

On the Substitution and Complementarity between Telework and Travel: A Review and Application

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Abstract

This paper offers a review of the scientific evidence regarding the relation between ICT and travel in general and ICT and commuting in particular. It focuses on the issue of teleworking at home and ignores other interesting phenomena as teleworking centers. The conclusions can be summarized as follows. In the short run, ICT and commuting are to be regarded as weak substitutes, although the relation differs across population groups and parts of the day. If total travel is taken into account, then the relation becomes less clear. However, there also seems to be substitution between non-commute travel and teleworking. This indicates particular recommendations for both environmental and traffic policy. The results are further illustrated by an empirical application from the Netherlands.

1 Introduction

In the late 90s, Information and Communication Technology – from now on the acronym ICT will be used – seemed to become a panacea for a wide range of societal problems, ranging from eternal economic growth (the network economy)¹ to bridging cultural gaps via the internet. In traveling issues, policy makers regarded promoting ICT to substitute commuting for telework as a viable instrument to solve (hyper)congestion problems. Moreover, teleworking would decrease total travel demand in the ‘knowledge’ economy (see, e.g., EC 2002). However, the empirical evidence indicates that the relation between using ICT for telework and travel is not as clear-cut as supposed. Therefore, this review focuses on this relation, where it in particular concentrates on the relation between teleworking and commuting.

In issues like this, it is most important to be clear in what is meant. We adopt the definition as used by the European Commission where teleworking is explicitly defined as work carried out using ICT at a place other than that where the results of the work are needed.² Moreover, although this definition covers home, mobile or ‘telecottage’-based teleworkers, the focus in this paper is explicitly on teleworkers who work at home. Note that in this definition nothing is mentioned about the duration nor about the frequency of working at home. Thus, working at home in the evening or in the weekends are also considered teleworking. In principle, we are not directly interested in self-employed work at home (artists, writers, etc.), although – according to the definition above – they are also considered as teleworkers as long as they use any form of ICT. Basically, we are interested in those workers who work occasionally at home, whether that is on a regular and formal basis or not. As already (Nilles 1988, p. 301) mentioned:

“... most home-based telecommuting is (and is likely to be) part-time.”

Note that this may have large consequences for travel and commuting behavior. Informal and flexible teleworking may have less impact on travel time than formal and regular telework.

With the surge in better and cheaper ICT appliances, most researchers state that working hours become more flexible, indicating that many workers have at least the opportunity to work at home. Coming from a post-industrial society, where most workers work out-of-home, it is not a bold statement to say that a significant part of the labor force will eventually choose to work at home at least part-time. With such profound changes in

¹See e.g. Shapiro & Varian (1999) for an extensive treatment or Woodall (1996) for a critical appraisal.

²For more information on the viewpoint of the European Union, visit http://europa.eu.int/information_society/.

working life, significant changes in travel behavior and demand are bound to happen. The question is to what extent and in what direction.

The remainder of this review is organized as follows. Section 2 provides an overview of the teleworking literature and presents some characteristics of the teleworking population with an emphasis on the European case. Although the surveyed literature is extensive, we do not aim to offer a complete overview. However, the references chosen represent an important subset of the existing literature in the authors' view. Subsequently, Section 3 offers an exposition of the relationship between commuting and teleworking and surveys the existing evidence for substitution between teleworking and commuting. In Section 4, we expand our view to the relationship between teleworking and total travel and look at possible travel generation effects of teleworking. Section 5 deals with the policy implications. The last section concludes.

2 A Primer in Teleworking

In order to understand the travel demand effects of teleworking, we first have to understand who the actors are and why they are doing it at all.³ Therefore, the first subsection looks at the characteristics of the typical teleworker. Most of this research has already been done in the 1980s and focuses mainly on the setting in the United States. Therefore, the second subsection deals with the European case and provides an international comparison.

2.1 The Archetypical Teleworker

Most research into the effects of ICT and the trade-off between telework and commuting starts usually with the work of Nilles et al. (1976), who accidentally also coined the term telecommuting in 1973 (Nilles 1988).⁴

Since the beginning of the 1980s, the impact of ICT on travel time and commuting received increasingly more attention; inter alia, Salomon (1986, 2000), Nilles (1988) and Mokhtarian (1990) provide some good overviews of the literature. Especially, much research was done into the characteristics of the teleworkers (see, i.a., DeSanctis 1983, 1984, Olson 1983, Olson & Primps 1984, Yap & Tng 1990, Mokhtarian et al. 1998, Bélanger 1999, Casimir 2001, Vilhelmson & Thulin 2001, Illegems & Verbeke 2003). The

³The title of this section is inspired by an early article of DeSanctis (1983).

⁴Researchers and policy makers in the United States often use the word telecommuting, while in Europe teleworking is more commonly used. As a matter of fact, telecommuting is a special case of teleworking. Telecommuting stands for the actual substitution of the commuting trip, while teleworking denotes literally working at a distance from the actual workspace (Salomon 2000).

early results indicate that especially women are *inclined* to telework, a result recently confirmed by Plaut (2004). Furthermore, significant characteristics of *actual* teleworkers include very specific job categories, computer access (thus, the availability of ICT appliances), employment type, in possession of a drivers license and especially income. When one looks at the individual *propensity* to telework then only income and computer access prevail (Vilhelmson & Thulin 2001, De Graaff & Rietveld 2004). This leads to the conclusion that drivers license, employment type and job category at the one hand and teleworking on the other hand are driven by the same common factors (e.g. unobservable skills, income, etc.). Or in the words of Vilhelmson & Thulin (2001, p.1023):

“This result indicates that the other factors considered here (for example, gender) are dominated by the fact that current teleworkers are high-income earners with good access to ICT technology and, probably, live under conditions, where they can quite generally control their use of time, place, and technology.”

The fact that income plays an important role in teleworking is theoretically justifiable. Namely, in an economic utility framework the amount of labor supply depends on the wage rate (see, e.g., Wales 1978, Deaton & Muellbauer 1980). Although the substitution effect between leisure and labor supply is negative as usual, it turns out that the (positive) income effect tends to increase in the wage rate and eventually dominates the substitution effect. Because working out-of-home usually invokes non-productive commuting time, shadow prices of commuting also increase in the wage rate. Therefore, high-wage earners are more likely to avoid commuting by teleworking. Another explanation could be that teleworking usually occurs in those jobs that require high schooling levels, which typically coincide with higher wage rates. In both ways, teleworkers are thus usually found in high-paid high-tech jobs, typically found in thick labor markets, i.e. cities. That is also why teleworking is less common in rural areas, as one could hypothesize a priori (as, e.g., in Clark & Unwin 1981).

As mentioned above, the literature describes a discrepancy between the characteristics of teleworkers and those who would like to telework. Olson (1983) and DeSanctis (1983) describe specific job⁵ and individual characteristics⁶ that are needed to ensure successful teleworking. However, these requirements were found for very specific job types and for regular and formal teleworking. Therefore, some of these requirements do not seem to

⁵Those are minimal physical requirements, individual control over work pace, defined deliverables, need for concentration, defined milestones, and a relatively low need for communications.

⁶Like self-motivation, self-discipline, skills provide bargaining power, family requirements, and few social contacts beyond work and family.

apply for more flexible and less formal teleworking.⁷

In the first of a series of papers, Mokhtarian & Salomon (1994) extend these requirements into a theoretical framework of constraints and incentives for the adaption of telework from the worker's perspective. Table 1 presents a slightly modified version of this framework. Basically, there are two reasons for not teleworking, external constraints set by the employer and an individual's internal disincentives to telework.

Table 1: Factors influencing the decision to telework.

Constraints & disincentives	Incentives
<i>External constraints</i>	Work related
- Awareness	- No disturbances
- Organization	Family related
- Monitoring costs	- More flexible
- Hubris	- More time with family
- Job constraints	Leisure related
<i>Disincentives</i>	- More time for self
- Lack of discipline	Travel related
- Utility from commuting	- No commuting costs
- Psychosocial factors	Ideological
- Risk constraints	- Saving energy
- Cost constraints	

The external constraints can be divided in three types. Firstly, there are awareness constraints, which deal with the lack of awareness or understanding concerning teleworking. These constraints are usually relatively easy to overcome. Secondly, there may be organizational constraints, which are more difficult to tackle. It could well be that the employer or the supervisor does not support or simply forbids the employee to telework. Namely, it is more costly to monitor the worker from a distance, while on the other side the supervisor could lose esteem when physically managing less people. Finally, there could be job-related constraints. Usually, a job does not suit teleworking, like in most capital intensive jobs (e.g. in the steel industry). An easier constraint to overcome is the availability of sector-specific technology. For example, the industrial-design sector requires different ICT appliances and applications compared with the banking sector.

Opposite to external constraints, a possible teleworker also faces personal disincentives to telework. Firstly, the possible teleworker may doubt his discipline in working productively at home. Secondly, workers may actually perceive utility from commuting. They may appreciate the traveling or the activities that can be conducted while traveling (Redmond &

⁷Especially 'low need for communications' and 'few social contacts beyond work and family' come here into mind.

Mokhtarian 2001, Mokhtarian & Salomon 2001). Thirdly, there are psychosocial constraints involved. Workers may like to interact physically with other workers and they may want to be physically noticed. Fourthly, workers may want to avoid risk. If not present at the office, they fear that their career opportunities are endangered. Finally, workers may face large costs when they start teleworking. Not only the ICT appliances and the connection with the Internet may be expensive, but also the additional space teleworking requires. Usually, a teleworker needs an extra room at home, which may be unavailable or costly to implement.

Opposite to constraints and disincentives, the literature reveals several incentives for workers to telework. To start with, workers may perceive to be less disturbed (like visits from colleagues, calls, emails, etc.) at home. Related with this, workers may actually be more productive at home, because they are able to work more successive hours without disturbance. Another reason to start teleworking is that one becomes more flexible and that working- and family-life can be better combined. This does not mean that teleworkers work and look after the children simultaneously, but, e.g., that workers have more time to bring their offspring to the day-nursery. Working at home also increases leisure time, because commuting time itself falls off and because lunch and coffee breaks can be spent more efficiently. The omission of commuting costs itself is the fourth incentive to telework. These costs break down in monetary, time, and psychological costs. Especially the last component may be important when workers perceive a great deal of stress when commuting. The last incentive to telecommute are ideological reasons. Namely, workers may feel better for, e.g., the environment when they avoid traveling and therefore save energy.

Knowing who are prone to telework and what the constraints and incentives are, it would be instructive to look at the actual situation. Therefore, the next subsection deals with surveying the existing evidence for teleworking in Europe.

2.2 Teleworking in Europe

In comparison with the United States, research into the effects of teleworking on travel demand is relatively scarce in Europe.⁸ Moreover, few empirical studies into the differences between European countries exist. Therefore, consistent comparisons are difficult to make. However, understanding the current level for telework in Europe is necessary to require an understanding of the limitations and possibilities of telework in Europe.

Recalling the constraints listed in Table 1, the first external constraint (awareness) is being tackled by most national governments and the Euro-

⁸For a general overview of teleworking in Europe see Korte & Wynne (1996).

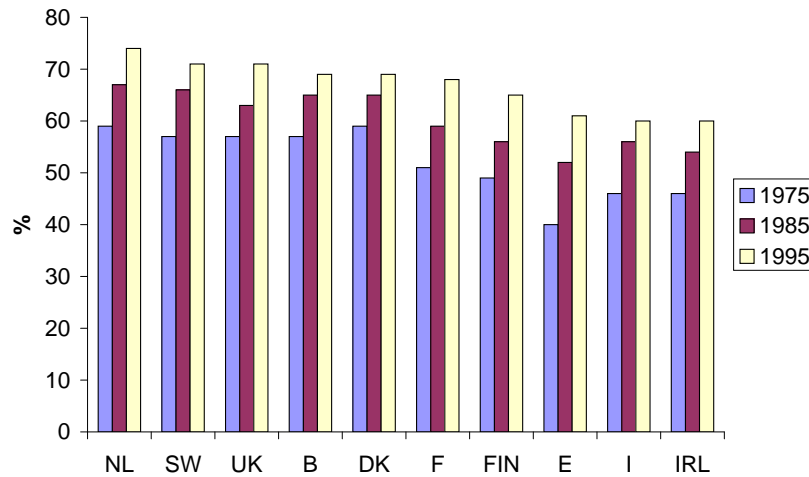


Figure 1: Share of services in % of total employment.

pean Commission.⁹ While we know less about organizational constraints, we do know something about job constraints throughout Europe.

Figure 1 depicts the growth in the service sector for several European countries.¹⁰ Figure 1 clearly shows that in the last 30 years the share of the service sector has grown rapidly in every country, even sometimes with more than 20%. And there is no evidence that this process is going to stop in the near future. Although the service sector itself contains a great variety of job types, there is much evidence that computer terminal work is becoming the dominant work type in most Western European countries. For example, the percentage of all Dutch workers who work with computer terminals grew from 52% in 1996 to 62% in 2002 (CBS 2003). This indicates that there is a huge potential – *ceteris paribus* – for teleworking in Europe.

Of the international teleworking comparisons carried out for the European Commission, ECaTT (2000) is the latest. They define home-based teleworking and supplementary telework. Both definitions fall into our definition, only home-based telework is telework carried out for at least

⁹For a comprehensive overview of governmental bodies, researchers and project dealing with teleworking, we refer to <http://www2.fmg.uva.nl/sociosite/topics/telework.html#EUROPE>.

¹⁰Figures obtained from the Telework and Telecommuting pages at European Telework Online, to be found at: <http://www.eto.org.uk/eustats/>.

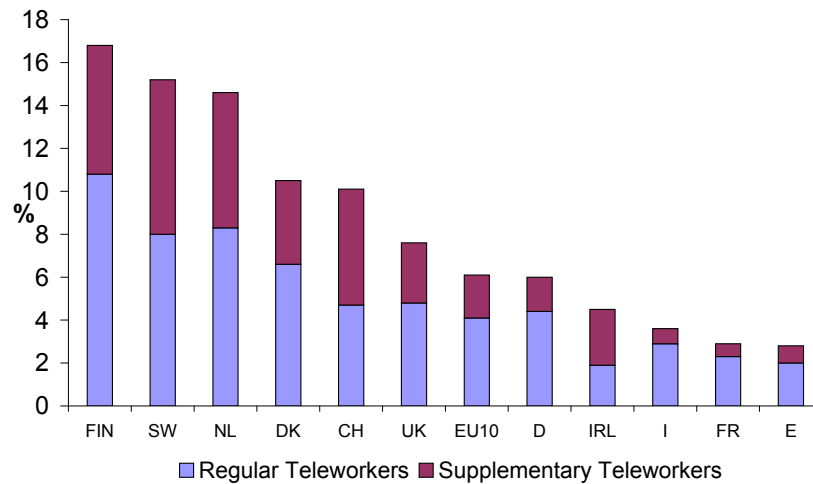


Figure 2: Regular and supplementary Teleworkers in % of total Labor Force (Source: ECaTT (2000)).

one full working day per week, while supplementary or occasional telework are those workers who telework less than one full working day per week. We see here that telework penetration is highest in the Scandinavian countries and in the Netherlands. Switzerland, the United Kingdom and Germany are still above the European average, while Italy, France, Spain and Ireland are lagging behind. Around 4% of the European labor force can be classified as regular teleworkers, while 2% occasionally works at home.

Further empirical evidence can be found in a study of Brewster et al. (1996), who use the '1995' Cranet-E survey. The survey contains about 300 questions and is comparative within countries. The questions are directed to the most senior human resource manager of the organizations with more than 200 employees. Because the survey only contains a question about the proportion of teleworkers and does not define teleworking, results are not comparable with the ECaTT results in an absolute sense. Figure 3 offers the results of the Cranet-E survey. It is obvious that the ECATT results are supported by the Cranet-E survey, although now Sweden has the largest proportion of teleworkers and Denmark and Switzerland have switched places.

However, although Figures 2 and 3 provide relatively high figures, this

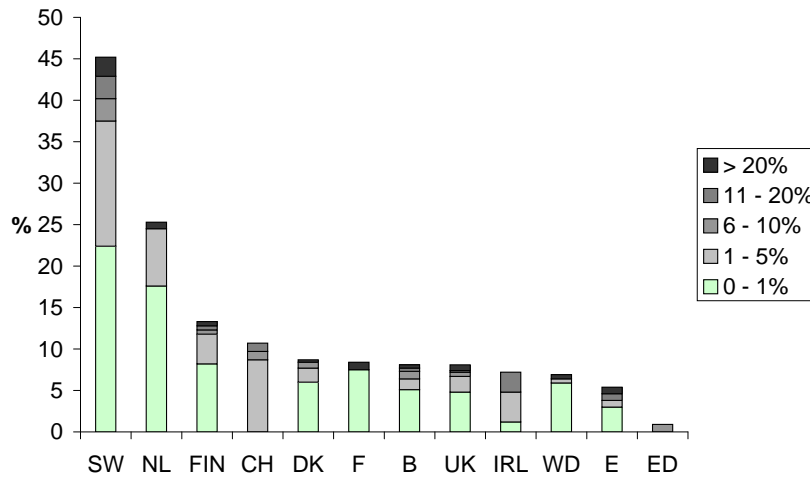


Figure 3: Estimated teleworking in % of total Labor Force. Note: 'WD' and 'ED' are the former West- and East-Germany respectively (Source: van Ommeren (2003)).

does not mean that teleworking is not a marginal issue. At any point in time, it seems that the number of teleworkers or individuals working at home does not exceed 2 or 3% (Mokhtarian & Salomon 1997, De Graaff & Rietveld 2004).

The differences between countries are relatively large, where – roughly – Northern Europe has the largest proportion of teleworkers, Central Europe is in between and Southern Europe has the lowest proportion. Those differences can probably be explained by both the external and the internal constraints. The differences in organizational culture between European countries form most likely the most important external constraint, while psychosocial constraints probably constitute the most important internal constraint.

The above shows that there is still room for considerable improvement in levels of telework throughout Europe. Most probably this will happen, because of a further increase in flexible work forms, the increase in the adoption of ICT and the gradual departure from the traditional '9 to 5' working hour scheme.

3 On the Substitution between Commuting and Teleworking

Superficially, it seems obvious that those who telework commute less, for they do not have to go to work. Moreover, with more flexible work forms, commuting itself does not have to occur within peak hours. Two strong arguments for a drastic reduction in commuting time and especially during peak hours. However, there are a few theoretical arguments for the case that this is – at least – not a one-to-one relation.

Timing: Although workers do not have to travel during peak hours, there still seems to be an intrinsic need to do so. Even worse, if workers are enabled to work at home, some evidence is found that workers substitute overtime at the office for overtime at home. This may even worsen peak hour congestion in the afternoon (De Graaff & Rietveld 2004). The same argument applies when workers replace working at the office with working at home during the weekends. With these flexible and informal work forms, working at home and working at the office are no longer complete substitutes, but reinforce each other instead.

Frequency: Even those who have formal telework contracts do not perfectly substitute office work for at home work. Workers always have to frequent the office floor once in a while – be it once in a fortnight or four times per week. Therefore, although there are full telework days, days exist that workers work both out-of-home and at home. Whether they then commute during peak hours or not, total amount of commuting is then at least not decreased and usually one trip (out of the two) is made during peak hours.

Non-constancy of the commuting distance: In the long term, teleworkers increase their search space for a residence, causing a larger commuting distance on telework days (HGC 1992, Lund & Mokhtarian 1994). Although the number of commuting trips may decrease, commuting increases and offsets the decrease in trips partly.

Although the reasons above are definitely not strong enough to expect that teleworking and commuting are complements, they lead to the conclusion that they are no perfect substitutes, i.e. the elasticity between commuting and teleworking is larger than -1 .¹¹

¹¹An elasticity between teleworking and a travel characteristic of x denotes an $x\%$ change in the travel characteristic when teleworking increases with 1%.

Table 2: Effects of Teleworking on Commuting

Authors	Type of elasticity	Value
Pendayala et al. (1991)	Morning peaks:	-0.30
	On telework days:	
	Morning-peak trips	-0.75
Hamer et al. (1992)	Afternoon-peak trips	-0.60
	Trips p/w:	
	During peak hrs:	-0.19
HGC (1992)	Outside peak hrs:	-0.15
	Comm. movements:	-0.75
Henderson & Mokhtarian (1996)	VMT	-0.90
van Reisen (1997)	Morning peak p/w:	-0.15
	Trips p/w:	-0.89
	Dist. aft. 20 yrs:	+0.04
Spittje (1999)	Direct trips:	[-0.23 -0.15]
	Indirect trips:	[-0.12 -0.07]
	Comm. kilometers:	[-0.18 +0.96]
Hjorthol (2002)	Comm. trips:	[-0.34 -0.06]

Table 2 presents empirical evidence for the elasticities between commuting characteristics and teleworking found in the international literature.¹²

The effects in Table 2 are derived from direct observations from telework experiments of large cross-sectional datasets. Note that all elasticities are point elasticities and thus should be compared with care.¹³ For an extensive treatment of mobility effects of teleworking for the Netherlands, we refer to Boumans & van Twuijver (2003).

The approach of Hjorthol (2002) is a bit of an outlier. He investigates directly the impact of ICT appliances (personal computers) on travel behavior. He concludes that the number of commuting trips for those people who have a personal computer decreases slightly (with 6%) while the number of commuting trips with a permanent work site at home decreases with 34%. Except for Hjorthol, the other studies in Table 2 are directly targeted at teleworkers and therefore – as acknowledged by most authors – suffer heavily from selection bias. In addition to the small samples used and usually the lack of control variables, the results in Table 2 should be carefully dealt with. Because of the selection bias, the elasticities are most likely biased upwards (in an absolute sense) and will probably significantly decrease when estimated for the whole population.

¹²Actually, one of the first studies into the travel effects of teleworking was that of Nilles et al. (1976) who studies 108 satellite centre teleworkers and reported a 65% reduction in one-way commuting distance. In the same fashion, Mokhtarian (1988) reported for videoconferencing a 18% reduction in travel time.

¹³A range of elasticities denotes several estimated elasticities found and all falling in this range

However, it is safe to say that – at least for a large part of the population – the possibility of telework will cause a reduction in commuting and especially during the (morning) peak hours. The empirical evidence indicates that the number of commuting trips will decrease with 60%–75% on telework days. Thus, telework and commuting are substitutes, though not perfect. Moreover, in the long term, it seems that workers will indeed move further away from work. The empirical evidence, however, is not conclusive in this respect.

In contrast to the revealed preference approaches in Table 2, there is the stated preference method, initiated by Bernardino et al. (1993). Here, workers are questioned whether they are willing to telework and to what degree, given a given scenario, which deals with e.g. salary, commuting costs allocation, commuting time, career prospects, etc (Mahmassani et al. 1993, Sullivan et al. 1993). On the basis of these responses, changes in travel behavior and teleworking can be *estimated*. Yen (2000) provides such estimates and reports cross-price elasticities between commuting and teleworking, which typically fall into the range [0.21 0.53] for private car use and into the range [0.03 0.36] for workers using public transport, indicating again an imperfect substitution between teleworking and commuting.

A third approach is taking all markets into account into a general equilibrium model. The only study up to now is Safirova (2002), who used an implicit congestion framework. Moreover, distance between the firms and the residences is taken into account, leading to – on average – larger commuting distances for teleworkers (and diminishing agglomeration economies). However, due to the rigorous setting (workers only telework or work at the office full time), impacts of telework on commuting are to be very carefully inferred.

Although the evidence above is certainly not yet conclusive, it seems apparent that working and teleworking are imperfect substitutes. However, working at home not only affect commuting behavior, but also total travel demand. Therefore, the next section looks whether total travel and teleworking are also substitutes.

4 Teleworking and Total Travel Time

As mentioned above, the relation between commuting and teleworking is not equal to the relation between total travel and teleworking. Using the classification of Salomon (2000), four types of relationships can be discerned. The first two – substitution and complementarity – have already been discussed. The first one is the actual substitution of working at home for travel (telecommuting) while the second is based on trip generation effects of ICT. For instance, using email enables workers to maintain more contacts, which in the end lead to (the perceived) necessity of face-to-face

contacts. Just like the use of the telephone has stimulated travel.

The third type of relation is the modification of travel patterns, where teleworking changes total travel demand, but not in one unique direction. In a sense, most authors have already acknowledged that the relationship between teleworking and travel is one of modification. Namely, teleworking causes less commuting, but teleworking is also expected to generate some additional travel demand. The issue is that teleworking affects travel demand differently for each individual worker, each sector, and for different parts of the day and the week. Therefore, *the* impact of teleworking on total travel most likely does not exist.

Salomon also distinguishes a fourth type of relation: namely, neutrality. That is the case when travel demand is totally inelastic with respect to changes in the amount of teleworking. Although, unlikely as it may be, some empirical studies actually report that total travel demand does not change when workers telework more. However, usually this means that an increase in non commute travel offsets the decrease in commuting, meaning that travel demand is modified (see, e.g., Nilles 1988, Pendayala et al. 1991).

One of the possible reasons for the sometimes observed neutrality of travel demand is the hypothesis of constant travel time. Therefore, the next subsection looks into the theoretical background of the constant travel time budget. The subsequent subsection deals with the empirical evidence for a modification in travel demand caused by teleworking.

4.1 Is Travel Time Budget also Constant for Teleworkers?

In studying the relation between teleworking and travel time, one sooner or later encounters the hypothesis of constant travel time budget. This hypothesis states that people have a travel time budget more or less constant across time and space (see, among others, Zahavi 1979, Schafer & Victor 1997, Mokhtarian & Chen 2003). If true, then this states that teleworking itself will not greatly reduce travel demand – although its components may be modified. Actually, micro data show that time used per day for travel even slightly increases (Van Wee et al. 2002). For example, in the period 1975-2000 the Dutch National Travel Survey (OVG) and the Dutch Time Use Survey (TBO) report respectively an 8% and a 26% increase. Although these (and other) datasets are not perfectly comparable, it seems highly likely that the travel time budget for an average individual has increased and will further increase in the future (Kraan 1996).

According to Van Wee et al. (2002), the observed increase of the travel time budget may be due to three factors, that we will also deal with consecutively in the light of an increase in teleworking – or at least the possibility for teleworking.

An increase in the utility of travel: If people travel more, then – in an economist’s view – benefits of travel have been increased or its costs have been reduced. Some of these benefits are especially important for teleworkers. The first one is due to the specialization on the labor market. Nowadays, many jobs require specialized education and training. High skilled workers have to increase their search space to find a suitable match and will therefore, on average, work further from home. The argument especially applies for teleworkers who are, as we have seen above, highly specialized and highly educated. Thus, teleworkers will on average work further away from home and will benefit more from longer distance traveling (Rietveld & van Woudenberg 2003).

Another argument for an increase in the utility of traveling is the segmentation in the housing market. Especially teleworkers may have specific housing demands (extra rooms, no interference with personal or family life) and are therefore inclined to increase their search space for a proper dwelling. Combined with higher incomes, this leads to longer commuting distances.

A third reason for an observed increase in average travel time is that, as already mentioned, people actually enjoy traveling and that traveling itself has become more attractive.¹⁴ Related with this, the choice of destinations for each purpose has also been diversified (Van Wee et al. 2002). This accounts for shopping, leisure activities, sports activities, etc, leading to a larger diversification of travel purposes and thus, on average, to longer travel distances. Teleworking in itself does not contribute in this case to a larger utility of traveling. However, if hypothesized that teleworkers travel more for non commute purposes, then their utility of non commute traveling will increase relatively more than that of non-teleworkers.

A decrease in the costs of travel: People travel more because costs of travel – in the broadest sense – have declined. As previously mentioned, comfort of cars still increases and there are increasing possibilities to combine travel with other activities. This is especially important for flexible workers. If one is able to work at home, then working in a train is also possible. Thus, an increase in ICT causes a decrease in the opportunity costs of travel, which causes especially flexible workers to travel more.

A change in the composition of population: Teleworking does not seem

¹⁴If not for the increased ease or luxury of traveling (Cars with CD players, better services in public transport, the possibility to plug in notebooks in high-speed trains, etc.), this argument still holds because the choice sets of modes, vehicles, routes, times, etcetera, has dramatically increased.

to be related to the decrease in household size, which seems to be the most important demographic cause for the increase in average travel time. However, teleworking enables workers to diversify and even increase their tasks to be done within the household (shopping, child-care, etcetera). It is expected that this increase in the share of combined tasks leads to an increase in average travel time. However, it seems that especially female teleworkers increase their share of combined tasks, and that male teleworkers are hesitant in this respect (see also Casimir 2001).

In conclusion, it seems that teleworking not so much causes the increase in average total travel time but that it merely correlates with it. Namely, increases in (labor)income, labor market specialization, housing market segmentation, diversification of travel purposes, and even an increase in the availability of ICT (see, e.g., Martens et al. 2004) seems to cause both the increase in teleworking and in average travel time. Therefore, it can be hypothesized that the latter two are merely contextually related. The next subsection offers empirical evidence from the literature.

4.2 Some Empirical Evidence

Empirical research concerning the relation between total travel and teleworking is relatively scarce, and is especially conducted in the last decade. Analogously to Table 2, a variety of estimated elasticities between total travel and teleworking can be discerned in Table 3.

When comparing Table 3 with Table 2 it stands out that the elasticities are different, so the hypothesis that teleworking modifies travel demand is at least not rejected. Moreover, the more recent the studies are, the higher the estimated elasticities appear. However, there does not seem to be any concluding evidence that the two types of elasticities differ significantly. Eyeballing the evidence, it seems that the elasticity between teleworking and total travel demand lies roughly between $[-0.2 + 0.1]$, which is slightly above the average elasticity between commuting and teleworking concluded from Table 2. A second conclusion one may draw, it that although the elasticity between the number of trips and teleworking is relatively low (in an absolute sense), the elasticity between time or distance spent to total travel is more distinct. So, seemingly, teleworkers do not make less trips in a week, but travel across smaller distances.

Table 3: Effects of Teleworking on Total Travel

Authors	Type of elasticity	Value
Pendayala et al. (1991)	trips per day:	[-0.22 -0.11]
	Cars trip per day:	
	Work purpose	[-0.33 +0.14]
	Home purpose	[-0.10 +0.00]
HGC (1992)	Other purpose	[-0.19 -0.06]
	Total trips:	[-0.17 -0.10]
	Henderson & Mokhtarian (1996)	VMT
Koenig et al. (1996)	Non-commute VMT	+0.23
	VMT p/d:	-0.77
	Total trips p/d:	-0.27
van Reisen (1997)	Personal trips	[+0.04]
	Total trips	[-0.02]
	Total km.	[-0.11]
Spittje (1999)	Total km. p/w	[-0.21 +0.44]
	Total min. tr. p/w	[-0.21 +0.21]
Hjorthol (2002)	Total trips p/d	[+0.09 +0.16]

Strikingly, the study of Hjorthol (2002) stands out with only positive elasticities. Note again that Hjorthol looks directly at the impact of ICT on traveling, not at teleworking itself. Most likely, increases in traveling and ICT availability are caused here by unobserved structural heterogeneity, probably income.

The same caveats we made when evaluating Table 2 again apply here: namely, the low number of observations in most studies and the selection bias most studies suffer from. The last one is rather serious. It is very difficult to say something about the travel demand of a whole population, when only specific groups of teleworkers are surveyed. Most likely these groups would already have chosen for teleworking and, in addition, are enabled to do it (concerning their family life, the sector they work in, but also their personal (unobserved) characteristics like stamina, discipline and self-reliance). Moreover, because of formal contract-based teleworking, these groups will have specific travel behaviors.

If one is interested in the effects ICT has on the flexibilization of the labor population and its corresponding travel behavior, then a different approach is needed. Preferably, one would like to have repeated observations over an unbiased subsample of the whole population, where the researcher is able to observe changes in travel behavior compared with changes in teleworking levels. A way forward would be to use time-use data and to apply panel data techniques for day-to-day changes. In this way, observed and unobserved personal characteristics can be canceled out. Thus, relations between activities like traveling and working at home are better observed. The following subsection gives an empirical illustration of such a model for

the Netherlands.

4.3 An Empirical Illustration

Here, we use two (stacked) waves of the time-use survey (TBO) conducted in the Netherlands in 1995 and 2000 respectively. In this survey individuals were asked to maintain a diary during a week, where each 15 minutes the main activity had to be recorded. From these data, we construct day-to-day changes in time spent on working at home on the one hand and travel activities on the other hand (only during weekdays).

To look at the impact of working at home on various sorts of travel, we use the following two-way fixed effects model (cf., e.g., Baltagi (1995)):

$$y_{i,t}^{(j)} = \alpha_i^{(j)} + \gamma_t^{(j)} + \beta_1^{(j)} x_{i,t}^{(j)} + \beta_2^{(j)} (x_{i,t-1}^{(j)} + x_{i,t+1}^{(j)}) + \epsilon_{i,t}^{(j)}, \quad (1)$$

where y denotes minutes travel time, x minutes working at home at time t , i stands for individual i , ϵ an i.i.d. error term, and j stands for a specific travel purpose. Note that β_1 capture the direct effect of working at home on travelling, while β_2 captures the combined effect of working at home on travelling the day before and after. We incorporate the latter effect to control for temporal substitution effects of activities. Note that this specification eliminates all individual and temporal effects. Thus, e.g., sectoral-, weekday-, educational-, and income-effects do not influence the results. Therefore, in this specification, individual structural heterogeneity is not an issue. However, due to the short observation spells (a week) it may well be that structural external factors (e.g. bad weather, strikes in public transport) are influencing the results. In this case we only look at those workers who at least work an hour per week at home¹⁵. Table 4 presents the results.

The results in Table 4 clearly show that commuting and working at home act as substitutes. Moreover, at home work and total travel seems to be substitutes too, a result in line with Mokhtarian et al. (1995). No significant complementary effects across the various types of travel could be found, indicating that working at home does probably not generate any additional trips. Concerning the temporal substitution effect, there is some evidence that at home workers shift their travel activities during the week. However, only for total travel, there seems to be a slight temporal substitution of activities. It seems that travel decreases of at home work days are for 20% compensated by the two days before and after working at home. Assuming that this temporal substitution would be the same for all working days (monday – friday), then the compensation would amount to 40%.

¹⁵Note that this also already introduces some sample selection bias

Table 4: Effects of daily changes in at home work on daily travel.
Standard errors are between parentheses and significancy at 5% in bold.

Purpose (j)	β_1	β_2
Business	-0.042 (0.014)	0.014 (0.011)
Commuting	-0.092 (0.013)	0.016 (0.010)
Household	-0.002 (0.002)	0.001 (0.002)
Childcare	0.008 (0.005)	0.002 (0.004)
Shopping	-0.003 (0.007)	0.003 (0.006)
Personal needs	-0.008 (0.004)	-0.004 (0.003)
Study	-0.003 (0.005)	0.001 (0.004)
Participation in activities	-0.015 (0.005)	-0.004 (0.004)
Leisure activities	-0.035 (0.010)	0.004 (0.008)
For fun	-0.007 (0.004)	0.003 (0.003)
Total	-0.197 (0.020)	0.037 (0.016)
Observations		1545

Obviously, working at home is not exactly equal to teleworking.¹⁶ But in the light of an increasing flexibilization made possible by ICT, this indicates that an increasing part of the labor force working at home will have significant negative effects on travel demand.

These results are in line with some of the earlier empirical literature (e.g. Hamer et al. 1992), although at first sight they seem contradictory to the constant travel time budget hypothesis and even to the empirical fact that individuals travel more and more. A first explanation for this inconsistency (at least for the case in Western-Europe) is that *actual* working at home at any time is a minor issue. It has to be estimated at around 2 or 3% of total time spent to working (more or less equal with the 2% of Mokhtarian & Salomon (1997) for the United States). For every hour they work at home they seem to travel 7.4 minutes less. On the other side, the increase in especially female labor participation and the increase in average mobility could offset the decrease in travel time of teleworkers. Therefore, aggregated statistics are less suitable to reveal the underlying process.

Secondly, these data reveal the *individual* behavior. Note that teleworkers are high skilled individuals with high incomes. Usually, these individuals travel more than low-skilled individuals, indicating that teleworking offsets parts of their increase in total travel caused by other factors (like

¹⁶There are two other possible sources of bias with this specification. First, there is the case of underreporting (Rietveld 2002). Namely, individuals only report their activities in quarters of an hours, where short-lasting activities may thus become underreported. Secondly, the model specification does not tell us anything about causality, but only about correlation: namely, it is possible that working at home is here an endogenous variable. However, because we are here not really interested in causality but in correlation, this possible source of bias does not greatly affect our interpretation.

income).

Possible reasons for the decrease in non commute travel are given by Mokhtarian et al. (1995). The most likely is that nonwork activities are linked to the commute trip, or the teleworker may find suitable destinations closer to home. Secondly, there may be some kind of threshold cost associated with traveling. If one travel for work, then other types of travel are easier conducted. If teleworking, then there may also be an increased awareness of the need to avoid travel. And finally, there may be some kind of underreporting. If people are working at home, then small trips may be 'forgotten'. We refer to Rietveld (2002) for a similar kind of bias. However, more research is definitely needed in order to fully explain the decrease in noncommute travel for teleworkers.

The next section deals with the policy implications implied by these results.

5 Policy Implications and Agenda

Policy makers are interested in teleworking because its potential to change travel demand. Although travel in itself is not an issue, its corresponding externalities are. Those externalities can be classified in two main groups: namely, congestion and environmental damage (Stopher 2004). Both externalities lead to welfare losses. Roughly, the relation between commuting and teleworking is of importance for congestion externalities, while the relation between total travel and teleworkers matters for environmental externalities.

As we have seen above, both relations are not necessarily the same, but have a high probability to show the same negative sign. Moreover, there is evidence – though yet not conclusive – that total travel demand drops more than travel demand for commuting alone. This result could be questioned, but even if teleworking generates additional travel demand, then it seems to be minimal and certainly not high enough to offset the decrease in commuting. This result may seem strange in the light of some circumstantial evidence. Moreover, in the words of Mokhtarian (1997):

It has been observed that ICT and travel demand have always been complements of each other and there is no reason to believe that teleworking is the exception.

Strangely enough, this hypothesis seems to be both true and false.

In aggregate data, one may observe that the more individuals telework the more it seems they travel. However, it seems not to be a *causal* relationship, but merely a contextual one. Namely, the increase in ICT pushes people to travel more and enables them in the same time to work just as well at home. In addition, as we have seen above, high-educated and

high-earnings workers usually use more ICT (notebooks, videoconferencing, palmtops) and also travel more. Figure 4 clarifies this relationship. ICT and income both cause an individual increase in travel demand and a higher propensity to telework. However, telework itself has a negative impact on travel demand and thereby (partly) offsets the effects of ICT and income.

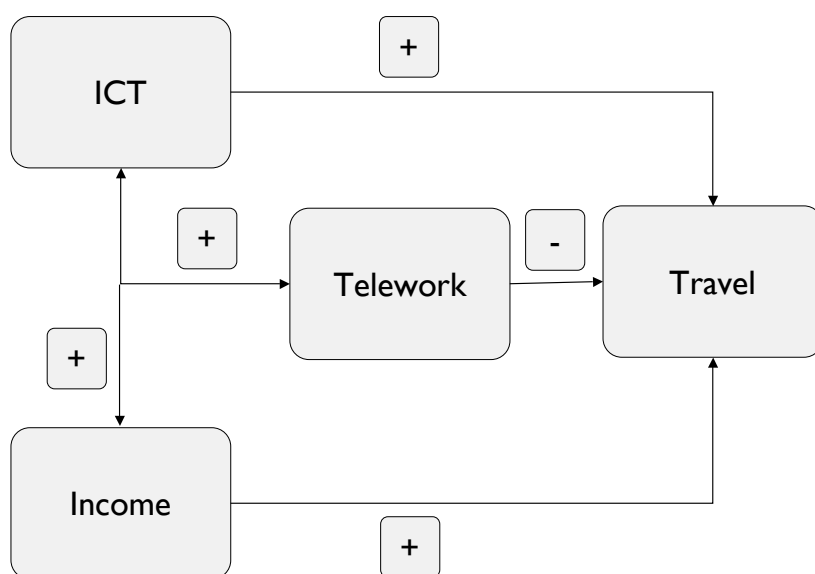


Figure 4: A framework for the relation between telework and travel.

However, most of the empirical literature suggests that at the individual level teleworking and travel demand are substitutes. The use of ICT both enlarges travel demand and make it possible for workers to work at home. And if workers use this possibility, their travel demand decrease both for work and non-work purposes – *conditional* on their personal characteristics like income, educations, experience, etcetera. That could be the reason why Hjorthol (2002) finds these large complementarity effects. He does not look at the fact whether people are working at home or telework, he looks directly at the impact of ICT on travel demand.

If ICT and travel are complements and telework and travel are substitutes, then this has large implications for policy recommendations. However, in the empirical application above we have shown that several types of problems arise when examining these relations. Firstly, there is (struc-

tural) unobserved heterogeneity which can seriously bias the results (see also Table 1 for possible sources of this heterogeneity). Income and to a lesser extent skill level and education should be taken into account. One way to get rid of these effects is to use a fixed effects estimator in a panel set-up. Secondly, there are endogeneity issues, which are more cumbersome to tackle. A possible solution is to use a demand system, where a structure is imposed instead of using an ad-hoc specification. Therefore, the next step would be to expand the specification in (1) in a system of reduced forms derived from a structural demand system.

As for the type of travel externality, it seems that promoting teleworking is somewhat more suitable to tackle congestion than to tackle environmental impacts. Reductions in distance or time traveled could be substantial during peak hours, causing promoting teleworking as a potential instrument to redistribute travel demand over the whole day. Concerning environmental impacts, teleworking is especially successful in reducing distance traveled, which reduces significantly NO_x (oxides of nitrogen) and PM (particulate matter) emissions. Because the decrease in the number of trips is not that large, the decrease in the amounts of cold starts, TOG (total organic gasses) and CO (carbon monoxide) are less affected (Henderson & Mokhtarian 1996, Koenig et al. 1996).

6 Conclusion

Teleworking is a minor issue. Although many workers indicate that they work at home sometimes and even more workers state that they are interested in teleworking, just a small part of the working population actually works at home at a given moment. This is not to say that workers are not going to work more at home or that work does not become more flexible, it is only intended to put teleworking into perspective and to explain why teleworking does not yet has a sizeable impact on aggregate travel statistics (see also Mokhtarian 2004).

In general, many workers indicate that they would like to telework, but those people who actually telework possess a few distinctive characteristics: they are well educated, have high incomes, live in urban areas and have access to ICT. In general, these characteristics cause a higher level of travel demand, so that it sometimes seems that teleworking causes additional travel demand. However, if you remove personal characteristics (e.g., by using fixed effects), then it turns out that teleworking does not act as a generator of new travel demand. On the contrary, teleworking causes a higher drop in total travel demand compared with commuting demand. Substitution of activities across the week only partly offsets the decrease of travel demand.

The substitution effect between total travel and telecommuting is esti-

mated to be rather substantial, namely around 20%. Or, in other words, individuals who work 8 hours at home in the Netherlands, travel $1\frac{3}{5}$ hours less. Taking temporal substitution effects into account, workers still travel 1 hour less. Unfortunately, only around 3% of the labor force works at home at any given time, so that the effect on total travel demand is rather limited. The labor force becomes more and more flexible and ICT decreases continually in costs (see, e.g., van Reisen 1997), so that one may hypothesize that the growth in teleworkers/homeworkers still continues. However, travel reductions caused by teleworking are expected to be *at least* partly offset by the growth in travel demand caused by the increasing level of ICT and income. Remarkably, the last conclusion suggests that the constant travel time budget hypothesis is not rejected.

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