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Telework, travel times, and peak hour avoidance in England: an overview using travel times across five weekdays

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Abstract

This study examines the association of telework and travel times for work and non-work purposes at peak and off-peak times over the five-day workweek (Monday-Friday). Two seemingly competing hypotheses are considered. The first is that teleworkers travel less and avoid peak hours because of a greater flexibility of their working hours. The second is that teleworkers have to travel at peak times as much as others, due to the temporal ordering of the cities and society. Data for residents of England from the 2015-2019 UK National Travel Surveys (NTS) are used. Overall, the analysis suggests that when considering the five-day workweek, teleworkers experience longer travel times than other workers for both work and non-work purposes. The longer travel times for work reflect the fact that teleworkers are more likely to hold professional or managerial positions, have higher incomes, commute by train, and/or work in London. The association of telework and non-work travel times remains once employment, commute, socioeconomic and location factors are taken into account. There is also indicative evidence for some net peak avoidance among teleworkers for commuting but not for non-work travel. The findings thus suggest that both hypotheses may hold, although the first for commuting and the second for non-work travel. Whether the conclusions extend to teleworking after the COVID-19 pandemic remains to be examined using NTS or similar data, but it is not implausible that qualitative differences in teleworkers' travel times and peak hour travel pre- and post-pandemic may not be as large as public discourse might suggest.

Keywords: commuting; England; non-work travel; path analysis; peak avoidance; telework; travel behavior

1. Introduction

Telework is often put forward as a way to reduce traffic, in particular congestion at peak times, but recent studies do not show a clear link between telework and reduced travel for work or other motives, especially during peak hours (Eldér, 2020). In fact, several studies have shown a greater number and

longer distances for work and non-work trips on teleworking days (Budnitz et al., 2020; Cerqueira et al., 2020; Caldarola and Sorrell, 2022). The discrepancy in results is to some extent a consequence of differences in the data available. Indeed, telework implies an organization of commuting on the scale of a whole week or even over a longer period. However, many studies are based on observational data of a random day, which does not allow the temporal variability of practices to be fully considered. The discrepancy in results also reflects heterogeneity in national contexts in terms of telework regulations and practices, as well as labor market structure, since not all jobs allow for telework and/or the same practices.

This study examines the association of teleworking and travel times during the morning and evening peak hours. Two seemingly competing hypotheses are considered. The first is that a lower commuting frequency and increased scheduling flexibility enable teleworkers to travel less and avoid peak hours more than other workers. The second is that the temporal ordering of cities and society (e.g., business hours, school and nursery times for workers with young children) imposes similar constraints on teleworkers as on other workers and that both groups travel roughly as much during peak hours.

In this paper the time travel of teleworkers are analyzed across five weekdays divided into three periods during the diurnal (24h) cycle: morning peak, evening peak and off-peak for the remaining part of the day and the night. Data for residents of England from the 2015-2019 UK National Travel Surveys (NTS) are used because they offer information about work and non-work trips for a whole week. It is indeed essential to have several days of observation to better capture and control the effects of the commuting frequency of teleworkers on their mobility, as several recent studies on teleworking in England have demonstrated (de Abreu e Silva and Melo, 2018; Budnitz et al., 2020; Cerqueira et al., 2020; Caldarola and Sorrell, 2022; Cerqueira and Motte-Baumvol, 2022). De Abreu e Silva and Melo (2018) show a very strong link of the frequency of telework days, the majority of which are organized on a weekly basis, with the total weekly commute distance and time.

The modelling indicates that the longer travel times of teleworkers at peak times are primarily related to the structure of the teleworker population, as well as many of them working in London and using the train to commute. The results also show a slight peak avoidance effect of teleworkers for commuting, while the extra travel for non-work motives leads rather to a spillover of these trips into the period before and after the evening peak. The implication is that both of the above hypotheses appear to have some validity.

These results are based on data from before the COVID-19 pandemic and questions might be raised about their validity and usefulness in the current time because the pandemic has made possible or accelerated changes to the spaces and time of work, including telework, for both organisations and workers. We are cautiously optimistic that the findings below remain valid and useful. First, given the current post-COVID-19 pandemic instability and uncertainty about the nature of telework, the findings in this paper – and other studies focusing on the pre-pandemic context – offer a helpful baseline against which studies using data from the last two or three years can be interpreted and evaluated. Second, as detailed in Section 5, our findings are broadly consistent with the results regarding changes in travel behaviour and teleworking from a panel study in English and Scottish cities that commenced at the start of the pandemic (Marsden et al., 2021; Anable et al., 2022).

The remainder of the paper is organized as follows. In the next section a literature review considers the associations of telework, commuting and peak avoidance, the issues around the observation

period, and the definition of telework. Section 3 presents the data and methods used, while Section 4 summarizes the results. The paper ends with conclusions and discussion in Section 5.

2. Literature review

2.1. Associations of telework and commuting

Regarding the link between telework and commuting, several studies have demonstrated that at the individual level teleworkers tend to reside farther away from their workplace and that their average commute is longer than for non-teleworkers (de Vos et al., 2018; Kim, 2016; Zhu, 2013; Zhu et al., 2018). Using an ad hoc retrospective survey among employees of six state agencies with telecommuting programs in California, Ory and Mokhtarian (2006) have shown that these longer commutes tended to be undertaken by workers who are starting to telework, while workers who were already teleworking and then relocated to another residential location tended to move closer to their workplace. De Abreu e Silva (2022) has recently shown for Lisbon in the aftermath of the COVID-19 pandemic that the intention to telework is greater as commutes are longer. Moreover, teleworkers' lower frequency of commuting (Caldarola and Sorrell, 2022) means that their average weekly commuting times and distances is lower than for non-teleworkers (He and Hu, 2015; Kim, 2017).

Not all results point in the same direction, however. For instance, a study conducted by Kim et al. (2012) in South Korea found a correlation between telework and shorter travel distances. According to Zhu (2012), teleworking is associated with an increase in distance, duration, and frequency of daily work trips in the US. These findings have been derived from analysis of the National Household Travel Survey for 2001 and 2009, which has a one-day observation period. The counter-intuitive result regarding the higher frequency of work trips for teleworkers is due to the inclusion of business trips alongside home-to-work travel. Also, Zhu notes that the gap between teleworkers and non-teleworkers in the US has decreased over time, probably due to the evolution and broadening of the teleworker base. Considering England and a seven-day observation period, neither Cerqueira et al. (2020) nor Caldarola and Sorrell (2022) observed a greater number of work trips, even when including business trips. However, they show greater distances travelled for work on a weekly basis despite the lower frequency of such trips.

2.2. Do flexible working practices allow teleworkers to avoid peak hour travel?

While there is ongoing debate regarding the impact of teleworking on the distance, duration, and frequency of daily work trips, several authors have drawn attention to the link of teleworking with travel during morning and evening rush hours. This is a major issue for transport, as it suggests that telework can have effects on and the seriousness of road congestion problems. For example, Stiles and Smart (2021), using the US Time Survey, show that teleworkers tend to travel less for work and non-work purposes during peak hours compared to regular commuters; this association is stronger for the morning than the evening peak hour. These differences have also been observed in other countries and cities with different types of data and methods (Asgari and Jin, 2018; Elldér, 2020; Hamer et al., 1991; Lachapelle et al., 2018; Shabanpour et al., 2018; van der Loop et al., 2019).

There are several possible explanations for the lower peak hour travel among teleworkers. Firstly, it may be an effect of reduced commuting frequency. A second factor could be a peak hour evasion effect for teleworkers who will often have more sovereignty over their schedules even when they have to travel to work (Asgari et al., 2019). Flexible working hours seem to be a critical factor for changing

commuting hours (Ben-Elia and Ettema, 2009). However, some literature suggests that sovereignty over one's working hours has little effect on commuting hours (Breedveld, 1998; Burkinshaw, 2018). Literature on peak-avoidance highlights the need to implement incentives or coercive measures to generate a real shift effect (Wang et al., 2020). If the working hours are not imposed by the employer and are rather left to the employee's discretion, this could be explained by implicit social norms that put pressure on all workers, including teleworkers, to arrive at the office around the same time as their colleagues (Munch, 2020).

Beyond flexibility in working hours, the temporal ordering of cities and society and the need to coordinate one's social activities with others may encourage people, including teleworkers, to adopt the same temporal pattern as others. This applies to commuting as well as to other trip purposes, given the opening and operating hours of the activities, services and shops used. Thus, teleworkers may still need to travel during peak hours, even on telework days, and are not exempt from space-time constraints on everyday travel (Schwanen et al., 2008). This point is particularly salient if telework is indeed linked to greater mobility for non-work activities, as multiple studies have suggested (Caldarola and Sorrell, 2022; Cerqueira et al., 2020; He and Hu, 2015; Kim, 2017; Kim et al., 2015; Silva and Melo, 2018; Zhu, 2012; Zhu and Guo, 2022; Zhu and Mason, 2014). This is particularly true for households with children, for whom telework makes escorting trips easier to undertake and therefore more frequent (Cerqueira and Motte-Baumvol, 2022). Several studies have highlighted that the presence of children in the household results in childcare activities that reduce mothers' ability to change their travel schedule more than fathers' (Saleh and Farrell, 2005; Ben-Elia and Ettema, 2011).

2.3. The issue of the observation period

So far, the literature review has suggested a significant degree of uncertainty about the effects of telework on people's overall amount of travel and the extent to which they avoid peak-hour travel. This uncertainty is partly explained by differences inherent to the study areas and countries which have very different labor market structures, rules governing telework, urban organization and/or modal practices. Nonetheless, a key factor in overcoming this uncertainty relates to the data used and the definition of telework chosen (Eldér, 2020). As far as the data is concerned, the period of observation of the trips seems crucial. Indeed, a single day of observation can lead to many biases and limitations in capturing teleworkers' travel and commuting practices. One-day observation does not allow for consideration of the frequency of telework and its possible concentration on certain days of the week, which could help to explain some of the divergent results across the wider literature.

In this context, it is important to appreciate that travel behavior is characterized by a greater variability at the intrapersonal level than at the interpersonal level (Schlich and Axhausen, 2003; Li et al., 2018). This means that the variability in an individual's daily routine across different days of the week is greater than the variability observed between individuals during the same day. Telework likely exacerbates this variability, primarily at the intrapersonal level and indirectly at the interpersonal level. Schlich and Axhausen (2003) highlight that a period of at least two weeks would be necessary to best capture the intrapersonal variability of travel, with one week being a good compromise, particularly if researchers are interested in workdays which are marked by lower variability. With regard to telework, using data from a one-week observation period seems to be an appropriate choice (de Abreu e Silva and Melo, 2018; Budnitz et al., 2020; Cerqueira et al., 2020; Caldarola and Sorrell, 2022; Cerqueira and Motte-Baumvol, 2022). De Abreu e Silva and Melo (2018) show a very strong link of the number of telework days, the majority of which are organized on a weekly basis, with commute distance and time. Thus, frequent teleworkers often have weekly commute distances and times that are comparable

to, or lower than, those of non-teleworkers (once household composition has been taken into consideration). In contrast, for those whose telework frequency is less than twice a week, the commute distances and times tend to be much greater than for non-teleworkers.

2.4. Who engages in telework?

Another reason for the uncertainty about the effects of telework on peak hour travel is the definition of telework and teleworkers in the data used. Elldér (2020) points out the great heterogeneity of the variables used in the various studies to define telework. These variables can be binary, categorical or ordinal in nature, and are often based on general statements, which do not necessarily apply to the period observed rather than on an observation of practices, since this requires an observation of several days. In addition to frequency, the effects of telework on travel differ according to the temporal and spatial organization of telework. However, the question of the definition of telework and its different forms is essential to properly assess its effects (Athanasiadou and Theriou, 2021). Lachapelle et al. (2018) show that the effects on travel behaviour differ between all day home working, part-day home working and a combination of working at other locations and home and/or workplace. Only all day home working is associated with shorter travel times in their study with data from the Canadian Time Use Survey.

Finally, the profile of teleworkers is quite particular. They are generally permanent full-time workers with a permanent contract, have higher qualifications and have more mobility resources (Allen et al., 2015; Elldér, 2020). In their study using the American Time Use Survey from 2003 to 2017, Stiles and Smart (2021) only consider knowledge workers, defined as those engaging in non-manual work because they are the ones who are able to telework. For England, Melo and de Abreu e Silva (2017) point to considerable differences between teleworkers and other workers in terms of type of occupation, economic sector of work, level of income, level of car ownership, number of children and home ownership. This means that, even after controlling for various factors in a study, comparisons between teleworkers and other workers, as well as between different countries or urban areas, can be challenging. This is due to the fact that, when populations differ greatly, there is an increased risk of biased conclusions due to unobserved factors that are not taken into account, as well as self-selection bias. For example, if researchers are unable to identify in their analysis that it is only the most motivated or well-suited employees who choose telework, they risk drawing conclusions about telework that should be attributed, wholly or in part, to the nature of the individuals who engage in telework.

2.5. Gaps in the literature and objectives

From the literature review three gaps can be identified that the current study aims to address. It will:

- Assess whether teleworkers spend less time travelling over a five working day period, especially during peak hours, compared to non-teleworkers;
- Examine differences in travel time for teleworkers between commuting and non-commuting days; and
- Evaluate the extent of peak-hour travel avoidance for among teleworkers.

The existing literature also suggests that the extent to which working from home is able to release teleworkers from the space-time constraints imposed by the temporal ordering of cities and society – office rhythms, school hours, opening hours of shops and other facilities, etc. – is crucial to their travel times and peak-hour travel. This is why two seemingly competing hypotheses have been put forward

in the Introduction, and why the analysis below distinguishes between commuting and non-work travel.

3. Method

3.1. Data

The microdata from the UK's National Travel Survey (NTS), limited to English residents, are used. The NTS is a continuous household survey of personal travel which involves a randomized and representative cross-section of the English population. Data is collected via interviews from a seven-day trip diary for each individual from a household. The data for the years 2015-2019 are used, in order to ensure a healthy sample size for the teleworker population of 1,191 individuals who represent 9% of the working population studied. This population does not represent the entire working population as home-based workers are excluded, because they do not or hardly commute and thus contribute marginally to peak hour traffic.

3.2. Telework and commute week-days

The analysis below is based on a declarative indicator to define teleworkers. Respondents were asked about the frequency of working at home instead of at their usual place of work. Those who declared at least one day of work at home per week are considered to be teleworkers. The home-working variable is used because it is not possible to identify telework from the other NTS variables. This is mainly because the survey does not provide information on actual working hours. The only information available on this quantity is a binary (yes/no) variable on part-time work. Thus, the absence of work trips on a given (week) day does not necessarily mean that workers stay at home to telework; they may undertake other activities there. It is therefore difficult to define the frequency or reality of telework from the NTS observation data. Limitations of the NTS data also make it impossible to consider telework outside the home, in third places such as a café, a car or a co-working space.

While it is problematic to study telework (half) days with the NTS data, it is of course possible to reverse the approach and look at the commute. Thus, the analysis below considers the number of weekdays with declared commuting during the observed week, which is here defined as Monday-Friday as these are the days on which commuting makes the greatest contribution to road congestion. A nuanced approach to the association of telework and travel behavior in the NTS is made possible by discriminating between declared teleworkers according to the number of commute days per week. For the purpose of comparing teleworkers and non-teleworkers, as well as studying the effects of commuting on other types of travel, we excluded from the study population all workers who do not have at least one day of commuting. Also, individuals with a least one holiday trip were excluded from the analysis, to ensure a minimum of five potential working days during the study period.

Considering the actual number of commuting days effectively carried out helps control for this effect for both teleworkers and non-teleworkers. It also allows two groups of workers to be excluded from the study, i.e., those who do not have a usual place of work outside the home, including self-employed individuals work from home all the time, and individuals who did not report any working during the surveyed week due to vacation, illness, or other reasons.

3.3. Travel time indicators as dependent variables

Travel time is the dimension of travel behavior that is selected to measure the association of telework and individual travel, particularly during peak hours. Indeed, travel time allows us to measure the intensity of travel during peak hours. Six dependent variables are defined, which capture the total weekly travel time for work trips (i.e., commute and work-related trips) and non-work trips (i.e., all other travel motives) for the morning peak, evening peak and off-peak. Commuting and work-related trips (i.e., 'in course of work' in the NTS data) have been combined into the single category of 'work'. Because work-related trips tend to be much higher among teleworkers than non-teleworkers, and cannot be overlooked among the various types of travel associated with work. Travel time during the peak hours corresponds strictly to the trips, or portions of trips, made during 06:30-09:30 AM and 04:30 to 07:30 PM. The off-peak period gathers all clock times outside those two blocks of three hours. As explained above, the analysis below only considers travel times during the conventional work week of Monday through to Friday.

3.4. Modelling framework

A simplified version of Structural Equation Modelling (SEM) – i.e., path analysis – is used below. SEM is a very general framework for modelling, in which equations are estimated as a system. In path analysis no latent variables are introduced, and only measured indicators are used as exogenous and endogenous variables and to examine direct and indirect effects in the model.

The model tested and examined in Section 4 proposes four levels of effects (Figure 1). The first level aims to better understand how telework varies according to workers' socioeconomic characteristics and places of work and residence. The variables that allow for the characterization of workplaces and residences are limited in a national survey such as the NTS. We have tested multiple spatial variables (e.g., region, population density, settlement size, rural-urban classification), but only found the region of residence and working in London to have statistically significant relationships with teleworking and various commuting variables for the workers considered in the analysis.

The second level focuses on the number of commute days using exogenous variables – socioeconomic characteristics – and also an endogenous variable – telework. At the same level, there are train and car as commute modes. Use of these modes of transport are here only statistically explained by workers' socio-economic characteristics and not by the endogenous variables of telework or the number of commuting days. Because the relationships of teleworking and commute day frequency with commute mode are complex and potentially bi-directional, we refrained from specifying direct effects and rather decided to allow the error terms in the equations for the two commute modes to be correlated with those for telework and commute day frequency.

The third level seek to explain travel time differentiated between work and non-work purposes and between the morning and evening peak with the help of the exogenous socioeconomic variables and all the previously introduced endogenous variables. Finally, the last level presents the effects of all exogenous and endogenous variables on off-peak travel times. These were placed on a different level as travel during peak periods because workers' off-peak travel times may be influenced by peak-hour avoidance. Besides, the model goodness-of-fit (GOF) indicators are much better for this specification compared to one in which peak and off-peak travel times are placed on the same footing.

The estimation method used below is the Weighted Least Squares (WLS) as it is best suited to dealing with binary and ordered variables and the estimation of indirect effects between two variables via one or more other variables (Golob, 2003). Since WLS uses correlation matrices, the resulting coefficients

are standardized, which facilitates comparison between coefficients in a given equation and across equations.

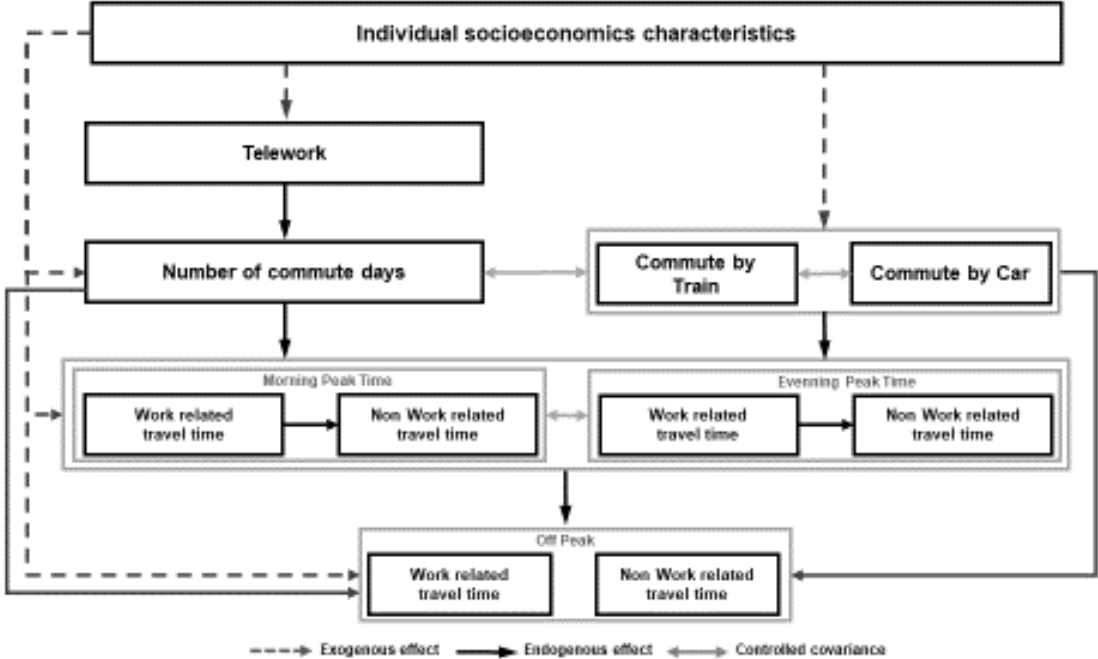


Figure 1. Modelling framework

When all variables included in the different model equations are observed, the general equation for this method is:

$$y = By + \Gamma x + \zeta \tag{1}$$

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, and ζ is the vector of the residuals from the structural relationships between y and x . The coefficients of the path model presented in Section 5 have been estimated using the lavaan R package (Rossee, 2012)

4. Teleworking in England: who, when and with what consequences?

The 1,191 workers in England declaring at least one day of telework per week and representing 9% of the combined number of workers in the 2015-2019 NTSs disproportionately commute by train and underground and much less by car and bus compared to non-teleworkers (Table 1). They also work in London much more often, hold professional/managerial jobs more frequently, have a much higher level of income, and are more often self-employed. They also live in households with children more frequently, are more likely to be or identify as man, and reside in London or in the neighboring East and Southeast England regions. In many ways, teleworking continues to be associated with privilege in England.

Table 1. Profile of teleworkers in England

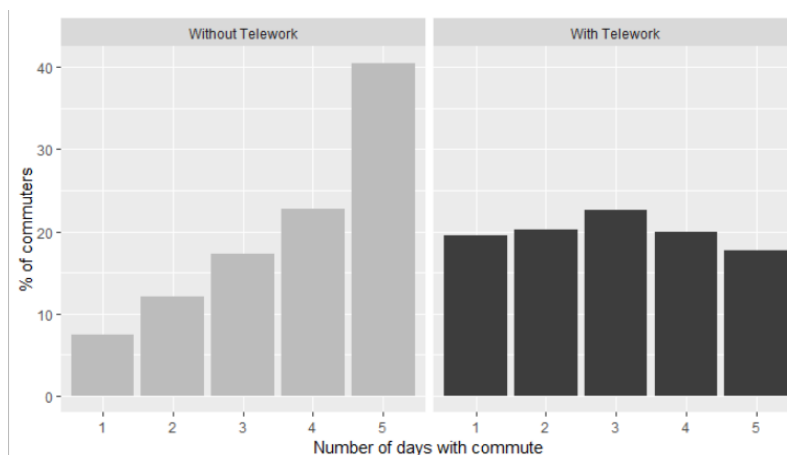
		Teleworkers	Non-teleworkers	All
Commute mode	Active	11.3%	12.2%	12.1%
	Car	67.2%	76.3%	75.4%

	Bus	5.6%	9.2%	8.9%
	Train	25.3%	9.5%	10.9%
	Underground	10.1%	4.3%	4.8%
Workplace location	In London	26.9%	12.2%	13.5%
Occupational status	Professional / managerial	47.9%	21.6%	24.0%
	Clerical	41.5%	43.9%	43.7%
	Manual	10.7%	34.5%	32.4%
Employment status	Part time	19.2%	22.8%	22.5%
Self-employment	Self-employed	9.9%	2.7%	3.4%
Annual personal income	Less than £25,000	25.7%	55.5%	52.8%
	£25,000 to £49,999	41.5%	34.1%	34.7%
	£50,000 and over	32.8%	10.5%	12.5%
Gender	Woman	48.4%	52.4%	52.1%
Age	Average	43.6 years	42.6 years	42.7 years
Children in the household	No child	58.5%	65.2%	64.6%
	1 child	18.6%	17.2%	17.3%
	2+ children	22.9%	17.6%	18.1%
Single-parent family	Yes	3.1%	3.1%	3.1%
Household with >2 adults	Yes	17.5%	26.4%	25.6%
Place of residence	London	21.8%	15.3%	15.9%
	East	12.1%	11.4%	11.4%
	South East	18.5%	15.8%	16.0%
	West	10.5%	9.1%	9.3%
	North Metropolitan*	16.8%	21.5%	21.1%
	North Non-metropolitan*	20.4%	26.8%	26.3%
# of individuals		1,191	12,107	13,298
% of individuals		9.0%	91.0%	100.0%

Source: data from UK National Travel Surveys 2015-2019

* North includes Midlands, Yorkshire and North of England

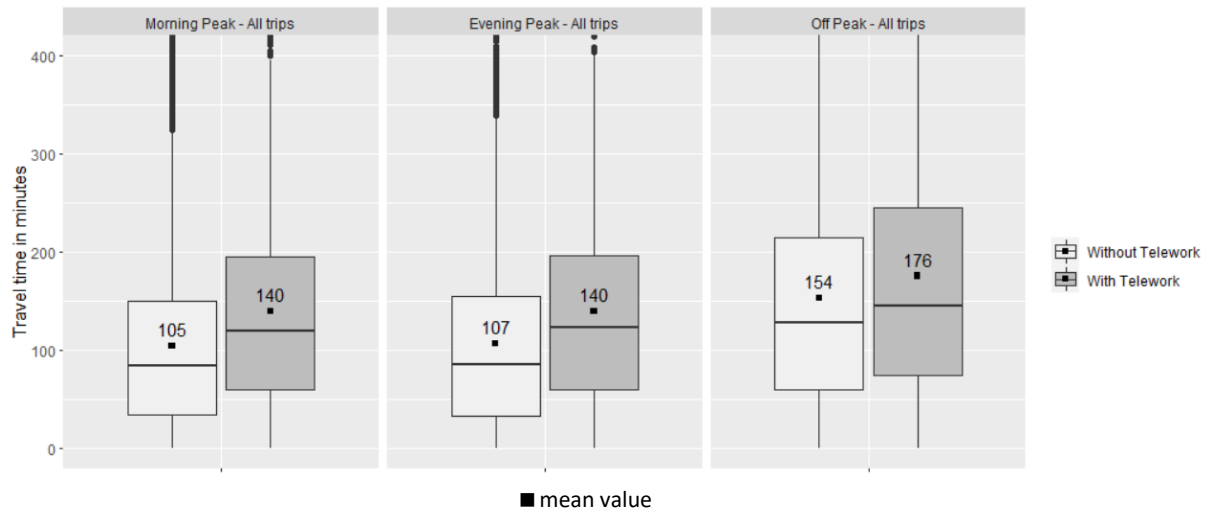
Unsurprisingly, teleworkers in our sample have fewer commute days than other workers, with slightly more than 60% having between 1 and 3 commute days compared to over 60% of other workers who have 4 or 5 commute days (Figure 1). For teleworkers, no category stands out, although the extreme categories one and five days are slightly less common. Almost 20% teleworkers, who declared to work from home at least one day during the week, engaged in commuting on all five days from Monday through to Friday in the week for which they reported travel patterns. This seeming contradiction may be due to the fact that the surveyed week differs from the usual reported frequency of teleworking, potentially because of an irregular weekly frequency of remote work or the unique nature of the surveyed week. Because the NTS does not provide information on the actual hours worked, we cannot ascertain the relative importance of these possibilities. It is also worth mentioning that some non-teleworkers commute for only one, two, or three days, likely due to working part-time or the unique circumstances of the surveyed week.



Source: data from UK National Travel Surveys 2015-2019

Figure 2. Number of commute days by telework status

Teleworkers, on average, spend 449 minutes travelling across the Mon-Fri period against 366 for people without telework. This amounts to 23% or slightly over 16 minutes extra travel time per day. During the morning or evening rush hour, this difference is even more pronounced, with teleworkers having more than 30% longer travel times (Figure 3). This difference is about 14% for the off-peak period. At first sight, there is little evidence to suggest peak avoidance among teleworkers.

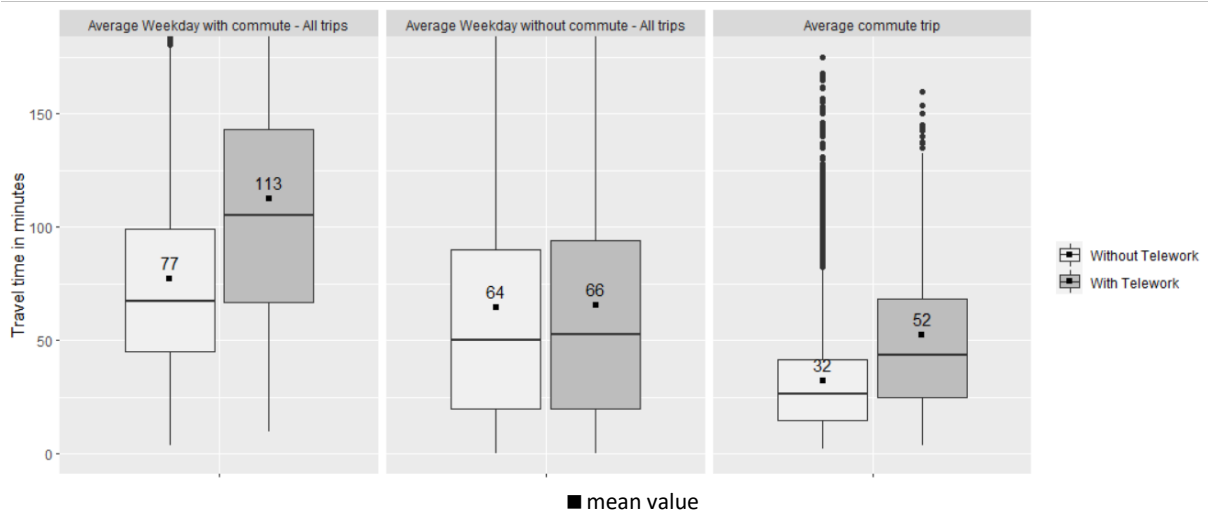


Source: data from UK National Travel Surveys 2015-2019

Figure 3. Total travel time over five weekdays, by time of day

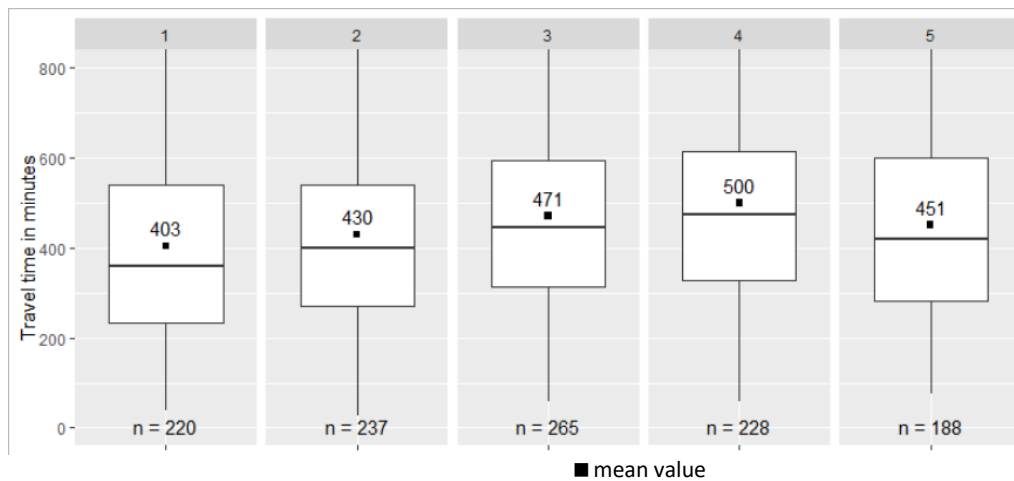
When travel times are disaggregated by mode, by type of residential location or by workplace location are considered, the differences between teleworkers and other workers are small. This suggests that most of the differences in Figure 3 reflect composition effects, with the teleworker group being different in terms of their mode, residential location and/or workplace location. This will be examined further in the modelling in Section 5.

Also, it can be observed that teleworkers have a significant impact on the morning and evening peak hours. For example, they account for about 11.5% of total travel time during the morning and evening peaks, whereas they represent only 9% of the working population. This impact on peak-hour traffic is, however, unevenly distributed across modes and destinations. For example, according to the NTS data, teleworkers account for nearly 21% of people travelling to work by train and 27.5% of people travelling by train to a workplace in London. In contrast, they represent only 8.3% of commuters by car.



Source: data from UK National Travel Surveys 2015-2019

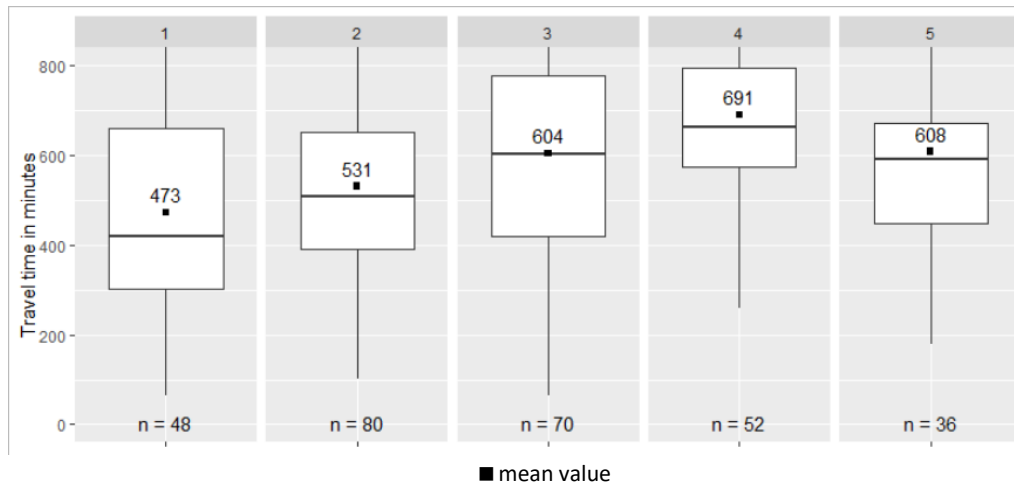
Figure 4: Travel time on weekdays with and without commuting and for an average commute trip



Source: data from UK National Travel Surveys 2015-2019

Figure 5: Total travel time over five weekdays for teleworkers, by number of commute days

The longer travel times of teleworkers in Figure 3 can be explained by particularly long travel times on days when teleworkers commute (Figure 4). On these days teleworkers' average travel times are almost 50% higher than those of other workers. This is mainly due to much higher commuting times: the average of 52 minutes is 63% higher than for non-teleworkers. Finally, for days without commuting, teleworkers' travel times are equivalent to those of other workers. This last finding suggests that travel times remain high for teleworkers on days they work from home, in part due to non-work and work-related of work trips (Caldarola and Sorrell, 2022; Cerqueira and Motte-Baumvol, 2022).



Source: data from UK National Travel Surveys 2015-2019

Figure 6: Total travel times over five weekdays for teleworkers commuting by train, by number of commute days

The number of commute days has a strong association with the total travel time of teleworkers in general (Figure 5) and those commuting by train in particular (Figure 6). In both instances, the total travel times are highest for those with four commute days, and respectively 24% and 46% higher than for those commuting only one day. The fact that the total travel time for those commuting five days are lower than for those commuting four days per week suggests that the (very) long physical commutes are only bearable because teleworkers can work at least one day per week from home. Although commuting less frequently, teleworkers still have longer total travel times than other workers. For instance, teleworkers with only one commute day on average travel for 403 minutes over the Mon-Fri period (Figure 5) compared to only 366 minutes for other workers, regardless of their commuting frequency. The moderating effect of fewer commute days for teleworkers is much stronger for those who commute by train (Figure 6). Below five commute days, one day of commuting by train represents more than 60 minutes of additional travel time. The very long travel times among teleworkers commuting by train make them an unusual group with the total population of working adults in England.

5. Understanding variations in telework, commuting and travel times in England

5.1. Model fit

The estimation of the path model outlined in Figure 1 on the NTS 2015-2019 data results in a model with very good scores on the GOF indicators that are commonly used in SEM analysis (Golob, 2003). The root mean square error of approximation (RMSEA) and the standardized root mean square residual (SRMR) are both clearly below 0.05, which is judged as satisfactory. Moreover, the comparative fit index (CFI), which compares the proposed model with a 'null' model, exhibits a value of 0.99, which is clearly above the threshold value for a good model of 0.90. The 'null' model assumes that all the observed variables are uncorrelated with each other, whereas the proposed model specifies the expected relationships among the variables.

1 Table 3. Total (indirect+direct) standardized effects in the path analysis

Dependent Variables → Independent variables ↓	Telework: yes	# commute days	Commute by train: yes	Commute by car: yes	Travel time, work trips, AM peak	Travel time, work trips, PM peak	Travel time, work trips, off-peak	Travel time, non-work trips, AM peak	Travel time, non-work trips, PM peak	Travel time, non-work trips, off-peak
Telework: yes		-0.34 ***			-0.05 **	-0.05 **	0.10 ***	0.04 *	0.22 ***	0.12 ***
# commute days					0.40 ***	0.34 ***	0.08 ***	-0.01 *	0.11 ***	-0.36 ***
Commute by train: yes					0.31 ***	0.27 ***	0.46 ***	-0.01 *	0.04 ***	
Commute by car: yes							0.26 ***	0.10 ***	0.21 ***	0.16 ***
Travel time, work trips, AM peak							-0.17 ***	-0.02 *		0.11 ***
Travel time, work trips, PM peak							-0.11 ***		0.14 ***	-0.10 ***
Workplace: in London	0.12 ***	-0.04 ***	0.48 ***	-0.39 ***	0.29 ***	0.28 ***	0.16 ***	-0.04 ***	-0.01 *	-0.02 .
Occupation status										
Professional/managerial	0.11 ***			0.04 **	0.05 ***	0.04 ***	0.05 ***	0.01 **	0.04 ***	0.01 .
Manual	-0.17 ***		-0.07 ***		-0.16 ***	-0.15 ***	0.06 ***	-0.02 *	-0.06 ***	-0.04 ***
Employment status: PT	0.08 ***	-0.28 ***			-0.13 ***	-0.14 ***		0.09 ***	-0.02 ***	0.20 ***
Self-employment: yes	0.10 ***	-0.03 ***		0.05 ***	-0.04 ***	-0.03 ***	0.03 ***	0.01 ***		0.02 ***
Personal annual income	0.24 ***	-0.04 ***	0.10 ***	0.09 ***	0.11 ***	0.11 ***		0.02 ***	0.09 ***	0.06 ***
Gender: Woman		-0.03 ***		0.04 ***	0.01	-0.04 ***	-0.07 ***	0.05 ***	0.07 ***	0.05 ***
Age		-0.03 ***	-0.11 ***	0.12 ***	-0.06 ***	-0.06 ***	-0.02 *	0.01 ***	-0.05 ***	0.03 ***
Children in the household										
One child	0.05 ***	-0.02 ***		0.05 ***	0.01 *	-0.03 ***	-0.03 **	0.10 ***	0.02 ***	0.02 ***
2 children or more	0.05 **	-0.04 ***	-0.04 **	0.10 ***	-0.03 ***	-0.06 ***	-0.04 ***	0.18 ***	0.02 ***	0.03 ***
Single parent family: yes								0.06 ***	0.02 *	0.02 *
Household w/ >2 adults: yes	-0.07 ***				-0.01 *	-0.01 *		0.01 .	-0.02 ***	-0.02 .
Place of residence										
London		0.03 **	-0.10 ***	-0.23 ***	-0.02 *	-0.02 **	0.03 *	-0.02 ***	-0.05 ***	-0.05 ***
East				-0.03 *	0.02 *	0.03 **	-0.01 **	0.02 *	-0.02 .	-0.01 *
South East			0.04 **	-0.05 **	0.04 ***	0.01 **		-0.01 ***	-0.01 **	-0.01 .
West	0.04 *	-0.01 *			0.02 .	0.01 .			0.01 *	0.01 **
North Metropolitan			0.08 ***	-0.10 ***	0.03 ***	0.05 ***		-0.01 ***	-0.01 ***	-0.02 ***
R ²	0.20	0.18	0.24	0.32	0.39	0.35	0.20	0.11	0.12	0.19

2 *** = p<0.001; ** = p<0.01; * = p<0.05; . = p<0.10

3 The missing coefficients correspond to effects constrained to zero after earlier analysis had indicated p>0.10

4 Source: data from UK National Travel Surveys 2015-2019

5

Table 2. Model goodness-of-fit indicators

Indicator	Value
agfi	0.998
cfi	0.999
chisq	126.383
npar	144.000
rmsea	0.006
rmsea.conf.high	0.008
srmr	0.019
tli	1.000

6

7 *5.2. Explaining variations in telework and commute frequency and mode*

8 As expected, whether a worker has declared to engage in telework (from home) is mainly linked to
9 employment-related factors. The strongest correlates are, in decreasing order of importance, income,
10 occupational status (smaller likelihood for manual labor, larger probability for a
11 professional/managerial occupation), working in London, being self-employed or working part-time
12 (Table 2). Socioeconomic characteristics of individual and their households and place of residence are
13 much less important. The presence of children in the household is positively correlated with
14 teleworking, while the presence of a third adult in the household, whether an adult child or a parent,
15 is negatively correlated. All else equal, teleworking is also more common among residents of West
16 England.

17 Employment-related factors are also most strongly associated with commute behavior. Commute
18 frequency is most dependent on whether workers engage in telework. In line with the findings in
19 Section 4, teleworking is linked to a lower number of commute days. Working part time is the second
20 factor that is strongly correlated to a lower number of commute days. Other factors are rather weakly
21 associated with the commute frequency. The number of commute days is lower among the self-
22 employed, those with a higher income, women, older workers, those with children and those living in
23 West England. The frequency is greater among London residents.

24 Commute mode is mostly dependent on workplace location, followed by place of residence. Workers
25 with a workplace in London are much more likely to commute by train and travel to work by car much
26 less compared to those who work outside London. There is also a strong London link for place of
27 residence, with those living in the capital considerably less likely to commute by car and to a lesser
28 extent by train. Residents of northern metropolitan regions areas are also less likely to commute by
29 car but travel to work by train more often. The same association, albeit in weaker form, can be
30 observed across the wider South East, while workers from East England are also slightly less likely to
31 commute by car than workers in West England and northern non-metropolitan areas.

32 Other important correlates of commute mode are age, income and presence of children. Older workers
33 commute by car more often but less so by train, whereas those on a higher income use both modes
34 more frequently. Car use is also higher for workers as the number of co-resident children increases.
35 Those with two or more children are also less likely to commute by train. Finally, the model shows that
36 commuting by car is more common among the self-employed and those in professional/managerial
37 occupations, while those undertaking whose job is classified as manual labor are less likely to commute
38 by train.

39 While all the results for commute mode are in line with expectations and previous studies (Dargay and
40 Hanly, 2007; Keyes and Crawford-Brown, 2018; Schwanen and Mokhtarian, 2005), First of all, it is
41 important to appreciate that these train and car are not necessarily mutually exclusive categories in

our analysis. This is because a small number of workers have reported different modes of transport on different days of the week, and the share of those using both trains and cars to commute to/from work is only 2.9% in our data but 27.6% of those using the train. To accommodate this behavior in the model, we have allowed the error terms of the two mode variables to be correlated. The estimated coefficient of -0.59 (Table 4) has the expected sign and magnitude.

47

48 *Table 4. Estimated correlation coefficients between error terms*

Variable 1	Variable 2	Coefficient
Telework: yes	Commute by train: yes	0.21 ***
# commute days	Commute by train: yes	-0.10 ***
Commute by car: yes	Commute by train: yes	-0.59 ***
Travel time, work trips, AM peak	Travel time, work trips, PM peak	0.61 ***
Travel time, non-work trips, AM peak	Travel time, non-work trips, PM peak	0.12 ***
Travel time, non-work trips, AM peak	Travel time, non-work trips, off-peak	0.16 ***
Travel time, non-work trips, PM peak	Travel time, non-work trips, off-peak	0.35 ***

49

50

51

*** = $p < 0.001$; ** = $p < 0.01$; * = $p < 0.05$; · = $p < 0.10$
 Source: data from UK National Travel Surveys 2015-2019

52 *5.3. Explaining variations in travel time for work during peak hours*

53 There is an association between teleworking and shorter travel times for work trips during both the
 54 morning and evening peak. Teleworkers spend less time on work trips during peak hours than other
 55 workers. However, the association between teleworking and travel time for work during peak times is
 56 modest and much smaller than the associations of other work-related variables with travel time for
 57 work during peak times.

58 Among these variables, the number of commute days has the strongest association with travel time
 59 for work at peak times. This association is 7-8 times larger than that for teleworking. The associations
 60 for commuting and workplace location are almost 6 times stronger than for teleworking, and the
 61 corresponding number for part-time employment and being in a manual occupation is 2.5-3 times and
 62 for personal income it is two times. Workers commuting more days per week, commuting by train, or
 63 working in London tend to have longer travel times for work trips during peak hours from Monday to
 64 Friday. Full-time workers, high earners, and non-manual workers also have longer travel times during
 65 peak hours. Workers with bosses and in professional/managerial roles, younger workers, those
 66 without children, and non-Londoners, particularly those from South East and East England and
 67 northern metropolitan areas, also have longer travel times for work during peak hours. However, the
 68 place of residence has only a weak association with travel time for work trips during peak hours.

69 The estimated coefficients for the correlates of travel time for work do not differ much between travel
 70 times for work trips during the morning and evening peak. The associations with commute days and
 71 commuting by train are more pronounced for the AM peak, while the opposite is true for gender (men
 72 only spend statistically significantly more time on commuting during the evening peak) and having two
 73 or more children.

74 *5.4. Explaining variations in travel time for non-work purposes during peak hours*

75 Based on Table 2, there is an association between teleworking and increased travel time for non-work
 76 purposes compared to other workers, especially during the evening peak hour. Additionally, workers
 77 who have more commute days tend to have longer travel times for non-work trips during the evening
 78 peak hour tend to be longer as worker commute on more days per day; the corresponding effect is

79 weaker for the morning peak. This could be attributed to non-work trips that workers make while
80 returning home.

81 Furthermore, non-work travel time varies significantly depending on commute time and mode.
82 Workers who commute more in the morning tend to travel less for non-work purposes during the AM
83 peak, suggesting that fitting in non-work trips is more challenging in the morning due to time
84 constraints (for similar results with older data in other cities, see e.g. Damm, 1981; Nisshii et al., 1988).
85 In contrast, longer commutes during the evening peak is associated with longer travel time for non-
86 work purposes, possibly suggesting that, all else equal, trip-chaining on the way home is more common
87 as commutes are (somewhat) longer.

88 Differences in commute modes largely reflect differences in flexibility. Car commuters tend to have
89 longer non-work travel times, particularly during the evening peak, as cars make trip-chaining during
90 commutes comparatively easy (Daisy et al., 2020; Hensher and Reyes, 2000; Scheiner and Holz-Rau,
91 2017). Car commuters devote most time to non-work travel in the evening peak, followed by train
92 commuters, and finally those using other modes. However, the negative coefficient for commuting by
93 train in the morning indicates that train commuters are least likely to travel for non-work purposes in
94 the morning peak hour, which may reflect that the time constraints of a long commute are most
95 binding in the early morning (Damm, 1982; Nishii et al., 1988).

96 Additionally, travel times for non-work purposes at peak times are associated with employment-
97 related factors, socioeconomic characteristics, and residential location. Non-work travel during peak
98 hours is most common among professionals/managers and least among manual workers, with
99 differences being most pronounced for the evening peak. Part-time workers devote more time to non-
100 work travel during the morning peak than full-time workers, suggesting that the former start working
101 later or have more flexibility in work start times which allows them to accommodate non-work trips.
102 Non-work travel times during peak hours are also relatively long among higher-income workers, the
103 self-employed (morning only), working women, workers with children and/or in single-parent families.
104 They are relatively brief during the PM peak for older workers, who do spend more time on non-work
105 travel during the morning peak, and those in households with three or more adults. Although
106 differences based on residential location are modest, working Londoners tend to devote less time to
107 non-work trips during peak hours than workers residing elsewhere.

108 *5.5. Explaining variations in travel time outside peak hours: peak avoidance?*

109 Signs of peak avoidance can be identified by comparing the correlation of a given variable on travel
110 time for trips during and outside peak hours, for both work and non-work trips. Here we focus first on
111 commuting, and then on non-work travel.

112 The results reveal that teleworkers, manual workers, self-employed and Londoners are among the
113 groups that exhibit signs of peak avoidance for work trips, as evidenced by the negative coefficients
114 for peak hours and positive coefficients for travel time outside of peak hours for the mentioned
115 categories of workers. Similarly, part-time and older workers also appear to avoid peak hours, although
116 coefficients for these categories also indicate shorter commutes in general compared to full-time and
117 younger workers, respectively. This is why the effect of travel time for work trips outside peak hours
118 by part-time workers has been constrained to zero in the model, and that for older adults is negative
119 but three times less so than for both peak hours.

120 In some instances, the comparison of estimated coefficients for work trips point towards a net peak
121 spillover effect, where commutes extend into the off-peak times immediately preceding or following
122 the defined peak hours of 6:30-9:30 AM and 4:30-7:30 PM. These effects are clearest for commuting

123 by train and working in London. It is challenging to distinguish peak avoidance and spillover effects
124 from day-to-day variability in work start and end times, which mean that on one or a few (but not all)
125 workdays workers travel to, from or for work outside peak hours. This pattern may be relatively
126 common among those commuting more days per workweek, commuting by car, or working in a
127 professional/managerial occupation. For yet other groups it is difficult to ascertain which type of effect
128 prevails. This is particularly the case for workers with children, where the three coefficients suggest
129 that, all else equal, having two or more children is associated with shorter commutes in general, quite
130 possibly to reconcile work with home demands.

131 For non-work travel, there are few suggestions of peak avoidance. Part-time and older workers are
132 exhibiting some peak avoidance, but only in the evening and not the morning. The model coefficients
133 are better compatible with the hypothesis of spillover from the evening peak to the off-peak period.
134 This is particularly so for teleworkers and workers commuting by car.

135

136 **6. Conclusions and discussion**

137 This study has used data for residents of England from the 2015-2019 UK National Travel Surveys to
138 assess the associations of teleworking with travel time over the five-day workweek (Mon-Fri), by trip
139 purpose and time of day. Descriptive analysis indicated that teleworking in England before the COVID-
140 19 pandemic were associated with longer total travel times over the workweek. This was shown to be
141 mainly due to longer commutes and in spite of a lower number of commute days than other workers.

142 Nonetheless, the path analysis has qualified the findings from the descriptive analysis in three major
143 ways. First, it confirms that teleworkers' longer travel times for work trips observed in the descriptive
144 analysis are population composition and location effects. Teleworkers are much more likely to hold a
145 professional/managerial occupation, have a high income, commute by train and/or work in London –
146 all factors that push up commute times during and outside peak hours. Second, the modelling has
147 shown that teleworkers do travel much more for non-work purposes at all times of the day, but
148 especially during the evening peak. This remains after other factors, including peak-hour commute
149 times, are taken into account. A comparison of model coefficients has suggested a tendency among
150 teleworkers to avoid peak hours for work-related travel only; there seems to be no such correlation
151 for non-work-related travel. This may mean that more telework adoption need not automatically
152 translate in notable reduction in peak-hour travel. Instead, the results of our study highlight that the
153 relationship between work and non-work trips is complex and varies among different groups and
154 regions. However, any interpretation needs to be undertaken with caution as the modelling using
155 cross-sectional data, such as those from the NTS, does not allow causal relationships to be tested. To
156 address this limitation, there is a clear necessity for a large-scale, longitudinal study focused on
157 commuting and work patterns.

158 The results allow the tension between the two seemingly competing hypotheses set out in the
159 Introduction to be resolved. Both may be valid, albeit for different trip purposes. The first hypothesis
160 about lower commuting frequency and increased scheduling flexibility enable teleworkers to travel
161 less and avoid peak hours seem to apply only to work travel by teleworkers in pre-COVID-19 England.
162 In contrast, the results for non-work travel by those teleworkers are consistent with the second
163 hypothesis about the temporal ordering of cities and society imposing similar constraints during peak
164 hours on teleworkers as on other workers. The results also indicate that teleworking one or several
165 days per workweek is a sensible strategy for dealing with long one-way commutes, such as those
166 experienced by many train commuters, those travelling to a workplace into London, and/or workers in

167 a professional/managerial role and/or higher income. This statement does not entail a claim what
168 comes first: the long commute or the (potential for) teleworking. It thus brings us back to old debates.
169 The existence of a rebound effect of telework on residential location choice and the lengthening of
170 commutes was discussed some time ago by Ory and Mokhtarian (2006), while de Abreu e Silva's
171 (2022) recent study shows a greater intention to telework among workers with longer commute.
172 Further work to disentangle the nature of causality between commute length and teleworking, which
173 may vary between groups of workers and geographers, remains urgently required.

174 Further to our inability to establish causality between telecommuting and travel behaviour variables,
175 the use of data from before the COVID-19 pandemic is another limitation of the current study. It
176 nonetheless remains unclear how serious that limitation is. An ongoing panel study of 6,000 individuals
177 in 9 urban areas in England and Scotland that started in the early stages of the pandemic (Marsden et
178 al., 2021; Anable et al., 2022) offers some indications that the post-pandemic effects of teleworking
179 on commuting and peak hour traffic are not as qualitatively different from those observed in this study
180 as the public discourse about working and commuting in pandemic times might suggest. Marsden et
181 al. (2021) have shown a marked reduction of the number of work trips among the teleworkers in their
182 sample, in a context where the number of teleworking days has more than quadrupled. At the same
183 time, there has only been a decrease in peak hour congestion overall of around 5% overall, with the
184 level of decline smaller on some parts of the road network (Anable et al., 2022). The observations by
185 Anable and colleagues may reflect some of ours in that telework is concentrated in certain types of
186 jobs and spatial contexts (see also Lee et al., 2020), and that the reduction in travel times during the
187 morning rush hour for teleworkers is rather small because lower commuting frequencies are partly
188 offset by more non-work trips. However, the total number of non-work trips in the post-pandemic
189 period may not (yet) be at the pre-COVID levels, since Marsden et al. (2021) point to a rate of online
190 purchasing in value terms of around 35% in January 2021, compared with 20% one year earlier. This
191 development, which is weakening some of the spatial and temporal constraints on shopping, may well
192 be challenging some of the results for non-work trips in the current study. It is further evident that
193 further research on developments of teleworking and its associations with work and non-work travel
194 remains necessary, but studies like ours can still help to unravel the complex relationships and offer a
195 baseline against which post-pandemic developments can be evaluated

196

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