MASTER'S THESIS

The Impact of Telecommuting on Mobility Behaviour and Kilometres Travelled

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Abstract

Telecommuting is perceived as an innovative and effective way to reduce commute travel and overall kilometres travelled. The topic has received much attention from the scientific community, though findings show contradictory observations. Telecommuters are often found to not only commute over longer distances, but also to cover longer daily distances. Unfortunately, most studies analyse small datasets that focus on specific characteristics, thus limiting generalizability of research results.

This study aims to draw conclusions in a broader context. For this purpose, data of two regional level surveys conducted in Germany (the Mobilität in Deutschland 2017 survey as well as the Mobilitätspanel) was analysed. Variables on household and individual level were included, to investigate their impact on telecommuting and to be able to precisely analyse the effect of commute length on telecommuting.

Eight logit models were applied to estimate the likelihood to telecommute, telecommuting frequency as well as the option and choice dimension of telecommuting. Furthermore, the relationship between telecommuting and relocation was investigated using descriptive statistics.

Several variables showed a statistically significant influence on telecommuting likelihood, telecommuting frequency and also the option and choice dimension of telecommuting. The variables that were found to affect all four dimensions are gender, age, educational level, level of employment, household income and residential location.

Results indicated that commute length was indeed connected to all analysed aspects of telecommuting. The likelihood to telecommute increased with longer commute lengths. Furthermore, longer commute lengths increased the likelihood to be given the option to telecommute and made it more likely that individuals took this opportunity. A long commute length though, was negatively affecting telecommuting frequency.

Telecommuting seemed to encourage people to move further away from their workplace. People also tended to increase their commute length and duration when changing jobs.

These observations weakened the assumption that telecommuting might be an effective way to reduce kilometres travelled. However, results indicated that the concept of telecommuting is highly complex. This prevents precise predictions regarding this topic, as effects of telecommuting depend on a great range of factors.

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1. Introduction

Telecommuting is strongly promoted as a means to reduce commute travel and thus decrease total kilometres travelled. And it is increasingly gaining importance, as it is closely connected to technological progress. To gain insight on the future working world in the context of mobility, it is crucial to understand the factors that drive telecommuting and to become aware of its consequences our life.
Though the reduction of commute and overall travel is an intuitive conclusion, research indicates different findings. Results indicate that telecommuters often commute over longer distances than non-telecommuters, which could compensate the effects on commute travel. Furthermore, telecommuting is commonly perceived as possibility to facilitate a more flexible lifestyle and a better work-life balance. Thus, telecommuters might tend to make more efficient use of leisure time on telecommuting days. This behaviour could increase non-work travel on telecommuting days which could also possibly increase overall travel distances. Furthermore, the possibility to telecommute could encourage employees to accept longer commutes in favour of preferential residential locations, which would not only compensate for reduced commute trips but could also counteract reductions of travelled distances. Although many researchers focus on telecommuting, its impacts on various aspects of life have yet to be clarified. The complexity of this innovative working form impedes a general approach and furthermore complicates joint work on this topic.

Generally, datasets used for the investigation of telecommuting are most often from pilot telecommuting studies or from large surveys of travel behaviour. The former are often limited to data from a small number of respondents but include detailed occupational information, whereas the latter comprise a variety of people but usually lack information on employers and occupational details of respondents (Safirova & Walls, 2004). Another problem both types of dataset often encompass are the temporal restrictions of the surveys, as only few datasets track workers over a longer period, which is crucial to fully understand the mechanisms of telework (Safirova & Walls, 2004). One of the main problems in the field of telework research is sampling bias. Most studies are based on data specifically selected to investigate the effectiveness of telework (e.g., Nilles, 1991). Respondents taking part in those telework programs are often screened by suitability criteria beforehand, to fully exploit the potential of telework in the program (Singh et al. 2012). While this approach enables good data coverage on important factors and increases the chances of success of a telework program, the pre-selection of respondents is also a source for potential bias in research findings and highly limits generalizability (Singh et al. 2012).

Most studies are limited to datasets collected in America, as telecommuting had its beginnings in the United States where numerous telecommuting pilot projects were initiated. As mobility behaviour varies across countries, it might not be feasible to completely transfer research findings to other nations.

This study aims to contribute to the knowledge about the concept of telecommuting, by analysing data from two nationwide, representative mobility surveys conducted in Germany. As most studies focus on small, detailed datasets in America, this study might add value to findings that are more applicable to the German population. Furthermore, it not only focuses on one aspect of telecommuting but attempts to shed light on various characteristics: the likelihood to telecommute, telecommuting frequency, the option and choice dimension of telecommuting and the effect of telecommuting on relocation choices.

In the first section of the thesis an overview over the literature on telecommuting is provided. The following section describes the data analysed in this study and explains research approach and methodology. The second last section presents the research findings, while in the conclusion a summary of research findings is provided.

2. Literature Review

2.1. History of telecommuting

The rise of telecommuting began with the oil crisis in 1973 stressing the importance to reduce travel. While several publications focused on this issue in the following years, Jack Nilles is considered the founder of the term “telecommuting” when addressing the possibility to substitute commute for telecommunication in the book “The Telecommunications-Tranportation Tradeoff” in 1976 (Kordey, 1994). Thereupon debate about telecommuting intensified and as of 1981 pilot projects were initiated, starting in California and rapidly spreading across the United States (Moktharian, 1991; Nilles, 1996).

Though attempts were made to integrate telecommuting into the working world in Germany in the 1980s, the concept failed to gain broad acceptance. The main obstacle was seen in organisational issues resulting in an overall negative image of telecommuting, until the early 1990s when the innovative working form made a comeback in Germany (Kordey,1994; Brandes, 1999). This delay in the rise of telecommuting resulted in its lower dissemination in Germany’s working world, especially compared to the United States.

According to the 2017-2018 America Time Use Survey Leave and Job Flexibilities Module around 25 percent of employees in the USA reported to practice telecommuting to some degree (U.S. Bureau of Labor Statistics, 2019) whereas in Germany, only 12 percent of employees were found to telecommute in 2017 (BAuA, 2018). Thus, it is not surprising that the majority of research only address telework in the United States. Especially early studies focus on telecommuting pilot projects

2.2. Definition of telework

An important factor resulting in inconsistencies and a lack of comparability among studies is the respective use and definition of the term telework. The European Framework Agreement on Telework defines telework as “a form of organizing and/or performing work, using formation technology, in the context of an employment contract/relationship, where work, which could also be performed at the employer’s premises, is carried out away from those premises on a regular basis” (Wojčák & Baráth, 2017). This rather broad definition underlines the complexity of the term telework and the difficulty to clearly define it as it can be classified according to several criteria (Singh et al. 2000). These criteria include, inter alia, occupational category, type and level of employment, the proportion of work time telework is exercised, location from which telework is executed and closely connected to the last criterion, changes in commute travel (Sullivan, 2003). Telework is closely connected to certain occupational categories, though technical progress is likely to allow for an increasingly broad application of telework (Kordey, 1994). Type and level of employment cannot be disregarded, as self-employed teleworkers working at home full-time exhibit a different work life from teleworking employees and full-time employees may behave differently from part-time employees when teleworking (Standen et al,1999). Walls (2004) mentioned the proportion of work time telework is exercised as another important criterion for the definition of telework. Research shows that the time spent teleworking at home is often tantamount to working overtime (Sturresson, 1997) while occasional work at home is the most widespread form of telework (New Ways to Work, 1998; Standen et al, 1999). This also implies temporal organisation of telework is another important factor. Some teleworkers may not work at home for a full day but spend one part of the day at the office and telecommute the other part of the day. Obviously, these teleworkers have a different effect on traffic as partial telecommuting days have no effect on trip reduction (Safirova & Walls, 2004; Nilles,1991). A crucial factor, especially in traffic research is the location of performance. The two most common forms are Home Office, which is the most widespread one in the United States and implies that the telecommuter is working at home, and telecenters, office spaces located outside the employer's premises but close to the workers' residential location, which are particularly found in Japan in Scandinavia (Kordey, 1994; Wojčák and Baráth, 2017). This distinction is especially crucial, as working from home implies an interaction between the teleworkers and the physical and social aspects of their home environment and as it is directly connected to commute and thus changes in commute resulting from telecommuting (Sullivan, 2000; Standen et al. 1999; Sullivan, 2003).

As mentioned before, the term "telecommuting" was developed by Nilles in 1976 and though it is used throughout research, it is usually defined as the use of telecommunications technology to partially or completely replace the commute to and from work (Moktharian, 1991; Nilles, 1988) an is thus a term specifically developed for research focusing on transportation and mobility.

Sullivan (2003) dedicated a paper to finding a universally accepted and academically applicable definition of telework. She reached the consensus that although a more common approach would be desirable to facilitate comparability, the importance of flexibility in the research paradigm and thus a variety of topic and case-by-case definitions cannot be neglected (Singh et al. 2012).

The main benefits seen in telecommuting involve organizational flexibility, enhanced work productivity and early on especially on its potential on reducing commute travel and emissions (Singh et al. 2012; Ham et al. 2018; Salomon, 1985; Nilles, 1991; Lund & Moktharian,1994). Generally, research indicates that telecommuters tend to have longer commutes than non-telecommuters though effect size varies depending on the utilised dataset, included control variables as well as the respective definition of the term “telecommuting” (Ham et al. 2018).

2.3. Likelihood to telecommute and telecommuting frequency

In 1995 Mannering and Mokhtarian analysed telecommuting frequency as a function of several sociodemographic variables using survey data from three government agencies in Sacramento, San Francisco and San Diego (Walls, 2004). Results indicate that the following variables seem to influence telecommuting frequency: the presence of children in the household, household size, gender, individual scheduling decisions as well as individual preferences in some areas. Interestingly, the authors found that distance to work was not statistically significant, though they mention that literature predicted contradictory findings.

Drucker and Khattak (2000) are one of the few to use a large national sample of respondents, the 1995 Nationwide Personal Transportation Survey in the U.S. including characteristics unavailable in previous analyses (i.e. socioeconomic, household, locational). The paper focuses on metropolitan statistical areas and analyses a final sample of 2,130 respondents. The results showed that the most important variables having a significant positive impact on telecommuting frequency were a high level of education, the presence of small children in single-adult households, being male, higher income, working part-time and a rural residential location.

Popuri and Bhat (2003) use a large sample as well, a survey of 6,532 employees (including 1,028 telecommuters) in the New York metropolitan area, to investigate telecommuting choice and frequency. They found that women in childless households were less likely to telecommute than men, though with children present there was no difference between genders. Women were also more likely to telecommute more frequently. Age had no impact on telecommuting choice, though older employees telecommuted more frequently. Household income and level education both had a positive effect on telecommuting, making it more likely to telecommute with a high level of education and high household income. Part-time workers were more likely to telecommute and to telecommute frequently as well.

Collantes and Mokhtarian (2004) analysed a survey distributed in 1998 to 218 employees of six California state agencies who had been telecommuting continuously since the start of the State of California pilot program in 1988 to evaluate long-term effects. Results indicated that telecommuters tend to have longer commute lengths than non-telecommuters though their telecommuting frequency resulted in lower mean commute length than seen in non-telecommuters. Also analysed the role of telecommuting as a facilitator of extensive residential locations. Though, it is underlined that the ability to telecommute was contributed to the relocation decision only for a small percentage of telecommuters, those people relocated significantly farther away from their workplace. The authors emphasize, that residential relocations are mostly influenced by factors not connected to telecommuting though the ability to telecommute can facilitate to increase commute length when relocating.

2.4. Telecommuting and relocation

To fully understand the effect of telecommuting on travel one must take causality into account. Is the ability to telecommute encouraging employees to accept longer commutes in favour of preferential residential locations and thus driving urban sprawl and increasing overall commute travel? Or is telecommuting seen as a possibility to commute less frequent for employees already having longer commute, hence reducing total commute amount?

Ory and Mokhtarian (2006) took a second look at pilot project more closely addressed this “friend or foe” scenario question examining relationships among telecommuting. residential relocation and commute travel using data from more than 200 State of California workers over a 10-year period. They found that people generally increased one-way commute length and duration when relocating, though telecommuters tended to move even farther away than non-telecommuters.

Furthermore. they investigated the temporal context between telecommuting adoption and residential relocation. The analysis is based on the assumption that in general, causes temporally precede their effects (Holland. 1986). This temporal precedence can by no means be guaranteed one hundred percent, as the actual timing of the decision to telecommute or relocate may mix up the order of cause and consequence. Thus, Ory and Mokhtarian additionally took the stated causality for residential relocation of respondents into account, as well as the stated importance telecommuting had for specific residential relocations.

They found that individuals whose telecommuting engagement was caused by their relocation, assuming temporal precedence of a cause, generally moved farther away from their workplace. However, those who supposedly relocated due to their telecommuting engagement decreased their commute length and duration. When analysing the stated causality for relocation, Ory and Mokhtarian found, that only a small percentage of respondents took the possibility to telecommute into consideration when relocating.

Foe: They highlight the role of telecommuting in individual decision-making: residential relocation is affected by many factors such as housing costs, combining of households or preferences in location. Thus, telecommuting may facilitate moves but cannot be seen as an actual driver of residential relocation.

Unfortunately, the study exhibits some limitations due to the data’s composition the authors could not overcome. The sample consists solely of state employees participating in a telecommuting pilot program conducted from 1988 to 1990 by the State of California. This means that the sample is by no means representative of the population and the predominant private sector employees are excluded completely. Furthermore,

as the survey was entirely dedicated to telecommuting, respondents may have been aware of the desired outcomes beforehand and thus unconsciously influencing/adapting their behaviour.
As mentioned earlier, Nilles (1991) also concluded that telecommuters tended to increase their commute length when relocating when analysing the State of Calirfonia Pilot Project.

2.5. Option vs. choice

Much attention has been devoted to investigating telecommuting preferences and model telecommuting likelihood. But only a few studies include the “option” dimension of telecommuting in their analysis (e.g., Singh et al. 2012; Bernardino & Ben-Akiva, 1996; Peters et al. 2003). Singh et al. (2012) emphasize that, not considering who is given the option to telecommute, but only whether an individual telecommutes or not, may lead to incorrect conclusions regarding telecommuters. To fully understand the potential impact of telecommuting practices on the transport sector and thus be able to actively develop the concept of telecommuting, it is crucial to comprehend the choice as well as the option side. With technological progress it is likely that telecommuting will gain importance and will probably extend to a broader base of people . Thus, when ignoring the option dimension, research may lead to misconceptions.
Singh et al. (2012) used data from the 2009 National Household Travel Survey (NHTS) conducted by the U.S. Department of Transportation and focused on the San Francisco Bay area resulting in a final sample of 2,563 workers. Peters et al. (2003) analyse data from 849 respondents from the Work & IT 2001 survey which is a representative survey from the Dutch population. Both studies found deviations of certain variables between the option and choice dimension, though they varied.
Singh et al. (2012) found that women as well as part-time employees were less likely to be given the option to telecommute compared to men and full-time employees but were both more likely to telecommute when given the opportunity. Middle-aged employees (36 – 50 years) were most likely to have the option but were less likely to telecommute frequently than other age groups. Employees belonging to high-income households as well as households living in urban areas were more likely to be given the opportunity to telecommute than those belonging to households with lower income and those living in rural areas. The latter were more likely to choose to telecommute, though. Individuals having a one-way commute length over 20 miles were not only more likely to be given the opportunity to telecommute but were also more likely to take this opportunity and were also more likely to telecommute frequently. The authors did not find a difference in the effect of education level and the presence of children in the household.

Contrary to the findings of Singh et al. (2012) Peters et al. (2003) found a difference in the effect of education on the "option" dimension. Highly educated individuals were more likely to be given the opportunity to telecommute than low educated employees, though it did not influence telecommuting choice. Moreover, the presence of children in the household decreased the likelihood that an employee would choose to telecommute. The authors did not find any gender impact. The findings concerning commute coincide with the findings of Singh et al. (2012), though Peters et al. (2003) analyse commuting duration. Employees with longer one-way commuting duration were not only more likely to be given the opportunity to telecommute but were also more likely to take this option.

2.6. Commute length

One of the main points of interest in traffic research regarding telework is whether telecommuting substitutes for travel or whether telecommuting and travel complement each other (Kitamura, 1991). While telecommuters are anticipated to reduce commute travel by cutting down commuting trips, they seem to have longer one-way commute lengths possibly resulting in an increase of overall commute travel (Hu & He 2016; Mokatharian et al, 2004; Ory & Mokhtarian, 2006). Furthermore, telecommuting may increase individual travel, as employees might non-work trips on telecommuting days (pick-up, drop-off, shopping, leisure) (Perch-Nielsen, 2014). The effect of telecommuting on number and length of nonwork trips is unclear as research reaches different conclusions.

As mentioned before, most of the early studies are based on data from one of the telecommuting pilot studies in the United States. Many researchers analysed datasets from the California Telecommuting Pilot Project conducted by the State of California from July 1987 to June 1990. The project included over 150 State employees telecommuting actively from January 1988 to December 1989 (Kitamura, 1991). Unfortunately, the project excludes respondents from the private sector. Results indicate that telecommuting reduces work trips and does not induce non-work trips. Moreover, household members of telecommuters seemed to reduce non-work trips as well (Kitamura et al. 1990). Kitamura (1991) also found a reduction in total travel distance on telecommuting days, as well as reduction in trip generation and peak period travel. On the downside, telecommuting does not reduce household travel in proportion to telecommuting intensity and was also associated with moves increasing commute length (Nilles, 1991). Furthermore, telecommuters generally lived farther from work than non-telecommuters, though Nilles mentioned a bias due to the selection criteria for the project, as State employees with longer commute lengths were chosen preferably. Pendyala et al. (1991) came to similar conclusions further adding the insight that telecommuters generally tended to have reduced action spaces on telecommuting and commuting days.

Varma et al. (1998) observed telecommuters over a longer period (1991 to 1996) to gain insight into changes in telecommuting frequency and duration (Safirova & Walls, 2004). They used data from 15 telecentres of the Neighborhood Telecenters Project carried out at the University of California and found out that almost half of the telecommuters telecommuted less than 1 day per week, while another 29% telecommuted 1 to 2 days per week. Furthermore, they conclude that more than half the respondents who quit telecommuting never resumed it.

Subsequent studies extend to other research areas and occupational groups. Wells et al. (2001) also included the private sector, as they analysed 796 employees at a public agency as well as a private firm in Minnesota, though they did not include statistical analysis. Their summary statistics though indicated that a longer commute increased the likelihood to telecommute. Furthermore, the results indicate that telecommuters did not increase kilometres travelled on telecommuting days, but chose to do errands on regular workdays (Safirova & Walls, 2004).

One of the few early studies conducted outside of the United States was conducted by Hamer et al. in 1991 in the Netherlands. The study is based on a small-scale experiment with 30 workers of the Ministry of Transport. The authors underlined that the sample was not representative for all workers and can therefore not be generalised. Nevertheless, results indicated that telecommuting decreases the number of commuting trips as well as trips for other purposes and that household members also reduced their number of trips.

Ravalet and Rérat (2019) used the dataset Mobility and Transport Microcensus (MTMC) conducted every five years by the Federal Statistical Office and the Federal Office for Spatial Development in Switzerland. The sample included 10,982 employees in 2010 (8,573 in 2015). The authors found that telecommuters have longer commute lengths than non-teleworkers and that this difference is increasing over time. Furthermore, non-work trips on telecommuting days partially compensated the absence of commute trips resulting in longer distances travelled per week in comparison to non-telecommuters.

Van Ham et al. (2019) expanded on the knowledge of telecommuting in the Netherlands, by analysing the Longitudinal Internet Studies for the Social Sciences panel data for the years 2008-2018. They found that telecommuters increase their commute length 12 percent on average and that especially occupations prone to the adoption of telecommuting show a clear effect on commuting.

Lachapelle et al (2018) addressed telecommuting and its potential to reduce overall travel time in Canada. The papers analyses data from the 2005 Canadian General Social Survey representative of the Canadian population and includes 19,597 respondents. Though it was found that working only from home for one day does reduce overall

travel time by 13 minutes and motorised travel, that this does not apply to other forms of telecommuting (part-time, out-off home).
Silva and Melo (2018) analysed the effect of telecommuting on number of trips and miles travelled per week and focused on one-worker households in Great Britain, using data between 2005 and 2012 from the National Travel Survey. Results indicate that though telecommuting reduces the number of commuting trips it does not reduce overall weekly commuting miles travelled and particularly increases miles travelled by car.
Zhu (2011) (gute Infos) analysed the impact of telecommuting on workers' overall travel patterns, to identify whether telecommuting complements or substitutes for personal travel. To eliminate the widespread weak point in telecommuting research of relying on small datasets, the study used data from two large national surveys, the 2001 and 2009 National Household Surveys (NHTS). Results indicated that telecommuters not only had longer one-way commute trips but also longer daily total non-work trips, thus potentially reducing the positive impact of telecommuting on travel reduction.
He and Hu (2015) analysed the effect of telecommuting on out-of-home activities by using a dataset of approximately 7,500 employees from the 2007 Chicago Regional Household Travel Inventory. Results indicate that although telecommuting is associated with a reduction of work-related trips, it positively impacts the number of total trips (pick-up, drop-off, maintenance/discretionary) which indicates that telecommuting might not be reducing individual travel demand.
Hu and He (2016) analysed the effect of telecommuting on a telecommuter's household, as they suspected different travel patterns due to greater flexibility in residential location choice and household scheduling. For this purpose, they used data from the 2008 Chicago Regional Household Travel Inventory. Generally, telecommuters are associated with longer one-way commute lengths, though this does not apply to frequent telecommuters. Furthermore, households of less-frequent telecommuters tend to travel equally to non-telecommuter households, and households of frequent telecommuters even travel less.
Perch-Nielsen (2014) analysed multiple factors connected to telework in Switzerland with data of 2,077 companies no statistical evidence.
Kim (2016) used the 2006 SMA data, which covers the Seoul Metropolitan City Incheon Metropolitan City and Gyeonggi Province, to analyse relationships between telecommuting, residential/job locations and household travel. Path analysis led to the conclusion, that it is likely that most of the time telecommuting is a consequence of residential/job location choice, though some employees might relocate due to the capability to telecommute, which is similar to other research. Furthermore, results indicate that telecommuting has a positive effect on non-commuting travel as well as on household members' travel which suggest a compensatory relationship between telecommuting and overall travel.

3. Material and Methods

3.1. Data Description

This study analyses datasets of two main mobility surveys in Germany to gain insight into the behaviour of telecommuters and the factors influencing them: the Mobilität in Deutschland 2017 (MiD 2017) survey as well as the Mobilitätspanel (MOP).

It should be noted, that due to different education systems across countries, it is not feasible to directly translate the German degrees used to classify graduates in MiD 2017 and MOP. Table 1 lists approximate translations the degrees will be referred to in this thesis. Owing to simplification, only one English equivalent will be used for each group of degrees with a similar level of education.

Table 1 Equivalents for German degrees

German degrees	English equivalent
Volksschulabschluss, Hauptschulsabschluss, POS 8. Klasse	Lower secondary school leaving certificate
Mittlere Reife, Realschulabschluss, POS 10. Klasse	General Certificate of Secondary Education (GCSE)
Fachhochschulreife, EOS 12. Klasse, Abitur	General Certificate of Education (GCE)
Fachhochschulabschluss, Universitätsabschluss	University degree

3.1.1. MiD 2017

To investigate sociodemographic and travel characteristics of telecommuters the database Mobilität in Deutschland 2017 is used. Mobilität in Deutschland 2017, also referred to as MiD 2017, is a representative cross-sectional survey with the objective of gaining valuable insights into day-to-day mobility among Germany’s residential population. The survey is a continuation of the MiD 2002 and 2008 surveys, commissioned by the Federal Ministry of Transport and Digital Infrastructure. MiD 2017 was carried out by the infas Institute for Applied Social Sciences and processed in collaboration with the Institute Transport Research at the German Aerospace Centre. The project team furthermore included IVT Research and infas 360 (Mobility in Germany 2017 study summary, 2017).

The survey itself extended over a period of over 12 months, from May 2016 to September 2017, gathering information from 156,420 households, 316,361 people and over 960,619 trips. Queried characteristics include information on household and personal level. The survey utilized four different interview methods CATI (Computer Assisted Telephone Interview). CAWI (Computer Assisted Web Interview). PAPI (Paper And Pencil Interview) and Proxy-Interviews. (PAPI and proxy reduced questions) (MiD Nutzerhandbuch. 2019). It was carried out in two consecutive phases:

- In the first phase, a household survey was conducted, querying household composition, sociodemographic characteristics (such as monthly income or residential location), available means of transport and further features.

- In the second phase, each household member was interviewed individually, providing information on personal characteristics and giving a detailed description on mobility behaviour and distances covered on the reporting date in a travel diary.

As MiD 2017 is a representative study, it includes weighting factors on each level to facilitate conclusions regarding Germany’s entire population.

This study utilises the MiD 2017 dataset to analyse the effect of household and individual characteristics on the likelihood to telecommute as well as their influence on telecommuting frequency. Furthermore, the study assesses whether telecommuters compensate for a reduced number of commute trips by traveling further on telecommuting days by means of the MiD 2017 dataset. To allow for a more representative statistical approach, weighting factors were integrated in descriptive statistics and certain analyses. As special focused was placed on the connection between telecommuting and commute length, it was crucial to include it when analysing the propensity to telecommute as well as telecommuting frequency. To achieve the best possible dataset for all research topics, the basic dataset was adapted individually to each analysis. Exact procedures are described in the methods section.

3.1.1.1. Likelihood to telecommute

Table 2. lists the descriptive statistics for the categorical variables in the dataset utilized to analyse the likelihood to telecommute. Proportions are stated as weighted percentages as well as number of individuals.

Table 2 Descriptive statistics for the likelihood to telecommute (categorical variables)

Variable	Complete dataset N = 12,147		Non-telecommuters N = 11,027 (92.9%)		Telecommuters N = 1,120 (7.1%)	
Gender						
male	55.6%	6385	55.3%	5758	59.8%	627
female	44.4%	5762	44.7%	5269	40.2%	493
Age						
< 20 years	0.2%	36	0.2%	36	-	-
20 - 29 years	14%	919	14.3%	865	9.7%	54
30 - 39 years	23.4%	1998	23%	1763	30%	235
40 - 49 years	27.6%	3275	27.6%	2950	27.8%	325
50 - 59 years	27.5%	4553	27.5%	4151	25.7%	402

Variable	Complete dataset N = 12,147		Non-telecommuters N = 11,027 (92.9%)		Telecommuters N = 1,120 (7.1%)	
60 - 69 years	7.1%	1323	7.2%	1226	6.5%	97
>69 years	0.2%	43	0.2%	36	0.3%	7
Level of education						
University degree	31.6%	5162	29.8%	4429	54.8%	733
GCE	14.7%	2262	14.9%	2089	12.4%	173
GCSE	34.6%	3359	35.5%	3203	22.4%	156
Lower secondary school leaving certificate	19.1%	1364	19.8%	1306	10.4%	58
Level of employment						
Full-time	77.4%	8970	77.7%	8190	73.5%	780
Part-time	20.2%	2892	19.9%	2579	23.8%	313
Marginal	2.4%	285	2.4%	258	2.7%	27
Household income						
Very high	8.5%	1759	7.9%	1481	16.3%	278
High	40.1%	5857	39.7%	5300	44.7%	557
Medium	39.3%	3640	40.1%	3415	28.9%	225
Low	9%	680	9.2%	636	7.2%	44
Very low	3.1%	211	3.1%	195	2.9%	16
Child < 14 years						
No	72.6%	9337	73%	8562	66.9%	775
Yes	27.4%	2810	27%	2465	33.1%	345
Federal states of Germany						
City states	5.8%	348	5.8%	311	6.2%	37
Northern states	12.5%	1006	12.7%	924	11.6%	82
Western states	30%	3600	29.3%	3257	37.9%	343
Southern states	35.4%	6365	35.4%	5746	35.1%	619
Eastern states	16.3%	828	16.8%	789	9.2%	39
Residential location						
Metropolitan area	28.5%	3746	27.9%	3310	35.2%	436
Regiopolitan area	38.7%	4746	38.6%	4304	40.8%	420
Rural area	32.8%	4724	33.5%	3413	24%	264
Carsharing membership						
No	95%	11500	95.5%	10516	88.3%	984
Yes	5%	647	4.5%	511	11.7%	136
Pedelec availability						
No	95.8%	11417	96%	10377	93.6%	1040
Yes	4.2%	730	4%	650	6.4%	80
Limited mobility						
No	97.7%	11885	97.7%	10792	97.8%	1093
Yes	2.3%	262	2.3%	235	2.2%	27
Commute length						
under 2 km	13.8%	1553	13.6%	1391	16.5%	162
2 to under 5 km	18.9%	2200	19.2%	2055	14.9%	145
5 to under 10 km	20.4%	2529	20.5%	2323	18.1%	206
10 to under 35 km	37.4%	4618	37.6%	4225	34.5%	393
35 to under 60 km	6.9%	874	6.7%	749	9.8%	125
60 to under 100 km	2.1%	295	1.9%	232	4.8%	63
Over 100 km	0.5%	78	0.5%	52	1.4%	26
Commute duration						
under 5 min	3.8%	128	0.9%	112	2.9%	16
5 to under 10 min	14%	940	8.2%	870	5.8%	70
10 to under 15 min	26.3%	1611	13.6%	1.498	12.7%	113
15 to under 30 min	65%	4559	38.6%	4.230	26.4%	329
30 to under 45 min	47.7%	2751	21.6%	2.492	26.1%	259
45 to 60 min	27.3%	1455	11.9%	1.257	15.4%	198
Over 60 min	15.9%	703	5.2%	568	10.7%	135
Household size						
1	22.5%	1882	22.5%	1722	23%	160
2	31.8%	4490	32%	4093	29.7%	397
3	21.1%	2577	21.4%	2369	15.6%	208
4	18.5%	2389	18%	2120	25.1%	269
>4	6.1%	809	6.1%	723	6.6%	86

Table 3. lists the weighted mean, weighted median and weighted standard deviation for the three continuous variables included in the dataset.

Table 3 Descriptive statistics (continuous variables)

Variable	mean	median	Standard deviation
Age [years]	47.26	49	10.77
Household income [€]	4303.012	4.000	1741.372
Household size [number of people]	2.667	2	1.196

Fig. 1 and Fig. 2 present a visual illustration over the distribution of commute length and duration among non-telecommuters (NTC) and telecommuters (TC). Distribution of commute length is similar in both groups, though a greater number of telecommuters have more extreme commute lengths (over 35 and under 2 kilometres) compared to non-telecommuters. A similar trend can be observed in commute duration, as a greater number of telecommuters has commutes longer than 45 minutes and shorter than five minutes.

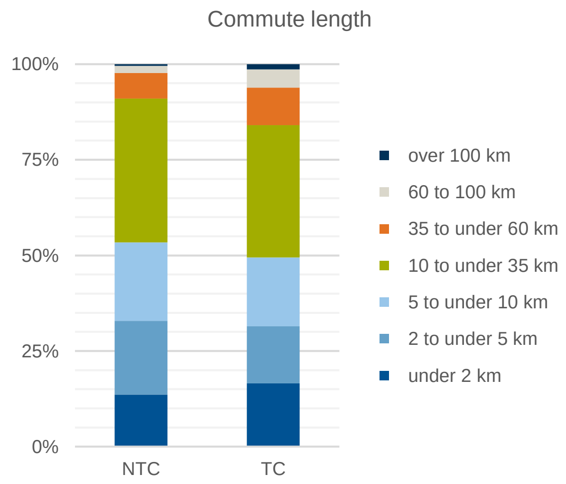

Figure 1

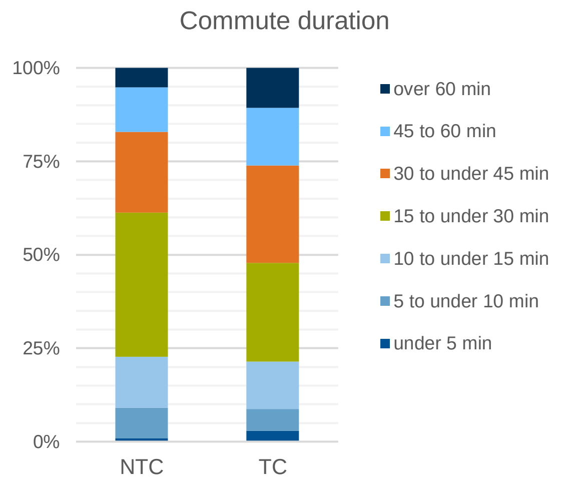

Figure 2

Figure 1 Commute length distribution of non-telecommuters and telecommuters (weighted percentages)
Figure 2 Commute duration distribution of non-telecommuters and telecommuters (weighted percentages)

3.1.1.2. Telecommuting frequency

The dataset used to analyse the effect of household and individual characteristics on telecommuting is significantly smaller than the dataset analysed for the likelihood to telecommute. As the descriptive statistics for the whole dataset provide little information, a table is shown in the Appendix, that presents detailed descriptive statistics on telecommuters categorized according to telecommuting frequency. To provide an overview over the characteristics of respondents, variables that exhibit considerable variation among the different groups are illustrated in Fig. 3 to Fig. 7.

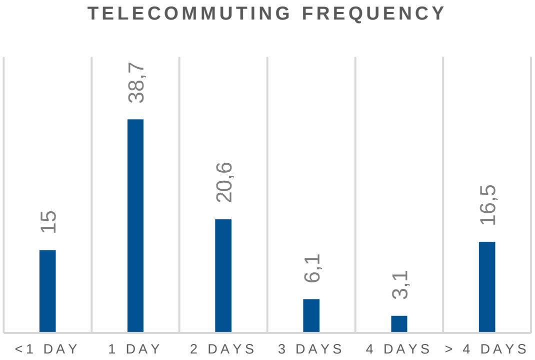

Figure 3

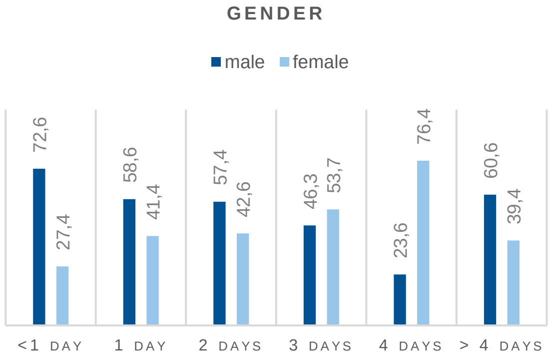

Figure 4

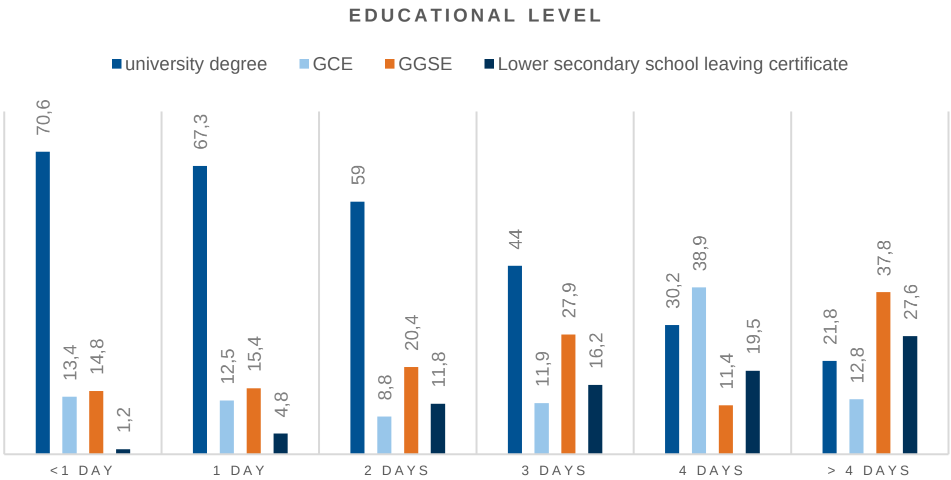

Figure 5

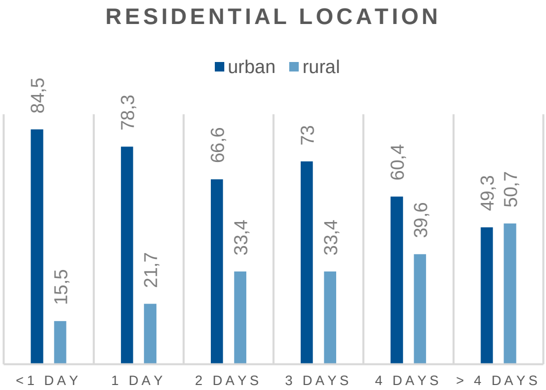

Figure 6

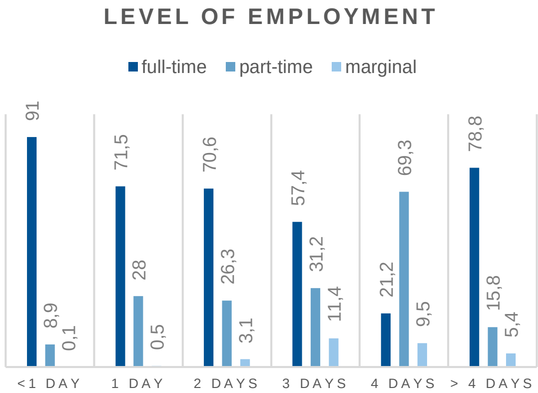

Figure 7

Figure 3 Distribution of telecommuting frequency
Figure 4 Distribution of gender for different telecommuting frequencies
Figure 5 Distribution of educational level for different telecommuting frequencies
Figure 6 Distribution of residential location for different telecommuting frequencies
Figure 7 Distribution of level of employment for different telecommuting frequencies

Fig. 3 indicates that most people telecommute one day per week. A similar number of people telecommutes less than one day, two days or over four days per week, while only a few telecommute three to four days per week. Fig. 4 shows that less frequent as well as highly frequent telecommuters (one to two days or over four days per week) are predominantly male. In the groups of individuals telecommuting three or four days per week, women are represented more strongly than men. Less frequent telecommuters (less than one day to two days per week) show a significantly higher percentage of people with a university degree. Telecommuters that telecommute more than two days per week exhibit a more balanced distribution of educational levels (Fig. 5). Telecommuters show a clear trend in the distribution of residential location among the different groups. While infrequent telecommuters are strongly dominated by urban residents, the difference becomes less pronounced with increasing telecommuting frequency. In the group of highly frequent telecommuters (over four days per week), the residential locations are represented almost equally (Fig. 6). The level of employment varies among telecommuters. Generally, full-time employees are strongly represented in all groups, though people telecommuting for three to four days show an increased share of part-time and marginally employed workers (Fig. 7).

Fig. 8 illustrates a clear trend of commute length distribution among the different groups of telecommuters. 60% of infrequent telecommuters (less than one day per week) have a commute length over 10 kilometres and almost 25% even commute for more than 35 kilometres. Only 15% commute for less than 5 kilometres. This distribution shifts with increasing telecommuting frequency. People telecommuting for one day a week show similar percentages for longer commute lengths, though 25% commute for less than five kilometres. This applies to 40% percent of those telecommuting two to four days a week and 50% of highly frequent telecommuters. In these two groups only 40% have commute lengths over 10 kilometres and only few highly frequent telecommuters (over four days a week) commute for over 35 kilometres.

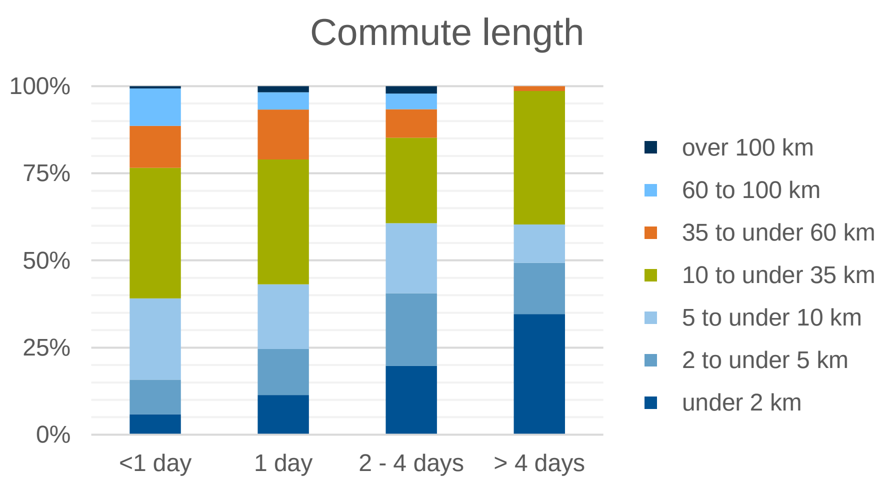

Figure 8 commute length distribution for different telecommuting frequencies (weighted percentages)

Although the descriptive statistics of telecommuters show notable trends, it is unclear to what degree these differences are influenced by telecommuting engagement and telecommuting frequency. They could also be facilitated by household and individual characteristics that are linked to telecommuting engagement.

3.1.2. Deutsches Mobilitätspanel (MOP)

The Deutsche Mobilitätspanel (MOP) is a panel survey, which is commissioned by the Bundesministerium für Verkehr und digitale Infrastruktur (BMVI). It is conducted annually since 1994 to gain insight into the mobility behaviour and its' development trends in the German population. The Institut für Verkehrswesen (IfV) of the Karlsruher Institut für Technologie (KIT) process the datasets. Similar to the MiD 2017, the MOP is carried out in two consecutive phases. In autumn, households are selected to be representative of the German population and report on their everyday mobility over a period of one week. Furthermore, respondents provide information on household and individual characteristics. The following spring, households with a car monitor their mileage and fuelling processes over a four-week period. Households are asked to participate in the MOP survey for three consecutive years to enable the monitoring of development trends. Each year, a share of participating households leaves the survey, while new households enter the MOP (Bericht Mobilitätspanel).

In this study, only datasets from the first survey phase are analysed, including information on household and individual characteristics, as well as information collected in the travel diaries. Due to its sample size, the MOP survey is less representative for the German population than the MiD 2017. Nevertheless, weighting factors are provided in the survey and are therefore included in certain analyses.

3.1.2.1. Telecommuting option vs. telecommuting choice

In the MiD 2017 survey, respondents were asked if they exclusively worked at home some days and if so, on how many days per week. Participants in the MOP had to provide information whether they had the option to exclusively work from home some days and if they seized this possibility. Disposing over this information provided the opportunity to analyse the option and the choice dimension of telecommuting. Table x. lists the descriptive statistics for the dataset including total numbers of respondents as well as weighted percentages.

Table 4 Descriptive statistics for the telecommuting option and choice datasets

Variable	Option				Choice			
	Yes 1,774		No 5,872		Yes 1,333		No 441	
	%	N	%	N	%	N	%	N
Gender								
Male	56.1%	990	51.2%	2.794	52.5%	709	66.2%	281
female	43.9%	784	48.8%	3.078	47.5%	624	33.8%	160
Education								
university degree,	83.9%	1.436	48.4%	2.782	84.6%	1.099	81.8%	337
GCE	12.1%	256	35.8%	2.145	10.9%	171	15.4%	85
GCSE	4%	82	15.8%	945	4.5%	63	2.8%	19
Lower secondary school leaving certificate								
Employment								
Full-time	71.9%	1.298	72.6%	4.179	70.1%	947	76.8%	351
Part-time	28.1%	476	27.4%	1.693	29.9%	386	23.2%	90
Office location								
Inner metropolitan	44.8%	799	29.2%	1.602	43.7%	591	47.7%	208
Outer metropolitan	15.2%	277	12.4%	747	15.5%	218	14.3%	59
regiopolitan	25.1%	414	27.6%	1.649	26%	315	22.7%	99
Small city	10.6%	206	21.3%	1.291	9.9%	145	12.6%	61
rural	4.3%	78	9.5%	583	4.9%	64	2.7%	14
Household type								
1 – 2 workers	52%	952	53.9%	3.234	49.8%	687	58.3%	265
Household with	41.4%	678	36.1%	1.906	43.3%	527	36.2%	151
children	6.6%	144	10%	732	6.9%	119	5.5%	25
> 2 people without children								
Household income								
> 5.000 €	24.5%	582	9.6%	794	26.5%	464	19%	118
3.500 – 5.000 €	31.4%	533	27.4%	1.780	30.9%	398	32.6%	135
2.500 – 3.500 €	21.8%	356	27.4%	1.600	18.8%	237	30.2%	119
1.500 – 2.500 €	17.4%	234	26.2%	1.286	17.8%	176	16.2%	58
< 1.500 €	4.9%	69	9.4%	412	6%	58	2%	11
Age								
< 30 years	0.7%	16	4%	138	0.8%	13	0.4%	3
30- 39 years	23.1%	272	15.2%	647	21.8%	200	26.8%	72
40 – 49 years	24.8%	408	21.6%	1.059	25.2%	305	23.9%	103
50– 59 years	33.3%	629	34.5%	2.165	33.9%	465	31.6%	164
>= 60 years	18.1%	449	24.7%	1.863	18.3%	350	17.3%	99
Commute length								
under 2 km	11.8%	171	11.2%	571	10.5%	117	15.7%	54
2 to under 10 km	35.4%	622	38.9%	2.209	34.4%	451	38%	171
10 to under 20 km	20.9%	384	22.6%	1.407	21.1%	290	20.4%	94
20 to under 50 km	23.1%	426	22.6%	1.399	23.1%	323	23%	103
over 50 km	8.8%	171	4.7%	286	10.9%	152	2.9%	19
Household size								
1 person	24.1%	332	24.4%	1.071	22.3%	216	29.2%	116
2 people	29.3%	645	31.2%	2.214	28.7%	489	31%	156
3 people	21.5%	346	20.6%	1.165	22.1%	274	19.9%	72
4 people	19.9%	349	18.9%	1.104	22.1%	275	13.9%	74
>4 people	5.2%	102	4.9%	318	4.8%	79	6%	23

Fig. 9 provides an overview over commute length distributions for employees that are given the option to telecommute as well as those taking this opportunity. The proportions are expressed as weighted percentages as this facilitates a higher representativity of the sample.

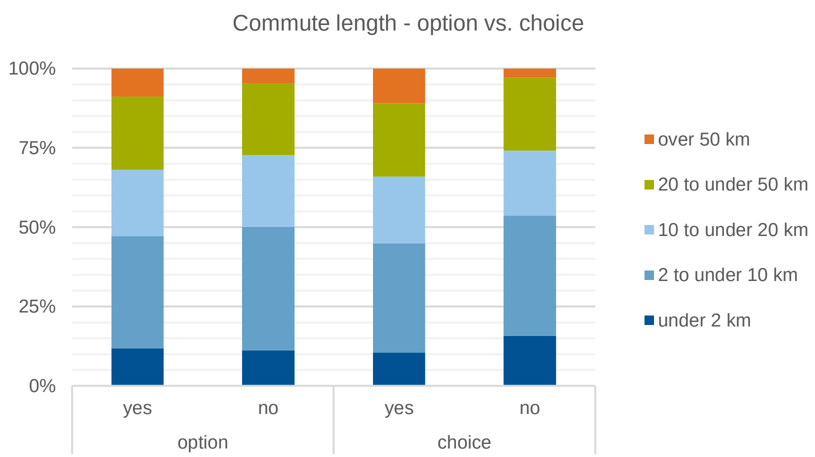

Figure 9 Commute length distribution for the option and choice dimension of telecommuting (weighted percentages)

Commute lengths seem to be distributed similarly among the three groups, though people given the option to telecommute tend to have a slightly higher percentage of longer commutes. This also applies to those people that take the opportunity to telecommute. Based on this observation it seems as though commute length only has a minor effect on the option and choice dimension of telecommuting.

3.1.2.2. Telecommuting and relocation

As households are generally part of the MOP survey for three consecutive years, it is possible to monitor their behaviour over a longer period of time. Furthermore, each year respondents are questioned on residential relocation and job changes during the last year. This information made it possible to analyse potential interactions between telecommuting and relocation processes. Table 5. lists the descriptive statistics for the dataset including total numbers of respondents as well as weighted percentages. This dataset is not used for statistical modelling but solely for analyses based on descriptive statistics. Thus, Table 5 is intended to give an overview of the sample's composition, while more detailed descriptive statistics on commute length and relocation are presented in the results section.

Table 5 Descriptive statistics of the dataset for telecommuting and relocation

Variable	Weighted percentage	Number of respondents
Gender		
Male	56.5%	134
female	43.5%	124
Education		
university degree, GCE	67.2%	158
GCSE	21.3%	65
Lower secondary school leaving certificate	11.5%	34
Employment		
Full-time	74.7%	182
Part-time	25.3%	75
Office location		
Inner metropolitan	59.7%	137
Outer metropolitan	17.9%	51

Variable	Weighted percentage	Number of respondents
regiopolitan	15.7%	46
Small city	2.4%	11
rural	4.3%	12
Household type		
1 – 2 workers	52.5%	135
Household with children	42%	105
> 2 people without children	5.5%	16
Household income		
> 5.000 €	23%	52
3.500 – 5.000 €	21.8%	59
2.500 – 3.500 €	25%	59
1.500 – 2.500 €	17.5%	45
< 1.500 €	11.7%	39
Age		
< 30	3.2%	11
30- 39	17.5%	70
40 - 49	34.7%	96
>= 50 years	44.6%	80
Household size		
1	23.7%	58
2	30.1%	79
3	26.1%	61
>3	20.1%	59

3.2. Methodology

3.2.1. Data preparation

MiD 2017

The MiD 2017 dataset was used to conduct different analyses to gain insight on sociodemographic and mobility characteristics of telecommuters, their influence on telecommuting frequency as well as commute length and daily distance travelled. Thus, for each analysis the dataset had to be slightly adapted to allow for optimal utilization of survey information. Out of the 316,361 respondents only 30,342 employed people were interviewed on their ability to telecommute regularly. Furthermore, those reporting unfamiliar surroundings (private/business travel or unnamed reasons), illness on the reporting date, having a secondary residence, being a long-distance commuter, as well as those lacking values for critical characteristics were omitted. Filtering the original MiD 2017 data this way resulted in a basic dataset of 25,220 respondents to work with. For further analysis the mean one-way commute length and duration for each respondent were calculated.

In this thesis, a strong focus is placed upon commute length differences between telecommuters and non-telecommuters. Thus, it was crucial to include it when analysing which factors had an influence on the likelihood to telecommute. As not every respondent commuted on the reporting date, only 12,147 employees (including 1,120 telecommuters) could be included in the analysis. Out of this dataset, 1,114 telecommuters provided information on the extent of their telecommuting practices and were analysed to investigate which factors influence telecommuting frequency.

To test the hypothesis that telecommuting complements travel and does in fact not substitute for it. A major weakness of this analysis is the lack of information if an individual actually telecommuted on the reporting date, as this was not queried in the MiD 2017 survey. The only information obtainable is, whether the respondent commuted or if he did not. Therefore, the dataset was filtered to only include full-time employees who reported on a working day (Monday to Friday). This approach increased the likelihood that days on which no commute was reported by telecommuters were real telecommuting days and that days off were omitted. Unfortunately, full-time work is not limited to working days and might also take place on fewer than five days a week. Given the circumstances, however, it is the most accurate approach possible. Filtering the basic dataset resulted in a sample of 22,034 respondents.

MOP

The MOP survey waves from 2012/2013 to 2018/2019 provided suitable information to investigate the option and choice dimension as well as the relationship between telecommuting and relocation. Prior to the survey wave 2012/2013 the question regarding work at home was not included in the questionnaire. Initially, the seven survey waves were aggregated in one dataset to obtain a larger sample. The resulting dataset was filtered according to the MiD 2017 dataset and mean one-way commute length and duration were calculated for each respondent.

To obtain a suitable dataset for the analysis of telecommuting option and choice, respondents providing relevant information were filtered. The resulting dataset comprises over 7,600 respondents, out of which 1,774 people had the option to work at home occasionally. Out of these 1,774 respondents 1,333 chose to work from home some days.

The generation of a dataset concerning telecommuting and relocation was harder to obtain and significantly reduced the basic dataset. Only respondents that either reported a residential relocation or job change and furthermore provided information on a potential telework engagement before and after their relocation were suitable for the analysis. The resulting dataset comprised 257 respondents who reported a relocation during the survey period, including two statistical outliers. They were considered in the analysis, as they added value to the research findings.

To allow for a better comparison with as well as complementation to Ory and Mokhtarians work. this study is structured equally. Respondents are categorized in two groups and four subgroups. depending on telecommuting status after the change. Employees telecommuting after their change are being referred to as current telecommuters, whereas those not telecommuting after the change are defined as non-telecommuters. This categorization has to be reiterated each year, as telecommuting status is a “moving target” (Ory & Mokhtarian, 2006).

3.2.2. Selection of variables

Pre-selection of variables for the regression models was based on their occurrence in literature. Unfortunately, most studies had more detailed information and more variables than were queried in the MiD 2017 and MOP surveys. Thus, no variables possibly adding new findings could be included in the models.

For all models, variables were then selected using the method of stepwise selection, at the 90% level of confidence. For some household and individual characteristics more than one variable was available (e.g. age either as continuous or categorical variable; residential location categorized in urban – suburban – rural or in number of inhabitants). These variables had to be included into the models separately, and the variable showing the highest significance as well as increasing McFadden’s adjusted R^2 the most was retained, while the others were omitted. It should be noted that the variable of the means of transport for commuting were considered in each model. Only a limited number of people provided information in this regard, thus, the variable was not found to be significant for any of the models.

Table 6 lists all variables included in this study, with information on variable type as well as their equivalents and the MiD 2017 and MOP datasets

Table 6 Overview of analysed variables

Variable	Type	MiD 2017	MOP
Personal level variables			
Weighting factor	continuous	P_GEW	GEWHHPWO
Gender	Dummy	HP_SEX	SEX
Age	continuous	HP_ALTER	ALTER
Age (groups)	categorical	alter_gr1 – alter_gr5	-
Educational qualification	categorical	P_BIL	SCHULAB
Level of employment	categorical	HP_BKAT	BERUF
Telecommuting status	Dummy	P_HOFF1	HOMEOFF
Telecommuting frequency	categorical	P_HOFF2	HOMEOFF
Driving license	Dummy	P_FSCHEIN	-
Car availability	categorical	P_VAUTO	-
Carsharing membership	Dummy	P_CS	-
Pedelec availability	Dummy	P_VPED	-
Bicycle availability	Dummy	P_VRAD	-
Limited mobility	Dummy	mobein	-

Variable	Type	MiD 2017	MOP
Commute length	categorical	Wegkm_imp_gr	-
Commute length	continuous	Wegkm_imp	-
Commute duration	categorical	Wegmin_imp_gr	-
Commute duration	continuous	Wegmin_imp	-
Means of transport	categorical	multimodal	-
Household level variables			
Residential location	categorical	RegioStaR2, RegioStaR4, SKTYP, POLGK	IDREGIOSTAR2, IDREGIO-STARGEM5
Federal states of Germany	categorical	BLAND_GEO	-
Household income (very low – very high)	categorical	oek_status	EINKO
Household income	continuous	Hheink_imp	
Household income [€]	categorical	Hheink_gr1 – hheink_gr2	
Household type	Categorical	hhtyp	HHTYP
Household size	continuous	Hh_gro	HHGRO
Generated manually			
Household with children under 18 years	Dummy		
Household with children under 18 years	Dummy		
Household with children under 18 years	Dummy		
Mode of transport on commute	categorical		
Type of day	categorical		

3.2.3. Statistic modelling

Regression analysis aims to allow insight into relationships among interrelated variables, more specifically among a dependent variable and one or multiple independent variables (Cho, 2010). Information on telecommuting is generally contained in categorical variables. Thus, eight logistic regression models were estimated, to analyse the likelihood to telecommute as well as telecommuting frequency and the option and choice dimension of telecommuting.

A logistic regression model models the likelihood of an outcome based on explanatory variables (Sperandei, 2014). It is used to investigate the relationship between a binary/categorical dependent variable and multiple independent variables which, again, can be continuous, binary or categorical. Unlike linear regression, a logistic regression model estimates the natural logarithm of the odds for a specific outcome or event as a function of the explanatory variables. Furthermore, the method of least squares cannot be applied to logistic models. Instead, maximum likelihood estimation is used, which selects the parameters that maximise the probability of the observed data. The log of the odds is given by (Sperandei, 2014):

$$\log\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots \beta_m x_m$$

Where

π = probability of an outcome (e.g., telecommuting)

$ß_0$ = intercept

β_i = regression coefficients

x_i = explanatory variables

In the logit model estimating the likelihood to telecommute, telecommuting status was chosen as dependent variable, taking the value 0 if not telecommuting and the value 1 if telecommuting.

A similar approach applies to both models for the option and choice dimension. In the logit model for the option dimension, the opportunity to telecommute was selected as dependent variable, taking the value 0 if not having the opportunity to telecommute and taking the value 1 if given the option. Whether an individual chose to telecommute was chosen as dependent variable in the third model, taking the value 0 if not choosing to telecommute even if given the option and taking the value 1 if taking the opportunity to telecommute.

Initially, attempts were made to fit multinomial logistic regression model to estimate telecommuting frequency. Due to several reasons it was not feasible to fit the model. Firstly, different variables were found to be significant for different telecommuting frequencies. Secondly, significant variables often required altered reference groups depending on telecommuting frequency. Thus, five separate logit models were generated. The small sample size as well as the complex relationship between variables and telecommuting frequency allowed little scope for the arrangement of dependent variables. Table 7 shows the dependent variables chosen for each model.

Table 7 Dependent variables in logit models estimating telecommuting frequency

Logit model	**Dependent variable**
Logit model for the likelihood to telecommute at least one day per week	0 if telecommuting less than one day per week 1 if telecommuting at least one day per week
Logit model for the likelihood to telecommute more than one day per week	0 if telecommuting less than two days per week 1 if telecommuting at least two days per week
Logit model for the likelihood to telecommute more than two days per week	0 if telecommuting less than three days per week 1 if telecommuting at least three days per week

Logit model	Dependent variable
Logit model for the likelihood to telecommute more than three days per week	0 if telecommuting less than four days per week 1 if telecommuting at least four days per week
Logit model for the likelihood to telecommute more than four days per week	0 if telecommuting less than five days per week 1 if telecommuting at least five days per week

It should be noted, that in each logit model at least two categorical variables exhibited a statistically significant interaction. As only some categories showed significant interactions, the reference groups had to be adapted, which resulted in a lower McFadden's Adjusted R^2. Furthermore, the dataset did not allow for the inclusion of more than one interaction. Thus, only the logit regression for telecommuting likelihood yielded a higher McFadden's Adjusted R^2 when including the interaction.

3.2.4. Total distances on working and telecommuting days

To analyse distance differences between different types of day, daily distances were calculated for telecommuters and non-telecommuters, both for normal workdays (record days with commute trips) and days off for non-telecommuters as well as telecommuting days for telecommuters (report days with neither commute trips nor business trips).

3.2.5. Analysis of telecommuting and relocation

To gain insight on the relationship between telecommuting and residential relocation as well as job change, a similar approach to Ory and Mokhtarian (2006) was chosen. They established this kind of analysis to draw an inference about the causality between relocation and telecommuting. It should be noted that the term "relocation" in this study signifies both residential location as well as job changes to allow for an easier comprehension.

Firstly, respondents were categorized in two different groups depending on their telecommuting status after relocation: people not telecommuting after their relocation were classified as non-telecommuters, while those telecommuting after relocating were classified as telecommuters. Thus, analysing changes in commute length and duration for both groups facilitated insights on whether telecommuters tended to relocate further away from their home or job than non-telecommuters.

Telecommuters and non-telecommuters were then categorized into four different subgroups: employees neither telecommuting before nor after the relocation (for reasons of simplicity hereafter referred to as NN – No No). those starting to telecommute after the CHANGE (NY – No Yes). workers ceasing to telecommute after the CHANGE (YN

– Yes No) and lastly those telecommuting before as well as after the CHANGE (YY – Yes Yes).

The next section analyses the chronological order of relocation and telecommuting engagement to allow for a statement about their causal relationship: is the ability to telecommute encouraging employees to increase their commutes or/and is telecommuting enabling people who move further away from work or accept jobs further away from home independently of telecommuting to commute less frequently?

And does those non-telecommuters telecommuting before the relocation behave from those never telecommuting
To facilitate more representative results, weighting factors were applied to both number of people as well as commute lengths and durations. Weighting factors on personal level slightly changed from the year preceding the relocation to the following year, especially for people changing their area of residential location (urban to rural or vice versa) or those modifying their household type when moving. Thus, only the weighting factors from the year after the relocation were applied to the dataset.

It should be noted no statistically significant difference were found between the four groups, probably due to the small sample. This issue was also stated by Ory and Mokhtarian (2006).

3.2.6. Multicollinearity

The variables used in the models are not only continuous variables, but categorical variables with often more than two levels, which made it unfeasible to test for multicollinearity using a correlation matrix. Thus, the continuous variables were tested individually. Multicollinearity between categorical variables was tested using both the Chi square test and the Cramer's V test (normalized chi-square), as the chi-square value is sensitive to sample size and multilevel categorical variables. (Kearney, 2017). It is defined as:

$$V = \sqrt{\frac{\chi^2}{N \cdot min(r-1; c-1)}}$$ (Finsel, 2009)

Where

χ^2 = chi square

n = total number of the sample

r = number of rows

c = number of columns

The smaller of the number of rows and the number of columns in the contingency table is taken into account (Finsel, 2009).

Cramer's V can take a value between 0 and 1, 0 if there is no relationship between two categorical variables and 1 if there is a strong relationship.

For two variables where the chi-square test yielded p-values lower than the significance level p = 0.05, a Cramer's V test was carried out to measure the strength of the association. As for no two variables Cramer's V was found to be higher than 0.2, strong relationships between variables could be excluded.

To test for multicollinearity between categorical and continuous variables and at the same time test each model for multicollinearity, the variance inflation factor (VIF) was calculated for each model. The VIF evaluates the variance of regression coefficient when predictors are correlated, a VIF equal to 1 indicating no multicollinearity among regressors, a VIF above 5 indicating a high and possibly problematic correlation (Akinwande, 2015). In no model the VIF reached a value over 2.09.

Software

RStudio was used to perform all statistical analyses in this study. For logistic regression the glm() function was used while Cramer's V was calculated with the cramersV() function in the "lsr" package. To compute VIFs, the vif() function in the "car" package was utilised.
Diagrams were created with Microsoft Excel.

4. Results

4.1. Likelihood to telecommute

Table 8 shows the estimation results of the logistic regression regarding the likelihood to telecommute. The variables found not to be significant were possession of a driver's license, car availability, bicycle availability as well as multimodality. The model yielded a low McFadden's adjusted R^2 of 0.073. This could support the assumption that unobserved factors have a strong influence on telecommuting. Furthermore, low R^2 values for similar models are not unusual in research.

Table 8 Logit model of telecommuting likelihood

Coefficient	**Estimate**	**Pr(>|t|)**
Intercept	-0.9798	0.000581 ***
Individual characteristics		
Gender		
Male	(Reference)	
Female	- 0.2234	0.005063 **
Age	0.0062	0.067722 .
Educational qualification		
University degree	(Reference)	
GCE	- 0.5629	9.47e-10 ***
GCSE	- 1.0251	< 2e-16 ***
Lower secondary school leaving certificate	- 1.1532	2.84e-15 ***
Employment relationship		
full-time	(Reference)	
part-time	0.499	8.71e-09 ***
marginal	0.5725	0.008512 **
Carsharing membership	0.7527	2.18e-11 ***
Pedelec availability	0.2201	0.087198 .
Limited mobility	0.3722	0.081787 .
Household characteristics		
Household income		
> 5000 €	(Reference)	
3.500 – 5.000 €	- 0.2503	0.000853 ***
2.000 – 3.500 €	- 0.4764	2.15e-07 ***
< 2.000 €	- 0.2912	0.08115 .
Children < 6 years	- 0.7566	0.12436 *
Federal states of Germany		
Northern. Western. Southern and City states	(Reference)	
Eastern states	- 0.6083	0.000491 ***
Residential location		
metropolitan area	(Reference)	
regiopolitan area	- 0.1631	0.043493 *
rural area	- 0.2435	0.008328 **

Coefficient	Estimate	Pr(>|t|)
Commute length		
< 2km	(Reference)	
2 – 5 km	- 0.5531	6.33e-06 ***
5 – 10 km	- 0.3156	0.005479 **
10 – 35 km	- 0.1762	0.084604 .
35 – 60 km	0.3679	0.005715 **
60 – 100 km	0.8807	3.27e-07 ***
>100 km	1.4911	2.33e-08 ***
Interactions		
Gender*children < 6 years	0.6663	0.000771 ***

*Note. Signif. Codes 0*** 0.001** 0.01* 0.1 . ;Log-likelihood: -3437.3; McFadden's Adjusted* R^2*: 0.073*

Individual socio-demographic factors

Among the individual sociodemographic variables gender was found to have a statistically significant influence on the likelihood to telecommute, though the effects depend on the presence of children in the household. In childless households, men are more likely to telecommute than women. Having children under 14 years in the household makes it less like to telecommute for both men and women, although women are then more likely than men to do so. While telecommuting is often perceived as an effective way to combine professional and family life, the opposite effect is often observed. Having children present when working can be distracting and exhausting, thus decreasing the desire to telecommute (Singh et al. 2012). The differences between men and women can be attributed to the still existing role allocation regarding family and working life (Popuri & Bhat, 2003). Women often bear a great deal of responsibility for household chores and family life and are less likely to attain leading positions than men (Singh et al. 2012). As telecommuting is facilitated by higher positions it is not surprising that women are less likely to telecommute than men and are slightly more likely to do so when having children due to higher responsibilities at home (Drucker & Katthak, 2000).

Age is another factor positively affecting telecommuting likelihood. This may also be a consequence of older, more experienced employees holding higher positions facilitating the likelihood to telecommute. Furthermore, due to limited supervision, telecommuting is often a matter of trust for the employer (Drucker & Katthak, 2000). This facilitates preferential treatment of long-term employees for telecommuting engagement.

The likelihood to telecommute increases with a higher level of education. Telecommuting is closely connected to professions that require a higher education, especially highly technologized occupations that may further facilitate telecommuting (Popuri and Bhat, 2003)

Individuals in professional, managerial and technical occupations are more likely to telecommute than clerical/administrative, manufacturing/construction/maintenance/farming workers (Singh et al. 2012).

Another significant factor contributing to the likelihood to telecommute is the type of employment, with minor employment facilitating telework the most while full-time employment decreases the likelihood. This may be due to part-time and especially minor employees' reasons to not work full-time, such as parenthood, a flexible working life or the desire for a good work-life balance, which in turn can be linked to the will to telework as an even more flexible work modification (Popuri & Bhat, 2003).
Two factors regarding mobility were found to be significant for the likelihood to telework. People having a pedelec available are more likely to practice telework than those who do not and having a carsharing membership even further increases the likelihood. As neither multimodality nor mode of transport were found to be significant factors and pedelec availability or carsharing membership do not imply their actual use, it could be argued that the two factors do not directly influence the likelihood to telework but that teleworkers are more inclined to make use of innovative and flexible modes of transport.
As might be expected, people with restricted mobility are more likely to practice telework, as it allows for virtual mobility compensating for spatial limitations.

Household socio-demographic factors

Results indicate that household income is another factor having a positive impact on telecommuting likelihood. Generally, a higher household income facilitates the likelihood to telecommute. Individuals living in very low-income households (below 2,000€ per month) though, are slightly more likely to engage in telecommuting than medium-income households (2,000 – 3,500 €). The higher likelihood for high-income households can most likely be attributed to the fact that telecommuting friendly occupations are commonly connected to high incomes (Popuri & Bhat, 2003). The slight increase for individuals living in low-income households might be connected to the perceived ability of telecommuting to reduce commute travel. As travel money expenditure per household is strongly related to household income, households with very low income might see a possibility to make savings on their travel budget by reducing their commute (Zahiva & Talvitte, 1980).

Spatial factors influence telework, as well. People in eastern German federal states are less likely to telework than in the rest of Germany, which could be due to the prevalence of the education sector, social services and healthcare in the eastern federal states' economic structure as well as sparse population as compared with the rest of Germany (Jahresbericht Statistisches Bundesamt, 2015). As the service sector, which

facilitates the possibility to telecommute, is more strongly represented in densely populated areas, occupations that are telecommuting friendly are probably not as widespread in eastern German federal states (KfW Research, 2019).
Location of residency is another factor affecting the likelihood to telecommute. People living in metropolitan regions are most likely to telecommute, while living in a regiopolitan and especially a rural region reduces the likelihood. This is likely due to academic and highly skilled employees predominantly living in metropolitan or at least urban regions. As the service sector is more strongly represented in urban regions than the manufacturing sector, which in turn prevails in rural regions, telecommuting friendly occupations are more prevalent in urban regions (KfW Research, 2019).
Results indicate that commute length has a statistically significantly effect on the likelihood to telecommute, after controlling for all above-mentioned factors. The relationship is complex. Generally, the likelihood to telecommute decreases with decreasing commute length and is highest above 100 kilometres and lowest for a commute length between two and five kilometres. For commute lengths under two kilometres though the likelihood to telecommute is higher than for those between two and 35 kilometres. This inconsistency can be attributed to the fact, that the individuals who commute under two kilometres possibly include self-employed people working at home full time having their office located closely to their residential location. Unfortunately, the MiD 2017 dataset does not provide precise information on profession, which prevents the distinction between real telecommuters and people working at home full-time. Probably reporting very short commutes. Though all individuals included in the study reported to commute more than 0 meters.

In the 5-35 km range significance is rather low which implies that the decision to telework is influenced by unobserved factors in those middle-ranged commute lengths, as commute length is neither short enough nor long enough to strictly justify not telecommuting.

4.2. Telecommuting frequency

Table 9 shows the results of the logistic regression models estimating telecommuting frequency. The value of McFadden's Adjusted R^2 increases for the models with higher telecommuting frequencies.

Table 9 Logit models for telecommuting frequencies

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
Variable	Estimate	Estimate	Estimate	Estimate	Estimate
Telecommuting frequency	At least one day	More than one day	More than two days	More than three days	More than four days
Intercept	- 2.4314 *	- 2.7919 ***	-3.8602 ***	-5.57891 ***	-3.25889 ***
Gender					
Male	(Reference)	(Reference)	(Reference)		
female	0.3776 *	0.4398 ***	0.3450 *		
Level of employment					
Full-time	(Reference)	(Reference)	(Reference)		(Reference)
Part-time	0.7887 **	(Reference)	(Reference)		-0.52715 *
marginal	1.7716 .	1.8202 ***	0.8419 .		(Reference)
Educational level					
University degree	(Reference)	(Reference)	(Reference)	(Reference)	(Reference)
GCE	(Reference)	(Reference)	0.6873 **	0.57541 *	0.72342 *
GCSE	(Reference)	0.8021 ***	1.2117 ***	1.15887 ***	1.32625 ***
Lower secondary school leaving certificate	1.4897 *	1.1906 ***	1.6152 ***	1.72266 ***	1.70495 ***
Household income					
high	(Reference)	(Reference)			
medium	(Reference)	(Reference)			
low	1.1081 .	0.6796 *			
Limited mobility	- 1.2613 *				
Age					
< 40	(Reference)	(Reference)	(Reference)	(Reference)	(Reference)
40 – 50	(Reference)	0.4154 *	(Reference)	(Reference)	(Reference)
	0.5512 **	0.7087 ***	0.5750 **	(Reference)	0.83920 ***

	Model 1	Model 2	Model 3	Model 4	Model 5
50 – 59	0.7414 *	1.2649 ***	1.1663 ***	1.42605 ***	1.67879 ***
> 60					
Residential location					
Urban area	(Reference)		-	-	-
rural area	0.6284 **		0.6317 ***	1.51337 ***	0.81089 ***
Commute					
< 5 km	(Reference)	-	-	-	-
5 – 10 km	- 0.7303 **	-0.8153 ***	-0.7324 ***	-0.86728 **	-1.10797 ***
10 – 20 km	- 0.6535 *	-0.8498 ***		-0.88249 ***	
20 – 50 km	- 0.6201 *	-1.2738 ***	-1.4055 ***	-1.49848 ***	-1.62499 ***
> 50 km	- 0.5376 .	-0.6347 **	-1.6177 ***	-1.98894 ***	-2.49145 ***

*Note. Signif. Codes 0*** 0.001** 0.01* 0.1 .*

Model 1: Log-likelihood: -469.194; McFadden's Adjusted R^2: 0.057

Model 2: Log-likelihood: -644.281; McFadden's Adjusted R^2: 0.107

Model 3: Log-likelihood: -477.719; McFadden's Adjusted R^2: 0.129

Model 4: Log-likelihood: -384.090; McFadden's Adjusted R^2: 0.140

Model 5: Log-likelihood: -324.318; McFadden's Adjusted R^2: 0.16.5

Individual variables

Results indicate that women are more likely to telecommute more frequently than men, though gender was not a statistically significant factor for a telecommuting frequency above three days per week. This observation reinforces the assumption, that women might telecommute to achieve a compromise between family and working life. It should be noted though, that no significant interaction was found between gender and the presence of children.

Type of employment was also found a significant factor for the frequency to telecommute. Part-time and especially marginally employed individuals are more likely to telecommute at least one day a week, compared to full-time employees. Marginally employed workers are also more likely to do so for more than one and even two days a week than full-time and part-time employees. Furthermore, the latter are less likely to telecommute more than four days a week than the other two work forms. This may be due to the same reasons of part-time and especially minor employees to be more likely to telecommute than full-time employees. As telecommuting enhances a more flexible lifestyle, desired due to personal or occupational reasons, increasing telecommuting frequency might intensify anticipated effects.

The drop in likelihood for part-time employees might be due to full-time and minor telecommuting employees distributing their working hours evenly throughout the week, while part-time employees tend to two to three full workdays. This makes telecommuting more than four days a week highly unlikely.

The level of education exhibits a converse effect for telecommuting frequency than for the likelihood to telecommute. While a higher educational level makes telecommuting more likely, it makes it less likely to do so for more days a week. A lower the level of education increases the higher the likelihood to telecommute more frequently. This fact is somewhat counterintuitive, as job positions which enable telecommuting can mostly be connected to higher educational level. Thus, reasons could be multifaceted. One reason might be that a higher educational level and resulting higher positions imply greater responsibility (Popuri & Bhat, 2003) and thus the need for a more frequent physical presence at the workplace and. Another factor could be higher commuting cost savings by telecommuting more often, as lower income also implies a lower travel money budget.
A low monthly household income increases the likelihood to telecommute more frequently, though income does not have a statistically significant effect on telecommuting frequency above two days. This observation strengthens the assumption that low-income households might telecommute in order to make savings on their travel budget by telecommuting more frequently (Zahiva & Talvitte, 1980).

Unexpectedly, restricted mobility decreases the likelihood to telecommute at least one day a week. This may be due to people with reduced mobility not necessarily occupying jobs or positions allowing for telecommuting but that they are given the choice to do so at times, to provide an incentive or facilitate their working life. Unfortunately, there was no indication on this topic in other studies.

While a higher age increases the likelihood to telecommute, it also increases the likelihood to do so multiple times a week. This may be a consequence of a greater need for a less active life at higher ages or might be facilitated by the fact, that older and often long-term employees can be trusted to telecommute for more days a week.

Household variables

Having a child under 14 years in the household increases the likelihood to telecommute at least one day a week and increases it to do so more than two days a week. A child under six years even increases the likelihood to telecommute more than four days a week. thought unexpectedly. It should be noted that there was found no significant interaction between sex and having children for the frequency of telecommuting, which may be due to limited data. Having children causes the need and the desire to dedicate more time to upbringing, transport and leisure which is facilitated by the possibility to work from home and thus more flexible working hours, as mentioned before. As younger children are less independent than teenagers, they generally need more attention/dedication, which is confirmed by the higher likelihood to telecommute when having a child under six years. Results indicate that although the presence of children in the household decreases the likelihood to telecommute, an individual telecommuting when having children is more likely to telecommute frequently.
The likelihood to telecommute over three and even four days a week increases when living in a larger household. Drucker and Khattak (2000) underline that a connection between household size and telecommuting has been observed in several studies, but there exists no satisfactory explanation for this fact. They hypothesise that larger households may be related to complex domestic relationships, which could be facilitated by a higher work flexibility.

While results indicate, that living in an urban area increases the likelihood to telecommute, having a residential location in a rural area increases telecommuting frequency. Residents living in an urban region tend to have shorter commutes than those living in less urban regions (Zhu, 2011). Thus, residents of rural regions could try to avoid the longer commutes.

The means of transport an individual uses during a week were found to have a significant influence on telecommuting frequency. While being a multimodal person traveling by bicycle, public transport and/or car decreases the likelihood to telecommute for more than one day a week. Only traveling by public transport increases the likelihood to do so for more than two and even three days a week. People restricted in their mobility also tend to telecommute over two days a week.

Additionally, car availability was found to be a significant factor for the frequency of telecommuting. Never having a car available increases the likelihood to do so more than one day a week. compared to having one available occasionally or at all times. To travel by car is seen as one of the most comfortable mode choices due to its convenience and comfort. Not having the possibility to use a car may encourage people to compensate for the inconvenience by commuting less.

Pedelec availability increases the likelihood to telecommute more than one day per week but it also renders it unlikely to telecommute more than four days per week. As for the likelihood to telecommute, the availability of modern means of transport probably does not directly influence telecommuting frequency. It is more likely that teleworkers are not only open to more flexible ways of working but also to innovative modes of transport. However, highly frequent telecommuters might not find it necessary to buy a pedelec, as they commute significantly less and might prefer other modes of transport for non-work trips.

After controlling for all mentioned individual and household characteristics, commute length was found to be a highly significant and complex factor for telecommuting frequency. Working from home at least one day a week becomes more likely with increasing commute length but is also most likely with a commute under five kilometres. To do so more than one day a week is less likely the longer the commute, though likelihood slightly increases above 50 kilometres. Telecommuting more than two, three or four days a week becomes less likely with increasing commute lengths. The continuously highest likelihood to telecommute multiple days a week if commute length is under five kilometres might be due to self-employed people exclusively working from home (close to home), thus connecting a very short commute to a high number of telecommuting days. This is underlined by the fact, that the likelihood to telecommute over two days a week is negatively influenced by commute length. Two observations suggest that telecommuting is connected to longer commutes, though people telecommuting for this reason are more likely to telecommute less frequently. Firstly, the positive influence of commute length (for commutes over 5 kilometres) on the propensity to work at home at least one day a week. Secondly, the increase in the likelihood to telecommute more than two days a week with a commuting length over 50 kilometres. This effect does not apply to telecommuting frequencies over two days a week, which are negatively influenced by longer commute lengths.

4.3. Option vs. choice

Table 10 Logit models for telecommuting option and telecommuting choice

	Option		**Choice**	
Coefficient	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)
Intercept	0.7025	0.00293 **	- 0.8151	0.061461 .
Gender				
Male	(Reference)		(Reference)	
female	- 0.3783	2.73e-07 ***	0.5309	9.69e-05 ***
Education				
GCE, university degree	(Reference)		(Reference)	
GCSE	- 1.2119	< 2e-16 ***	- 0.7973	6.47e-06 ***
Lower secondary school leaving certificate	- 1.4581	< 2e-16 ***	(Reference)	
Employment				
Full-time	(Reference)			
Part-time	0.4475	1.06e-07 ***		
Office location				
Inner metropolitan	(Reference)		(Reference)	
Outer metropolitan	- 0.2119	0.03027 *	0.3528	0.065383 .
regiopolitan	- 0.5448	4.13e-11 ***	0.4977	0.020354 *
Small city	- 0.8736	< 2e-16 ***	(Reference)	
rural	- 0.8855	1.09e-08 ***	0.6748	0.059012 .
Household type				
1 – 2 workers or household with children	(Reference)			
> 2 people without children	- 0.3171	0.00866 **		
Household income				
> 5.000 €	(Reference)		(Reference)	
3.500 – 5.000 €	- 0.7423	< 2e-16 ***	(Reference)	
2.500 – 3.500 €	- 0.9368	< 2e-16 ***	- 0.3236	0.046473 *
1.500 – 2.500 €	- 1.1419	< 2e-16 ***	0.5883	0.008706 **
< 1.500 €	- 1.4175	2.12e-14 ***	1.5421	0.000905 ***
Age	0.0056	0.07035 .	- 0.0152	0.014465 *
Commute				
under 2km	(Reference)		(Reference)	
2 to under 10 km	- 0.2739	0.01871 *	0.3652	0.091271 .
10 to under 20 km	- 0.2660	0.03266 *	0.5178	0.028673 *
20 to under 50 km	- 0.2088	0.09084 .	0.5577	0.015957 *
over 50 km	0.3693	0.01900 *	1.8271	5.06e-07 ***
Household size			0.7037	0.000106 ***

	Option	Choice

*Note. Signif. Codes 0*** 0.001** 0.01* 0.1 .*

Option model: Log-likelihood: -2922.782; McFadden's Adjusted R^2: 0.289

Option model: Log-likelihood: -723.852; McFadden's Adjusted R^2: 0.257

Variables significantly influencing the option and choice dimension of telework, are similar to the factors connected to telecommuting likelihood. However, results suggest a more complex nature of telecommuter characteristics that cannot be explained solely by telecommuting likelihood. Women are less likely to be given the option to telecommute but are more willing to take the opportunity. Several authors (Singh et al., 2012; Safirova and Walls, 2004; McCrate, 2005) see a possible explanation in the fact, that women are receiving less autonomy and flexibility in their working life, as they often hold lower positions than men.

Household composition does affect the option to telecommute, but no statistically significant influence on telecommuting choice was found. Individuals living larger, childless households are less likely to be given the opportunity to telecommute than those part of smaller households or households with children. Employees with children are probably given the option to telecommute by their employers, to facilitate a better work-life balance (Sing et al., 2012). The insignificance for the choice dimension might be due to dataset limits but could also be the consequence of the perceived drawbacks of telework when having children, thus compensating for the option dimension. Furhtermore, household size positively affects the choice to telecommute, which strengthens the assumption of Drucker and Khattak (2000) that individuals of larger households might feel a greater need for a flexible working life due to more complex familiarly relationships. As stated previously, the connection between household size and telecommuting is well known but a satisfactory explanation does exist to date.

Age was found to positively influence the option to telecommute but to have a negative impact on the choice dimension. This is probably a consequence of older, more experienced and trustworthy employees holding higher positions, as mentioned previously. This might encourage the employer to give an employee the option to telecommute. However, younger employees are more likely to take the opportunity of a telecommuting engagement. It is likely that younger, more active individuals pursue telecommuting for a more flexible lifestyle.

The likelihood to be given the option to telecommute increases with a higher level of education, since telecommuting is often closely connected to professions requiring a certain degree of education (Singh et al., 2012; Peters et al., 2003). Choosing to telecommute though, is equally likely for individuals with a high or a low level of education. Singh et al. (2012) found similar results for the option dimension but no statistically significant effect of the level of education on the choice dimension. Unfortunately, literature does not yield any satisfactory explanation on this topic.

Household income is another factor positively influencing the option to telecommute. Higher incomes are closely linked to higher operating position, which are more likely to be telecommuting friendly. Conversely, living in low-income households facilitates the choice to telecommute. This observation further strengthens the assumption that telecommuting can be perceived as a possibility to make savings on one's travel budget.
Working part-time increases the likelihood to be given the option to telecommute, though no statistically significant effect was found for the choice dimension. Part-time positions could be linked to jobs generally allowing for more flexibility, which would ease telecommuting adoption. The results of Peters et al. (2003) exhibit similar effects. It should be noted that the results of Singh et al. (2012) indicate an opposite effect of the part-time employment on the option to telecommute, though due to fragmentary literature on this topic, it is not feasible to draw conclusions.

Office location affects the option and the choice dimension differently. A higher degree of urbanisation facilitates the likelihood to be given the opportunity to telecommute compared to more rural areas. As previously mentioned, the service sector is closely connected to telecommuting friendly occupations. Since it is more prevalent in urban regions, telecommuting friendly companies can be expected to be better represented in more densely populated areas. However, when given the opportunity to telecommute individuals working at locations in less populated areas are more likely to choose to telecommute. A possible explanation could be poorer traffic connections in rural areas, facilitating the desire to commute less frequently. Unfortunately, literature on the relationship between office location and telecommuting is sparse. This makes it difficult to draw conclusions on this topic and especially on the similar effect of inner metropolitan areas and small cities on the choice dimension.

Commute length

Results indicate that commute length has a statistically significant effect on both the option as well as the choice to telecommute, after correcting for above previously mentioned variables. Individuals with a commute length of over 50 kilometres are the most likely to be given the opportunity to telecommute. The likelihood to be given the option to work at home decreases with decreasing commute length. It is slightly higher for individuals with commutes under two kilometres, possibly because this group may include self-employed people working close to their residential location. Furthermore, longer commute lengths highly facilitate the choice to telecommute.

This observation suggests that employees with long commutes are more likely to be given the opportunity to work at home and are also more likely to engage in telecommuting. However, it is not clear if they were given the opportunity due to their longer commute or if they chose a longer commute due to the option to telecommute.

4.4. Total distances on working and telecommuting days

Fig. 10 illustrates the distribution of total distances for non-telecommuters and telecommuters, depending on the type of day. Slightly over 50% of telecommuters travelled over 35 kilometres per day and around 15% even travelled over 100 kilometres, while around 45% of non-telecommuters covered over 35 kilometres and slightly over 10% travelled further than 100 kilometres. On a day off, non-telecommuters exhibited a shift to shorter distances with 35% covering distances under 10 kilometres and only 25% travelling over 35 kilometres. The distribution of total distances of telecommuters on potential telecommuting days was found to be almost identical to total distances of non-telecommuters on their free days.

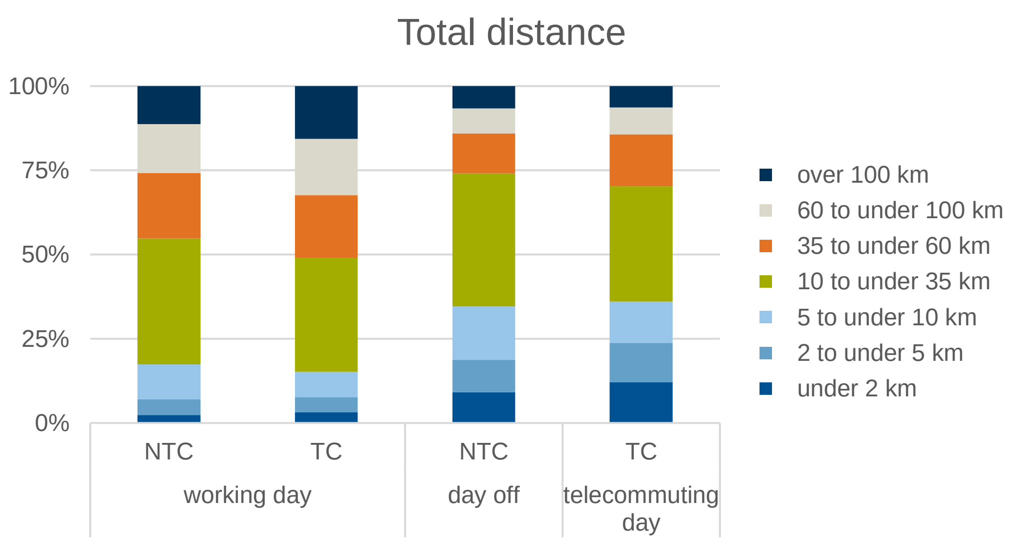

Figure 10 Distribution of total distances depending on type of day (weighted percentages)

Though Fig. 10 does not indicate significant differences between non-telecommuters and telecommuters, Fig. 11 and Fig. 12 show slightly different results. Compared to non-telecommuters, people telecommuting less than one day per week covered longer distances on working days: while around 45% of non-telecommuters travelled over 35 kilometres per day and 10% covered over 100 kilometres, the same applies to almost 60% of telecommuters and around 15%, respectively. These differences get less pronounced for more frequent telecommuters and highly frequent telecommuters (over four days per week) show an even higher percentage of short distances under 10 kilometres (30%) but a lower percentage for long distances.

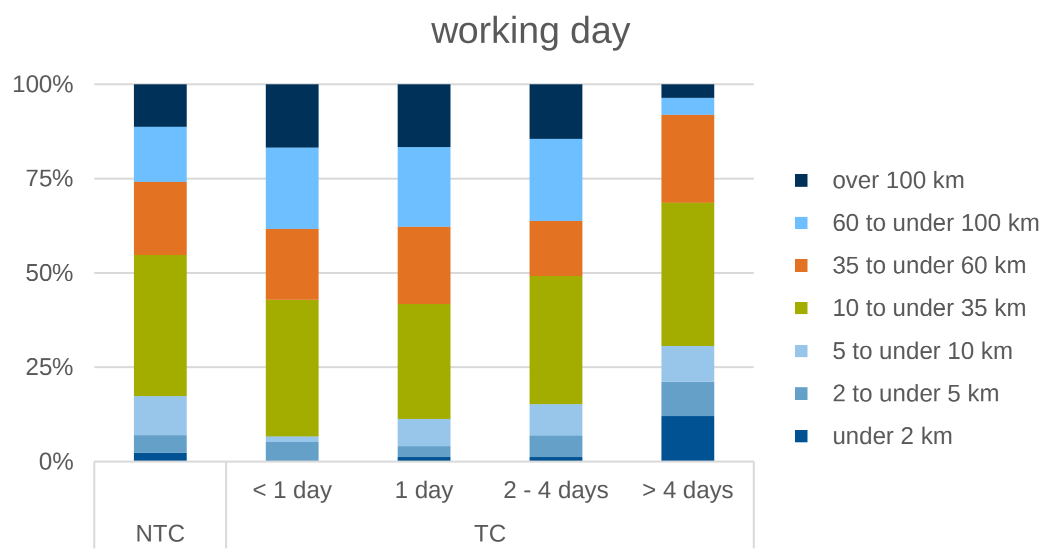

Figure 11 Distribution of total distances on working days for non-telecommuters and telecommuters

The distribution of total distance on days without commute is almost identical for non-telecommuters and more frequent telecommuters (at least two days per week), though a slightly higher percentage of telecommuters covered total distances of less than 10 kilometres. People telecommuting one day per week showed a similar distribution to non-telecommuters though slightly more telecommuters travelled longer distances over 35 kilometres (30%). Infrequent telecommuters (less than one day per week) exhibited an even higher percentage of distances over 35 kilometres (40%) and a lower percentage of shorter distances under 10 kilometres (25%).

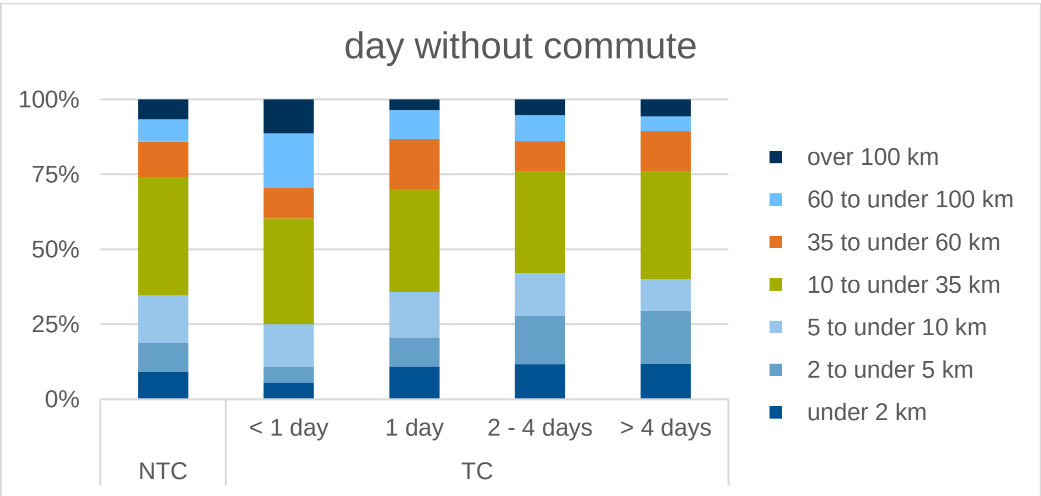

Figure 12 Distribution of total distances on days without commute trips for non-telecommuters and telecommuters

Table 11 provides an overview over weighted means, weighted medians and weighted standard deviations for non-telecommuters and telecommuters on working days and days without commute. The values confirm the trends seen in Fig. 10 to Fig. 12. No significant differences can be observed between non-telecommuters and telecommuters, though telecommuters covered slightly longer distances on working days and marginally shorter distances on telecommuting days. When taking telecommuting frequency into account, differences between the different groups become more obvious.

Table 11 descripitve statistics for working days and days without commute trips

	Working day				**Day without commute trips**			
	N (%)	**Mean**	**Median**	**SD**	**N (%)**	**Mean**	**Median**	**SD**
non-telecom-muter 17,814	11,650 (65.8%)	*46.14*	*29.67*	*56.52*	6,164 (34.2%)	*31.30*	*17.10*	*48.50*
Telecommuter 2,944	1,177 (58.6%)	*55.25*	*39.2*	*58.03*	1,767 (41.4%)	*29.44*	*15.51*	*40.73*
<1 day 334	201 (54.5%)	*60.69*	*39.9*	*66.41*	133 (45.5%)	*63.30*	*47.47*	*67.04*
1 day 968	524 (52%)	60.13	47.46	53.31	444 (48%)	*28.32*	*16.43*	*34.80*
2- 4 days 1033	305 (33%)	59.49	36.02	68.62	728 (67%)	27.04	15.70	34.92
>4 days 597	141 (31.3%)	27.30	22.36	26.75	456 (68.7%)	30.94	14.79	51.97

4.5. Telecommuting and relocation

As it was already shown before that telecommuters are generally more likely to have longer commutes, this part focuses on the changes in commute length and duration.

Table 12 and 13 present changes in average one-way commute length and duration of current telecommuters as well as non-telecommuters due to residential or workplace relocation (without outliers). Tables including the outliers can be found in the Appendix.

Table 12 Residential relocation

			Commute length [km]			**Commute duration [min]**		
Telecommuting status	N (%)		before	after	change	before	after	change
everyone	76	100%	16.27	15.21	-1.07 (6.5%)	25.18	26.66	+1.48 (5.9%)
Current	15	19.3%	14.46	20.17	+5.71 (39.5%)	28.43	38.69	+10.26 (36.1%)

			Commute length [km]			Commute duration [min]		
Non	61	80.7%	16.71	14.02	-2.68 (16%)	24.41	23.79	-0.62 (2.5%)

Table 13 Change of job

			Commute length [km]			Commute duration [min]		
Telecommuting status	N (%)		before	after	change	before	after	change
everyone	178	100%	14.48	13.38	-1.10 (7.6%)	26.13	25.86	-0.27 (1%)
Current	20	11.5%	12.57	16.28	+3.71 (29.5%)	23.65	29.63	+5.98 (25.3%)
Non	158	88.5%	14.73	13.56	-1.16 (7.9%)	26.45	25.37	-1.09 (4.1%)

Table 14 Statistical outliers

Group	Relocation type	Length before relocation	Length after relocation	Change in length	Duration before relocation	Duration after relocation	Change in duration
YY	workplace	13.00	135	+122 (983%)	17.33	130	+112.67 (650.%)
YY	workplace	0.7	27.0	+26.3 (3.757%)	5.0	85.0	80.0 (1.600%)
YN	residential	158.5	4.79	-153.7 (97.3%)	185	18.1	-166.9 (90.2%)

Both tables show similar trends. with a slight decrease in commute length of 1.07 kilometres (a 6.5% decrease from the pre-move average commute length of 16.27 kilometres) for residential relocations and 1.10 kilometres (7.6%) for job changes. Regarding commute duration. effects are even smaller. though residential relocations seem to slightly increase commute by 1.48 minutes (5.9%). while job changes decrease it by 0.27 minutes (1%). This result indicates that employees tend to slightly decrease commute length independent of due to residential location or job change. As changes in commute duration are minor changing patterns they seem to have less of an impact on it. It should be noted, that even if proportions for average commute length and duration are weighted, the sample still comprises a majority of non-telecommuters who highly influence the sample’s values.

Thus, the changes seen in non-telecommuters commute mostly comply with the overall sample, as can be expected, though they are more pronounced. They decrease commute length and duration irrespective of change type. When moving, non-telecommuters move closer to their workplace by 2.68 kilometres (16%) and 0.62 minutes (2.5%) on average. Following a job change. commute length decreases by 1.16 kilometres (7.9%) while commute duration is 1.09 minutes shorter (4.1%).

Disparities become apparent when looking at current telecommuters. Unlike non-telecommuters, telecommuters tend to strongly increase commute length and duration. irrespective of change type. Job changes increase commute by 3.71 kilometres (29.5%) and 5.98 minutes (25.3%) while residential relocation even increases commute by 5.71 kilometres (39.5%) and 10.26 minutes (36.1%).

These results clearly indicate that telecommuting after a move or job change highly increases commute length and duration compared to not telecommuting after the change. Though it should be noted that the differences between the two groups were not found to be statistically significant which may be due the small sample size, a problem already encountered by Ory and Mokhtarian (2006).

Table 15 presents an overview over the distribution of commute length and duration among telecommuters and non-telecommuters.

Table 15 Residential relocation and change of job in telecommuters and non-telecommuters

Telecommuter

Commute length [km]

Direction of relocation	N (%)	Commute length before relocation	Commute length after relocation	Change
all	*35 (100%)*	*13.39*	*17.99*	*+4.60 (34.4%)*
closer	10 (27.6%)	21.95	15.38	-6.56 (29.9%)
zero	2 (4.6%)	19.23	19.23	0
farther	*23 (67.8%)*	*9.52*	*18.97*	*+9.45 (99.3%)*

Commute duration [min]

Direction of relocation	N (%)	Commute duration before relocation	Commute duration after relocation	Change in min
all	*35 (100%)*	*25.74*	*33.59*	*+7.85 (30.5%)*
closer	15 (43%)	22.77	22.05	-5.72 (20.6%)
zero	-	-	-	-
farther	*20 (57%)*	*24.22*	*42.30*	*+18.09 (74.7%)*

Non-telecommuter

Commute length [km]

Direction of relocation	N (%)	Commute length before relocation	Commute length after relocation	Change
all	*219 (100%)*	*15.32*	*13.70*	*-1.62 (10.6%*
closer	*96 (47.7%)*	*22.52*	*10.00*	*-12.53 (55.6%)*

zero	16 (5.4%)	13.32	13.32	0
farther	107 (46.9%)	8.21	17.52	+9.31 (113.4%)

Commute duration [min]

Direction of relocation	N (%)	Commute duration before	Commute duration after	Change in min
all	*219 (100%)*	*25.84*	*24.09*	*-0.95 (3.7%)*
closer	*111 (51.8%)*	*33.25*	*20.14*	*-13.11 (39.4%)*
zero	9 (2.8%)	15.81	15.81	0
farther	99 (45.4%)	18.00	30.90	+12.91 (71.7%)

Results indicate that non-telecommuters do not show a clear tendency. as 47.7% (51.8% for commute duration) reduce their commute length while 46.9% (45.4%) have a longer commute after their relocation or job change. The small general trend of non-telecommuters to shorten their commute can be attributed to the slightly more pronounced change in commute reduction. While increasing commute is on average happening by 9.31 kilometres and 12.91 minutes, reducing commute length is on average 12.53 kilometres and 13.11 minutes.

Differences in the direction of change are much more pronounced in telecommuters. While 67.8% increase their commute length (57% for commute duration), only 27.6% shorten it (43% for commute duration). Furthermore, the increase of commute is on average 9.45 kilometres and 18.09 minutes, its decrease is significantly less, with 6.56 kilometres and 5.72 minutes.

While the percentage of people not changing their commute length when moving or changing their job is similar in both groups (4.6% in telecommuters. 5.4% in non-telecommuters), the weighted mean of commute length is higher in telecommuters

46.9% of non-telecommuters decrease their commute length or at least keep it the same. Almost 70% of telecommuters increase their commute length. Moreover, employees reducing their commute length significantly (at least 10 kilometres) make up almost 20% in non-telecommuters, whereas only 5% of telecommuters do so. In contrast, the groups significantly increasing their commute length (at least 10 kilometres) are more strongly represented in telecommuters (30%) than in non-telecommuters (slightly above 10%).

Commute duration changes exhibit a similar trend as commute length changes. though less pronounced. Around 55% of non-telecommuters do not change their commute duration or even reduce it, while around 60% of telecommuters increase their commute duration. As already seen in commute length, employees significantly decreasing their commute duration (at least 15 minutes) are more strongly represented in non-telecommuters (20%) than in telecommuters (<5%). On the contrary, people significantly increasing their commute duration (at least 15 minutes) are less represented in non-telecommuters (15%%) than in telecommuters (over 35%).

This trend is supported when looking at the exact distribution of commute length and duration changes among telecommuters and non-telecommuters. Fig. 13 and 14 display the percentage distribution of grouped kilometre and minute changes for residential relocations as well as job changes.

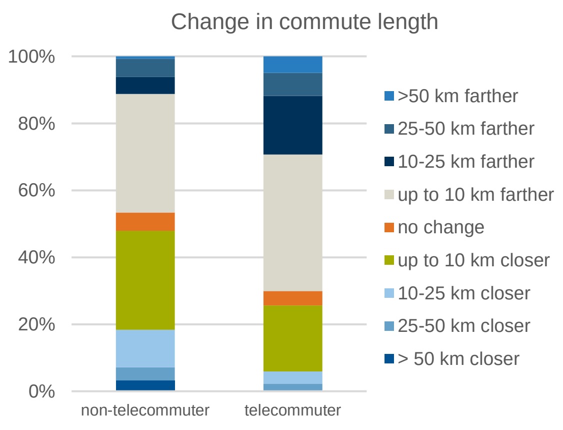

Figure 13

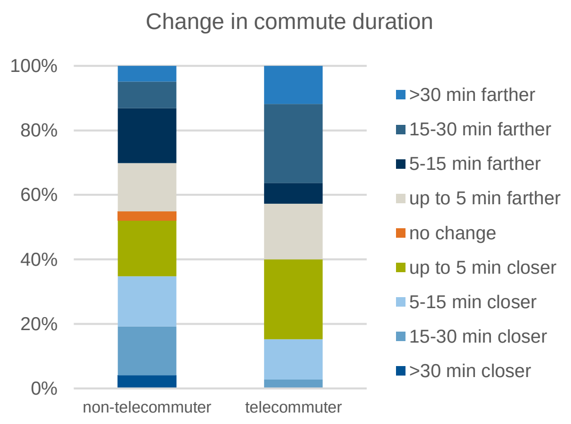

Figure 14

Figure 13 weighted distribution of changes in commute lengths for non-telecommuter and telecommuters

Figure 14 weighted distribution of changes in commute duration for non-telecommuter and telecommuters

As trends in employees moving and changing jobs are similar, both groups are combined which also allows to compensate for small sample sizes (especially in telecommuters). Furthermore, outliers are included, as their extreme values do not interfere and their existence add value and allow for insight.

It was already shown that non-telecommuters tend to slightly reduce their commute while telecommuters increase it.

Employees significantly reducing or increasing their commute length and duration (at least 10 kilometres or 15 minutes respectively) are disparately distributed among telecommuters and non-telecommuters. Those reducing their commute length significantly make up almost 20% in non-telecommuters. whereas only 5% of telecommuters do so. In contrast. the groups significantly increasing their commute length are more strongly represented in telecommuters (over 35%) than in non-telecommuters (around 10%). Furthermore. telecommuters even increasing their commute by over 25 kilometres make up over 10%.

As already seen in commute length, employees significantly decreasing their commute duration are more strongly represented in non-telecommuters (almost 20%) than in telecommuters (<5%). On the contrary, people significantly increasing their commute duration are less represented in non-telecommuters (15%) than in telecommuters (over 35%). Similarly, as seen in commute length. telecommuters increasing their commute duration over 30 minutes make up over 10%.

Furthermore, results contradict those of Ory and Mokhtarian, whose analysis indicates that telecommuters as well as non-telecommuters increase their commute length and duration following a residential move. though the trend is stronger in telecommuters.

Causal relationship

Table 16 presents commute length and duration for the four groups before and after the relocation as well as the magnitude of relocation. The YN as well as YY groups show two different values: The first row shows the weighted mean of the group without statistical outliers whereas the second row (grey) includes the three outliers.

Table 16 telecommuting status and relocation

telecommuting status before relocation		telecommuting status after relocation: No	telecommuting status after relocation: Yes
	No	**NN - no telecommuting** (N =195) Commute length [km] before: 15.89 · after: 14.18 · change: -1.71 (10.8%) Commute duration [min] before: 25.56 · after: 25.08 · change: -0.48 (1.9%)	**NY - commencement of telecommuting** relocation causes telecommuting (N=17) Commute length [km] before: 12.38 · after: 17.97 · change: +5.59 (45.1%) Commute duration [min] before: 22.65 · after: 31.53 · change: +8.88 (39.2%)
	Yes	**YN - cessation of telecommuting** (N=24) (N=25) Commute length [km] before: 11.22 · after: 10.27 · change: -0.92 (8.4%) before: 15.84 · after: 10.10 · change: -5.74 (36.2%) Commute duration [min] before: 27.85 · after: 23.58 · change: -4.28 (15.4%) before: 32.78 · after: 23.41 · change: -9.38 (28.6%)	**YY - continuation of telecommuting** telecommuting causes relocation (N=18) (N=20) Commute length [km] before: 14.54 · after: 18.02 · change: +3.47 (23.9%) before: 13.29 · after: 25.12 · change: +11.83 (89.1%) Commute duration [min] before: 29.23 · after: 35.92 · change: +6.69 (22.9%) before: 26.53 · after: 45.18 · change: +18.66 (79.3%)

As the majority of non-telecommuters are in the NN group. it is not surprising that their values match the findings of the previous sections. They slightly decrease both their commute length and duration by 1.71 kilometres (10.8%) and 0.48 minutes (1.9%). The second group of non-telecommuters is the YN group. Generally, they seem to behave similarly to the NN group in reducing both commute length and duration, though the trend intensifies when including the statistical outlier. Without the outlier the YN group decreases commute by 0.92 kilometres (8.4%) and 4.28 minutes (15.4%), a greater change than seen in the NN group. Including the statistical outlier though. even reduces commute by 5.74 kilometres (36.2%) and 9.38 minutes (28.6%). Due to the small sample size and a large variation in commute and commute changes it is not sensible to directly compare exact values. Nevertheless, there is a recognisable trend in both the NN and the YN group to reduce commute length and duration. Furthermore, the outlier indicates that being in the YN group could call for reducing commute more significantly due to long commutes connected to telecommuting before the relocation.

The key groups to analyse a possible causal relationship between telecommuting engagement and relocation are the NY and YY groups. Under the assumption of "temporal prevalence" the telecommuting engagement in the NY group is a consequence of relocation as telecommuting started after the relocation while in the YY group relocation is caused by telecommuting. as the decision to relocate was made when already telecommuting.

The NY group shows a clear trend to increase both commute length and duration when relocating, on weighted average by 5.59 kilometres (45.1%) and 8.88 minutes (39.2%). This indicates that employees increasing their commute by either moving or changing their job have a greater tendency to start telecommuting.

The YY group displays a similar trend. as they increase commute by 3.47 kilometres (23.9%) and 6.69 minutes (22.9%) on average. Including the two statistical outliers even increases commute by 11.83 kilometres (89.1%) and 18.66 minutes (79.3%). Overall, there is a recognisable trend in telecommuters to increase commute length. independently of whether telecommuting engagement was a consequence or the cause relocation. When directly comparing values in both groups. the trend seems to be slightly more pronounced in the NY group, though the small sample sizes might contribute to bias reality. As in the YN group, the outliers further reinforce the trend of the group, which indicates that the ability to telecommute may enable people to accept significantly longer commutes, thus increasing the distance of relocation changes.

It should be noted though, that when considering residential relocation and change of job separately, the YN and YY groups show a different trend when not including the outliers, though only minor. The YN group slightly increases commute length (by 1.34 kilometres) when moving while the YY group decreases commute length and duration (by 1.30 kilometres and 0.87 minutes) when changing their job. However, when including the outliers of both groups becomes even more obvious than in the table combining both groups. The YN group decreases commute by 22.72 kilometres and 27.39 minutes while the YY group increases commute by 26.62 kilometres and 39.42 minutes. This observation shows the influence of individual respondents in a small sample size and demonstrates its weak points. This simply indicates different relocation patterns when moving or changing job, independently of telecommuting.

While a strong trend in the four groups could be observed in the previous section, a closer look at the distribution of commute changes reveals even clearer differences and tendencies. especially between both non-telecommuter and the two telecommuter groups. Fig. 15 shows the proportional distribution of commute length and duration changes in all groups.

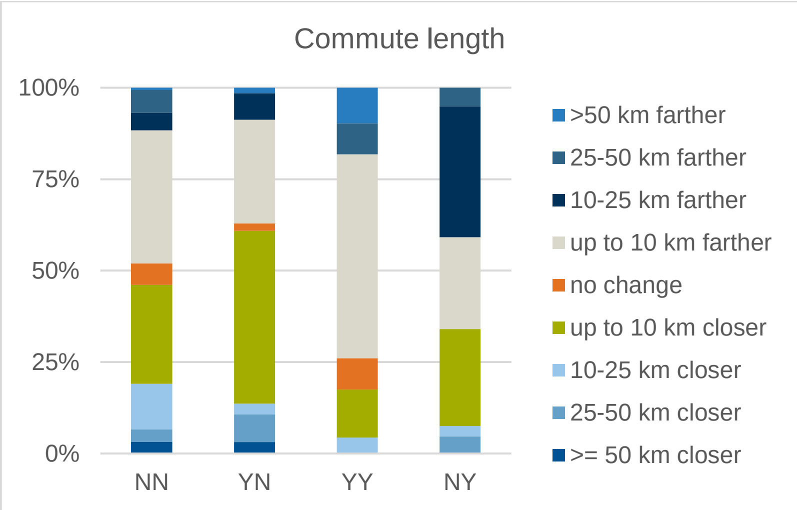

Figure 15 weighted distribution of commute duration for NN, YN, YY and NY

Around 46% of the NN group decrease commute length. 48% increase it. In the YN though, over 60% decrease commute length and only 37% increase it. Employees significantly changing their commute length (at least 10 km) are more strongly represented in the NN group with almost 20% decreasing and over 10% increasing commute. Over 5% even increase it by more than 25 kilometres. In the YN group only around 12% decrease commute while slightly under 10% increase it, like the NN group. Over 10% even decrease commute by more than 25 kilometres.

Only around 17% of the YY group decrease commute length while 74% increase it. Changes in the NY group are more balanced, with 34% decreasing and 66% increasing commute. In this case, too, differences become even more obvious when looking at those people significantly increasing their commute length. While over 60% of the NY group increase their commute by over 10 kilometres only around 20% of the YY group do so. Those 20% though, increase commute length by at least 25 kilometres. 10% even increase it by over 50 kilometres, while only around 5% of the NY group increase it by 25-50 kilometres.

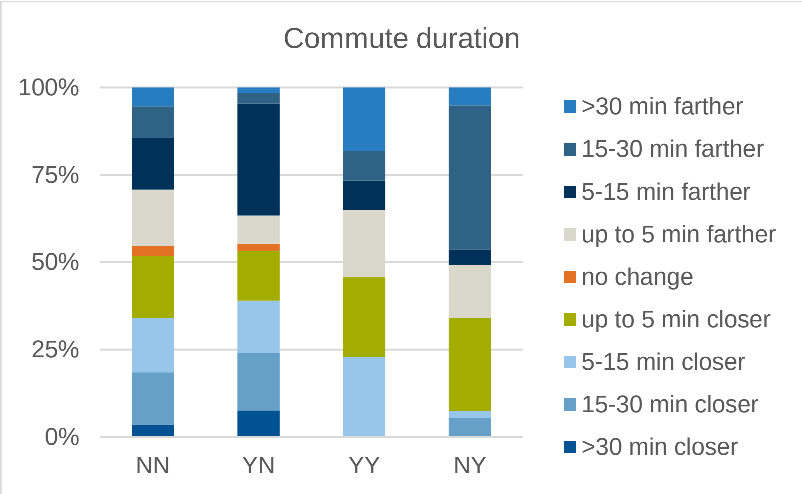

Figure 15 weighted distribution of commute duration for NN, YN, YY and NY

Differences in commute duration changes are less pronounced (Fig. 16). Around 52% of the NN group and 54% of the YN group decrease their commute duration, while 45% respectively 44% increase it. Even the distribution among those decreasing their commute is quite similar in both groups. Differences are slightly more noticeable in those employees increasing their commute duration. While the majority in the YN group (around 30%) increases commute 5 – 15 minutes. only 15% in the NN group do so, but 15% even increase it by over 15 minutes.

Differences in commute duration are slightly more pronounced between the YY and NY groups. While 54% of the YY group increase their commute, over 66% of the NY group do so. Disparities are again more noticeable in those employees significantly changing their commute duration. More people decrease their commute by over 5 minutes in the YY than in the NY group, though those decreasing their commute by over 15 minutes are only present in the NY group. In contrast, less people increase their commute by over 15 minutes in the YY group, but those increasing their commute over 30 minutes are more strongly represented (almost 20% compared to around 5%).

Results indicate that when telecommuting neither before nor after a relocation (NN) changes in commute length and duration are evenly distributed though there seems to be a minor tendency towards a considerable decrease in commute length (over 10 kilometres). When ceasing to telecommute after relocation (YN) there is a visible trend to decrease commute length. Furthermore, more employees tend to significantly decrease commute (over 25 kilometres or over 15 minutes) than significantly increase it.

People telecommuting before as well as after relocation (YY) are prone to increase commute length and exhibit a tendency to even increase it significantly (over 25 kilometres). The general trend to also increase commute duration is not as pronounced, though there seems to be a propensity to significantly increase commute (by over 30 minutes).

When starting to telecommute after relocation, people tend to increase commute length, though not as pronounced as those already telecommuting before relocating. However, the former show a stronger tendency to increase it considerably (10-25 kilometres). They exhibit a slightly stronger trend to increase commute duration as well. Again, they also tend to considerably increase commute (by 15-30 minutes).

Presuming the existence of temporal prevalence results indicate that telecommuting enables people having a longer commute to do so less frequently. especially those having a medium to long change in commute (10-25 kilometres. 15-30 minutes). The ability to telecommute though. seems to strongly facilitate extensive relocations. encouraging employees to increase their commute length by over 25 kilometres and commute duration by over 30 minutes.

5. Conclusion

The impacts of telecommuting on mobility behaviour are complex and multidimensional, as they are connected to often unknown factors that influence people's response. Though accurate comparisons are impeded by differences in various characteristics regarding research design, the results of this study mostly match other research findings.

Telecommuting is closely related to a wide range of factors that interactively influence different aspects of telecommuting. While characteristics such as being male or being a full-time employee facilitate the likelihood to telecommute, they can simultaneously have a negative effect on telecommuting frequency or the option and choice dimension of telecommuting. This interconnectedness makes it difficult to make reliable predictions.

In regards to its anticipated effect to reduce overall travel, this study's findings underline the impossibility to exactly identify a generalized impact, without having a high-quality dataset and detailed information on respondents. This is reflected by the discrepancies in literature regarding this topic. The observed outcomes in this study however indicate that having a longer commute length is linked to a higher likelihood to telecommute, a trend that can be transferred to both the option and the choice dimension of telecommuting. A long commute length though, is mainly connected to a lower telecommuting frequency. This observation raises concern about unintended impacts of telecommuting in commute travel reduction, as individuals with long commutes might not telecommute frequently enough to compensate for the longer one-way commute lengths.

Unfortunately, the research findings regarding differences in overall travel between working days and telecommuting days could not be proven statistically due to the lack of explicit information on telecommuting engagement on telecommuting days. Though when not controlling for factors such as age, gender or household income, the results show that infrequent telecommuters cover longer distances on telecommuting days than frequent telecommuters. This might even further underline the unsuitability of infrequent telecommuters to reduce commute travel and overall travel.

Results furthermore indicate that telecommuting might encourage people to increase their commute when relocating, though there is no definite evidence for this cause-and-effect relationship.

Telecommuting is gaining more and more importance in the modern working world and will probably keep evolving in its manifestation, due to a rapidly developing technological progress. It is crucial to acquire the ability to better assess the interrelationships and consequences of telecommuting, to allow for a perfect adaption of this complex type of work. At present, data quality and suitability are the major limitations in telecommuting research. It is thus important to keep generating and analysing data on telecommuting, to continuously contribute updated research findings. Today’s complex and fast changing world provides us with the opportunity to constantly develop our potential. To consciously connect technological development, telecommuting and data science could create a well thought out and ever evolving form of telecommuting engagement, highly adaptable to individual characteristics and enabling the most efficient use regarding mobility.

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Statement of independent work

I hereby confirm that this thesis was written independently by myself without the use of any sources beyond those cited, and all passages and ideas taken from other sources are cited accordingly.

Appendix

Change in residential location and office location with outliers

	Average change in commute length		Average change in commute duration	
Status	Number of changes	Change [km]	Number of changes	Change [min]
everyone	257	-3.8% (-0.59)	-	+2.6% (+0.69)
Current telecommuter	14.8% (37)	+68.2% (8.76)	-	+56.2% (13.83)
Non-telecommuter	85.2% (229)	-14% (-2.22)	-	-6.1% (1.61)

Change in residential location with outliers

	Average change in commute length		Average change in commute duration	
Status	Number of changes	Change [km]	Number of changes	Change [min]
everyone	77	-15.2% (- 2.70)	-	- 1.2% (- 0.32)
Current telecommuter	19.1% (15)	+39.5% (+ 5.71)	-	+ 36.1% (+ 10.26)
Non-telecommuter	80.9% (62)	-25.2% (- 4.67)	-	- 10.6% (- 2.81)

Change in office location with outliers

	Average change in commute length		Average change in commute duration	
Status	Number of changes	Change [km]	Number of changes	Change [min]
everyone	180	+2.7 (0.39)	-	+4.5% (1.16)
Current telecommuter	12.9% (22)	+92.5% (10.85)	-	+74.1% (16.31)

Telecommuting frequency

Descriptive statistics

	all 1114 people		< 1 d/w 193 p. 15%		1 d/w 496 p. 38.7%		2 d/w 196 p. 20.6%		3 d/w 67 p. 6.1%		4 d/w 30 p. 3.1%		>= 5 d/w 132 p. 16.5%	
Variable	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Gender														
Male	624	59%	130	72.6%	282	58.6%	102	57.4%	26	46.3%	11	23.6%	73	60.6%
Female	490	41%	63	27.4%	214	41.4%	94	42.6%	41	53.7%	19	76.4%	59	39.4%
Education level														
University degree	729	56%	137	70.6%	363	67.3%	129	59%	33	44%	16	30.2%	51	21.8%
GCE	172	12.7%	36	13.4%	66	12.5%	28	8.8%	14	11.9%	4	38.9%	24	12.8%
GCSE	155	20.7%	17	14.8%	50	15.4%	29	20.4%	16	27.9%	7	11.4%	36	37.8%
Lower secondary school leaving certificate	58	10.6%	3	1.2%	17	4.8%	10	11.8%	4	16.2%	3	19.5%	21	27.6%
Household income														
Very high	277	16.7%	44	13.8%	142	20.3%	31	15.4%	14	22.8%	12	14.6%	28	10.6%
high	554	45.7%	111	59.1%	238	47.4%	107	40.6%	29	31%	11	51.7%	58	39.9%
medium	224	27.3%	35	24.6%	96	22.3%	41	35.1%	16	21.2%	5	26.9%	31	34.1%
low	43	7.3%	2	1.2%	16	8.8%	7	7.7%	6	16.1%	1	1.9%	11	6.6%
very low	16	3%	1	1.3%	4	1.2%	4	1.2%	2	8.9%	1	4.9%	4	8.7%
Residential location														
Urban	802	71.2%	161	84.5%	365	78.3%	145	66.6%	44	73%	21	60.4%	66	49.3%
Rural	312	28.8%	32	15.5%	131	21.7%	51	33.4%	23	27%	9	39.6%	66	50.7%
Age														
< 30 years	54	9.9%	12	10.6%	25	12.1%	10	11.5%	3	9.5%	1	1.9%	3	3.9%
30-39 years	233	28.4%	59	42.1%	115	29.1%	31	27.3%	7	9.5%	5	21.4%	16	24.3%
40-49 years	325	28.4%	53	24.7%	154	33.1%	56	29.2%	21	24.8%	12	43.9%	29	18.3%
50-59 years	400	26.3%	58	18.1%	172	22.8%	76	25.9%	30	50.1%	8	27.2%	56	33.7%
60-69 years	96	6.6%	10	4.4%	28	2.8%	23	6.1%	5	5.9%	4	5.6%	26	18.6%
>=70 years	6	0.3%	1	<1%	2	0.1%	0	0%	1	0.2%	0	0%	2	1.2%
Professional activity														
Full-time	777	73.1%	166	91%	349	71.5%	124	70.6%	30	57.4%	13	21.2%	95	78.8%
Part-time	310	24.2%	26	8.9%	142	28%	63	26.3%	32	31.2%	13	69.3%	34	15.8%
marginal	27	2.7%	1	<1%	5	0.5%	9	3.1%	5	11.4%	4	9.5%	3	5.4%
Multimodality														
Car	471	44.3%	81	45.1%	186	36.1%	94	51.1%	40	69.8%	9	34.8%	61	46.8%
Public transport	47	4.5%	7	5.6%	21	4.1%	7	1.9%	3	6.2%	1	1.6%	8	7.9%
Bicycle	52	9.4%	12	8%	19	9.4%	11	12.9%	3	13%	1	12.9%	6	4.4%
Car + bicycle	291	23.1%	48	19.3%	130	23%	48	22.9%	13	7.2%	12	31%	40	31.5%
Car + public transport	96	5.8%	16	5.6%	51	8.4%	19	6.5%	2	0.8%	2	1.1%	6	1.8%
bicycle + public transport	61	6.1%	15	7.9%	30	7.7%	8	3.4%	2	1.4%	3	6.5%	3	5.1%
car, bicycle + public transport	91	6.3%	14	8.5%	58	10.4%	9	1.3%	4	1.6%	2	12.1%	4	1.5%
less mobile people	5	0.4%	0	0%	1	0.8%	0	0%	0	0%	0	0%	4	1%
Limited mobility														
No	1087	97.8%	186	97.3%	489	99.5%	189	98%	67	100%	28	90%	128	94.8%
yes	27	2.2%	7	2.7%	7	0.5%	7	2%	0	0%	2	10%	4	5.2%
Child < 18 years														
No	678	60.3%	130	67.7%	273	52.4%	129	67.7%	42	69.8%	15	43.1%	89	62.8%
Yes	436	39.7%	63	32.3%	223	47.6%	67	32.3%	25	30.2%	15	56.9%	43	37.2%
Child < 14 years														
No	771	66.2%	143	75.7%	323	59.9%	141	70.8%	48	74.7%	17	44.8%	99	67.7%
yes	343	33.8%	50	24.3%	173	40.1%	55	29.2%	19	25.3%	13	55.2%	33	32.3%
Child < 6 years														
No	966	82.5%	169	88.9%	417	78.3%	175	84%	63	94.6%	25	78.1%	117	81.3%
yes	148	17.5%	24	11.1%	79	21.7%	21	16%	4	5.4%	5	21.9%	15	18.7%
car availability														
always	998	88.1%	171	89.6%	445	88.9%	180	91.5%	58	82.5%	22	66.2%	122	86.5%
mostly	96	8.8%	19	8.6%	47	10.1%	10	4.6%	7	16.1%	5	14.4%	8	7.4%
never	20	3.1%	3	1.8%	4	0.1%	6	3.9%	2	1.4%	3	19.4%	2	6.1%
Pedelec availability														
No	1008	90.7%	180	97.2%	460	92.9%	170	82.6%	59	86.3%	28	98.1%	111	90.1%
yes	106	9.3%	13	2.8%	36	7.1%	26	17.4%	8	13.7%	2	1.9%	21	9.9%
Commute length														
under 2km	161	16.9%	16	5.8%	51	11.4%	36	19.4%	11	20.2%	3	20.5%	42	34.6%
2 to under 5	145	15.2%	17	10%	54	13.2%	28	23%	12	15%	10	18.3%	29	14.7%
5 to under 10	205	18.5%	42	23.3%	86	18.5%	35	15.5%	14	33.3%	2	25%	18	11%
10 to under 35	390	33.1%	79	37.5%	191	35.8%	57	24.2%	21	23.9%	10	27.8%	36	38.3%
35 to under 60	124	10%	19	12%	73	14.3%	18	10%	4	4.7%	4	3.1%	7	1.4%
60 to under 100	63	4.9%	18	10.7%	25	5.1%	15	4.9%	4	2.6%	1	5.3%	-	-
>100	26	1.4%	2	0.7%	16	1.7%	7	3%	1	0.3%	-	-	-	-
Household size														
1	159	23.5%	34	29.7%	63	19.9%	25	28.8%	13	23.8%	5	8.9%	21	22.4%
2	394	28.2%	79	30.8%	171	28%	76	25.1%	25	35.4%	5	41.9%	33	24.8%
3	207	15.9%	30	12.5%	90	17.4%	41	16.3%	9	16.2%	10	2.7%	35	17.1%
4	268	25.7%	43	21.8%	138	29.2%	34	21.6%	13	15.3%	6	15.2%	30	31.8%
>=5	86	6.7%	7	5.2%	34	5.5%	20	8.2%	7	9.3%	4	31.3%	13	3.9%

Job change and residentials: statistical ouliers in grey

Telecommuter

Commute length [km]

Direction of relocation	N (%)	Commute length before relocation	Commute length after relocation	Change in km (%)
all	37 (100%)	12.84	21.60	+8.76 (68.2%)
closer	10 (25.6%)	21.95	15.38	-6.56 (29.9%)
zero	2 (4.3%)	19.23	19.23	0
farther	25 (70.1%)	9.11	24.02	+14.91 (163.6%)

Commute duration [min]

Direction of relocation	N (%)	Commute duration before relocation	Commute duration after relocation	Change in min (%)
all	37 (100%)	24.63	38.46	+13.83 (56.2%)
closer	15 (40%)	22.77	22.05	-5.72 (20.6%)
zero	-	-	-	-
farther	22 (60%)	22.52	49.39	+26.87 (119.3%)

Non-telecommuter

Commute length [km]

Direction of relocation	N (%)	Commute length before relocation	Commute length after relocation	Change in km (%)
all	220 (100%)	15.89	13.67	-2.22 (14%)
closer	97 (47.9%)	23.65	9.95	-13.70 (57.9%)
zero	16 (5.4%)	13.32	13.32	0
farther	107 (46.7%)	8.21	17.52	+9.31 (113.4%)

Commute duration [min]

Direction of relocation	N (%)	Commute duration before	Commute duration after	Change in min (%)
all	220 (100%)	26.47	24.87	-1.61 (6.1%)
closer	112 (52%)	34.41	20.12	-14.28 (41.5%)
zero	9 (2.8%)	15.81	15.81	0
farther	99 (45.2%)	18.00	30.90	+12.91 (71.7%)

Residential relocation: statistical outlier in blue

Telecommuter

Commute length [km]

Direction of relocation	N (%)	Commute length before residential relocation	Commute length after residential relocation	Change in km (%)
all	15 (100%)	14.46	20.17	+5.71 (39.5%)
closer	2 (11.3%)	47.43	40.51	-6.91 (14.6%)
zero	2 (10.7%)	19.23	19.23	0
farther	11 (78%)	9.06	17.36	+8.31 (91.8%)

Commute duration [min]

Direction of relocation	N (%)	Commute duration before residential relocation	Commute duration after residential relocation	Change in min (%)
all	15 (100%)	28.43	38.69	+10.26 (36.1%)
closer	7 (46.5%)	32.01	27.12	-4.89 (15.3%)
zero	-	-	-	-
farther	8 (53.5%)	25.32	48.76	+23.44 (92.6%)

Non-telecommuter

Commute length [km]

Direction of relocation	N (%)	Commute length before residential relocation	Commute length after residential relocation	Change in km (%)
all	61 (100%)	16.71	14.02	-2.68 (16%)
	62 (100%)	18.58	13.90	-4.67 (25.2%)
closer	25 (45.4%)	25.03	12.51	-12.52 (50%)
	26 (46.1%)	28.85	12.29	-16.56 (57.4%)
zero	5 (5.9%)	7.02	7.02	0
	5 (5.9%)			
farther	31 (48.7%)	10.12	16.29	+6.17 (60.9%)
	31 (48%)			

Commute duration [min]

Direction of relocation	N (%)	Commute duration before residential relocation	Commute duration after residential relocation	Change in min (%)
all	61 (100%)	24.41	23.79	-0.62 (2.5%)
	62 (100%)	26.53	23.72	-2.81 (10.6%)
closer	28 (48.8%)	31.14	20.13	-11.01 (35.4%)
	29 (49.5%)	35.24	20.08	-15.16 (43%)
zero	4 (4.9%)	16.58	16.58	0
	4 (4.8%)			
farther	29 (46.3%)	18.14	28.40	+10.27 (56.6%)
	29 (45.7%)			

Change of job

Telecommuter

Commute length [km]

Direction of relocation	N (%)	Commute length before residential relocation	Commute length after residential relocation	Change in km (%)
all	20 (100%)	12.57	16.28	+3.71 (29.5%)
	22 (100%)	11.73	22.58	+10.85 (92.5%)
closer	8 (40.3%)	16.40	9.92	-6.49 (39.5%)
	8 (35.5%)			
zero	-	-	-	-
farther	12 (59.7%)	9.99	20.60	+10.61 (106.2%)
	14 (64.5%)	9.16	29.54	+20.38 (222.6%)

Commute duration [min]

Direction of relocation	N (%)	Commute duration before residential relocation	Commute duration after residential relocation	Change in min (%)
all	20 (100%)	23.65	29.63	+5.98 (25.3%)
	22 (100%)	22.00	38.31	+16.31 (74.1%)
closer	8 (40.3%)	23.95	17.49	-6.47 (27%)
	8 (35.5%)			
zero	-	-	-	-
farther	12 (59.7%)	23.45	37.81	+14.36 (61.3%)
	14 (64.5%)	20.93	49.75	+28.82 (137.7%)

Non-telecommuter

Commute length [km]

Direction of relocation	N (%)	Commute length before job change	Commute length after job change	Change in km (%)
all	158 (100%)	14.73	13.56	-1.16 (7.9%)
closer	71 (48.7%)	21.53	9.00	-12.53 (58.2%)
zero	11 (5.2)	16.38	16.38	0
farther	76 (46.1%)	7.35	18.07	+10.72 (145.9%)

Commute duration [min]

Direction of relocation	N (%)	Commute duration before job change	Commute duration after job change	Change in min (%)
all	158 (100%)	26.45	25.37	-1.09 (4.1%)
closer	83 (53.1%)	34.07	20.14	-13.93 (40.9%)
zero	5 (2%)	15.00	15.00	0
farther	70 (44.9%)	17.94	32.00	+14.06 (78.4%)

Residential relocation

telecommuting status before relocation or job change	telecommuting status after relocation/job change: No	telecommuting status after relocation/job change: Yes
No	**NN - no telecommuting** (N =55) Commute length [km] before 17.35 · after 14.35 · change -3.00 (17.3%) Commute duration [min] before 24.80 · after 24.28 · change -0.53 (2.1%)	**NY - commencement of telecommuting** relocation causes telecommuting (N=1) Commute length [km] before 1.17 · after 11.97 · change +10.80 (+925.8%) Commute duration [min] before 12.22 · after 30.71 · change +18.49 (151.3%)
Yes	**YN - cessation of telecommuting** (N=6) (N=7) Commute length [km] before 8.47 · after 9.81 · change +1.34 (15.8%) before 31.74 · after 9.03 · change -22.72 (71.6%) Commute duration [min] before 19.41 · after 14.02 · change -1.78 (9.2%) before 45.09 · after 17.70 · change -27.39 (60.7%)	**YY - continuation of telecommuting** telecommuting causes relocation (N=14) Commute length [km] before 16.90 · after 21.67 · change +4.77 (28.2%) Commute duration [min] before 31.41 · after 40.15 · change +8.75 (27.9%)

Change of job

telecommuting status after relocation	telecommuting status after relocation: No	telecommuting status after relocation: Yes
No	**NN - no telecommuting** (N =140) Commute length [km] before 15.22 · after 14.10 · change -1.12 (7.3%) Commute duration [min] before 25.91 · after 25.45 · change -0.45 (1.8%)	**NY - commencement of telecommuting** relocation causes telecommuting (N=16) Commute length [km] before 14.03 · after 18.85 · change +4.82 (+34.4%) Commute duration [min] before 24.18 · after 31.65 · change +7.47 (30.9%)
Yes	**YN - cessation of telecommuting** (N=18) Commute length [km] before 11.81 · after 10.37 · change -1.44 (12.2%) Commute duration [min] before 29.66 · after 24.85 · change -4.81 (16.2%)	**YY - continuation of telecommuting** telecommuting causes relocation (N=4) (N=6) Commute length [km] before 5.88 · after 4.58 · change -1.30 (22.1%) before 5.71 · after 32.33 · change +26.62 (466.1%) Commute duration [min] before 21.22 · after 20.35 · change -0.87 (4.1%) before 16.30 · after 55.72 · change +39.42 (241.8%)