Will telework reduce travel? An evaluation of empirical evidence with meta-analysis

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Abstract
Flexible work arrangements, including telework, emerged in the 1970s with ICTs as an effective travel demand management tool since working from home could eliminate commuting trips or change their timing to avoid peak time congestion Over the years, researchers focused on studying the implications of telework adoption on travel, but the empirical results have been mixed. Early studies indicate travel reduction, while recent ones show neutral or negative impacts. In addition, the COVID-19 pandemic promoted a global telework experience and changed the perceptions about it. Since then, the studies about telework effects on travel patterns increased, as well as the variety in the magnitude and direction of the results. This diversity may result from differences in data collection, sample sizes, sampling methods, modelling methods, specification of empirical models, and the incorporation of individual-level attitudinal variables and preferences. The effects of telework on travel behavior in the current post-pandemic era are unclear. To understand the factors driving the diversity of results, we developed a meta-analysis of previous empirical studies on the effects of telework on travel. Specifically, the objective is to explain the variation in the percentage change in the number of trips made by teleworkers compared to non-teleworkers, considering trip purposes. The meta-analysis included 39 estimates from 12 studies conducted before the COVID-19 pandemic, covering the period from 1988 to 2019. The OLS and GLS-RE meta-regressions showed that telework has a substitute effect on commuting and work-related trips. The method matters: more recent studies using robust models show smaller positive impacts on the number of trips. Finally, controlling by telework regime also is important: full-day teleworkers reduce trips more significantly.

1. Introduction

Telework has been pointed out as a potential demand management strategy since the 1970s when Information and Communication Technologies (ICTs) emerged and allowed flexible ways of organising work practices (Choo et al., 2005; Helminen & Ristimäki, 2007; O'Keefe et al., 2016). It was envisioned that telework could potentially eliminate commuting trips. Since then, several studies have focused on the effects of telework on travel, but the results are mixed. Early studies focused on analysing telework effects on travel behaviour confirmed the expectations towards a substitution effect: a drastic reduction in the number of work trips and work trips times (Harkness, 1977), reduced

distances travelled, and reduced peak-hour traffic congestion (Mokhtarian et al., 1995). More recent studies concluded that the impacts of telework on travel are negative or neutral at best (e.g., Zhu, 2012; Melo & de Abreu e Silva, 2017; Zhu et al., 2018; de Abreu e Silva & Melo, 2018a; de Abreu e Silva & Melo, 2018b; Cerqueira et al., 2020). They often suggest that teleworkers travel longer accumulated distances (Mokhtarian et al., 2004; Zhu, 2012; Melo & de Abreu e Silva, 2017; de Abreu e Silva & Melo, 2018a; de Abreu e Silva & Melo, 2018b; Yum, 2021; de Abreu e Silva, 2022), use cars more frequently (Yen, 2000; Shakibaei et al., 2021) or active modes of transport (Yum, 2021; Ozbilen & Akar, 2021; Echaniz, 2021), make more trips for leisure purposes (Yum, 2021; Wöhner, 2022; Costa et al., 2022), and make more non-work and business-related trips (de Abreu e Silva & Melo, 2018a). Nevertheless, still, some recent studies conclude that telework reduces travel (e.g., Elldér, 2020; Wöhner, 2022).

Until 2020, telework adoption was marginal. The COVID-19 pandemic made telework a vast worldwide experiment, resulting in substantial changes in urban travel patterns. More recent studies developed during the pandemic and post-pandemic period focused on modal shift, indicating an increase in car use and active travel modes (Wöhner, 2022; Costa et al., 2022) and a decrease in public transport use (Shakibaei et al., 2021; Echaniz, 2021).

However, in the aftermath of the pandemic, a decrease in telework engagement was noticed, but it is very unlikely that it will drop to the pre-pandemic level (Soler et al., 2023). Since telework frequency is likely to remain widely high(er), it could several effects, including changes in the location patterns of households and induce urban sprawl, the total amount of travel by different transport modes, thus impacting the transition to more sustainable urban mobility patterns. It is important to understand the impacts of telework engagement to help policymakers and planners. So, how could empirical evidence improve news methods for data collection and analysis of their results? What are the factors that influence conclusions? This work aims to generate evidence that can help to answer these questions and identify motives for the variation of the estimatives found in the literature until now, making a meta-analysis focused on explaining the variation in percentage of the number of trips from teleworkers and non-teleworkers controlling by methodological factors that explain the variation. The meta-analysis sample included 39 estimates from 12 studies that evaluated the number of trips of teleworkers and non-teleworkers before the COVID-19 pandemic, covering the period between 1988 and 2019. Studies during the pandemic were excluded of our analysis since they may introduce heterogeneity and endogenous problems that we could not measure if they can be explain only because the pandemic period and measures or if there is also an effect of telework adoption increased.

The paper is organised as follows: Section 2 gives the scope of the meta-analysis, its advantages and limitations. Section 3 contains an overview of the empirical evidence of the effects of telework on travel behaviour. Section 4 presents the empirical design of the meta-analysis. The results are presented

and discussed in section 5, and the main conclusions are summarised in section 6.

2. Scope of the meta-analysis

Meta-analysis is a quantitative literature search review involving a robust research protocol and statistical analysis. It does not present new findings but rather serves as a reference point from the existing empirical evidence, describing the pattern of their results and helping researchers build new studies (Lipsey & Wilson, 2001; Melo et al., 2013). The fundamental principle is to enhance the sample size and the numerical outcomes of the studies with the same research question (Verma & Verma, 2020).

However, some rules must be followed. First, the results must be conceptually comparable (Lipsey & Wilson, 2001). Some studies do not provide sufficient information to allow the conversion of the results in a standardised effect size, limiting the number of observations (Mohammad et al., 2013). The research must be complete and direct, including at least two different databases to reduce publication bias (Hansen et al., 2021). The investigators have to create eligibility and exclude criteria to select or not a study for the meta-analysis (Lipsey & Wilson, 2001).

Meta-regression is one type of model to make meta-analysis, which uses a set of explanatory variables (categorical or discrete) to measure the observed variation in the effect size (Lipsey & Wilson, 2001). To help identify the set of adequate explanatory variables, it is crucial to carry out an extensive literature review (Melo et al., 2013). The meta-analysts must also decide whether to include only one estimative per study or all the estimates of the studies collected. In the first case, despite the result is a smaller sample, each study has the same weight. In the second case, the sample size will be considerably larger, but studies have differing weights which could bias the results in favour of the larger studies.

3. Overview of the literature

This section describes the main characteristics that distinguish studies that estimate the effects of telecommuting on travel behavior and demonstrates that there is variation in the empirical results.

3.1. Telework adoption effects on travel behaviour

The studies evaluating the effects of telework on travel behaviour date back to the 1970s, when it was expected that telecommunication might substitute transportation and reduce travel demand (Harkness, 1977). Initial studies argued that working from home could drastically reduce commuting (Harkness, 1977), weekday miles travelled, and peak-hour traffic (Mokhtarian et al., 1995) and contribute to reducing total household travel (Hamer, 1991). However, it was identified that teleworkers had longer commutes than conventional workers, particularly those who travel by car (Mokhtarian et al., 1995). Initial empirical studies relied on simpler modelling methods and small samples with weaker

behavioural foundations, limiting the conclusions about why people telework and why teleworkers travel or not (Salomon, 1994). At the end of the 1990s, some researchers argued that teleworkers' commute trips could be longer than those of conventional workers (Mokhtarian et al., 1995). They designed specific questionnaires, which included three to seven days travel diaries. Other factors have also influenced the conclusions drawn from empirical studies, such as surveying methods, sample sizes, characteristics of the travel diaries (de Abreu e Silva & Melo, 2018a), and indicators of telework practices (Elldér, 2020).

More recent studies tend to be less optimistic about the impacts of telework adoption on travel behaviour, indicating negative to neutral impacts on travel reduction (e.g., Melo & de Abreu e Silva, 2017; Zhu et al., 2018; Cerqueira et al., 2020). Nevertheless, there are still studies arguing that telework reduces travel (e.g., Elldér, 2020; Foltýnová & Brůha, 2024). Teleworkers were found to travel longer total distances than conventional workers (de Abreu e Silva & Melo, 2018a; Yum, 2021; de Abreu e Silva, 2022), use cars more frequently (Yen, 2000; Shakibaei et al., 2021) or active modes of transport (Ozbilen & Akar, 2021; Wang, 2020; Echaniz, 2021), especially for leisure purposes (Yum, 2021; Wöhner, 2022; Costa et al., 2022), and engage more in non-work and business-related trips (de Abreu e Silva & Melo, 2018a). Commuting distance contributes strongly to explaining teleworkers' longer accumulated travel distances, as teleworking tends to be associated with suburban residential locations (Melo & de Abreu e Silva, 2017; de Abreu e Silva & Melo, 2018b).

More recent studies focusing on the pandemic and post-pandemic period point to stronger impacts on modal shift with a relevant decrease in public transport use (Shakibaei et al., 2021; Echaniz, 2021) associated with an increase in private car and non-motorised modes (Wöhner, 2022; Costa et al., 2022). The high telework adoption and substantial travel reduction were also associated with the pandemic restrictions (Ameen et al., 2023). There is an expectation that after the pandemic, the reluctance to use public transport might prevent the return to the pre-pandemic modal split (Tsavdari, 2022). Telework adoption is expected to reduce the number of trips (Foltýnová & Brůha, 2024), particularly for those who do not use private cars (Baldassa et al., 2023), and the distances travelled by motorised modes (Faber et al., 2023). There is also an expectation for increased distances travelled by non-motorised modes for leisure purposes (Ceccato et al., 2022). However, these effects are still unclear since they relate to telework adoption, which could be influenced by telework performance during the pandemic (Ameen et al., 2023).

3.2. Attitudes and perceptions about telework and socioeconomic characteristics that influence telework adoption

Telework adoption is associated with several socioeconomic characteristics and attitudinal traits. While controlling for socioeconomic characteristics is common in empirical studies about telework, including personal attitudes and perceptions is much rarer. Telework is associated with jobs with

more flexibility and autonomy and with managerial and professional occupations (Singh et al., 2013; Aguilera et al., 2016; Adobati & Debernardi, 2022). Also, workers with university degrees (de Graaff & Rietveld, 2004; Denham, 2021) and higher household income (He & Hu, 2015; Hensher et al., 2022) are more likely to telework since jobs that could be done remotely are usually better paid (Dingel & Neiman, 2020). The effects of age on telework adoption are less conclusive; some studies indicate that telework adoption is more frequent in younger people (de Graaff & Rietveld, 2004; de Abreu e Silva & Melo, 2018a), while others conclude that it is more common in older age groups (Pouri & Bhat, 2003). More recently, studies conducted in the context of the COVID-19 pandemic showed evidence of stronger reticence from young adults to telework (Conway et al., 2020; Beck & Hensher, 2021). Regarding gender, the results from previous studies are also mixed, some authors found no evidence of gender influencing telework adoption (e.g., Peters et al., 2004), while others argue that being a man increases the likelihood of engaging in telework (e.g., Hjorthol & Nossum, 2007; de Abreu e Silva & Melo, 2018b). Also, previous experience (Salomon, 1998) and social influence (Páez & Scott, 2007) could affect the intention to telework.

Moreover, personality characteristics (Brüggen et al., 2017) and attitudes (Jain et al., 2021; Tahlyan et al., 2022) influence telework adoption. Hence, it is important to consider attitudinal variables to measure telework engagement (Haddad et al., 2009). Attitudinal constructs are affected by social and employer support (Jain et al., 2021). These variables are associated with perceived advantages and disadvantages and barriers to telework (Jain et al., 2021). The most common advantages reported are: better work-life balance (including spending time with the family), higher productivity, and commute avoidance (Loo & Wang, 2018; Jain et al., 2021; Olde Kalter et al., 2021). Telework stronger disadvantages are: missing socialisation at work, feeling isolated, missing promotion opportunities, working more, and personal life conflicts (Jain et al., 2021; Tahlyan et al., 2022; Colaço et al., 2024).

Other factors associated with the perception of the employer and family or friends about telework and the workplace environment are also relevant (Loo & Wang, 2018; Jain et al., 2021). Furthermore, some difficulties are associated with the home environment and individual skills (Tahlyan et al., 2022; Dianat et al., 2022). However, to date, only a small number of studies incorporated attitudinal variables and preferences to explain telework adoption and satisfaction (Loo & Wang, 2018; de Abreu e Silva, 2022).

4. Design of the Meta-analysis

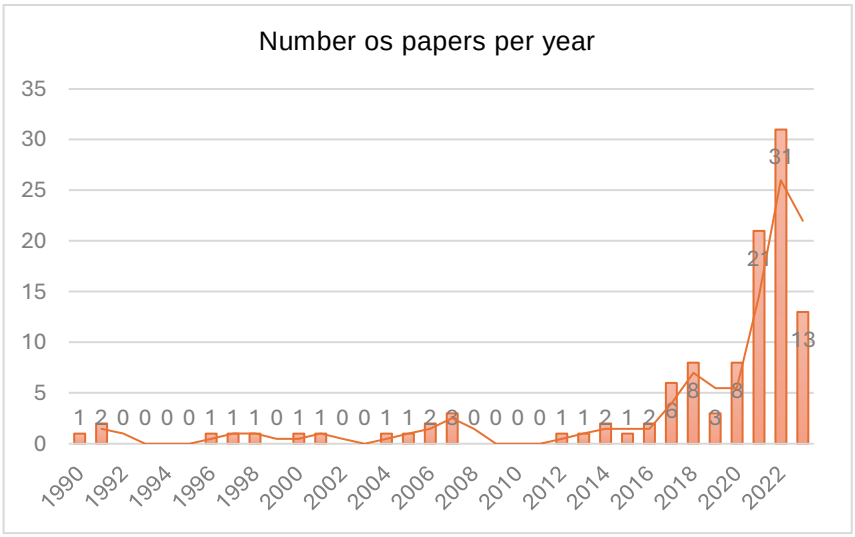
To develop the meta-analysis, a systematic literature review was made on two of the more relevant databases in transportation literature, SCOPUS and Web of Science, in March 2023, to find studies aiming to evaluate the impacts of telework adoption on travel patterns. The search includes the following keywords on the title, abstract, and keywords: ("travel behavior" OR "distances traveled" OR "mode choice" OR "travel patterns" OR "trips purpose" OR "modal share" OR

"commuting trips" OR "commuting distance" OR "commuting travel" OR "number of trips" OR "kilometers traveled" OR "trip scheduling" OR "total amount of travel" OR "residential location" OR "residential preferences") AND ("telework" OR "teleworking" OR "telecommuting" OR "work from home" OR "home-based telework" OR "home-based teleworking" OR "home-based telecommuting"). The search only included peer-reviewed journals in English. A total of 664 documents were found on SCOUPS and 158 on Science Direct; 100 of them were repetitive. A total of 822 papers were obtained, and only 183 were selected for a deep read. In the end, only 112 studies were allowed to make analysis (empirical studies, with data collection, which evaluated the effects of telework adoption on travel behavior). The conclusions were reported in terms of number of trips (total, by mode and purpose), travel distance, commuting distance, travel frequency, modal splits, emissions, and other mobility variables.

4.1. Published papers in data

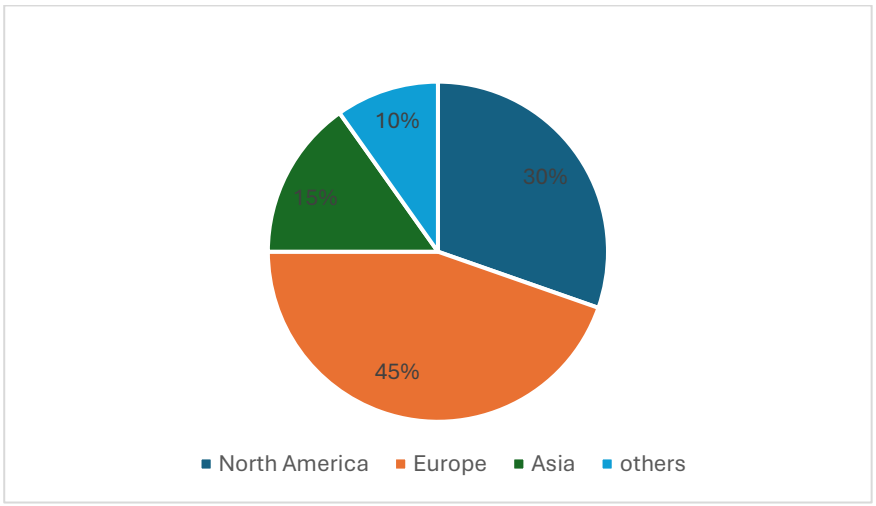
Research has increased over the years, especially in the last two decades. The type of data used in the reviewed papers varies strongly. Travel surveys started to be used in papers published during the 1990s, but there is significant variability in the duration of their travel diaries, one to seven days. More recently, some studies have started to include questions about telework engagement. The employed questionnaires are very diverse; ranging from generic questions about telework engagement to specifically linking telework and travel. Sample sizes are very diverse, ranging from 30 respondents to about 113,000 observations. The modelling methods were very different, including a simple comparison of means, regression-based models, path analysis and Structural Equation Models, before and after analysis, and descriptive analysis. More than 90% of the studies included socioeconomic control variables (gender, age, and occupation were extensively considered), but only the more recent considered attitudinal variables and preferences about telework in the analysis.

As we see in Graphic 1, the number of publications that analysed the effects of telework in travel behaviour increased in the last years, especially after the COVID-19 pandemic. Since 2020, there is a high increase and, in 2022, the number of publications peaked with 31 empirical studies about the effects of telework on travel behaviour.



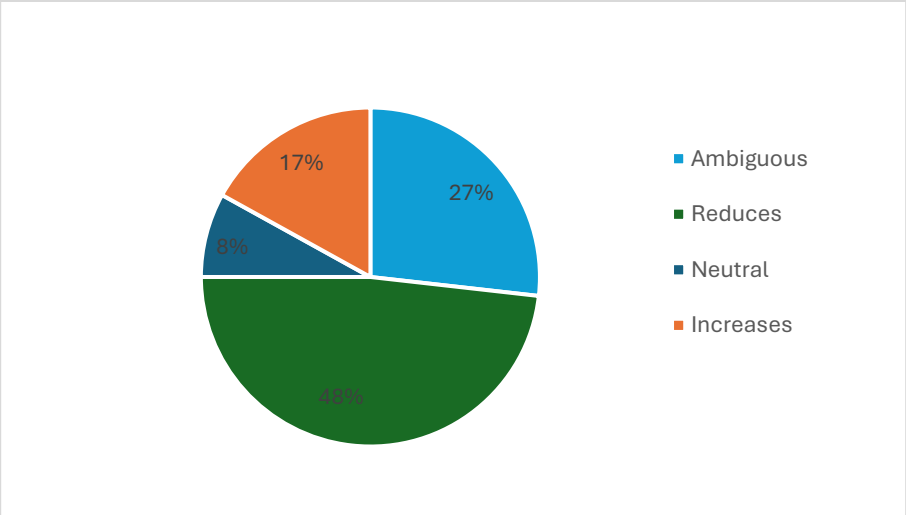
Graphic 1. Number of papers published per year

Graphic 2 shows the geographic region of publications, strongly represented by North America with 35% of studies (mostly from the United States) and European countries with 45% of the studies. Asia also has important contributions in this field (15%), and the other 10% represent countries from Latin America, Africa and Oceania.

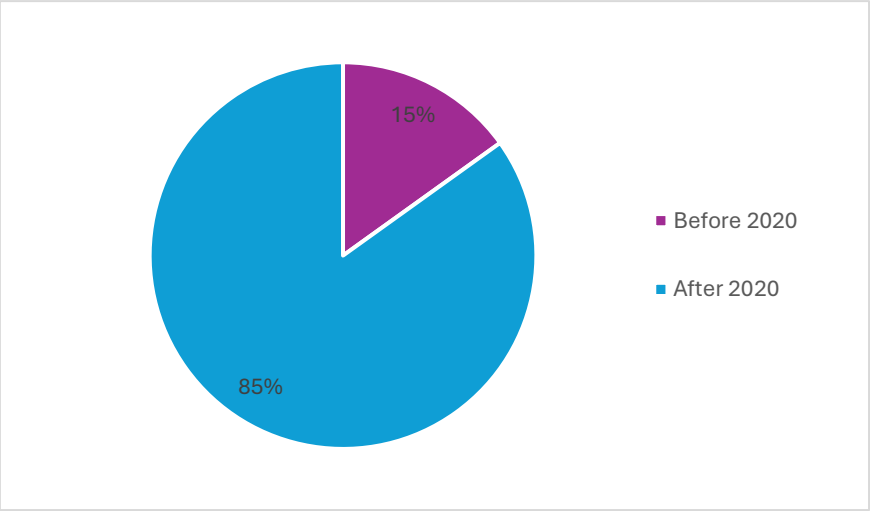


Graphic 2. Papers distribution by geographic region of publications

Regarding the results produced by the empirical studies, the conclusions are mixed, as seen in Graphic 3. Almost half of the studies (48%) indicate that telework reduces travel. However, most of these studies (85%) were published after the COVID-19 outbreak (see Graphic 4), indicating that there could be a strong bias because of the pandemic restrictions that were in place. 27% of the papers presented ambiguous outcomes, and 8% neutral results. However, only 17% of the studies concluded that telework increases travel.



Graphic 3. Reported outcomes on the effect of telework on travel



Graphic 4. Share of studies that reported travel reduction after telework adoption published before and after the COVID-19 pandemic

4.2. Meta-analysis

To make an initial meta-analysis using meta-regressions, we just evaluated the effect size of the number of trips (total and by purpose) as a function of telework engagement. From the total sample of the studies allowed to be meta-analysed, only 25 papers had as dependent variable the total number of trips and/or the number of trips by purpose (commuting trips, business trips or work trips, non-work trips or others), resulting in 39 estimates. The inclusion criteria included surveys applied before the COVID-19 pandemic outbreak (since during the pandemic, there could be a strong bias in the results because of the mandatory curfews and telework adoption, as the travel restrictions); the results had to be quantitative and to be (or to be converted) in the logarithmic scale to be comparable; the definition of telework excluded cases where use of ICT was considered as a proxy as well as non-home-based telework, to guarantee that the effect sizes of the studies could be comparable.

Table 1 shows some descriptive statistics of the 25 studies that reported the number of trips and whether it was included or excluded in our analysis, providing a motive for the exclusion. The studies were mainly from the United States (28%), Great Britain (24%), and the Netherlands (12%). There were studies from other European countries and Asia. The period analysed by the studies covers data from 1988 to 2019. The few empirical studies before 2000 could be partly explained because, generally, older papers are not easy to find.

Table 2 lists the studies included in the meta-analysis. For each study, the table shows the author and year of publication, the type of publication, the number of estimates per study and its share in the meta-sample, the mean, median, and the coefficient of variation of the estimated effect size, that is, the percentage change in the number of trips between teleworking and non-teleworking. Most of the studies are papers published in international journals since 2012, but the results have a good distribution between 1988 and 2019. Some studies have a huge variance in their observations and the means also are very discrepant. The global mean of the percentage change in the number of trips is -8.40%, and the global median is -5.65%.

The literature review presented in Section 3 guided our choice of the study design characteristics that can influence the results of the studies. We give particular attention to the following study characteristics: (1) trip purpose, (2) quality of the estimation (considered the method, if there is a self-selection control, self-selection bias, if they considered a control group), (3) time period, (4) telework regime (namely, if the study considered full or part-day telework or it did not specify the telework regime). Making a qualitative review of the studies, we found that the more recent studies used more robust methods and considered some endogenous effects in sampling and data collection, resulting in more conservative results about the effects of telework adoption on travel behaviour (like less positive, neutral or negative impacts). Studies controlled by telework regime, in general, concluded that full-time teleworkers significantly reduced their number of trips, especially for work purposes, while part-time teleworkers increased the total number of trips.

Table 1. Studies that reported the number of trips

ID	Authors of the study	Time period	Country	Included/ excluded	Motive of exclusion
1	Hamer et al., 1991	1990 to 1991	Netherlands	Included	
2	Pendyala et al., 1991	1988 to 1989	United States	Included	
3	Koenig et al., 1996	1988 to 1991	United States	Included	
4	Mokhtarian & Varma, 1998	1993 to 1996	United States	Excluded	Analysed only center-based teleworkers.
5	Harvey & Taylor, 2000	1992	Canada	Excluded	Focused on activity settings (not telework) and the number of trips was stratified in terms of level of interaction in the workplace — not comparable.
6	Wang & Law, 2007	2002	Hong Kong	Excluded	The independent variable was “use of ICT”.
7	Zhu, 2012	2001 and 2009	United States	Included	
8	Ben-Elia, 2014	2007	Netherlands	Excluded	The independent variable was “use of ICT”.
9	Asgari et al., 2016	2010 to 2011	United States	Included	
10	de Abreu e Silva & Melo, 2017	2005 to 2012	Great Britain	Excluded	Number of trips by mode — not comparable.
11	de Abreu e Silva & Melo, 2018	2005 to 2012	Great Britain	Included	
12	Zhu et al., 2018	2001 and 2009	United States	Excluded	Used the same data of Zhu, 2012, but the variable was stratified by the Metropolitan Area size — not comparable.
13	Elldér, 2020	2011 to 2016	Sweden	Included	
14	Budnitz, 2020	2002 to 2016	Great Britain	Excluded	Only analysed the number of trips by non-work purposes very stratified and telework were very stratified — not comparable.
15	Cerqueira et al., 2020	2002 to 2017	Great Britain	Excluded	
16	Echaniz et al., 2021	2020	Spain	Excluded	Data collected during the COVID-19 pandemic.
17	Hensher et al., 2021	2020	Australia	Excluded	Data collected during the COVID-19 pandemic.
18	Long & Reuschke, 2021	2018 to 2019	Great Britain	Included	
19	Su et al., 2021	2016 to 2017	United States	Included	
20	Caldarola & Sorrell, 2022	2005 to 2019	Great Britain	Included	
21	Taale et al., 2022	2019 to 2021	Netherlands	Excluded	Data collected during the COVID-19 pandemic.
22	Abe et al, 2023	2018	Japan	Included	
23	Huang et al., 2023	2019	Switzerland	Included	
24	Rizki et al., 2023	2020	Indonesia	Excluded	The independent variable was “use of ICT” and the data was collected during the COVID-19 pandemic.
25	Thaithatkul et al., 2023	2020	Bankok	Excluded	Data collected during the COVID-19 pandemic.

Table 2. Studies included in the meta-analysis

Authors of the study	Journal	N	Share (%)	CS	Percentage change in # trips (mean)	Percentage change in # trips (median)	CV
Hamer et al., 1991	Transportation	4	10.26	10.26	-19,75%	-16.00%	45.17
Pendyala et al., 1991	Transportation Research Record	6	15.38	25.64	-25.50%	-22,88%	47.74
Koenig et al., 1996	Transportation Research Part C	2	5.13	30.77	-9.64%	-9.64%	53.69
Zhu, 2012	Annals of Regional Science	4	10.26	41.03	6.025%	7.00%	50.64
Asgari et al., 2016	Transportation Research Record	2	5.13	46.15	-0.086%	-0.086%	11.51
de Abreu e Silva & Melo, 2018	Journal of Transport and Land Use	3	7.69	53.85	3.88%	17,58%	651.03
Elldér, 2020	Journal of Transport Geography	2	5.13	58.97	-18.66%	-18.66%	221.75
Long & Reuschke, 2021	Computers, Environment and Urban Systems	2	5.13	64.10	-5.30%	-5.30%	160.10
Su et al., 2021	Transportation Research Part A	1	2.56	66.67	12.77%	12.77%	
Caldarola & Sorrell, 2022	Transportation Research Part A	6	15.38	82.05	7.60%	7.62%	341.40
Abe et al, 2023	Case Studies on Transport Policy	6	15.38	97.44	-44.70%	-32,28%	103.21
Huang et al., 2023	Travel Behaviour and Society	1	2.56	100.00	-7.55%	-7.55%	
				Total	-8.40%	-5.65%	

N — number of observations, CS— Cumulative share, CV — Coefficient of variation

Figure 1 shows the histogram (using Kernel density estimates) of the percentage variation in the number of trips due to telework adoption.

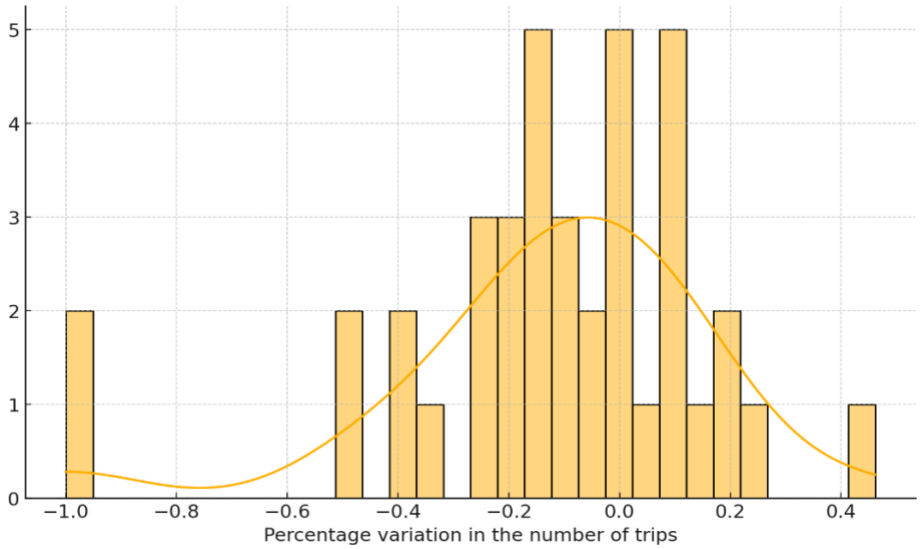


Figure 1. Histogram of the percentage variation in the number of trips due to telework adoption

Table 3 shows the summary statistics of the meta-sample. Most studies reported the total number of trips (38.46%). Total number of trips, commuting/work trips and business trips have negative means, indicating telework adoption reduces work and business-related trips and the total number of trips, besides the mean of non-work trips is positive, with a very low magnitude. Almost half of the observations (46.15%) have a good quality of the estimation, using data collection and methods that consider self-selection bias, like regional and national studies with a large and representative sample, using a control group of non-teleworkers to compare with teleworkers travel behaviour, and most sophisticate models like SEM and regression models. The mean of the percentage of variation in the number of trips varies pretty well depending on the quality of the estimation. More than half of our observations are from recent studies (56.41%) after 2010. As we see in the literature review (Section 3), more recent studies are more robust regarding data collection and study design. Also, controlling by partial or full-day telework is not very recurrent in the studies that analysed the effects of telework on travel behaviour (almost 70% of the studies did not collect data about that). As shown in Table 3, there is a vast difference in the percentual variation of the number of trips from those who telework full-day.

Table 3. Summary statistics of the meta-sample

Dimension of the study design		Share (%)	N	Percentage change in # trips (mean)	Percentage change in # trips (median)
Trip Purpose	Total number of trips	38.46	15	-11.53%	-7.55%
	Commuting/work trips	25.64	10	-25.20%	-20.14%
	Business trips	15.38	6	-10.05%	1.05%
	Non-work trips	20.51	8	0.54%	7.41%
Quality of the estimation based on different empiric methods (from the lowest (1) to the highest (4) quality)	Simple comparison between means (1)	17.95	7	-39.40%	-17.24%
	Econometric models controlled by individual characteristics (2)	15.38	6	7.60%	7.62%
	Comparison of means between teleworkers (3)	20.51	8	-22.41%	-18.60%
	Comparison of means between teleworkers x control group (4)	46.15	18	-3.97%	0.35%
Period	Until 1990	20.51	8	-21.54%	-18.81%
	1990-1999	10.26	4	-19.75%	-16.00%
	2000-2009	12.82	5	5.35%	8.5%
	2010-2019	56.41	22	-11.65%	-0.0086%
Telework regime	There is no specification about telework	69.23	27	-6.10%	-10.20%
	Part-day teleworkers	15.38	6	-1.44%	-0.0040%
	Full-day teleworkers	15.38	6	-51.25%	-48.09%

N — number of observations

Table 4 summarises the explanatory variables used in the meta-regressions, identifying the reference case for each variable.

Table 4. Explanatory variables used in the meta-regressions

Dimension of the study design		Reference case
Trip Purpose	Commuting/work trips	Total number of trips
	Business trips	
	Non-work trips	
Quality of the estimation based on different empiric methods (from the lowest (1) to the highest (4) quality)	Econometric models controlled by individual characteristics (2)	Simple comparison between means (1)
	Comparison of means between teleworkers (3)	
	Comparison of means between teleworkers x control group (4)	
Period	1990-1999	Until 1990
	2000-2009	
	2010-2019	
Telework regime	Part-day teleworkers	There is no specification about telework
	Full-day teleworkers	

5. Results and discussion

This section contains the results and discussion of the meta-regression models. Since our database contains many observations per study, the results of the estimations of the same study are likely to be correlated because they share study-specific factors. The meta-regression model is given by the Equation 1:

$$\hat{\eta}_{ij} = \eta_0 + \sum_{k=1}^{K} \beta_k D_{ij,k} + \mu_j + \varepsilon_{ij} \quad (1)$$

Where i and j are the estimate and its study respectively. $\hat{\eta}_{ij}$ is the dependent variable (percentage variation of the number of trips due to telework adoption), η_0 is the model constant, Dij,k is meta-regressor k, βk measures its effect on the percentage variation, μj is a study-specific term and ε_{ij} is the error term. The meta-regression was estimated using OLS and also GLS-RE, that weighted the estimatives by the study.

Table 5 shows the meta-regression results. The meta-regression OLS model is well-adjusted, indicating a R-squared of 0.726. The adjusted R-square of 0.614 reinforces this conclusion by accounting for the number of predictors and the complexity of the model, indicating that the proportion of explained variation remains significant even after adjustment. The GLS-RE model has a reasonable adjustment: R-squared of 0.7260 and adjusted R-square of 0.5835. However, there is no group variability in the model; this may be a consequence of the small number of groups considered. The OLS model is more parsimonious than the GLS-RE. Table 5 shows the coefficient and p-value from each dummy variable according to its reference (i.e., the total number of trips, a simple comparison between means, time period until 1990, and “there is no specification about

telework" are the references for "trip purpose", "quality of the estimation", "period", and "telework specification" variables, respectively).

Table 5. Meta-regression results

	OLS model		GLS-RE model	
Variable	Coefficient	p-value	Coefficient	p-value
Constant	-0.364	0.018	-0.364	0.003
Trip Purpose (ref: Total number of trips)				
Commuting/work trips	-0.242	0.007	-0.242	0.000
Business trips	-0.069	0.508	-0.069	0.420
Non-work trips	-0.068	0.466	-0.068	0.375
Quality of the estimation based on different empiric methods (ref: Simple comparison between means)				
Econometric models controlled by individual characteristics	0.285	0.045	0.285	0.012
Comparison of means between teleworkers	0.191	0.244	0.191	0.153
Comparison of means between teleworkers x control group	0.261	0.013	0.261	0.001
Period (ref: Until 1990)				
1990-1999	0.070	0.589	0.070	0.512
2000-2009	0.294	0.027	0.294	0.005
2010-2019	0.0281	0.038	0.0281	0.008
Telework regime (ref: There is no specification about telework)				
Part-day teleworkers	-0.015	0.931	-0.010	0.917
Full-day teleworkers	-0.508	0.000	-0.508	0.000
Group variable			0.000	

The results of the OLS and GLS-RE models are very similar. There is a negative effect of commuting/work trips compared with the total number of trips, although business trips and non-work trips do not have a significant difference. These results are in accordance with some literature conclusions, which indicated that telework adoption has a substitution effect on commuting trips and has a neutral or complementary effect on business-related or non-work trips (e.g. de Abreu e Silva & Melo, 2018a; Abe et al., 2023). The quality of the estimations has a significant positive effect regarding using econometric models controlled by individual characteristics and using a control group, indicating that using more robust models and studies designs, as well as controlling self-selection, can result in less positives (or better, less super-estimated) conclusions regarding telework adoption effects in the number of trips, also by some empirical evidence conclusions (e.g. de Abreu e Silva & Melo, 2018a). Not controlling by non-teleworkers versus teleworkers individuals does not have a significative difference in the simple comparison between means. The time period of the data collection, actually, studies since the 2000s also have a positive effect on percentage variation. They corroborate the more recent studies, which use more robust data collection methods and models, that concluded that the magnitude of

the results of telework adoption on travel is smaller than the earlier ones reported. Finally, there is an important effect by controlling full-day teleworkers, since teleworkers the whole day might reduce the number of trips. These conclusions follow the more recent literature, which is separated by full and partial-day teleworkers (e.g. Éllder, 2020; Long & Reuschke, 2021).

The results reinforce that telework might reduce the number of trips, especially commuting and work trips, but the magnitude of the effects depends on the study design and method used in the study. Also, it is important to control for self-selection bias during the data collection, including representative data of the teleworker population, and select a robust method, including control group, statistical models, control sociodemographic and, ultimately, attitudinal variables. Controlling by full-day teleworkers and part-day teleworkers is also fundamental to understanding the conclusions since full-day teleworkers reduce the number of trips. Many studies did not specify if the teleworker worked from home on the exact day the travel diary was reported, so here we might have an endogenous issue regarding those studies that did not specify it. This question can be important to discern if teleworkers travel more or less during the days they telework or not.

6. Conclusions

This work aimed to understand the impact of telework on travel behaviour by conducting a meta-analysis of empirical studies, namely, the objective was to evaluate the variation in the estimated percentage change in the number of trips after teleworking adoption. The analysis considered various trip purposes and study-specific factors which might influence the direction and magnitude of the effect of telework in the amount of travel. The meta-analysis included 39 estimates from 12 studies conducted before the COVID-19 pandemic, covering the period from 1988 to 2019. The main results indicate that telework generally reduces the number of commuting and work-related trips but may have neutral or complementary effects on business and non-work trips. The quality of the estimations significantly affects the size of the effect, with more robust models showing less positive impacts on the number of trips. Full-day teleworkers are found to experience a greater reduction in the number of trips compared to part-day teleworkers.

One strength of this study is the use of meta-analysis to enhance the robustness of the findings by increasing the sample size and providing a more reliable estimate of the impact of telework on travel behaviour. Additionally, the careful selection of explanatory variables in the meta-regression model, including trip purpose, quality of estimation, time period, and telework specification, ensures that the analysis accounts for the most relevant factors influencing the variation in the number of trips. This methodological rigour strengthens the validity and reliability of the study's conclusions. However, this work also has some limitations. First, the meta-analysis only included studies published before the COVID-19 pandemic, which may not fully capture the current dynamics of

telework and travel behaviour. Second, the variability in data collection methods, sample sizes, and modelling approaches across studies may introduce biases and affect the generalizability of the results. Lastly, many studies did not specify whether the teleworkers worked from home on the day the travel diary was reported, leading to potential endogeneity issues.

For future research, we aim to incorporate additional dimensions of travel behaviour — such as mode choice, travel distance by purpose, and commuting distance -, to increase the number of studies and observations and include all the studies selected during the systematic literature review. Furthermore, future research should consider the long-term impacts of telework in the post-pandemic period, incorporating more recent data to capture the evolving travel patterns. Finally, some recommendations for researchers are to consider data collection methods and ensure the inclusion of representative samples and robust modelling approaches. Additionally, the differentiation between full-day and part-day teleworkers and control for self-selection biases by including control groups and considering sociodemographic and attitudinal variables might produce more confident results.

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