [16]. Our final sample includes 1,223,939 trips made by 62,806 working individuals from 47,275 households over the period 2005 to 2019. 21,298 of these individuals are from one-worker households and the remainder are from two-worker households.

The NTS asks participants how often they work from home instead of travelling to their usual place of work –excluding working from home at weekends or for only part of the day. We use these responses to classify individuals as low-, medium-or high-frequency teleworkers (Table 1), with the remainder being the reference group of non-teleworkers. We find that 17 % of our sample telework at least once a year, split between 1.1 % 'high-frequency', 4.1 % 'medium-frequency' and 12.1 % 'low-frequency' teleworkers. An alternative approach would be to merge the low-frequency teleworkers with the reference category.

Figure 1 indicates the increasing popularity of teleworking over the sample period. The proportion of medium-frequency

Table 1. Classification of teleworking frequency.

Teleworking Frequency	NTS question on frequency of working from home
Non-teleworker	Less than once a year or never
Low-frequency teleworker	Once or twice a year
	Less than one a month more than twice a year
	Once or twice a month
	Less than once a week more than twice a month
Medium-frequency teleworker	Once or twice a week
High-frequency teleworker	3 or more times a week

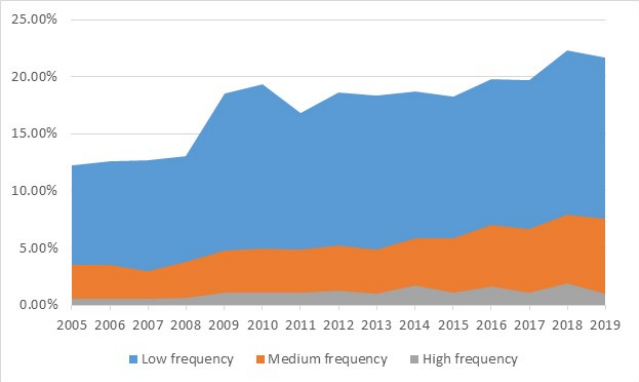


Figure 1. Trends in the proportion of people teleworking.

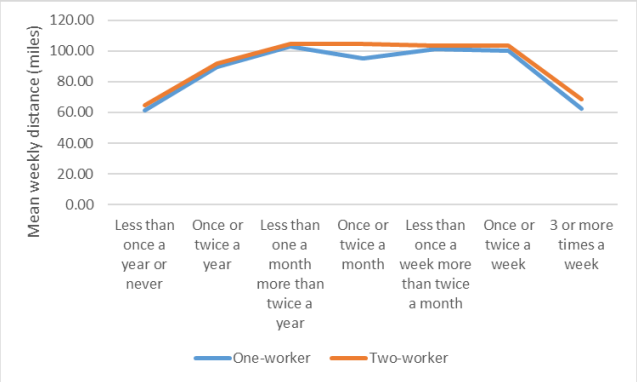


Figure 2. Mean weekly individual commuting distances by frequency of working from home.

Table 2. Weekly commuting distance by household type and teleworking frequency.

Home teleworking frequency	Observations	Distance (miles)		
		Mean	Median	Standard deviation
One worker sample (individual commute)	*21,298*	*66.72*	*36.00*	*91.27*
Less than once a year or never	17,755	61.13	32.80	84.77
Once or twice a year	524	89.38	54.39	98.52
Less than one a month more than twice a year	616	102.61	62.00	118.14
Once or twice a month	865	95.05	56.00	108.99
Less than once a week more than twice a month	338	101.35	53.20	114.92
Once or twice a week	914	99.97	53.00	131.47
3 or more times a week	286	62.54	33.98	82.62
Two-worker sample (individual commute)	*41,508*	*70.98*	*40.00*	*92.16*
Less than once a year or never	34,227	64.74	36.00	84.96
Once or twice a year	1,181	91.67	55.00	100.41
Less than one a month more than twice a year	1,426	104.66	65.00	115.70
Once or twice a month	1,868	104.56	63.00	121.58
Less than once a week more than twice a month	770	103.33	62.90	120.92
Once or twice a week	1,664	103.67	62.20	121.71
3 or more times a week	372	68.57	32.20	88.20
Two workers sample (household commute)	*41,508*	*137.09*	*96.00*	*138.31*
Less than once a year or never	34,227	131.04	91.50	133.81
Once or twice a year	1,181	155.31	116.00	136.38
Less than one a month more than twice a year	1,426	174.09	126.00	162.15
Once or twice a month	1,868	168.19	123.00	157.69
Less than once a week more than twice a month	770	164.88	122.50	161.53
Once or twice a week	1,664	169.34	123.40	157.38
3 or more times a week	372	136.16	96.50	130.89

teleworkers increased from 3.6 % in 2005 to 7.6 % in 2019, while the proportion of high-frequency teleworkers increased from 0.6 % to 1.0 %. However, the small sample size for the latter (286 one-worker households and 372 two-worker households) contributes to an erratic time series and less precise coefficient estimates. The proportion of low-frequency teleworkers increased from 12.3 % in 2005 to 21.7 % in 2019, but many individuals in this category only rarely telework.

Figure 2 and Table 2 show the inverse U-shaped relationship between weekly commuting distance and the frequency of working from home. Taking the mean values, low and medium-frequency teleworkers commute approximately ~65 % (~40 miles) *farther* each week than non-teleworkers, while high-frequency teleworkers commute approximately the *same* distance as non-teleworkers. This pattern, which was first observed by White [31], should not be interpreted as a causal effect of teleworking since there are likely to be systematic differences between the two groups (e.g. income, car ownership, profession). We control for at least some of these differences in our regression model.

Prior research suggests that a range of socio-economic and demographic variables can influence weekly commuting distance [5,14,16,30]. To control for these, we collect NTS data on age, gender, education, employment status (employee or self-employed), employment regime (part- or full-time), occupation (SOC), occupational sector (SIC), household income, the number of children, the number of adults of state pension age, the number of vehicles per licenced driver, housing tenure and length of time living in the residence. We also include local authority population density and the Government Office Region of both the residence and the workplace – which distinguishes between metropolitan and non-metropolitan areas. We experimented with including additional variables on residential and workplace geography, but ultimately dropped these owing to multi-collinearity (VIF>KOKO).

Table 3 provides summary statistics on these explanatory variables. This suggests that teleworkers are more likely to have a higher education degree, to be self-employed, to be female, to be managers or professionals, to work in the real estate, transport or education sectors, to earn more than £50k/year, and to live in London or the south-east.

Econometric models

Following a similar approach to Melo, *et al.* [5], we estimate the log of weekly distance travelled as a function of *S* socio-economic and demographic variables, *R* regional variables, the frequency of teleworking (*f* = low, medium or high) and *T-1* time controls. We specify the weekly distance travelled for *commuting* by individual *i* (C_i) as follows:

$$\ln C_i = \alpha + \sum_{f=L,M,H} \theta_f TW_{fi} + \sum_{s=1,S} \beta_s X_{st} + \sum_{r=1,M} \beta_r X_{rt} + \sum_{t=1,T-1} \delta_t + \varepsilon_t \quad (1)$$

Where TW_{fi} are dummy variables indicating whether individual *i* is a low, medium or high-frequency teleworker (*f*), X_{st} is a vector of sociodemographic variables ($s = 1,S$), X_{rt} is a vector of regional variables ($r = 1,R$), and δ_t ($t = 1,T-1$) are year dummies. The reference category ($\theta_f\big|_{f=L,M,H} = 0$) is non-teleworkers. We take the log of weekly commuting distance (C_i) as our dependent variable, since the distribution of C_i is negatively skewed. We estimate the percentage change in weekly commuting distance associated with teleworking frequency $f(\theta_f^P)$ as follows [32,33]:

$$\theta_f^P = 100 * \left[\exp\left[\theta_f - 0.5V(\theta_f) \right] - 1 \right] \quad (2)$$

Where $V(\theta_f)$ is the variance of θ_f. We estimate Equation 1 separately for one-worker and two worker households, and estimate similar equations for *non-work* (N_i) and *total* (T_i) weekly distance travelled. In addition, for each of these measures we estimate separate equations for weekly distance travelled by *car* and by *other* modes of transport; and we further disaggregate other modes into *public* transport and *active* travel (cycling and walking).

The above models relate to weekly distance travelled by the teleworkers themselves. To explore intra-household effects, we estimate a parallel set of models for the weekly distance travelled by the worker's partner. In the case of weekly commuting travel (C_i), this takes the form:

$$\ln C_i = \alpha + \sum_{f=L,M,H} \theta_f TW_{fi_p} + \sum_{s=1,S} \beta_s X_{st} + \sum_{r=1,M} \beta_r X_{rt} + \sum_{t=1,T-1} \delta_t + \varepsilon_t \quad (3)$$

Where i_p is the partner of individual *i*, and TW_{fi_p} is the frequency of teleworking by the partner.

Combining three categories of travel purpose (commuter, non-work, total), five categories of travel mode (all, car, other, public, active) and three categories of individual (teleworker in one-worker household, teleworker in two-worker household, partner of teleworker) leads to a total of 45 econometric models.

Results

We present the full results of the econometric analysis in the accompanying Supplementary Information. As an illustration, the Annex summarises the coefficient estimates for commuting, non-work and total distance travelled by workers in one-worker households. This illustrates that weekly commuting distance tends to be longer for: males; for people on higher incomes; for people with higher education qualifications; for parents; for managers and professionals; for workers in the construction, transport, financial, real estate and energy sectors; for people who have recently moved residence; for people living in areas of low population density; and for people who work in London, Wales or Scotland. These variables have a smaller influence on non-work and total travel, but the sign of the influence is the same in most cases. Perhaps because we control for population density, the residential area controls are rarely significant.

Given space constraints, we focus here upon the estimates for the percentage change in weekly distance travelled (θ_f^P). Table 4 summarises our estimates of θ_f^P for *commuter* travel, while Table 5 and Table 6 do the same for *non-work* and *total* travel respectively. In each case, we present three sets of results: a) teleworkers in one-worker households; b) teleworkers in two-worker households; and c) the partners of teleworkers.

Table 3. Summary statistics of explanatory variables.

Variable	One-worker		Two-workers	
	Non TW	TW	Non TW	TW
Age (mean)	46.17	46.94	43.46	43.69
Education (% with higher education degree)	23.19	44.42	25.16	43.52
Part-timers (%)	22.40	19.17	22.29	18.86
Self-employed (%)	7.86	20.58	7.47	19.70
Male (%)	47.49	42.00	49.91	44.94
Occupations (%)				
Managers and senior officials	14.71	33.58	17.83	36.59
Professional occupations	13.11	29.25	14.30	28.73
Associate professional and technical occupations	14.58	21.33	16.85	20.73
Administrative and secretarial occupations	11.92	6.75	12.21	5.99
Skilled trades occupations	9.05	2.92	8.45	2.55
Personal service occupations	8.93	2.42	8.23	2.95
Sales and customer service occupations	6.43	1.25	5.51	1.03
Process, plant and machine operatives	8.73	1.17	7.44	0.64
Elementary occupations	12.53	1.33	9.18	0.79
Sector (%)				
Manufacturing	13.05	8.67	13.42	8.25
Electricity, gas and water supply	1.31	1.17	1.31	1.33
Construction	5.15	2.67	5.32	4.91
Wholesale and retail trade	13.91	6.58	13.93	7.02
Accommodation and food service activities	5.16	2.00	3.78	1.62
Transport and storage and communication	9.67	14.17	8.47	12.97
Financial intermediation	4.45	6.92	4.39	8.69
Real estate, renting and business activities	11.13	20.75	11.07	20.28
Public administration and defence	6.75	7.67	7.41	7.37
Education	9.28	11.92	11.13	11.35
Health and social work	15.99	11.58	16.05	11.39
Community, social and personal services	3.93	5.92	3.60	4.81
Activities of private households	0.16	0.00	0.12	0.00
Extraterritorial organisations	0.05	0.00	0.01	0.00
Income bands (%)				
Less than £25,000	45.78	22.33	11.44	5.16
£25,000 to £49,999	37.50	38.25	41.95	23.04
£50,000 and over	16.72	39.42	46.62	71.81
No. of children in household (mean)	0.55	0.55	0.71	0.84
No. of adults with state pension age (mean)	0.20	0.21	0.07	0.06
No. of vehicles per person with driving licence (mean)	0.62	0.69	0.65	0.67
Local authority population density (mean)	21.11	24.00	16.58	17.19
Government Office Region of Residence (%)				
North East Metropolitan	2.38	1.67	2.21	1.72
North East Non-Metropolitan	2.85	1.50	3.12	1.72
North West & Merseyside Metropolitan	7.72	5.67	7.36	5.35
North West & Merseyside Non-Metropolitan	6.01	5.00	6.65	4.76
Yorkshire & Humberside Metropolitan	6.45	5.75	6.65	5.26
Yorkshire & Humberside Non-Metropolitan	3.11	2.17	3.73	3.29
East Midlands	8.47	6.42	9.53	8.84
West Midlands Metropolitan	4.62	2.75	3.96	2.60
West Midlands Non-Metropolitan	5.52	4.00	6.46	5.35
East of England	11.16	12.00	11.73	12.97
Greater London	17.01	22.75	12.18	14.83
South East	15.43	20.92	16.29	22.64
South West	9.26	9.42	10.13	10.66
No. of households in sample	***20,098***	***1,200***	***39,472***	***2,036***

Table 4. Percentage change in weekly *commuting* distance travelled associated with teleworking.

	One-worker – teleworker				Two-worker – teleworker				Two worker – partner			
Mode	**Low**	**Med**	**High**	R^2	**Low**	**Med**	**High**	R^2	**Low**	**Med**	**High**	R^2
All	**10.7**	**15.0**	-12.8	*0.206*	**13.0**	**15.9**	**-15.5**	*0.222*	1.0	0.4	2.6	*0.220*
Car	-5.5	**-10.2**	**-20.5**	*0.344*	-0.3	-5.2	**-25.9**	*0.282*	0.1	-5.0	-4.7	*0.281*
Other	**24.3**	**36.0**	6.9	*0.344*	**18.3**	**31.6**	6.6	*0.300*	1.0	**8.5**	7.3	*0.298*
Public	**25.3**	**36.7**	9.0	*0.305*	**20.8**	36.1	3.8	*0.308*	-0.2	**6.6**	2.6	*0.305*
Active	**8.2**	**7.7**	-2.6	*0.146*	**5.2**	4.1	-0.3	*0.109*	2.4	2.9	5.2	*0.109*

Table 5. Percentage change in weekly *non-work* distance travelled associated with teleworking.

	One-worker – teleworker				Two-worker – teleworker				Two worker – partner			
Mode	**Low**	**Med**	**High**	R^2	**Low**	**Med**	**High**	R^2	**Low**	**Med**	**High**	R^2
All	**18.7**	**21.1**	-8.1	*0.140*	**17.4**	**17.1**	**19.0**	*0.105*	**17.2**	1.2	6.3	*0.105*
Car	**13.2**	**10.5**	-11.0	*0.288*	**14.9**	**13.6**	**22.7**	*0.184*	**17.1**	-2.9	6.1	*0.184*
Other	**11.4**	**20.7**	-0.9	*0.151*	**11.9**	**17.9**	3.4	*0.096*	**10.3**	**6.8**	-1.2	*0.095*
Public	**9.9**	**14.8**	-8.1	*0.156*	**9.0**	**12.6**	1.8	*0.101*	**7.2**	**6.2**	0.0	*0.101*
Active	3.4	**8.2**	10.2	*0.071*	**5.7**	**8.2**	6.3	*0.058*	**5.6**	1.0	-0.9	*0.058*

Table 6. Percentage change in weekly *total* distance travelled associated with teleworking.

	One-worker – teleworker				Two-worker – teleworker				Two worker – partner			
Mode	**Low**	**Med**	**High**	R^2	**Low**	**Med**	**High**	R^2	**Low**	**Med**	**High**	R^2
All	**11.4**	**15.8**	**-6.3**	*0.211*	**14.1**	**16.6**	**1.6**	*0.172*	7.5	3.3	8.5	*0.170*
Car	1.0	**0.8**	**-14.1**	*0.417*	8.4	6.4	**2.2**	*0.314*	8.9	-0.6	4.1	*0.314*
Other	**27.9**	**42.6**	5.3	*0.302*	**23.4**	**44.1**	7.0	*0.249*	7.4	**10.7**	3.3	*0.246*
Public	**27.8**	**38.9**	5.6	*0.299*	**24.4**	**44.8**	4.5	*0.276*	4.9	**10.0**	1.6	*0.273*
Active	**8.7**	**12.7**	8.2	*0.149*	**8.1**	**9.9**	5.6	*0.110*	6.0	2.9	2.8	*0.110*

For each set, we present estimates of the percentage difference in weekly distance travelled associated with low, medium and high-frequency teleworking, relative to the weekly distance travelled by non-teleworkers. The first row of each table indicates the percentage difference in the *total* distance travelled by all modes, while the subsequent rows indicate the percentage difference in distance travelled by individual modes (note that: All=Car+Other; and Other=Public+Active). Figures in bold indicate that the coefficient estimates were significant at the 5 % level. The goodness of fit (R^2) is better for the commuting and total models than for the non-work models, and is poorest for non-work travel by public and active modes.

Looking first at the results for *commuting* distance travelled (Table 4), we observe that low- and medium-frequency teleworkers commute 10–15 % *further* each week than non-teleworkers, while high-frequency teleworkers commute 12–16 % *less*. However, the estimate for high-frequency teleworking by one-worker households is not significant. Low- and medium-frequency teleworkers commute 18–36 % further by public transport each week, but 10 % less by car (although only one of the four estimates are significant). High-frequency teleworkers commute 20–25 % less distance by car, suggesting that the largest savings from frequent teleworking may occur in the most polluting mode. There is little evidence that teleworking by one individual influences the commuting travel of their partner, since only two of the 15 estimates from these models are significant. Overall, the results suggest that individuals who telework at least three times a week commute *a shorter distance* each week than non-teleworkers, while individuals who telework less frequently commute *a longer distance* each week.

Table 5 summarises the results for weekly distance travelled for *non-work* purposes. Compared to non-teleworkers, we find that low-and medium-frequency teleworkers travel 17–21 % *further* each week for non-work purposes. This additional travel is observed for both one-worker and two-worker households, and for all modes. The same applies for high-frequency teleworkers in two-worker households, but most of the difference here relates to additional car travel. While the results suggest that high-frequency teleworkers in one-worker households travel *less* each week than non-teleworkers, none of these estimates are significant. The evidence that teleworking influences the partner's travel patterns is weak, but the results suggest that the partners of low-frequency teleworkers travel 17 % further each week than the partners of non-teleworkers. Overall, the results suggest that teleworking is associated with additional *non-work* travel by the telecommuter and, to a lesser extent, their partner.

Table 6 summarises the results for weekly *total* travel (commuting + non-work). We find that low-and medium-frequency teleworkers travel 11–17 % further each week than non-teleworkers. Again, this additional travel is observed for both one-worker and two-worker households, and for all modes. However, most of the difference relates to travel by public transport and active modes – the estimated difference for car travel is

smaller, and only one of these estimates is significant. We also estimate that high-frequency teleworkers in two-worker households travel 1.6 % *further* each week than non-teleworkers, while those in one-worker households travel 6.3 % *less*. In the latter case, a large reduction in car travel is offset by greater use of other modes. Again, there is little evidence that teleworking influences the partner's travel patterns, since all but two of the estimates from these models are insignificant. However, it is notable that all but one of these estimates are positive, providing weak evidence that the partners of teleworkers travel further than the partners of non-teleworkers.

The main conclusion from this analysis is that **teleworkers travel further each week than non-teleworkers**, and there is some evidence that their partners travel further as well. The main exception is high-frequency teleworkers in one-worker households, whose mean weekly distance travelled is 6.3 % less than that of non-teleworkers.

Discussion and Conclusion

Our preliminary results provide little support for the claim that teleworking reduces travel. Indeed, after controlling for a range of variables, we find that the majority of English teleworkers travel *farther* each week than non-teleworkers. Confirming and updating the earlier results of Melo, et al. [5] and de Abreu e Silva, et al. [6], we find this additional travel results from a combination of greater distances between home and workplace (fewer commutes offset by longer commutes) and additional travel for non-work purposes. There appears to be a 'tipping point' however: if people telework three or more times a week, their weekly commuting distance may be *less* than that of non-teleworkers – and in the case of single-worker households, this may be sufficient to offset the associated increase in non-work travel. Even here, however, the savings appears to be modest – 6 % of the mean weekly commuting distance, or ~3.6 miles per week. As a crude estimate, if we assume that 1.1 % of UK workers telework three or more times a week; *all* of them achieve a 6 % reduction in weekly distance travelled; and commuting accounts for ~20 % of UK passenger kilometres [7], this translates to a 0.01 % reduction in UK passenger travel (pkm). From this perspective, teleworking appears to have contributed very little to sustainable travel over the last 15 years.

There are important caveats to this conclusion, however. First, our results may be sensitive to the definition of teleworking, the treatment of zero-commute households, the neglect of travel by other household members and other methodological choices. We propose to explore the sensitivities in the next stage of the research, and also to estimate parallel models for the number of trips and the carbon emissions associated with those trips.

Second, we must be cautious in assuming a causal relationship between teleworking and the observed travel patterns. Our results may be biased since it is difficult to control for the endogeneity of residential location and the adoption of teleworking. Moreover, differences in travel patterns between teleworkers and non-teleworkers may arise from unobserved differences between the two groups, rather than from teleworking *per se*. This is analogous to the debate on residential self-selection, where it is unclear whether factors such as residential density, diversity and design lead to sustainable urban travel [34], or whether people with preferences for sustainable travel choose to live in high-density urban areas [35]. In both cases, the causal mechanisms may act in both directions. In the absence of panel data, a promising approach to this problem is to estimate a structural equation model - also planned for a further stage of our work.

Third, the patterns observed in the past are unlikely to be a good guide to the future. The global pandemic has led to such a dramatic change in working patterns that longer-term reductions in commuting travel appear likely. The pandemic has led to a much larger group of people working from home, and many of these people may continue to telework after the pandemic has ceased. The 'new teleworkers' may be more diverse in terms of their socio-economic and demographic characteristics, they may be more likely to telework three or more times a week, and they may be less likely to live further from their workplace. In these circumstances, we may expect larger savings in commuter travel. These new teleworkers may take more non-work trips, but the environmental impacts of those trips will depend upon the choice of mode and the associated distance. A key lesson from our study, therefore, is the need to discourage residential relocation to areas of low population density, so the benefits of teleworking can be maximised.

Finally, the environmental benefits of teleworking are contingent upon broader developments in sustainable travel and land use planning. While teleworking seems likely to increase the number of non-work trips, the impact on non-work distance travelled will depend upon the accessibility of relevant destinations and the relative cost, and convenience of different modes. The lesson for policy is to invest in high-density, mixed-use neighbourhoods where a variety of destinations are readily accessible through walking, cycling and public transport. This will help maximise the benefits of teleworking, whilst at the same time facilitating the broader shift to sustainable travel.

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Annex

Table A1. Coefficient estimates for weekly distance travelled by all modes for one-worker households.

Teleworking variables (ref.: non-teleworking)	Commuting		Non-work		Total	
Less than once a week	0.102***	(0.027)	0.172***	(0.035)	0.108***	(0.020)
Once or twice a week	0.140***	(0.034)	0.192***	(0.042)	0.147***	(0.025)
Three or more times a week	-0.135**	(0.067)	-0.080	(0.093)	-0.064	(0.052)
Individual variables						
Age	0.001	(0.001)	0.002	(0.001)	0.001	(0.001)
Female	-0.298***	(0.017)	0.195***	(0.023)	-0.086***	(0.014)
Higher Education	0.054***	(0.021)	0.133***	(0.027)	0.100***	(0.016)
Self-Employed	-0.146***	(0.031)	-0.038	(0.040)	-0.056**	(0.024)
Part time	-0.418***	(0.020)	0.386***	(0.026)	-0.019	(0.016)
Income (ref.: First quintile)						
2nd income quintile	0.040	(0.025)	0.097***	(0.034)	0.070***	(0.020)
3rd income quintile	0.090***	(0.026)	0.154***	(0.035)	0.125***	(0.021)
4th income quintile	0.123***	(0.027)	0.203***	(0.037)	0.168***	(0.022)
5th income quintile	0.184***	(0.029)	0.211***	(0.040)	0.203***	(0.023)
Household variables						
Number of children	0.058***	(0.009)	0.128***	(0.013)	0.095***	(0.007)
Number of members of pensionable age	-0.047***	(0.017)	0.003	(0.023)	-0.024*	(0.013)
Number of driving licences per vehicle	0.262***	(0.020)	0.636***	(0.028)	0.417***	(0.017)
Occupations (ref.: managers and senior officials)						
Professional occupations	0.029	(0.029)	0.045	(0.038)	0.037*	(0.022)
Associate professional and technical	0.019	(0.027)	0.035	(0.036)	0.014	(0.021)
Administrative and secretarial	-0.089***	(0.030)	-0.034	(0.038)	-0.088***	(0.023)
Skilled trades	-0.081**	(0.034)	-0.200***	(0.047)	-0.116***	(0.027)
Personal service	-0.232***	(0.035)	-0.092**	(0.046)	-0.162***	(0.028)
Sales and customer service	-0.267***	(0.039)	-0.164***	(0.053)	-0.215***	(0.032)
Process, plant and machine operatives	-0.163***	(0.035)	-0.339***	(0.047)	-0.224***	(0.027)
Elementary	-0.192***	(0.031)	-0.338***	(0.042)	-0.267***	(0.025)
Industry (ref.: Manufacturing)						
Electricity, gas and water supply	0.130*	(0.067)	-0.187**	(0.092)	0.036	(0.051)
Construction	0.324***	(0.042)	-0.273***	(0.058)	0.161***	(0.033)
Wholesale and retail	-0.119***	(0.031)	-0.242***	(0.042)	-0.149***	(0.025)
Hotels and restaurants	-0.088**	(0.040)	-0.276***	(0.056)	-0.143***	(0.034)
Transport, storage, information & communication	0.104***	(0.031)	-0.051	(0.042)	0.065***	(0.024)
Financial intermediation and insurance	0.039	(0.040)	-0.165***	(0.056)	0.011	(0.031)
Real estate, renting and business service	-0.004	(0.031)	-0.075*	(0.040)	-0.017	(0.024)
Public administration; defence; social security	-0.082**	(0.035)	-0.027	(0.046)	-0.040	(0.028)
Education	-0.311***	(0.035)	-0.006	(0.044)	-0.147***	(0.027)
Health and social work	-0.193***	(0.031)	-0.124***	(0.041)	-0.135***	(0.024)
Community, social and personal services	-0.185***	(0.043)	-0.047	(0.055)	-0.098***	(0.034)
Activities of private households	-0.210	(0.193)	0.015	(0.215)	-0.006	(0.126)
Extraterritorial organisations	-0.146	(0.287)	-0.311	(0.680)	-0.060	(0.303)
Home tenure						
Rents house	-0.121***	(0.018)	-0.239***	(0.025)	-0.168***	(0.015)
Length of residence (ref: less than 2 years)						
More than 2 years and less than 5 years	0.030	(0.023)	-0.061*	(0.031)	-0.031*	(0.019)
More than 5 years and less than 10 years	-0.024	(0.025)	-0.120***	(0.032)	-0.081***	(0.019)
More than 10 years	-0.053**	(0.025)	-0.142***	(0.033)	-0.109***	(0.020)
Always lived here	-0.118***	(0.028)	-0.214***	(0.037)	-0.168***	(0.022)
Living area population density	-0.008***	(0.000)	-0.006***	(0.001)	-0.008***	(0.000)

Teleworking variables (ref.: non-teleworking)	Commuting		Non-work		Total	
Year dummies (ref.: 2005)						
Year: 2006	0.032	(0.036)	-0.066	(0.048)	-0.000	(0.029)
Year: 2007	0.035	(0.037)	-0.082*	(0.048)	0.003	(0.029)
Year: 2008	0.033	(0.037)	-0.047	(0.048)	0.001	(0.029)
Year: 2009	0.011	(0.036)	-0.103**	(0.048)	-0.027	(0.029)
Year: 2010	0.010	(0.037)	-0.052	(0.049)	0.002	(0.029)
Year: 2011	0.047	(0.037)	-0.147***	(0.049)	-0.030	(0.030)
Year: 2012	0.003	(0.037)	-0.065	(0.049)	-0.004	(0.030)
Year: 2013	0.054	(0.038)	-0.193***	(0.050)	-0.038	(0.030)
Year: 2014	0.042	(0.037)	-0.192***	(0.050)	-0.036	(0.030)
Year: 2015	0.106***	(0.038)	-0.201***	(0.052)	-0.017	(0.031)
Year: 2016	0.139***	(0.038)	-0.221***	(0.051)	0.019	(0.030)
Year: 2017	0.087**	(0.040)	-0.149***	(0.053)	0.031	(0.032)
Year: 2018	0.049	(0.042)	-0.302***	(0.056)	-0.049	(0.033)
Year: 2019	0.016	(0.041)	-0.250***	(0.054)	-0.058*	(0.033)
Work GOR (ref. DNA)						
North East Metropolitan	-0.078	(0.102)	-0.392***	(0.130)	-0.248***	(0.077)
North East Non-Metropolitan	-0.313***	(0.110)	-0.324***	(0.123)	-0.328***	(0.079)
NW & Merseyside Metropolitan	0.076	(0.067)	0.026	(0.087)	-0.036	(0.051)
NW & Merseyside Non-Metropolitan	0.013	(0.071)	0.124	(0.089)	0.022	(0.052)
Yorkshire & Humberside Metropolitan	-0.044	(0.075)	-0.025	(0.089)	-0.060	(0.058)
Yorkshire & Humberside Non-Metropolitan	-0.036	(0.099)	-0.085	(0.120)	-0.100	(0.073)
East Midlands	-0.196***	(0.065)	-0.096	(0.078)	-0.156***	(0.048)
West Midlands Metropolitan	0.008	(0.077)	-0.011	(0.097)	-0.038	(0.057)
West Midlands Non-Metropolitan	-0.133*	(0.069)	0.064	(0.082)	-0.082	(0.051)
East of England	-0.138***	(0.053)	0.124*	(0.065)	-0.098**	(0.039)
Greater London	0.450***	(0.040)	-0.024	(0.052)	0.225***	(0.030)
South East	-0.060	(0.046)	0.012	(0.055)	-0.079**	(0.034)
South West	0.005	(0.066)	-0.028	(0.075)	-0.059	(0.048)
Wales	0.652***	(0.143)	-0.074	(0.201)	0.349***	(0.117)
Scotland Metropolitan	0.636	(0.469)	0.495**	(0.250)	0.433*	(0.253)
Scotland Non-Metropolitan	0.268*	(0.139)	-0.167	(0.190)	0.107	(0.100)
Residence GOR (ref.: North East Metropolitan)						
North East Non-Metropolitan	0.215**	(0.088)	0.158	(0.111)	0.197***	(0.063)
North West & Merseyside Metropolitan	-0.118	(0.117)	-0.315**	(0.147)	-0.169*	(0.089)
North West & Merseyside Non-Metropolita	-0.229*	(0.117)	-0.339**	(0.147)	-0.257***	(0.088)
Yorkshire & Humberside Metropolitan	-0.112	(0.120)	-0.146	(0.147)	-0.141	(0.092)
Yorkshire & Humberside Non-Metropolitan	-0.147	(0.134)	-0.034	(0.163)	-0.073	(0.099)
East Midlands	0.060	(0.115)	-0.047	(0.142)	-0.004	(0.087)
West Midlands Metropolitan	0.044	(0.124)	-0.239	(0.154)	-0.043	(0.094)
West Midlands Non-Metropolitan	-0.007	(0.117)	-0.151	(0.144)	-0.044	(0.088)
East of England	0.114	(0.109)	-0.215	(0.137)	0.039	(0.082)
Greater London	0.025	(0.107)	-0.267**	(0.134)	-0.083	(0.081)
South East	0.017	(0.107)	-0.174	(0.133)	-0.031	(0.081)
South West	-0.221*	(0.117)	-0.117	(0.141)	-0.146*	(0.087)
Observations	**21,298**		**21,298**		**21,298**	
R-squared	**0.203**		**0.140**		**0.211**	

*Robust standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1*