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Telework and daily travel: New evidence from Sweden

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ABSTRACT

Telework, long promoted as a way to reduce daily travel and address congestion problems, has been extensively studied in transport research. Empirical consensus has long held that telework reduces overall travel, but several updated studies now suggest the opposite. Meanwhile, telework has steadily increased in many countries, and few studies have examined contexts where regular teleworkers have grown to form an early majority. We study how telework influences daily travel in such a context, namely, Sweden from 2011 to 2016. Using representative micro-data from the Swedish National Travel Survey, this study also captures travel behaviour during the defined period when the telework was actually practiced, distinguishing different telework arrangements and analysing a range of travel behavioral outcomes. We conclude that telework leads to reduced travel demand, more use of active transport modes, and congestion relief. Important differences between full- and part-day teleworkers are also highlighted, stressing the importance of understanding telework as a diversified coping strategy for organizing the spatiotemporality of everyday life.

1. Introduction

Relationships between telework[1] – i.e., paid work performed at home or at a location other than the regular workplace – and travel demand have been extensively studied in transport research for decades (Andreev et al., 2010; Moktharian, 1991). In particular, telework has received considerable attention due to its potential to replace or modify (e.g., avoiding rush-hour travel) daily commuting, resulting in fewer and shorter trips and reduced stress on transport systems. Since the 1970s, many have put great hope in rising telework levels and predicted major changes in daily activity patterns and spatial structure (e.g., Nilles, 1975; Toffler, 1980). The empirical research was also for a long time more or less consistent, finding that telework replaces and therefore reduces travel in the short run (Andreev et al., 2010; Moktharian, 1991).[2] Moktharian (1991) reviewed the early studies and concluded that among those who telework, commuting is reduced, non-commuting trips do not increase, and proportionally fewer peak-period trips are made. Twenty years later, Andreev et al. (2010) reviewed over 30 studies and concluded that all found substitution effects, for example, that telework leads to fewer vehicle miles travelled (VMT) (e.g., Henderson and Mokhtarian, 1996) and fewer commuting trips (e.g., Hjorthol, 2002). However, despite these encouraging conclusions, telework as a work practice did not appear to be the great success that early visionaries predicted. Only a small part of the workforce engaged in telework, and its effects on total travel were estimated to be quite small (Choo et al., 2005).

However, there are now several good reasons for rekindled interest. Teleworking has increased in many contexts and the number of teleworkers now amounts to a considerable proportion of the workforce in many countries (Elldér, 2019; Ojala and Pyöriä, 2018; Vilhelmson and Thulin, 2016), and will most likely increase even more in the near future when many employers around the world now lifts restrictions on telework as a response to Covid-19. Considering the results of the early studies, this development would mean that telework should now be reconsidered as a potent policy instrument and an accessible route for reducing the environmental impact of travel. However, many early telework–travel studies suffered from being confined to specific demonstration projects or to workplaces where telework has traditionally been widespread, often in the advanced services sector (Moktharian et al., 1995). It can also be suspected that this ongoing and rapid diffusion has brought about new spatiotemporal practices and impacts as telework spread to new groups of workers and workplaces (Thulin et al., 2019). Recently, several updated studies using data representative of larger populations provide a more nuanced and, to some extent, more fragmented picture of the effects of telework on daily travel than did early studies. Many of the updated empirical studies

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[1] Or telecommuting – these concepts are used interchangeably in this paper.

[2] It should be mentioned that many studies also found rebound effects, though these did not exceed the overall decrease in travel; see Kim (2017) for an overview on the rebound effects of telecommuting.

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suggest that the substitution effects are offset by rebound effects, i.e., the resulting work-related travel savings stimulate additional travel of other types, and that telework actually promotes more travel (e.g., Kim, 2017; Zhu and Mason, 2014). Meanwhile, other innovative empirical studies have been presented that refine the picture in other dimensions critical for sustainability; for example, several studies suggest that teleworking makes room for more non-motorized and active travel (e.g., Chakrabarti, 2018; Lachapelle et al., 2018) and emphasize the importance of distinguishing different telework arrangements, such as part- and full-day teleworking (Haddad et al., 2009; Lachapelle et al., 2018). This testifies to telework being a diversified spatiotemporal practice and coping strategy for organizing everyday life.

In summary, there is a great need for updated and more nuanced studies from contexts where telework has increased since an early adoption phase, becoming routine for substantial parts of the workforce. One such context is the country of Sweden, where the share of regularly teleworking workers increased from 10% in 2005 to over 20% in 2012 and continues to grow, now representing an early majority of the Swedish workforce (Elldér, 2019; Vilhelmson and Thulin, 2016). Studies rarely use micro-data capturing the actual daily telework arrangements and practices representative of an entire nation, simultaneously examining their effects on a wide range of travel activities. Due to the rapid diffusion of telework, micro-data from the Swedish National Travel Survey now allow this. Our overall aim is to investigate how telework influences daily travel in Sweden, nuancing telework–travel relationships in different dimensions critical for sustainable mobility. Three research questions operationalize this aim and guide our study:

RQ1. Do teleworkers travel less on teleworking days?

RQ2. Do teleworkers travel more by active modes on teleworking days?

RQ3. Do teleworkers travel less in peak-hour traffic on teleworking days?

This article is structured as follows. This introduction is followed by a review of previous literature relevant to the aim of this study. The third section presents the data, variable definitions, and statistical techniques used. The results are presented in the fourth section and discussed in the fifth section, and the conclusion is presented in the sixth and final section.

2. Literature review

The focus here is on recent empirical studies of the relationships between telework and travel.[3] In our updated literature search, we searched for empirical–statistical studies of the effect of telework practices on revealed travel behaviour while controlling for relevant background factors. We identified a total of 15 relevant studies. These are presented in Table 1, which summarizes their data, contexts, telework indicators, dependent variable(s)/travel operationalization, and main results. Strikingly, a picture emerges differing greatly from the apparently empirical consensus of a decade ago. Almost all updated studies suggest complementarity effects on telework, i.e., that telework generates additional travel. Several studies illustrate how teleworkers report more total travel than those who do not telework (e.g., de Abreu e Silva and Melo, 2018; He and Hu, 2015; Zhu, 2012), and many studies examining effects on non-work travel also find positive relationships with telework (e.g., Kim et al., 2015; Zhu and Mason, 2014). Some studies even conclude that telework increases commuting duration (de Vos et al., 2018) and length (Melo and de Abreu e Silva, 2017).

An important difference from the early studies is that most of the updated studies use high-quality data representative of large populations, perhaps allowed by telework becoming generally more widespread or by questions on telework practices being included in many large-scale travel surveys. On first sight, this is welcome as it provides opportunities to generalize results beyond specific demonstration projects and workplaces, though this does entail other risks. Notably, the increasing use of general travel surveys seems to have led to telework practices often being generally and crudely defined. Most studies use what we here call general indicators of telework practices that convey no information on whether or not a respondent actually teleworked during the day or period of the travel survey. For example, many studies only include a simple indicator of whether or not a worker teleworks frequently. In contrast, a direct measure would include specific information on telework performance during the actual period of the travel survey.

Only three studies, i.e., by Asgari and Jin (2018), Hu and He (2016), and Lachapelle et al. (2018), include proper direct measures of telework performance. Asgari and Jin (2018) only measured effects on commute departure time. Hu and He (2016) considered a binary indicator of teleworking on the travel survey day in only one model measuring total daily household trip duration, finding a negative association. This model is difficult to interpret, however, since general indicators of frequent and infrequent telework are also included. Lachapelle et al. (2018) were the only authors finding clear substitution effects, concluding that all-day teleworking results in less travel time. Three other studies used cruder proxies, i.e., 'working at home' (He and Hu, 2015) or 'not commuting to work' (Chakrabarti, 2018; Kim, 2017), but it is not known whether these capture actual telework in a traditional sense (i.e., paid work performed at home instead of at the regular workplace). Kim (2017) found that commuting is actually reduced by telecommuting but, when measuring travel impacts on a household level, concluded that the increase in travel for other purposes and by other household members is slightly greater. However, Kim (2017) only had access to Euclidean distances (calculated from the centroids of travel analysis zones on which trip origins and destinations are based) as a proxy for actual travel.

All other studies use general indicators of telework performance that do not capture whether the respondent actually teleworked during the period when travelling was surveyed (usually a random day). Admittedly, the use of general indicators can to some extent indirectly capture average rebound effects and long-term effects. For example, if some teleworkers seize the opportunity to move to car-dependent peripheral locations, farther from everyday activities, with added everyday travel as a long-term consequence, and/or if telecommuting results in the acceptance of longer commutes in general, this will to some extent be captured indirectly by the averages. It is very rare, however, to take direct account of how long telework has been practiced and/or possible locational changes of work and/or home,[4] although a few studies measure travel over a period longer than a random day (e.g., Melo and de Abreu e Silva, 2017, used a week). The direct effects of telework on travel therefore remain unclear, as it is very difficult to isolate effects using a general indicator of telework. For example, it is known from various studies that many teleworkers are often privileged, have more mobility resources, live more active lives in families with toddlers, are permanently employed full-time workers, etc. (Allen et al., 2015; Elldér, 2019). Many studies control for selected similar background

[3] See, for example, Moktharian (1991) and Andreev et al. (2010) for exhaustive reviews of earlier empirical telework–travel studies; for more in-depth conceptual treatments of possible relationships, see Mokhtarian and Tal (2013) and Mokhtarian (2013). Effects other than travel-behavioral effects, for example, on stress, wellbeing, career opportunities, and workplace and residential location choices, are beyond the scope of this paper, and the reader is referred to, for example, Allen et al. (2015), Gajendran and Harrison (2007), and Tavares (2017) for extensive summaries.

[4] One exception is the study by de Vos et al. (2018) using panel data from the Dutch Labour Supply Panel (2002–2014) to analyse how telecommuting influences usual commuting time.

Table 1
Summary of relevant empirical studies.

Reference	Data and context	Telework indicator	G/D[a]	Dependent variable(s)	Overall result[b]
de Abreu e Silva and Melo and de Abreu e Silva (2017)	UK National Travel Survey (2005–2012)	Ordinal (home-based telework frequency) Separate analysis for one- and two-worker households	G	Travel distance and number of weekly trips by car, active modes, and transit	*Complementarity* Telework frequency has positive influence on all dependent variables in one-worker households, and positive influence on VKT and number of car trips in two-worker households.
de Abreu e Silva and Melo (2018)	UK National Travel Survey (2005–2012)	Ordinal (home-based telework frequency) Separate analysis for one- and two-worker households	G	Travel distance and number of weekly trips by car, active modes, and transit	*Complementarity* Higher home telework frequencies are positively associated with total weekly household travel in single-worker households, but not significantly so in two-worker households.
Asgari and Jin (2018)	2010–2011 Regional Household Travel Survey, covering 28 counties of New York, New Jersey, and Connecticut, U.S.A.	Categorical ('full-day commuters', 'regular telecommuters', and 'non-regular telecommuters') Only salaried workers working on the survey day who commuted were included	D	Commute departure time	*Modification* Part-time telecommuters avoid rush-hour travel.
Chakrabarti (2018)	2009 U.S. National Household Travel Survey	Categorical ('frequent' 'occasional', and 'non-teleworkers')	G/D[c]	Number of walking and transit trips, walked at least one mile, 30+ min of physical activity, VMT (binary indicators for < 10 miles on survey day and > 20,000 miles annually)	*Complementarity/modification* Both frequent and occasional telecommuting are positively associated with most dependent variables.
de Vos et al. (2018)	Dutch Labour Supply Panel (2002–2014)	Binary (telecommuter or not), ordinal (telecommuting days per month), and continuous (average weekly hours working from home)	G	Commute time	*Complementarity* All telecommuting measures are positively associated with longer commute times.
Garden (2012)	2005 TRANS origin–destination Survey, the National Capital Region of Canada	Categorical ('teleworker', 'regular worker', and 'non-worker')	G	Active travel or not	*Modification* Teleworkers more likely to travel via active modes than are regular workers and non-workers.
He and Hu (2015)	2007 Regional Household Travel Survey, Chicago, U.S.A.	Categorical ('frequent', 'infrequent', and 'non-telecommuters')	G/D[d]	Number of out-of-home activities for different purposes and travel time	*Complementarity* The impact of telecommuting is positive on the number of total trips, pick-up and drop-off trips, and maintenance/discretionary trips, whereas it is negative on commute trips.
Hu and He (2016)	2007 Regional Household Travel Survey, Chicago, U.S.A.	Categorical ('frequent', 'infrequent', and 'non-telecommuters') and binary (telecommuted on survey day)	G/D	One-way commute distance, household commute distance, and travel time for various non-work purposes	*Complementarity* Less-frequent teleworking is positively associated with longer commutes and total household travel.
Kim et al. (2015)	2006 household travel survey data, Seoul, South Korea	Categorical for household head ('telecommuter', 'full-time office worker', and 'part-time office worker') Only households led by white-collar workers included	G	PKT and VKT for different purposes	*Complementarity* Telecommuting household head travels less for commuting but more for all other purposes; other members of household headed by telecommuter also travel more.
Kim (2017)	2006 household travel survey data, Seoul, South Korea	Two binary indicators of whether or not a household telecommutes and whether or not the household telecommuted on the survey day	G/D[c]	PKT and VKT for different purposes	*Complementarity* Commuting travel is reduced by telecommuting, but the increased travel for other purposes and by other household members is greater.
Lachapelle et al. (2018)	Time-use data from the 2005 Canadian General Social Survey	Categorical ('working only from the workplace', 'only from home', 'combining home and workplace, and 'combining elsewhere, home and/or workplace')	D	Overall travel time, whether a person walked or bicycled 30 min or more, and motorized trip departure time during the day	*Substitution/modification* All-day home working is associated with less travel time and higher likelihood of > 30 min of active travel. Most telecommuting arrangements are associated with lower probabilities of peak travel.
Melo and de Abreu e Silva (2017)	UK National Travel Survey (2005–2012)	Binary (indicator of working from home at least once a week) and ordinal (work-at-home frequency)	G	Weekly length and duration of individual, partner, and total household commuting	*Complementarity* Binary indicator is positively associated with commute length; mixed results for ordinary measure.

(*continued on next page*)

Table 1 (*continued*)

Reference	Data and context	Telework indicator	G/D[a]	Dependent variable(s)	Overall result[b]
Zhu (2012)	2001 and 2009 U.S. National Household Travel Surveys	Binary (frequent telecommuter or not)	G	Distance, duration, and frequency of trips for various purposes	*Complementarity* Telecommuting increases workers' one-way commute trips, total work trips, and total non-work trips.
Zhu (2013)	2001 and 2009 U.S. National Household Travel Surveys	Binary (household with or without at least one frequent telecommuter) Comparison of one- and two-worker households	G	One-way commute distance and duration	*Complementarity* Telecommuting increases the commute distance and duration for both one- and two-worker households.
Zhu and Mason (2014)	2001 and 2009 U.S. National Household Travel Surveys	Binary (frequent telecommuter or not)	G	Daily work and non-work VMT	*Complementarity* Telecommuters have more VMT for both daily work and non-work trips than do non-telecommuters.

[a] 'G' refers to a general indicator of telework (e.g., whether or not a worker teleworks regularly) that includes no information on whether or not a respondent actually teleworked during the period when the travel information was collected. Direct measures ('D') include information on telework practices during period when the travel information was collected.

[b] For a quick overview, we use the standard typology of first-order interactions between ICT and travel that comprises four main effects that telework can have on travel (Andreev et al., 2010; Salomon, 1986): *substitution* occurs when telework simply replaces physical travel; *complementarity* refers to when telework generates additional travel; *modification* is when travel is not generated or replaced but altered in other dimensions, such as timing, mode, routing, and trip chaining; and *neutrality* is when telework has no effect on travel.

[c] These studies take into account whether or not the respondent reported commuting to work on the survey day but convey no information as to whether or not this actually represents teleworking.

[d] He and Hu (2015) include an indicator of whether or not the respondent worked at home on the day of the travel survey, but it is not known whether this represents actual telework.

factors, but it is impossible to rule out that other factors explain some of the complementarity effects.

One advantage of several recent studies is that the travel effects of telework are analysed at the household level (de Abreu e Silva and Melo, 2017, 2018; Hu and He, 2016; Kim, 2017; Kim et al., 2015; Melo and de Abreu e Silva, 2017). de Abreu e Silva and Melo (2017) considered commuting distance as the total travel of both workers in two-worker households, finding that frequent teleworking is positively correlated with vehicle kilometres travelled (VKT) and number of car trips. Kim et al. (2015) concluded that some of the telework-induced travel savings are offset by the travel of other household members, partly since the household vehicle made available by the telecommuting spouse can be used by other household members.

Kim (2017) also considered other household members' travel, analysing both general and direct indicators of telework, presenting a more nuanced picture. On a general level, not commuting to work is found to have a complementarity effect on overall travel, as the travel savings from the usual commute are offset by other travel, though this rebound effect occurs only on telecommuting days in telecommuting households. However, Kim's (2017) direct but binary definition of telework probably hides important variation. The other two studies that directly measure telework practices find major differences between full- and part-day teleworking arrangements (Asgari and Jin, 2018; Lachapelle et al., 2018). On days that teleworking takes place all day, clear substitution effects can be discerned. When teleworking part day, similar declines in travel demand cannot be distinguished, although travelling in rush-hour traffic seems less likely.

Furthermore, several of the updated studies also analyse effects on mode choice and whether telework facilitates more active travel (de Abreu e Silva and Melo, 2018; Chakrabarti, 2018; Garden, 2012; Lachapelle et al., 2018), an issue previously receiving little attention. All these studies find that teleworkers make more use of active modes, though the direct effects of telework are subject to uncertainty as several of these studies use general telework measures. One explanation could be that teleworkers in these studies generally make more trips for other reasons, which should also increase the likelihood of travelling by active modes. Again, as Lachapelle et al.'s (2018) study testifies, there may be important differences between different telework arrangements.

In summary, there is still a great need for studies of telework–travel interactions. Compared with early studies, studies of the last decade give a somewhat scattered picture of the effects of telework. The updated studies have many advantages, being based on impressive datasets representative of large populations and using advanced statistical analysis techniques. However, the present study finds a great need for representative studies using direct measures of actual telework performance. It should also be noted that most studies reviewed here use data that are ten or more years old. As previously discussed, it is very possible that rapid telework expansion has resulted in new practices as new groups of workers gain the opportunity to telework. The rapid telework diffusion in Sweden thus provides good opportunities to contribute substantially to the literature. The next section describes our empirical approach in detail.

3. Data and method

3.1. Data

We use micro-data from the recurrent Swedish National Travel Survey (RVU), which has studied a randomized and representative cross-section of the Swedish population. Travel data are collected using one-day trip diaries in which each respondent records all out-of-home movements on a randomly assigned survey day. The diary is sent by mail before the survey day, and followed up by phone interviews a few days afterwards. Each trip is characterized by a range of variables, for example, travel mode, travel distance, purpose, duration, and time of day.[5] Information is also collected on a range of background factors, including gender, income, education, family status, residential location, and car ownership.

The RVU is also designed to capture daily practices of actual telework performance, and has previously been used to study telework and telework–travel interactions in Sweden, more recently by Vilhelmson and Thulin (2016) and Elldér, (2017). In the survey, respondents answer a range of questions about telework, including when in the day, for how long, how often per week and month, and where. Telework is defined as work sometimes performed at any place other than the usual workplace during contracted working hours. This means that it is not considered telework if the respondent (as stated in the survey): 'works on the way to or from work (e.g., reading a report on the bus)', 'brings work home after working hours', 'goes on an errand during work', or 'temporarily works at home due to a sick child, etc.'. Workers with mobile workplaces are also not defined as teleworkers. Also, telework is not regarded as a full-time practice, nor is a minimum time threshold used. Instead, the respondents are asked whether or not they practice telework regularly (i.e., a general measure) and whether or not they teleworked on the day of the survey (i.e., a direct measure).

We use RVU data covering the 2011–2016 period. The survey design remained largely the same throughout this period, and the overall response rate was about 40%. For the purpose of the analysis, we selected only respondents who worked on the survey day. We also excluded some respondents who did not start and end their travelling at home (e.g., respondents taking a flight on the survey day). This left a total of 11,693 respondents.

3.2. Variable definitions

3.2.1. Independent variables – telework

When preparing the paper, we explored a range of indicators of telework practices. For example, attempts were made to indirectly capture various rebound effects discussed in the above literature review by analysing various general measures of telework. First, we investigated whether or not teleworkers commute farther than do other workers on non-teleworking days, but found no significant differences. We also fitted models examining whether daily travel differs between all regular teleworkers and other workers in general. Space does not permit presentation of these models, but their results were in line with those obtained using the two indicators finally chosen (see below). However, as in most previous studies, we had limited opportunities for the in-depth exploration of potential rebound effects. RVU covers only one day and contains no information on either how long the respondents have teleworked or on possible workplace/home relocations in relation to changing opportunities to telework. Unfortunately, we also could not explore effects at the household level, since RVU does not include travel data for other household members.

Finally, for the models presented here, we settled on two indicators: *Telework full day* is a binary indicator of whether or not the respondent teleworked for the whole survey day, and *Telework part day* is a binary indicator of whether or not the respondent teleworked for part of the survey day. Of the respondents, 3.0% reported teleworking for the whole day and 4.4% for part of the day.

3.2.2. Dependent variables – travel activities

We defined a total of six dependent variables capturing different aspects of the respondents' travel activities on the survey day, which together capture four travel dimensions important for sustainable transport: trip generation, travel distance, mode choice, and timing. *Any trip* is a binary indicator of whether or not the respondent reported one or more trips. *Trips* measures the total number of trips completed on the survey day. *PKT* is the total distance travelled and *VKT* is the total distance travelled by car on the survey day. *Mode choice* is a categorical variable including categories of whether the respondent only travelled by car, only by active modes, multimodal or did not report any trips. Finally, *Rush-hour* is a binary indicator of whether or not a trip started or finished during peak hours on the survey day.

3.2.3. Control variables – sociodemographics and built environment

We also include a range of control variables capturing various individual sociodemographic traits and built environment features of the respondent's residential location. These variables were selected since previous research has found them to be strongly correlated to both telework eligibility and adoption (Elldér, 2019; Vilhelmson and Thulin, 2016), as well as to daily travel activities in Sweden and elsewhere (Elldér, 2018; Elldér, 2014). Men have traditionally had greater opportunities to telework than women, while men generally also travel longer and by car to a greater extent. The same positive relationships also generally apply to income and education. Age and family situation have also been shown to be important. For example, parents of small children are overrepresented among teleworkers in Sweden (Elldér, 2019). Car ownership correlates strongly with travel habits as the car enables longer trips, while teleworkers to a greater extent have access to a car. Spatial factors are also important to control for. Previous studies have found that teleworking is more common among those living in sparsely built areas as acceptance for longer commuting increases when having the option to telework, although telework in Sweden is more common in metropolitan regions (Vilhelmson and Thulin, 2016). In addition, the built environment typically has a strong impact on individuals' travel behaviour. In summary, it is important to confirm that there are still significant differences between teleworkers and non-teleworkers after controlling for these variables.

However, it should be mentioned that some of the variables included might have indirect effects that we are not able to consider with the cross-sectional data used here. This applies not least to the built environment variables and car access. For example, a teleworker might consider moving to a larger suburban house, farther from everyday activities, with car dependency and added everyday travel as longer-term consequences. Finally, it can however be mentioned that we have tested for multicollinearity by estimating bivariate correlations among independent variables and collinearity diagnostics when fitting the models. When it comes to the final models presented in the paper there are no multicollinearity (VIF > 2) between the variables included.

Table 2 presents descriptive statistics and precise definitions of each variable included in the analysis.

3.3. Statistical approach

Capturing human behaviour with statistical models is always a challenge, not least when it comes to travel behaviour. Many different decisions and factors influence each trip, and all trip elements – destination, mode, distance, duration, timing, etc. – have different underlying rationales and are not isolated from one another, but are closely interlinked in various ways. Given the many factors involved in individuals' travel decision-making processes, there is obviously no single theoretically perfect statistical model of telework–travel interactions. We have chosen to analyse each dependent variable separately using various multivariate regression models depending on the measurement levels of the dependent variables. The two binary variables (i.e., *Any trip* and *Rush-hour*) were analysed using logistic regression models. *Mode choice* was analysed using a multinomial regression model. *PKT* and *VKT* were analysed using tobit regression models,[6] and the total number of trips was analysed using a binomial regression model. We

[5] In RVU, trips are defined as all movements outside a main trip location (i.e. the respondent's home, secondary home, temporary overnight abode, workplace, or school). Note that Vilhelmson (1997) compared RVU with the national Swedish time use survey and found that some shorter trips, most notably shorter walks in the neighbourhood (e.g. walking the dog), are slightly underreported in RVU. However, we do not believe that this will have any major impacts on the results.

Table 2
Descriptive statistics and variable definitions.

		n (total)	Freq. (%)	Mean	SD
Dependent variables – travel activities					
Any trip	One or more trips reported (1 = yes, 0 = no)	11,693	96.3		
Trips	Number of trips reported	11,693		2.334	1.101
PKT	Natural log of distance travelled in km	10,686		3.075	1.402
VKT	Natural log of vehicle km travelled	7410		3.404	1.158
Mode choice	Only car (used as a reference category in regressions)	11,693	47.8		
	Only active travel (i.e. walk/cycle)		12.9		
	Multimodal		35.5		
	No trips		3.8		
Rush-hour	Started or finished a trip during peak hours, i.e., 06:00–09:00 and/or 15:00–18:00 (1 = yes, 0 = no)	11,693	87.9		
Independent variables – telework					
Telework full day	Reported telework full survey day (1 = yes, 0 = no)	11,693	3.0		
Telework part day	Commuted to work and reported telework (1 = yes, 0 = no)	11,693	4.4		
Control variables – sociodemographics					
Female	Female (1 = yes, 0 = no)	11,693	48.2		
Life course	Younger, 15–44 yrs. old, no children	11,593	14.7		
	Parent, children 0–6 years old		17.6		
	Parent, children 7–18 years old		30.1		
	Older, ≥45 yrs. old, no children (used as reference category in regressions)		37.6		
Car access	Own a car and hold driver's license (1 = yes, 0 = no)	11,681	85.3		
Higher education	Higher education, more than two years (1 = yes, 0 = no)	11,693	25.4		
Income	Lowest quartile (used as reference category in regressions)	10,315	25.3		
	Second quartile		25.6		
	Third quartile		25.6		
	Highest quartile		23.5		
Control variables – built environment[a]					
Entropy index	Entropy index measuring the mixture of residential, industrial, retail, office, and public-sector activities within 1 km. The index ranges from 0 (single activity) to 1 (activities evenly divided among the five options).	11,565		0.825	3.875
Population density	Population (in thousands)/km^2 within 1 km	11,688		2.185	2.882
Distance from city centre	Natural log of driving time to closest centre of a city > 10,000 population	11,427		6.134	0.878

[a] See Elldér (2018) for precise definitions and data underlying these variables.

first guide the reader through the results and then provide a common interpretation and discussion of all models. In this way, we believe that we can achieve a relatively comprehensive understanding of the links between telework practices and daily travel activities, given the limitations of statistical models.[7] Note, however, that since we use a cross-sectional database, we cannot offer far-reaching conclusions on dynamics and causality. Our results are based on conditional correlations and on unobserved heterogeneity.

4. Results

4.1. Travel demand (trip generation, PKT, and VKT)

We begin the analysis by examining whether teleworking leads to fewer trips. Table 3 presents a logistic regression with *Any trip* as the dependent variable. The model shows that workers who telework throughout the survey day are significantly more likely not to travel than are those who telework part of the day or not at all.[8] It is also shown that the probability of not making a trip is significantly greater for men, the elderly, low-income earners, and those who live farther from a city centre. In the next model, we investigate whether teleworking affects the *number of trips* made on the survey day (see Table 4). In line with the previous model, we find that those who telework all day make fewer trips than those who do not telework. Part-day teleworkers make significantly more trips than do non-teleworkers. However, the marginal effects are considerably larger for full day teleworkers compared to the part-day teleworkers. The control variables have similar effects as in the previous model.

When it comes to *PKT*, it is clear that those who telework full days travel shorter distances than do those who do not telework (see Table 5). However, those who telework part of the working day travel significantly farther. But again, the marginal effects are much larger for

Table 3
Logistic regressions on *Any trip*.*

	B	Sig.	Exp(B)
Telework full day	−2.386**	0.000	0.092
Female	0.717**	0.000	2.049
Younger, 15–44 yrs. old, no children	0.169	0.363	1.184
Parent, children 0–6 years old	0.678**	0.000	1.971
Parent, children 7–18 years old	0.388**	0.008	1.474
Car access	0.006	0.977	1.006
Second income quartile	−0.098	0.492	0.907
Third income quartile	0.742**	0.000	2.100
Highest income quartile	0.504**	0.003	1.655
Higher education	0.247	0.147	1.281
Entropy index	0.510	0.152	1.666
Population density	−0.041	0.080	0.960
Distance from city centre	−0.268**	0.001	0.765
Constant	4.327**	0.000	75.693
Cox & Snell R^2	0.026		
Nagelkerke R^2	0.107		
n	9940		

* $p < .05$.
** $p < .01$.

[6] All respondents with zero PKT were censored from below.
[7] See, for example, Næss (2004, 2015) for more detailed discussion of the limitations and potentials of regression analysis in travel behavioral research.
[8] This result is expected as almost all non-teleworkers commute to work. This also explains the low odds ratio of the *Telework full day* variable (as well as the high odds ratio for the no trips category of the *Mode choice* model in Table 6). If we instead run a model that measures the likelihood of doing a non-work trip, the effect is as expected the opposite; i.e. that full day teleworkers are more likely to make a non-work trip. But overall, we can conclude that full day teleworkers are less likely to make a trip during the days that the teleworking takes place.

Table 4
Negative binomial regression on *Trips*.

	B	Sig.
(Intercept)	0.653**	0.000
Telework full day	−0.652**	0.000
Telework part day	0.101**	0.001
Female	0.036**	0.009
Younger, 15–44 yrs. old, no children	0.033	0.125
Parent, children 0–6 years old	0.009	0.626
Parent, children 7–18 years old	0.049**	0.002
Car access	0.098**	0.000
Second income quartile	0.001	0.932
Third income quartile	0.040*	0.030
Highest income quartile	0.033	0.080
Higher education	0.000	0.981
Entropy index	0.104**	0.007
Population density	−0.002	0.426
Distance from city centre	0.006	0.500
Likelihood ratio chi-square (14)	270.531**	
n	9940	

* $p < .05$.
** $p < .01$.

Table 5
Tobit regressions on *PKT* and *VKT*.

	PKT		VKT	
	B	Sig.	B	Sig.
Telework full day	−1.109**	0.000	−0.082	0.385
Telework part day	0.218**	0.001	0.126	0.055
Female	−0.161**	0.000	−0.297**	0.000
Younger, 15–44 yrs. old, no children	0.168**	0.000	0.143**	0.004
Parent, children 0–6 years old	0.172**	0.000	0.025	0.531
Parent, children 7–18 years old	0.115**	0.001	0.050	0.148
Car access	0.466**	0.000	0.646**	0.000
Second income quartile	−0.075*	0.032	−0.050	0.161
Third income quartile	0.203**	0.000	0.103*	0.012
Highest income quartile	0.325**	0.000	0.166**	0.000
Higher education	0.354**	0.000	0.256**	0.000
Entropy index	−0.590**	0.000	−0.372**	0.000
Population density	−0.046**	0.000	−0.056**	0.000
Distance from city centre	0.112**	0.000	0.090**	0.000
Constant	2.178**	0.000	2.448**	0.000
Likelihood ratio chi-square (14)	927.020**		502.510**	
n	9167		6422	

* $p < .05$.
** $p < .01$.

the full day teleworkers. The control variables have the expected effects. Women, the elderly, those without a car, and low-income earners travel shorter distances. Travel distance also decreases with distance from the nearest city centre and with higher density and land use mix. We find no significant differences in *VKT* between those who telework and those who do not telework (see Table 5). The control variables have similar results as in the *PKT* model.

4.2. Mode choice

The mode choice model is presented in Table 6. Respondents who only travelled with car is used as the reference category. Full-day teleworkers are more likely to only use active modes of travel. Women, people lacking higher education, older people, high income earners, and those who do not own a car are also more likely to only use active modes. As the density and land use mix around the dwelling increase and as the distance from the dwelling to the nearest city centre decreases, the likelihood of active travel also increases. There are no significant differences between teleworkers and non-teleworkers when it comes to the probability of multimodal trips. When it comes to the probability of not making any trips, the results are similar to those presented in the previous section.

4.3. Congestion relief

The last model measures the probability of any trip being made during *rush-hour* traffic (Table 7). The model confirm that those who telework throughout the day are significantly less likely to travel during rush hour. Those who telework part day make trips during rush hour more often than do those who do not telework. The marginal effects are however again more than twice as large for those who telework throughout the day. Women, the elderly, low-income earners, workers without car access, and those lacking higher education are less likely to travel during rush hour.

5. Discussion

As expected, the models present a complex picture of the links between telework and daily travel activities. The relationships appear to differ between different telework arrangements and travel outcomes; however, by discussing them together a clearer picture emerges. It is evident that those who telework throughout the day reduce their travel. The models show that full-day teleworkers make significantly fewer and shorter trips than do those who do not telework. We find no significant differences in *VKT*, but the likelihood of a non-teleworker making a car trip is higher than for a full-day teleworker. These results stand in stark contrast to those of most other studies of the last decade using similar representative data. However, we believe that this is partly because no studies concluding that telework has a complementary effect capture travel activities during the period when telework was actually performed. Our results are in line with those of Lachapelle et al. (2018), who used a direct measure of telework and found that teleworking was associated with less overall travel time; they also to some extent parallel those of Kim (2017), who found that commuting is reduced on actual telecommuting days.

Part of the explanation for the differing results probably also lies in the fact that context matters. No similar study of which we are aware has examined a Scandinavian context during the past decade, and most studies use data older than ten years. Above all, no study known to us has examined contexts where teleworkers formed an early majority of the workforce.

Importantly, our literature review also revealed that previous studies seldom distinguish between different telework arrangements. We, however, find important differences between part- and full-day teleworking. The travel demand benefits of full-day telework are partly offset by those who telework part day. The models show that part-day teleworkers generally make more trips, and also travel farther than do those who do not telework. Even though the effects are the opposite for part-day teleworking, the effect sizes are smaller than those for full-day teleworking. Therefore, the positive association with part-day teleworking does not compensate for the total effects of telework on daily travel demand.[9]

However, we want to stress that it can be problematic to look at this only through a narrow substitution–complementarity lens. Rather, we believe that the measured differences indicate that telework is a complex practice and coping strategy used differently by different individuals to organize everyday life. Full- and part-day teleworking represent different spatiotemporal strategies with different consequences for everyday travel, and should be analysed separately.

We believe that this can also help explain the effects of telework on mode choice. The time freed up by full-day teleworking facilitates the use of slow transportation modes, while part-day teleworking does not.

[9] When preparing this paper, we also ran models comparing all workers who reported regular teleworking with other non-teleworkers, and found substitution effects. These models are not presented due to space restrictions.

Table 6
Multinomial logistic regression on *Mode choice*.

	Only active travel			Multimodal			No trips		
	B	Sig.	Exp(B)	B	Sig.	Exp(B)	B	Sig.	Exp(B)
Intercept	1.228**	0.000		1.194**	0.000		−2.263	0.000	
Telework full day	0.668**	0.000	1.950	−0.194	0.238	0.824	2.379**	0.000	10.793
Telework part day	−0.049	0.767	0.952	−0.005	0.963	0.995	–	–	–
Female	0.415**	0.000	1.515	0.501**	0.000	1.650	−0.468**	0.001	0.626
Younger, 15–44 yrs. old, no children	−0.354**	0.001	0.702	0.041	0.615	1.042	−0.195	0.307	0.823
Parent, children 0–6 years old	−0.456**	0.000	0.634	−0.147*	0.032	0.863	−0.763**	0.000	0.466
Parent, children 7–18 years old	−0.253**	0.002	0.777	−0.033	0.571	0.968	−0.424**	0.004	0.654
Car access	−2.503**	0.000	0.082	−2.565**	0.000	0.077	−1.915**	0.000	0.147
Second income quartile	0.606**	0.000	1.832	0.495**	0.000	1.640	0.403**	0.006	1.497
Third income quartile	−0.037	0.684	0.964	0.070	0.311	1.073	−0.703**	0.000	0.495
Highest income quartile	−0.386**	0.000	0.680	0.106	0.131	1.112	−0.482**	0.006	0.618
Higher education	−0.405**	0.000	0.667	0.056	0.466	1.058	−0.205	0.242	0.815
Entropy index	1.656**	0.000	5.239	0.347*	0.015	1.415	−0.215	0.553	0.807
Population density	0.146**	0.000	1.157	0.140**	0.000	1.150	0.145**	0.000	1.156
Distance from city centre	−0.226**	0.000	0.798	0.003	0.926	1.003	0.266**	0.001	1.305
Cox & Snell R^2	0.221								
Nagelkerke R^2	0.249								
n	9940								

* $p < .05$.
** $p < .01$.

Table 7
Logistic regression on *Rush hour*.

	B	Sig.	Exp(B)
Telework full day	−2.164**	0.000	0.115
Telework part day	0.830**	0.001	2.292
Female	0.384**	0.000	1.468
Younger. 15–44 yrs. old. no children	−0.089	0.365	0.915
Parent. children 0–6 years old	0.334**	0.001	1.396
Parent. children 7–18 years old	0.239**	0.004	1.270
Car access	0.239*	0.013	1.270
Second income quartile	0.243**	0.006	1.276
Third income quartile	0.808**	0.000	2.243
Highest income quartile	1.070**	0.000	2.915
Higher education	0.912**	0.000	2.490
Entropy index	−0.045	0.817	0.956
Population density	−0.019	0.155	0.981
Distance from city centre	−0.130**	0.002	0.878
Constant	1.877**	0.000	6.535
Cox & Snell R^2	0.052		
Nagelkerke R^2	0.103		
n	9940		

* $p < .05$.
** $p < .01$.

Our analysis shows that full-day teleworkers are more likely to only walk or cycle. This speaks in favour of the real reprioritization of travel modes and of full-day teleworking making room for more active travel. This conclusion is also supported by other studies of the relationship between telework and active travel (de Abreu e Silva and Melo, 2018; Chakrabarti, 2018; Garden, 2012; Lachapelle et al., 2018).

We find evidence that full-day telework leads to less rush-hour traffic. Previous studies also conclude that telework relieves congestion (Asgari and Jin, 2018; Lachapelle et al., 2018). This shows that promoting telework could reduce stress on transport systems and should be an attractive policy alternative for cities and regions struggling with congestion problems.

6. Conclusion

The purpose of this article was to examine how telework influences daily travel in a context where those who telework regularly have grown to form an early majority, namely, Sweden from 2011 to 2016. Using representative micro-data from the Swedish National Travel Survey, we addressed three research questions concerning how full- and part-day telework influence i) travel demand, ii) mode choice, and iii) rush-hour traffic. Overall, our results indicate that telework changes individuals' daily travel. When it comes to travel demand, we find that full-day teleworkers, on the day they engage in telework, make significantly fewer and shorter trips and are less likely to drive a car than those who do not telework. However, some of the decrease in travel demand is offset by those who telework part day. The models show that part-day teleworkers generally make more trips, and travel farther than do workers who do not telework. However, since full-day teleworking have greater marginal effects, we conclude that teleworking substitutes for and leads to reduced daily travel in Sweden. Our results also show that teleworking affects mode choice. Workers are more likely to use active travel modes when teleworking full days. Finally, we also conclude that full-day teleworking leads to less rush-hour traffic. From a transport perspective, an optimistic picture of telework in Sweden emerges: teleworking leads to reduced travel demand, more use of active transport modes, and congestion relief.

The main strengths of this study are that it uses comparatively new data, representative of an entire nation where telework has taken hold, and that our analysis is on the micro level, allowing important nuancing in several dimensions ignored by many previous studies. Specifically, our study stands out in that it: captures travel behaviour during the defined period when telework was actually performed; distinguishes different types of telework arrangements; and analyses a range of dependent variables capturing different aspects of daily travel. This shows the importance of understanding telework as a diversified practice and coping strategy for organizing everyday activities. It is important that further research should build on such a nuanced understanding of telework. Opportunities for similar studies in other contexts should arise as the number of teleworkers continues to grow.

The main weakness of our study is that we were unable to analyse potential rebound effects in depth, including possible offsets of travel between different days during a longer period (e.g. teleworking and non-teleworking days within the same week). There is a great need for longitudinal and panel studies that follow and survey teleworkers over time, examining longer-term mobility-related decisions such as moving, changing jobs, and buying a car. Nor were we able to take account of the travels of household members other than the surveyed workers. Previous studies indicate that some of their travel reductions are offset by other family members, for example, when the household car is made available (Kim et al., 2015). Considering daily travel on a household level is thus also an important task in future studies. Finally, the recent fast increase in telework as a result of Covid-19 further emphasizes the need for further research. It is not yet clear to what extent the restrictions on telework lifted by many employers will be restored or not, but telework will most likely be more widely accessible and commonly practised than before Covid-19 and many employees are already much more experienced in different forms of telework. What the outcomes on daily travel will be is yet to be seen. The need for telework–travel studies is in other words far from satisfied.

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Author statement

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