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Conference Paper

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44th Congress of the European Regional Science Association: "Regions and Fiscal Federalism",
25th - 29th August 2004, Porto, Portugal

Provided in Cooperation with:

European Regional Science Association (ERSA)

Suggested Citation: de Graaff, Thomas; Rietveld, Piet (2004) : Telework, Frequency of Working Out-of-home, and Commuting: A Labor Supply Model and an Application to the Netherlands, 44th Congress of the European Regional Science Association: "Regions and Fiscal Federalism", 25th - 29th August 2004, Porto, Portugal, European Regional Science Association (ERSA), Louvain-la-Neuve

This Version is available at:

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Telework, Frequency of Working Out-of-home and Commuting: A Labor Supply Model and An Application to the Netherlands

Thomas de Graaff* Piet Rietveld

June 8, 2004

Preliminary version! Do not quote

Abstract

This paper analyzes the case where workers have to choose between the location of work, leisure, commuting hours and the frequency to work out-of-home. Both a short-run and a long-run model are presented. In the short-run, workers are not able to set their optimal amount of commuting time, where in the long-run commuting time is treated as an endogenous variable. Moreover, frequency of working out-of-home is explicitly taken into account, where it is assumed that there is an optimal frequency of commuting trips. An empirical model and estimation results for the Netherlands are offered. Preliminary results are that workers have an intrinsic preference to work out-of-home approximately 2.5 days a week and need at least 14 hours of leisure time.

1 Introduction

Telework is a hot issue, both from a policy as from a scientific perspective. Policy makers advocate teleworking to be the most effective instrument for reducing commuting externalities – more in particular congestion and environmental damage. Researchers are particularly interested in teleworking, because it affects individual spatial and temporal behavior patterns, both in the short as in the long-run.¹ Namely, in the short-run, workers may e.g. commute less because they work more at-home (see for an early account of

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¹For comprehensive overview of the literature see inter alia Salomon (1986, 2000), Nilles (1988), Mokhtarian (1990).

the trade-off between telework and commuting Nilles et al. 1976), while in the long-run workers may adjust their commuting time by moving job or residence when working more at-home or somewhere else than the regular workplace (HGC 1992, Lund and Mokhtarian 1994).

Despite the considerable amount of attention the concept of telework receives, it remains a marginal issue in most countries. Although in countries like the United States, The Scandinavian countries and the Netherlands more than 10% of the labor population indicates to telework or to be interested in telework (ECaTT 2000, van Ommeren 2003), less than 4% of the labor population actually works at home at any given time (Mokhtarian and Salomon 1997, De Graaff and Rietveld 2004). A large body of literature focussed on this marginal existence of telework, which resulted in an extensive list of barriers and constraints to telework (Mokhtarian and Salomon 1994). For instance, some (economic) researchers focus on productivity and wage differences between working at-home and working out-of-home or on monitoring costs of teleworkers. Other research focussed on institutional constraints to telework, on psychological barriers, on cost restrictions, technological constraints and lack of space at-home. In conclusion, barriers to telework seem to be a complex mixture of individual preferences and socioeconomic processes.

Yet no research has focussed on the frequency of working out-of-home in combination with commuting time and telework.² Whether workers have a specific preference for regular out-of-home work is debatable from an economic perspective, but they certainly have some preference for the amount of days they work per week. For example, some workers prefer to work 4 days of 10 hours while others like to work 5 days of 8 hours. In the field of labor economics it is already widely accepted that frequency of work plays an important role in labor supply (Hanoch 1980). The reason why is straightforward. On the one hand, there are decreasing returns to labor supply. If workers work too many hours a day they become less productive. On the other hand, if they work a few hours each day of the week they have to incur a large amount of commuting time, which can be reasonably assumed to be non-productive. Therefore this paper focusses on the interaction between frequency of working out-of-home, leisure, commuting and working at-home. It does so in providing a theoretical model based on labor supply theory and in estimating a demand system of the various activities involved. Based on these estimates elasticities are provided for

²We use the following definition for teleworkers: teleworkers are those workers who work at-home while using communication and information technology. Note that this could also include using ICT equipment as telephones and that we leave out other possible work arrangements as e.g. telecenters. We are in this paper more interested in those workers who work at-home – and assuming they have at least a telephone. Thus, in this paper we are less interested in the effect of ICT on the possibility of working at-home and more of the actual effects of a more flexible work schedule.

the relations between working at-home, leisure, travel, commuting and the frequency of working out-of-home.

The remainder of this paper is organized as follows. Section 2 presents the basic model, which consists of a short-run and a long-run part. The main difference between those two is that we assume that workers choose their optimal amount of commuting time in the long-run, while in the short-run they do not. Subsequently, Section 3 presents estimation issues and the data to be used, together with specific sample descriptions. Thereafter, we offer the preliminary estimation results for both the short-run as the long-run model and a discussion of the results as well. The last section offers a research agenda and conclusions.

2 Demand for Telework, Commuting and Frequency of Out-of-home work

That telework, commuting time and frequency of working out-of-home are highly related is not very surprising. A worker who decides to work one day at home, will in total have less commuting time and his trips to the office will decrease with one. However, in practice, this relation is usually not as clear cut as suggested above. Evidence for the Netherlands suggest that teleworking often occurs during non-office hours (De Graaff and Rietveld 2004). It seems that workers have a particular taste to work over-time at home. Moreover, workers may also prefer to work at home during the morning and thereafter go to their workplace. Though at first sight un-logical from a commuting perspective, it may actual be optimal because workers may then avoid congestion hours.

Microeconomic labor supply theory in the line of Deaton and Muellbauer (1980) offers a suitable framework to connect location of work, commuting and the frequency of out-of-home work with each other. The basic set-up is that workers make a trade-off between income (consumption) and free time (leisure). In principle, workers do not have a specific preference for working. Namely, with labor income they can buy goods or – for those hours they do not work – they can buy free time. Working at-home offers the possibility to forego commuting time. However, implicit wage rates at-home and out-of-home do not necessarily be the same. Furthermore, due to the difference in work location, working at home and out-of-home may be considered as heterogeneous jobs and a relative preference for the location of the job is therefore not unlikely.

Working out-of-home incurs commuting time. However, the amount of commuting time is only limited proportional to the number of working hours. Namely, an additional increase in working hours, will not automatically result in an additional increase in commuting time. By nature, commuting time increases discretely. More precisely, when workers make

an additional trip to the work place and back. Therefore, the frequency of working out-of-home is usually more interesting than commuting time. Especially because commuting time per day can be regarded as a constant in the short-run.

In the long-run, employees will make a simultaneous decision about the place, amount and frequency of labor supply and the amount of commuting time. Usually, when workers move occupation they usually lag in moving residence, but eventually they move when commuting time is far from optimal. Likewise, when people move residence they probably will restrict their search space within the commuting reach of their current job. Therefore, the distance between residence and the work place is not exogenous in the long-run. In the next subsection, we first deal with the short-run decision an individual usually makes regarding his amount and location of labor supply. The section thereafter we continue with the long-run decision.

2.1 A Short-run Perspective

We first assume that there is a representative utility maximising worker, i , who want to maximise his utility function, U_i . First – and above all –, U_i depends on the amount of leisure and consumption an individual is able to purchase. Because we assume an absence of a capital market (no savings) and a government (no taxes), i 's consumption is equal to i 's income. If individual i only receives labor income and if labor income is composed out of labor income from teleworking ($h_{a,i}$) and working out-of-home ($h_{o,i}$), then the monetary budget can be written as:

$$C_i = \varphi(\xi_i)\omega_i h_{a,i} + \omega_i h_{o,i}, \quad (1)$$

with ω_i the hourly wage rate. Here, we assume that working at-home yield a different *implicit* wage rate than working out-of-home, which is captured by $\varphi(\xi_i)$, where $\varphi(\xi_i)$ larger than 1 entails higher implicit wage rates and $\varphi(\xi_i)$ lower than 1 means lower implicit wage rates when working at-home. The argument, ξ_i , measures the availability of information and communication technology (ICT) at home for individual i , where we assume that workers will become more productive when they have a higher availability of more (advanced) ICT at home ($\varphi' > 0$). Furthermore, when individuals work out-of-home, they incur (time-)losses from commuting time (t_c), which, for convenience, we measure per day. Let F_i be the frequency of working out-of-home per week, then time devoted to working out-of-home per week is defined as $F_i(\bar{h}_{o,i} + t_{c,i})$, with $\bar{h}_{o,i}$, the average working hours per working day, which yields a weekly out-of-home labor income of $\omega_i F_i \bar{h}_{o,i} = \omega h_{o,i}$. In standard labor supply models, individual i would be indifferent between working 20 hours in 1 day, or 4 hours in 5 days. Be-

cause this would be highly unlikely, we introduce an optimal amount of frequency of working out-of-home, F^* , in the utility function. Thus, frequency affects the amount of commuting time and it affects the level of utility. We need the former effect because workers in general do not like to make the same trip to work 20 times a week. The latter effect is needed because, although working 36 hours work in a row may be beneficial from a time savings view, in general workers do not like to work more than a specific number of hours per day, usually around 8.

Assuming that individuals spend all their *available* time (T_i) to working, leisure time (l_i), commuting ($t_{c,i}$) and non-commuting travel (t_i), yields the following time constraint:

$$T_i = h_{a,i} + F_i(\overline{h_{o,i}} + t_{c,i}) + t_i + l_i = h_{a,i} + h_{o,i} + t_i + F_i t_{c,i} + l_i. \quad (2)$$

Note that available time varies over individuals, basically because each individual spends different amounts of time to sleep, bathing, eating, child-care, etceteras.³

If we now assume that total utility not only depends on leisure and consumption, but also on the location of work, the frequency of going to work out-of-home and the non-commute travel time, then we have a utility function with the following inputs:

$$U(C_i, h_{a,i}, l_i, t_i, F_i), \quad (3)$$

where $h_{a,i}$ denotes the relative preference workers have to work at home compared to working out-of-home. We are now able to combine time budget (2) with the money budget (1), which leaves us with the following full budget (M_i) constraint:

$$M_i = \omega_i T_i = C_i + (1 - \varphi(\xi_i))\omega_i h_{a,i} + \omega_i F_i t_{c,i} + \omega_i l_i + \omega_i t_i. \quad (4)$$

To relate optimal frequency (F^*) with observed frequency (F), we use the following transformation:

$$F' = F^* - |F - F^*|. \quad (5)$$

Thus, we assume that workers are symmetric in their preferences regarding commuting frequency. This implies that workers value a frequency of one less than the optimal frequency the same as a frequency of one more. Inserting (5) in (4) leaves us with the following full budget constraint:

³One might argue that the amounts of time spent to sleeping, eating, bathing, and so forth are endogenous upon the levels of consumption and leisure. For reasons of clarity, we choose it here to be exogenous.

$$\begin{aligned} M_i &= \omega_i(T_i - I_{F>F^*}(F_i - F_i^l)t_{c,i}) \\ &= C_i + (1 - \varphi(\xi_i))\omega_i h_{a,i} + \omega_i F_i^l t_{c,i} + \omega_i l_i + \omega_i t_i, \end{aligned} \quad (6)$$

where $I_{F>F^*}$ is an indicator function being one if F is larger than F^* and zero otherwise. Note that prices for leisure, working at-home and traveling are highly related due to their dependence on the wage rate. This is not very surprising, because every activity that is not productive has opportunity costs, which depend on the (market) wage rate.

Although this model explains commuting and labor supply behavior in the short-run, it does not explain the *size* of commuting time, t_c . In the long-run, individuals will adjust their commuting time on their labor or housing market situation. Therefore, the next subsection will deal with relating commuting time and labor supply behavior.

2.2 Commuting in the long-run

In the previous section we assumed that commuting time (t_c) was fixed, i.e. individuals do not choose their commuting time in order to maximize their utility. In the long-run this seems a too harsh conclusion. First of all, workers are inclined to sooner accept jobs near by home or move jobs faster when commuting times are large. Secondly, when moving residence, new residences are chosen more likely when one works nearby or when one's prospects on future jobs are better (i.e., in thick labor markets). Here, we limit our attention to the first reason. However, the reasoning for moving residence is not very different. To explain the relation between wages and commuting time, we use the theory of rent gradients (see, e.g., Muth 1969). Namely, analogous to the theory of rent gradients, one can hypothesize a spatial relation between wages and commuting time (Rees n.d., Rees and Schultz 1970). When commuting time is seen as a disutility, then, *ceteris paribus*, workers have to be offset for a larger commuting distance by offering higher wages. Furthermore, we also take into account the possibility that individuals may actually enjoy commuting (Redmond and Mokhtarian 2001, Mokhtarian and Salomon 2001). To specify the relation between wages and commuting in the full budget constraint, we pursue an idea of Wales (1978) and Van der Veen and Evers (1985). First, we assume that the wage rate (ω) depends on the individual commuting time (t_c), besides a vector of the usual explanatory variables, \mathbf{X} . A straightforward specification for individual i would then be:

$$\omega(t_{c,i}, \mathbf{X}_i) = \exp(\psi t_{c,i} + \mathbf{X}_i \beta_\omega), \quad (7)$$

with ψ and β_ω the parameter values that determine the wage rate. Inserting this in the full income budget restriction leaves us with the following budget equation:

$$M_i = C_i + (1 - \varphi(\xi_i))\omega(t_{c,i}, \mathbf{X}_i)h_{a,i} + \omega(t_{c,i}, \mathbf{X}_i)F'_i t_{c,i} + \omega(t_{c,i}, \mathbf{X}_i)l + \omega(t_{c,i}, \mathbf{X}_i)t_i. \quad (8)$$

Secondly, the utility function now amounts to:

$$U(C_i, h_{a,i}, l_i, t_i, F'_i, t_{c,i}). \quad (9)$$

Note that we still assume that the individual wage rate, ω_i , is independent of the amount of working hours, $h_{a,i}$ and $h_{o,i}$. Obviously, the budget equation is now non-linear for two reasons. First, the frequency to work out-of-home times the commuting time $F'_i t_{c,i}$ is nonlinear and, secondly, the wage rate, ω_i , depends upon $t_{c,i}$. Therefore, we first have to linearize (8) about an individual's *observed* decision vector $(C_i^*, h_{a,i}^*, l_i^*, t_i^*, F_i^{**}, t_{c,i}^*)$ in two steps.⁴

First, linearize for $F'_i t_{c,i}$:

$$C + (1 - \varphi(\xi))\omega h_a + \omega F'^* t_c + \omega F' t_c^* + \omega l + \omega t = M_i. \quad (10)$$

Secondly, linearize for the fact that commuting time enters the wage:

$$\begin{aligned} M_i = & C + (1 - \varphi(\xi))\omega(t_c^*, \mathbf{X})h_a + \omega(t_c^*, \mathbf{X})l + \omega(t_c^*, \mathbf{X})t + \omega(t_c^*, \mathbf{X})F' t_c^* \\ & + \omega(t_c^*, \mathbf{X})F'^* t_c + (1 - \varphi(\xi))h_a^* \frac{\partial \omega(t_c^*, \mathbf{X})}{\partial t_c} t_c + 2F'^* t_c^* \frac{\partial \omega(t_c^*, \mathbf{X})}{\partial t_c} t_c \\ & + l^* \frac{\partial \omega(t_c^*, \mathbf{X})}{\partial t_c} t_c + t^* \frac{\partial \omega(t_c^*, \mathbf{X})}{\partial t_c} t_c, \end{aligned}$$

and rewrite using (7)

$$\begin{aligned} & C + (1 - \varphi(\xi))\omega(t_c^*, \mathbf{X})h_a + \omega(t_c^*, \mathbf{X})l + \omega(t_c^*, \mathbf{X})t + \omega(t_c^*, \mathbf{X})t_c^* F' \\ & + (\omega(t_c^*, \mathbf{X})F'^* + ((1 - \varphi(\xi))h_a^* + 2F'^* t_c^* + l^* + t^*)\psi\omega(t_c^*, \mathbf{X})) t_c = M_i, \end{aligned} \quad (11)$$

where M_i now yields:

$$\begin{aligned} M_i = & (1 + \psi t_{c,i})\omega_i(T_i - I_{F>F^*}(F_i - F'_i)t_{c,i}) \\ & - (\varphi(\xi_i)h_{a,i} + h_{o,i})\psi t_{c,i}\omega_i + (1 + \psi)F'_i t_{c,i}\omega_i. \end{aligned} \quad (12)$$

Due to the linearization made above, full income changes, due to the increase corresponding to the increase in the various activities. These changes

⁴Again, we omit here the subscript i for clarity.

are induced by the change in wages, which in its turn follows from the endogenous character of commuting time. Obviously, – although commuting is now another endogenous variable – the structure of (11) is more or less the same as in (6) .

3 Estimation and Results

3.1 Data

The data we use consist of two waves (no panel) from the Dutch time budget survey (TBO, 1995; TBO, 2000). In these time budget surveys households members were asked to keep up a diary during a week, in which their activities were recorded for each quarter of an hour. Amongst others, these activities include working (including the location of work – out-of-home or at-home), shopping, traveling (for different purposes and using different modes), leisure and sleeping activities. In addition to individual activities, background characteristics (demographic, educational, work-related, etc.) were also sampled. In total 5,040 individuals – 3,227 respondents in 1995 and 1,813 in 2000 – were surveyed.

From these variables, we calculate the frequency of going to the workplace per week and the amount of leisure time individuals consume per week. The latter is strictly formed by adding the hours spent on reading, watching TV or VCR, listening to the radio, going out, traveling for pleasure, time spent to sports and hobby, receiving or making visits and resting (not sleeping) during daytime.⁵ The amount of available hours per week was then determined as the summation of hours spent on working, leisure, traveling and commuting. Unfortunately, the surveys only provide information about monthly household income; in multiple earner households individual incomes are not reported. Therefore, we first sample only those households in which the respondent was single and working or where only one household member worked. This results in 745 observations of monthly wage incomes. We then calculate wage rates as monthly wage incomes divided by *contractual* working hours per month. Moreover, in order to measure the impact of ICT we use the availability of internet within a household. Finally, we sample only those individuals who *reported* that they both worked at home and out-of-home.⁶ This resulted in a total sample of 392 individuals, who have a job, work at-home and out-of-home

⁵This is a very strict definition, because we left out activities like bathing, eating, shopping, and the like. Of course, the amount of leisure time is subject to considerable change regarding the definition employed.

⁶This is in order to avoid censoring. Note, however, that the sample is now not representative for the total population, but only for those work both at-home and out-of-home. We return to this issue in the last section

and thus have to make a choice between commuting, location of work, frequency of working out-of-home, leisure time and consumption.

Figure 1 displays the frequency of working out-of-home for our sample. Clearly, most workers work 5 days a week out-of-home. However, there seems to be a large dispersion in the frequency of going to the work place, where workers seem to have a larger preference for workin less than 5 days per week than more.

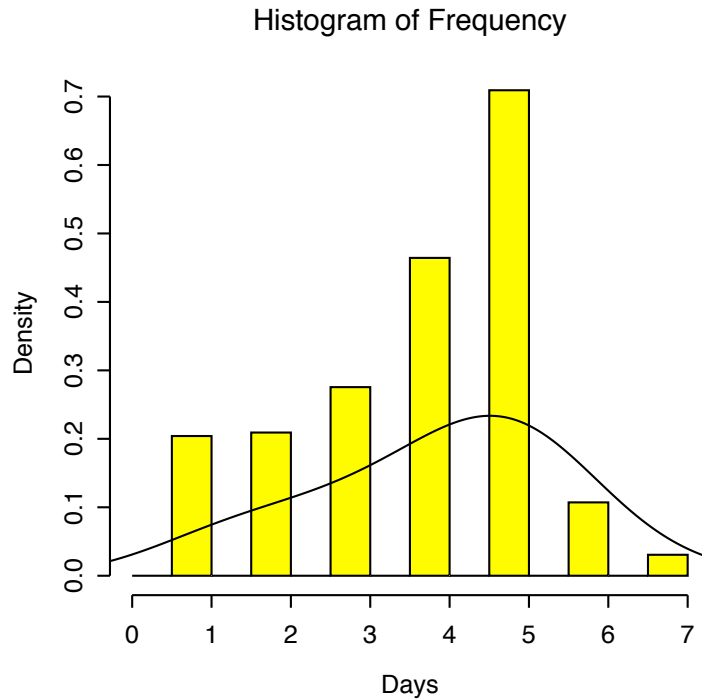


Figure 1: Frequency of working out-of-home.

Some descriptive statistics of the sample can be found in Table 1. Table 1 shows that workers work almost just as much at-home as out-of-home – naturally conditional on the fact that both types of work are non-zero. Moreover, the standard deviation compared to the means are relatively large – especially for at-home work, out-of-home work, wage rates, and the various sorts of travel. Not surprisingly, those activities heavily depend on individual characteristics – like education, demographic characteristics, work attitudes, etc. Therefore, heterogeneity is expected to be a serious issue.

In detail, the average Dutch worker seems to go the work place roughly four times a week and spends about 1 hour to commuting per working day.

Table 1: Some selected descriptive statistics of the data used.

Description	Variable	Mean	St. dev.
Wage rate (euro's per hour)	ω	15.41	6.52
Work at-home (hrs. per week)	h_a	5.65	7.90
Work out-of-home (hrs. per week)	h_o	7.29	5.49
Leisure (hrs. per week)	l	32.90	9.51
Non-commute travel (hrs. per week)	t	7.21	4.73
Commuting (hrs. per day)	t_c	1.16	0.81
Frequency of commute (per week)	F	3.85	1.47
Total time available (hrs. per week)	T	72.82	14.30

Moreover, on average about 33 hours are spent on pure leisure per week and 95 hours (168 minus 73 hours) are spent on sleeping, eating, childcare, bathing, etc.

3.2 Estimation Procedure

Before directly estimating a demand system for (6) and (9) we first have to find an implementation for $\varphi(\xi)$ and, at the same time, a method to find the relation between wages and commuting (ψ). The next part deals with such a method. Thereafter, we discuss the demand system and the econometric issues involved.

3.2.1 Wage Estimation

In order to specify a relation between the implicit wage rates for working at-home and out-of-home, we consider an individual i who works both out-of-home $h_{i,o}$ hours and at-home $h_{a,i}$ hours, so that total monthly wage (W_i) income for individual i is defined as:

$$W_i = \omega_{o,i}h_{o,i} + \omega_{a,i}h_{a,i}, \quad (13)$$

where $\omega_{o,i}$ and $\omega_{a,i}$ are (implicit) wages rate for working out-of-home and at-home, respectively. Moreover, if we assume a linear relation between $\omega_{o,i}$ and $\omega_{a,i}$ and a linear influence of the availability of ICT appliances, then the two wages are related to each other like follows:

$$\omega_{a,i} = (\alpha_0 + \alpha_1\xi_i)\omega_{i,o}, \quad (14)$$

where ξ_i is a variable that measures the availability of ICT appliances for individual i . Note that when $\alpha_0 = 1$ and $\alpha_1 = 0$ there is no difference in productivity in working at home and out-of-home and ICT will have no influence on the productivity difference between working at home and

out-of-home. Now, with the assumption made above that $\omega_{o,i}$ depends loglinearly on a set of exogenous variables X_i (including commuting), it follows from (7) that:

$$\omega_{o,i} = f_o(X_i) = \exp(\psi t_{c,i} + \mathbf{X}_i \beta), \quad (15)$$

and

$$\omega_{a,i} = (\alpha_0 + \alpha_1 \xi_i) \exp(\psi t_{c,i} + \mathbf{X}_i \beta). \quad (16)$$

Typically, exogenous variables that influence the wage rate are education, age, experience, sector of employment, etcetera. Now, (15) and (16) in combination with (13) yields:

$$W_i = \exp(\psi t_{c,i} + \mathbf{X}_i \beta) (h_{o,i} + (\alpha_0 + \alpha_1 \xi_i) h_{a,i}). \quad (17)$$

Thus, $\alpha_0 + \alpha_1 \xi_i$ can be considered as a measure of the productivity of working at home *relative* to the productivity of working out-of-home. Namely, it measures the change in hours working at-home causes to finish the *same* work. Consequently, the implicit price or gain from working at home is: $1 - \alpha_0 - \alpha_1 \xi_i$. For each individual follows that when $\alpha_0 + \alpha_1 \xi_i < 1$, he is paying a price for working at home and when $\alpha_0 + \alpha_1 \xi_i > 1$, he gains from working at home. (17) will be empirically implemented in the next subsection.

3.2.2 Estimating the Demand System

The literature on demand systems is quite extensive. We choose a Stone-Geary type specification to implement (3) and (9). The resulting demand system of (6) and (11) is the well-known Linear Expenditure System (LES) (see, e.g., Deaton and Muellbauer 1980, for details), or:⁷

$$s_k(\omega T, \mathbf{p}, \alpha, \gamma) = \frac{p_k \gamma_k}{\omega T} + \alpha_i \left(\frac{\omega T - \sum_{j=1}^K p_j \gamma_j}{\omega T} \right), \quad (18)$$

where s_k is the share of commodity k in the full budget, α ($\alpha > 0$) and γ are the structural parameters of the linear expenditure system, and \mathbf{p} is the vector of prices for all commodities k ($\in \{1, \dots, K\}$) in the utility function (3) and (9). Note that the full budget constraints in (6) and (11) reflect this price vector. Thus, the implicit price for leisure and travel is ω , for working at-home $(1 - \varphi(\xi))\omega$, for commuting $F\omega$ and for the frequency $t_c\omega$.⁸ Moreover, γ denotes a certain minimum amount of every good k an individual needs. For instance, every individual needs a certain amount of leisure time γ_l in order to reflect upon his or her job. If γ_k is negative, then

⁷For clarity we leave the subscript i out.

⁸We assume that C is a Hicksian composite good, where the price is normalized at one.

demand for k would be non-existing and thus zero, which implies that k is a non-essential good. Note that when we set all γ at zero, (18) results in a Cobb-Douglas demand system, where α reflect the average shares of the commodities individuals consume.

Following Davidson and MacKinnon (1993), we assume that the commodities k are measure with a normally distributed error term. For each individual i , define now \mathbf{S}_i , $\mathbf{F}_i(\omega T, \mathbf{p}, \alpha, \gamma)$, and \mathbf{U}_i , as $1 \times K$ vectors, then we are able to construct the following multivariate regression model:

$$\mathbf{S}_i = \mathbf{F}_i(\omega T, \mathbf{p}, \alpha, \gamma) + \mathbf{U}_i, \quad \mathbf{U}_i \sim N(\mathbf{0}, \Sigma). \quad (19)$$

It is well known that the concentrated loglikelihood for (19) reads as:

$$\ell^c = C - \frac{N}{2} \log \left| \frac{1}{N} \sum_{i=1}^N (\mathbf{S}_i - \mathbf{F}_i(\omega T, \mathbf{p}, \alpha, \gamma))^T (\mathbf{S}_i - \mathbf{F}_i(\omega T, \mathbf{p}, \alpha, \gamma)) \right|, \quad (20)$$

with C being a constant. In order to estimate (20) we must leave out one share equation, otherwise the error terms will sum to zero over all expenditure shares (Barten 1968). Because we are least interested in individual consumption we leave that out.⁹

3.3 Estimation results

Table 2 offers the maximum likelihood estimates of (17). In addition to hours worked at-home and out-of-home and the number of commuting hours, we use the following socioeconomic control variables: age, education, sector, gender, child younger than 12, driver's license and year of observation. Especially the sector dummies are important in this respect, in order to control for jobs in which individuals are not able to work at home (e.g. postmen, nurses, etc.). Sectors have been measured on a two-digit scale on the classification used in 1984 by the Dutch Central Bureau of Statistics (CBS, 1992). In this way, a total of nineteen sectors have been identified with enough variation. Table 2 does not show those sector dummies, but note that wages (and also the impact of the location of work) are controlled for sectors.

Table 2: Maximum likelihood results of income estimation

<i>Variable</i>	<i>Coefficient</i>	<i>Standard error</i>
Constant	0.07	0.22

continued on next page

⁹Because we are using maximum likelihood it does not matter which good we leave out; the estimations of the parameters will always be equal due to the restrictions on the parameters – e.g., the α_i 's have to sum to unity.

<i>continued from previous page</i>		
<i>Variable</i>	<i>Coefficient</i>	<i>Standard error</i>
Commuting time	0.06	0.03
<i>Age dummies (ref. case = age > 60)</i>		
age < 20	-1.09	1.32
age 20 - 30	-0.48	0.19
age 30 - 40	-0.32	0.18
age 40 - 50	-0.16	0.18
age 50 - 60	-0.11	0.19
<i>Educ. variables (ref. case = university)</i>		
basic	-0.14	0.14
lower vocational	-0.20	0.10
medium vocational	-0.14	0.11
craft education	-0.11	0.08
high vocational	0.05	0.09
college	-0.02	0.06
<i>Background variables</i>		
dummy female = 1	-0.03	0.05
dummy female \times child < 12 = 1	0.05	0.07
drivers license = 1	0.12	0.08
dummy year 2000 = 1	0.07	0.08
<i>Structural parameters</i>		
$\widehat{\alpha}_0$	0.80	0.21
$\widehat{\alpha}_1$	0.16	0.29
$\widehat{\sigma}$	234.40	7.70
Mean logl.		0.014
N		745

As could be expected, there is a positive relation between the wage rate and commuting. Basically, the result state that an increase in commuting time of an hour requires roughly a 6% wage increase to offset the loss in time. The other main result is that *on average* people working at home receive 20% less wage than people who working out-of-home. Individuals who own an internet account only earn 4% less. Note that the latter is not significantly different from zero, while the former is not statistically different from 1. However, the point estimates do have intuitive meaningful interpretations, so we use these estimates in order to construct $\varphi(\xi)$ ($= 0.80 + 0.04\xi$).

The other estimates are – although not all significant – conform intuition. The wage increase with age and with education. Females earn less and people with a drivers license earn more (they are more mobile and have a larger space to search better jobs). Oddly, females with young children seems to earn more than females without. Perhaps, those females

have chosen for a high-profile career, while their husbands are taken care for the children (remember that we only sample single-earner households. Finally, it seems that between 1995 and 2000 wages increased nominally with 7%.

With the use of the coefficients of commuting and working at-home, we are now able to estimate (20). For both the short-run and the long-run models the estimation results are displayed in Table 2. Note that at this stage we have not yet incorporated individual characteristics, so heterogeneity most likely still plays a role. For comparative reasons, column (I) displays the results for the short-run Cobb-Douglas system, column (II) displays the results for the short-run Linear Expenditure System and column (III) displays the results for the long-run Linear Expenditure System.

Table 3: Estimation results for the LES sytem (standard errors between parentheses and significant at 5% in bold).

Variable	Cobb-Douglas	Linear Expenditure	
	I	Short-run II	Long-run III
α_{h_a}	0.0107 (0.0008)	0.0076 (0.0024)	0.0062 (0.0018)
α_l	0.4570 (0.0063)	0.3353 (0.0343)	0.2879 (0.0201)
α_t	0.1017 (0.0034)	0.0186(0.0184)	0.0189(0.0146)
$\alpha_{F'}$	0.0151 (0.0017)	0.0065 (0.0021)	0.0382 (0.0021)
α_{t_c}			0.0979 (0.0040)
γ_{h_a}		2.6898 (0.6226)	2.5571 (0.5975)
γ_l		16.8131 (2.3478)	15.2790 (1.4465)
γ_t		6.3237 (0.8553)	6.0821 (0.8509)
$\gamma_{F'}$		1.9183 (0.0788)	-1.1799 (0.0479)
γ_{t_c}			-0.5269 (0.0406)
F^*	2.6321 (0.0536)	3.5142 (0.0439)	2.5695 (0.0618)
mean logl.	7.166	7.642	11.112
N	392	392	392

In Table 3, Column (I) presents the average shares for each activity. The results imply that consumption has a share of about 40%.¹⁰ The share of at-home work is estimated to be very small. So it seems that the price of working at-home is not very substantial in the total full budget. If we only look at the short-run LES estimates, then it seems that people need at least 16 hours of leisure time per week and a frequency of commuting between 1.5 and 5.5 (3.5 ± 2) times per week, whereas the optimal frequency of going

¹⁰Usually, leisure has a higher share, but due to our strict definition of leisure, other activities as eating and bathing will end-up in the rest category, which we here have labeled consumption.

to the work floor is estimated to be 3.5. However, this is *conditional* on commuting time. Moreover, workers prefer to work at least 2.6 days at-home and seem to have a very low preference for the frequency of commuting trips. Note that this is the deviation of the *optimal* commuting time, which explains its low share.

In the long-run, workers like to have at least 15 hours per week allocated to leisure time, 2.5 hours allocated to at-home work and 6 hours to non-commute travel. Interestingly, the optimal frequency is lowered to 2.6, indicating that when commuting time can be chosen, individuals like to lower their amount of commuting trips. In the long-run, the γ coefficients of commuting and frequency are negative, indicating that these activities are not considered as essential goods. Where in the short-run the frequency is still considered to be essential – in the long-run it is not. This is probably due to the fact that commuting time in itself is not considered as an essential activity, thus the frequency of commuting is not either.

Probably, estimates in Table 3 are biased due to (unobserved) heterogeneity. Therefore, we introduce variation in preferences across individuals by treating the parameters α_k as individual specific. A straightforward specification is:

$$\alpha_{k,i} = \mathbf{Z}_i \beta_k, \quad (21)$$

where \mathbf{Z}_i is a matrix of individual specific variables and β_k a commodity specific vector of coefficients. Table 4 shows the estimation results for the long-run demand system.

Qualitatively, the estimates of the structural parameters in Table 4 are not very different than those in Table 3. Concerning the individual-specific parameter, it seems that older individuals prefer more leisure, higher commuting times and a larger deviation from the optimal frequency to go to work. Younger persons also seem to prefer larger commuting times and have a low preference for travel. Singles work less at-home while individuals who reported to have flexible jobs work more at-home and have smaller commuting distances. Finally, females seem to prefer to spend much time to non-commute travel.

Instead of these figures, it may be more insightful to look at the price and income elasticities. These are easily calculated by the results. Namely, the own price elasticities are:

$$\frac{\partial \ln y_k}{\partial \ln p_k / M} = -1 + \frac{(1 - \hat{\alpha}_k) \gamma_k}{y_k},$$

where y_k is an evaluation (usually around the mean) of the amount of commodity k consumed. Moreover, cross-price elasticities may be calculated as:

Table 4: Estimation results for the long-run LES system (standard errors between parentheses and significant at 5% in bold).

	At home	Leisure	Travel	Frequency	Commute
γ_k	2.594 (0.636)	14.795 (1.511)	6.372 (0.872)	-1.181 (0.049)	-0.530 (0.042)
F^*				2.577 (0.062)	
β_k					
Constant	0.015 (0.004)	0.355 (0.030)	0.006 (0.018)	0.035 (0.005)	0.099 (0.009)
Age < 20	-0.015 (0.017)	-0.005 (0.004)	-0.006 (0.003)	-0.004 (0.003)	-0.002 (0.002)
Age 20 – 30	-0.008 (0.003)	0.006 (0.002)	-0.002 (0.002)	0.163 (0.133)	-0.041 (0.026)
Age 30 – 40	-0.072 (0.019)	0.034 (0.019)	0.031 (0.017)	-0.004 (0.019)	-0.044 (0.015)
Age 40 – 50	-0.032 (0.015)	0.061 (0.069)	0.008 (0.014)	-0.005 (0.011)	-0.009 (0.010)
Female = 1	0.007 (0.010)	0.010 (0.011)	0.016 (0.008)	-0.011 (0.009)	-0.017 (0.027)
Single = 1	-0.012 (0.005)	-0.002 (0.004)	-0.004 (0.004)	0.001 (0.003)	0.002 (0.004)
Flexible = 1	0.008 (0.003)	0.005 (0.003)	-0.014 (0.049)	-0.027 (0.010)	-0.011 (0.007)
Year = 2000	-0.010 (0.007)	0.004 (0.006)	0.004 (0.007)	0.011 (0.005)	0.003 (0.006)
$\hat{\alpha}_i$	0.006	0.295	0.015	0.038	0.098

$$\frac{\partial \ln y_k}{\partial \ln p_j} = -\hat{\alpha}_k \frac{p_j \gamma_j}{p_k y_k},$$

with $j \neq k$. Finally, income elasticities are to be calculated as:

$$\frac{\partial \ln y_k}{\partial \ln M} = \frac{\hat{\alpha}_k}{p_k y_k}.$$

Tables 5 and 6 present the price elasticities as implied by the estimation results of Table 4, evaluated at the means of the exogenous variables and the mean shares of the activities.

Table 5: Price Elasticities of the LES.

Quantities\Prices	At-home	Leisure	Travel	Frequency	Commute
At home	-0.544	-0.100	-0.043	0.009	0.013
Leisure	-0.004	-0.683	-0.047	0.012	0.017
Travel	-0.001	-0.030	-0.135	0.003	0.004
Frequency	-0.017	-0.304	-0.259	-2.325	0.077
Commute	-0.010	-0.350	-0.150	0.031	-1.412

Table 6: Income Elasticities of the LES.

At home	Leisure	Travel	Frequency	Commute
0.522	0.696	0.157	3.169	1.836

All activities are price elastic, where commuting and especially frequency seems to be highly sensitive to their own prices. Moreover, they both seem to be luxurious goods, as the expenditure elasticities are higher than one. Thus, the larger the time available or the wage rate, the more workers are inclined to commute and go to their work space. At-home work, leisure and travel are – according to this estimation – necessary goods. If available time or the wage rate increases, people will spend even more time to leisure than on working at-home. Interestingly, at-home work responds in a substitutional manner to price changes of frequency and commuting, while commuting and frequency respond complementary to price changes in at-home work. The latter may be explained by the fact that price changes in at-home work are induced by changes in ICT availability. Thus, it seems that frequency and commuting are positively related with changes in ICT availability. Moreover, it seems that commuting and frequency are substitutes of each other, which is not surprising, because their corresponding

prices are a function of each other. Finally, travel, leisure and working at-home are clearly complements of each other, indicating that they are all substitutes of consumption – and indirectly of working out-of-home.

4 Concluding Remarks

In this paper, we deal with the decision of workers regarding the location of work, the frequency to visit their work space and – in the long-run – also the amount of commuting time. This would imply that there is a trade-off between working at-home and working-out-of-home, and that in the long-run workers get higher wages to offset larger commuting times. Indeed, it seems that at-home work offers a slightly lower wage rate (–20%) and that the availability of ICT lowers this penalty (to –4%). However, the empirical evidence for this relation is not very conclusive. In the long-run, our empirical results show that workers earn a 6% higher wage rate for every hour they commute per day. Results from the demand system estimation suggest that workers' optimal frequency of going to work is about 2.5 times a week and that individuals need at least 14 hours of pure leisure time per week. For this particular sample, working at-home is considered as a necessary good, from which at least 2.5 hours per week should be consumed.

The prices of at-home work are considered here to be dependent upon ICT availability. Relative to individuals' preferences it seems that those prices only explain a small part of why people work at home. Moreover the price elasticities between commuting or travel on the one hand and working at home on the other are negative, indicating that working at home and commuting or travel are complements. This is probably explained by the fact that ICT usually generates more travel. On the other hand larger prices of commuting times seems to ensure a larger share of working at-home, indicating substitutability.

However, the results from the demand system suffer from two problems. Firstly, decisions made on the labor market are rather individual specific – in particular the choice of working at-home. Therefore, our results may still suffer from (unobserved) heterogeneity bias. Therefore, more variation should be introduced in the empirical model, in the form of adding more individual characteristics. An ideal but less straightforward way would be to specify the α parameters as stochastic, where the mean would depend upon the set of individual characteristics.

The second problem is caused by the non-negativity constraints of the activities. For example, in the sample of all workers there are only 17.5% non-zero entries of working at-home during the observation spell. Actually, since Deaton (1986) it is widely known that zero expenditures are one of the most important problems in demand system analyses. Therefore, non-negativity constraints should be taken explicitly into account in order

to make use of the full sample.

Preferably, heterogeneity of observations and non-negativity constraints should be dealt with in the near future. Hopefully, these approaches would result in more consistent price elasticities between commuting, travel and working at-home. These would then be the first – to the authors' knowledge – to take endogenous commuting and individual wage rates into account.

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