Is the intertemporal income elasticity of the value of travel time unity?

Jan-Erik Swärdh [a,*]

[a] *VTI - Swedish National Road and Transport Research Institute, Box 55685, SE-102 15 Stockholm, Sweden*

Abstract

The purpose of this study is to estimate the intertemporal income elasticity of the value of travel time (VTT) and test whether it differs from one. The empirical analysis is performed on Swedish revealed preference data, where voluntary job changers' individual wage premium for commuting time changes is used as an estimate of VTT. The panel structure of the data implies the opportunity to use a lagged net income variable on individual level to estimate the income elasticity in an intertemporal way. The result does not support an intertemporal income elasticity of VTT that is different from one and this result is robust over several different empirical specifications. Hence, the policy implication of this study is in contrast to a recent recommendation by an EU-financed project, Heatco, which propose an intertemporal income elasticity of 0.7.

Keywords: Value of travel time; Value of travel time savings; VTTS; Intertemporal; Income elasticity; Revealed preferences

1 Introduction

The intertemporal income elasticity of the value of travel time (VTT) has a substantial influence on cost benefit analyses (CBA) of investments in transport infrastructure. One reason is that travel time savings usually account

* Tel.: +46 8 555 770 28; fax: +46 8 28 50 43.
Email address: `jan-erik.swardh@vti.se` (Jan-Erik Swärdh).

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for the largest share of the benefits related to such investments. For instance, Hensher and Brewer (2001, p. 85) note that more than 70 percent of total user benefits in many transport investments correspond to travel time savings while in a Swedish study (Persson and Lindqvist, 2003), the travel time savings correspond to about 46 percent of the total benefits of road investments. The other reason is that the long lifetime of transport infrastructure implies that VTT changes within the lifetime will have a large influence of CBA.

In early years, VTT was assumed to change proportionally with income implying that the income elasticity of VTT is unity. Later, evidence from various empirical studies suggested that VTT increases less than proportionally to income, with an elasticity between 0.25 and 0.75. (Hensher and Goodwin, 2004)

Nevertheless, some of these empirical studies lacked the time dimension completely since they were performed on cross-sectional data, while others just compared cross-sectional studies from different years by meta-analysis. To my knowledge, no previous study has used individual level data in different time periods to estimate the income elasticity of VTT intertemporally, making the motivation of such a study straightforward.

The purpose of this study is to estimate the intertemporal income elasticity of VTT and test whether this elasticity differs from one. The Swedish revealed preference data used here has a longitudinal structure and consists of a rich administrative matched employee-establishment data set combined with actual road travel times between small homogeneous geographical areas. Another special feature of the analysis is the use of a rather simple revealed individual estimate of VTT based on the theory of compensating wage differentials (see Rosen (1986) for an overview of this theory) as the dependent variable.

The estimated results show no support for distinguishing the intertemporal income elasticity of the value of travel time from one. This result is evidently robust over different models and definitions of the estimation sample.

The terminology of this paper has to be clarified. I will use the term "value of travel time" (VTT) for the monetary value assigned to a given time unit. In the literature, the term "value of travel time savings" (VTTS) is most common but there are also other expressions such as "subjective value of travel time" (SVTT) and "value of time" (VOT). The reason for me to use VTT instead of the more conventional VTTS is that the travel time variable in this application can not only be reduced but also increased. Hence, the word "savings" does not tell the complete story and may be seen as confusing. Note that VTT, for simplicity, is used consistently in this paper also when referring to other scientific work, although the terminology used in most of these studies is different.

The rest of the paper is organized as follows. The next section outlines the background of how the income elasticity of VTT has been assessed in recent decades. This section also describes previous empirical evidence and discusses the weaknesses of these studies. Section 3 contains the methodology, including model, data, sample restrictions and sample selection problems. In section 4, the results are presented, which also includes several differently specified estimations as sensitivity analyses. Section 5, finally, concludes the paper.

2 Background

A well accepted opinion, supported by most theoretical and empirical work, is that VTT is an increasing function of income, i.e. the income elasticity of VTT is positive (Hensher and Goodwin, 2004). From the simplest theoretical microeconomic model of time that derives VTT equal to the wage rate (Becker, 1965), it immediately follows that the income elasticity of VTT is unity. This holds also for a goods-leisure model (e.g. McFadden, 1974) as well as for models interpreting VTT as a fraction of the wage rate. Based on those results, a unit intertemporal income elasticity of VTT has been the practice in most countries up to now.

In recent decades, however, a number of empirical studies have resulted in estimates of the income elasticity that are significantly lower than one. The British time valuation study in 1987 (MVA Consultancy et al.) was the first to point out that although a positive empirical relation between income and VTT exists, this relation is decreasing when income increases. Furthermore, Wardman (2001a) suggests an intertemporal income elasticity of 0.6 based on a meta-study of a large number of British cross-sectional VTT studies. Rejection of a unit income elasticity in favor of a lower elasticity is also found in later empirical work such as Fosgerau (2006) and Wardman (2004).

Gunn (2001) draws conclusions from several VTT studies based on data of both revealed preferences and stated preferences from different countries. One of his findings is that the mean VTT in the Netherlands hardly changed between 1988 and 1997 despite a considerable mean income increase during this period, thus implying a net systematic decrease in the disutility of travel time. What has driven this decrease is not clear; nevertheless conceivable reasons are better opportunities of devoting travel time to valuable activities, e.g. by using lap-tops and mobile phones, or better travel comfort.

Axhausen et al. (2006) estimate the cross-sectional income elasticity of commuting travel time in Switzerland to be as low as 0.17. However, their income variable is defined in intervals that might yield low precision of the estimates.

An EU-financed project aiming to harmonize CBA input values in Europe, Heatco (2006), suggests that, when no country-specific results are obtainable, VTT should be adjusted over time with an intertemporal income elasticity of 0.7 based on the results of different meta-studies (Wardman, 2001b; Shires and De Jong, 2006).

In Sweden, some previous evidence of the income elasticity of VTT relies on cross-sectional data from the time valuation study of Algers et al. (1995). The results show positive but rather weak relations between income and VTT. The estimated elasticity is 0.46 for single-person households. For two-person households, the elasticity is lower than for single-person households when the estimation is based on household income. If individual income is used instead, the elasticity is similar for two-person households as for single-person households. Further analyses of car trips, using the same data, suggest that the lowest income group has a VTT of 95 Swedish Crowns (SEK[1]) per hour and

[1] 1 EUR is approximately equal to 9.40 SEK.

that this value increases by 21 SEK per additional 100 000 SEK increase in income, which implies a relatively low income elasticity (Lindqvist Dillén, 2003).[2]

Fosgerau (2005), however, can not reject the hypothesis that the cross-sectional income elasticity of VTT is unity using Danish binary within-mode stated choice data. Furthermore, he points out several reasons why the estimated income elasticity of VTT has been significantly lower than unity in most recent applications. First, conventional studies are performed using gross income instead of net income. Net income should be more relevant for the traveler since it is the part that can be used for private consumption, and when the income tax system is progressive the income elasticity is higher when net income is used instead of gross income (Fosgerau, 2005). The empirical relationship between the individual after tax income and VTT can also be applied to the relationship between GDP per capita and VTT if the factor shares of GDP are assumed to be roughly constant over time (Fosgerau, 2005).

Another point in Fosgerau (2005) is that the total travel time could be positively correlated with income and, hence, the estimated direct income elasticity applies only when the covariates are holding constant. Nevertheless, Swedish figures obtained from the Swedish Level of Living Survey, which is a longitu-

[2] In Sweden, the CBA praxis is to use VTT of the base year for all years within a project. However, new VTT studies are not produced yearly, so the latest established VTT is inflated with the relative change in GDP per capita. In this way, the practice in Sweden is to use unit intertemporal income elasticity. (SIKA, 1999) Nevertheless, my objective in this paper is not to discuss whether Swedish practice should be changed to adjust VTT with respect to expected income changes in CBA. The result of the present study may, however, have implications for how to revise the latest estimated VTT up to the relevant base year.

dinal data set containing a representative sample of the Swedish population, suggest that the average daily commuting time was 39.7 minutes in 1981 and 39.4 minutes ten years later indicating that the commuting time is notably stable over time so this problem should not be of substantial importance for this study. Finally, another reason stated by Fosgerau (2005) is that the parametric assumption of the model may not be fulfilled and the estimates, thus, are not consistent. However, a semi-parametric approach is not applied in this study.

A major drawback of most previous studies is that they are using a cross-sectional sample while the policy relevant elasticity to use in CBA is the intertemporal one when the issue is whether and how VTT should be adjusted over time. Equality across cross-sectional and intertemporal elasticities of VTT requires the strong assumption that the cross-sectional relationship will apply also over time meaning that there are no underlying changes in preferences or technology over time (Heatco, 2006; Wardman, 2001b). Although some meta-analyses that try to take care of the intertemporal dimension exist (e.g. Shires and De Jong, 2006; Wardman, 2001a,b, 2004), no study uses data on the individual level to this end. Nevertheless, as noted by Wardman (2001a), there are limitations of Meta-analyses, inter alia its aggregate characteristic which is a disadvantage compared to individual behavioral analysis. Hence, this study with the use of longitudinal disaggregate data is an important contribution to the literature. In addition, the income variable measured as a continuous variable in this study helps to avoid the problem of income-interval data in Axhausen et al. (2006) and Fosgerau (2005, 2006).

3 Methodology

This section first describes the model used in the paper and then the data including definitions of the variables and necessary sample restrictions. Finally, sample selection problems are discussed.

3.1 Modeling the income elasticity of VTT

One of the special features in this study is the use of a simple observable revealed individual-specific estimate of VTT as the dependent variable in the analysis, where this estimate is measured as the trade-off between wage and commuting time. This approach is inspired by the theory of compensating wage differentials with the assumption that commuting time is a negative job characteristic that, ceteris paribus, has to be compensated by a higher wage to be accepted by the worker.

For all workers that voluntarily change jobs between time $t-1$ and t, the following condition for the utility function must hold

$$U(w_{it}, \tau_{it}, \psi_{it}, \theta_{it}) > U(w_{i,t-1}, \tau_{i,t-1}, \psi_{i,t-1}, \theta_{i,t-1}), \tag{1}$$

where w is the daily after-tax wage, τ is the daily commuting time, ψ is individual observable and unobservable characteristics and θ is unobserved job characteristics.

Furthermore, for all voluntary job changers the value of travel time corresponding to the accepted job offer, $\textit{VTT-offer}_{it}$, that is characterized by the observable trade-off between wage and commuting time is higher than the unobserved individual value of travel time, VTT_{it}

$$\textit{VTT-offer}_{it}(w_{it}, \tau_{it}, w_{i,t-1}, \tau_{i,t-1}) > VTT_{it}. \qquad (2)$$

Henceforth, the offer in equation (2) is denoted as $\overline{VTT_{it}}$ and defined as the net wage change divided by the corresponding commuting time change that follows from the job change

$$\textit{VTT-offer}_{it}(w_{it}, \tau_{it}, w_{i,t-1}, \tau_{i,t-1}) \equiv \overline{VTT_{it}} \equiv \frac{w_{it} - w_{i,t-1}}{\tau_{it} - \tau_{i,t-1}} = \frac{\Delta w_{it}}{\Delta \tau_{it}}. \qquad (3)$$

This VTT definition of the accepted job offer may take a negative value for some individuals because of different reasons. First of all, individuals may have been given a job offer which improves both their wage and their commuting time. According to the definition of the offer in equation (3), these individuals that have a positive wage change and a negative commuting time change will have received a negative offer. By rationality assumption, the VTT has to be non-negative and, consequently, these individuals will be excluded from the estimation sample.

Individuals which have to accept a lower wage and a longer commuting time will also have a negative $\overline{VTT_{it}}$. The reason in this case may be lay-offs; a decrease in the number of yearly working hours which is not observed in the data; or improvements of other important job characteristics than wage and commuting time. These individuals can not be claimed to reveal a trade-off between wage and commuting time by their job changing between $t-1$ and t. Hence, these individuals will also be excluded from the estimation sample.

The unobserved individual VTT is assumed to be a function of wage, commuting time, a vector of observable characteristics other than wage and commuting time, $\mathbf{z}_{it}$, and a random term, ϵ_{it}, assumed to be $N(0, \sigma_\epsilon^2)$ distributed

$$VTT_{it} \equiv f(w_{it}, \tau_{it}, \mathbf{z}_{it}, \epsilon_{it}). \tag{4}$$

Using the definitions of equation (3) and equation (4) in equation (2) will establish the following relationship

$$\overline{VTT_{it}} > f(w_{it}, \tau_{it}, \mathbf{z}_{it}, \epsilon_{it}). \tag{5}$$

To be able to replace $>$ with $=$ in equation (5), the right-hand side is multiplied by an individual-specific scaling term

$$\overline{VTT_{it}} = f(w_{it}, \tau_{it}, \mathbf{z}_{it}, \epsilon_{it}) \times \eta_{it}, \tag{6}$$

where $\eta_{it} > 1$. The parameterization of $f(w_{it}, \tau_{it}, \mathbf{z}_{it}, \epsilon_{it})$ is inspired by the specification in Wardman (2004)

$$f(w_{it}, \tau_{it}, \mathbf{z}_{it}, \epsilon_{it}) = \rho w_{it}^{\sigma} \tau_{it}^{\beta} \exp(\mathbf{z}_{it}\gamma' + \epsilon_{it}). \tag{7}$$

Inserting equation (7) into equation (6) yields

$$\overline{VTT_{it}} = \rho w_{it}^{\sigma} \tau_{it}^{\beta} \exp(\mathbf{z}_{it}\gamma' + \epsilon_{it})\eta_{it}. \tag{8}$$

By noting that $\overline{VTT_{it}}$ is revealed through a voluntary job change somewhere in between time $t-1$ and t, the variables on the right hand side of equation (8) can not be measured in t but consequently have to be measured in period $t-1$

$$\overline{VTT_{it}} = \rho w_{i,t-1}^{\sigma} \tau_{i,t-1}^{\beta} \exp(\mathbf{z}_{i,t-1}\gamma' + \epsilon_{it})\eta_{it}. \tag{9}$$

Equation (9) can be transformed to its log-log form in the following way

$$\ln\overline{VTT_{it}} = \ln\rho + \sigma\ln w_{i,t-1} + \beta\ln\tau_{i,t-1} + \mathbf{z}_{i,t-1}\gamma' + \epsilon_{it} + \ln\eta_{it}, \tag{10}$$

where the intertemporal income elasticity of VTT is given by σ. However, equation (10) consists of two error terms where ϵ_{it}, as stated earlier, is assumed to be $N(0, \sigma_{\epsilon}^2)$ distributed whereas the condition $\eta_{it} > 1$ implies that $\ln\eta_{it} > 0$. Hence, the total error term of equation (10), $\epsilon_{it} + \ln\eta_{it}$, is not symmetrically distributed wherefore OLS is, although unbiased and consistent for all parameters except the intercept, not an efficient estimation procedure (Greene, 2003, p. 503). Instead, by assuming that $\ln\eta_{it}$ is half-normally $N^{+}(0, \sigma_{\eta}^2)$ distributed equation (10) is efficiently estimated with a maximum likelihood technique following the procedure of a stochastic cost frontier model (Greene, 2003).

A description of the stochastic cost frontier model is, for example, given in Kumbhakar and Lovell (2000, ch. 4.2).

The assumption of the functional form of the asymmetric part of the error term, $\ln\eta_{it}$, may be important for the estimated parameters. However, tests in Kumbhakar and Lovell (2000, p. 90) provide support for a relatively simple distribution as the half-normal or the exponential which is an argument presented also by Ritter and Simar (1997). Although these claims are considered for small estimation samples, it may still be relevant in this application.

The model in equation (10) is the base model for estimation whose results are presented in section 4.

The approach of this study also implies a number of caveats. First, $\overline{VTT_{it}}$ is measured as the ratio between an individual's net wage premium and the individual's corresponding change in commuting time between two observation time points. Nevertheless, this ratio probably reflects aspects other than VTT, involuntary job changes, for example, may be a problem in this respect. However, a number of different sample restrictions are made with the purpose of creating a sample where $\overline{VTT_{it}}$ can be treated as a reasonable upper boundary of the unobservable VTT. Furthermore, the rich data material used in this paper makes it possible to control for a large number of other individual variables that may affect $\overline{VTT_{it}}$, which is helping to isolate the effect of income.

Second, only job changers can be used in this study since non-job changers do not receive a VTT-offer between $t-1$ and t that is observable in data.

Finally, the commuting variable is based on car trips and I do not know if the workers actually commute by this mode. Still, most actual commuting times are likely to be highly correlated with the travel time for cars between the same places. In addition, two of the estimation sample specifications described in section 4 aim to assess this potential problem explicitly.

3.2 Data

The data consists of Swedish administrative longitudinal matched employee-establishment data randomly stock sampled in 1998 including, given employee status, observations in 1993, 1990 and 1986. The establishment-level data identifies different establishments and their characteristics. Also, this matched data identifies a small geographical area (SAMS[3]) of both the residence and the establishment. From this information, all workers' commuting time is imputed in the data by the use of a travel time matrix for the road network of all possible combinations of SAMS. Those travel times correspond to the fastest car route between the central points of each SAMS according to the speed limit. The matched employee-establishment data is provided by Statistics Sweden while the travel time matrix is provided by Swedish Road Administration. See Isacsson and Swärdh (2007) for a more detailed description of the data used in this study.

[3] SAMS is short for Small Area Market Statistics and Sweden consists of 9230 SAMS. Although the population is not equally distributed among the SAMS, the Swedish population of approximately 9 000 000 citizens means that each SAMS consists of about 1000 citizens on average.

3.2.1 *Variable specification*

A necessary condition for the VTT-variable to be a credible estimation of VTT is that the individuals change their jobs voluntarily between two years of observation. However, voluntary job changes can not be directly observed in the data and, hence, to check the sensitiveness of the result, I will use three different definitions of job changers. The base definition is all individuals that are coded to another establishment in t as compared to $t-1$. This definition will also include some laid-off workers for whom the observed trade-off between wage and travel time may not be a good estimate of their VTT. Hence, I will also use two other definitions of job changers where the first one excludes workers whose establishment in $t-1$ was closed in t, whereas the second one also excludes workers whose establishment has decreased its number of employees between $t-1$ and t.

The income variable used is the sum of employment income, self-employment income and payments from labor-related insurances. To be comparable with the income in t, the income variable in $t-1$ is inflated by a within-sample inflator, which takes into account age, education, job changing and time period. The inflator formula is given by

$$\overline{w}_{ik,t-1} = \frac{\sum_{i=1}^{n_k} w_{ik,t}}{\sum_{i=1}^{n_k} w_{ik,t-1}} \times w_{ik,t-1}, \tag{11}$$

where the "bar" denotes the inflated wage used in the estimations. Three age groups, four education groups, the job changing indicator and the three time periods are used in all possible combinations to create 72 distinct groups denoted as k [4]. This inflated wage is calculated after excluding observations where the individual is assumed to be working part-time. The exclusion of observations is explained in more detail in subsection 3.2.2.

The procedure in equation (11) assumes that $\overline{w}_{ik,t-1}$ is the best estimate of the wage that individual i would have had in period $t-1$ if she back then would have had the job she had in period t and if this job had been located in the same SAMS as the job the individual had in period $t-1$. Hence, the extra wage premium denoted as $w_{ikt} - \overline{w}_{ik,t-1}$ is the compensation for the change in commuting time that is used as the numerator of the VTT-variable.

Furthermore, this method of wage inflating allows me to control for the effect that employees with different characteristics receive different wage premiums when changing jobs [5]. A necessary assumption is that, within each k, the mean value of commuting time change between $t-1$ and t is 0. These figures have been checked and most of them are close to 0 or at least less than 1 minute in absolute value per commuting trip. Three of the mean values of commuting time changes per trip are larger than 2 minutes but to my opinion this fact will not affect the result of this study in any considerable way.

[4] The age groups are below 30, between 30 and 45 and above 45, measured in period $t-1$. The education groups are compulsory school, high school, university degree and change of educational attainment between $t-1$ and t. The time periods are 1986-1990, 1990-1993 and 1993-1998.

[5] I have also tested to not include the job changing indicator and to include the indicator variables getting married, more children aged 0-6 and less children aged 0 to 6 in the creation of the groups k respectively. However, the main results of the estimated intertemporal income elasticity of VTT are unchanged.

Finally, since there are three distinct time periods in the sample, all income variables are inflated to the income value of 1998 by using the average wage increase between the observation years in the total sample.

The Swedish income tax system was reformed in 1991, i.e. during the observation period. This will lead to problems when the pre-tax income variable given in data has to be recalculated to arrive at the individual net income. Fortunately, the post-reform labor income tax system consists of basically three different marginal tax rates; one basic deduction, one income interval where only a local tax is paid and one income interval where both a local tax and a national tax are paid. This tax system is also applied to the income in 1986 and 1990 with the motivation that, prior to the tax reform, capital income and labor income were brought together and taxed in the same system. Applying the pre-reform tax system to my data will probably lead to severe measurement errors since capital income is not observed in the data.

I use the average local tax in 1998 of 31.65 percent for all municipalities in all observation years. The threshold value for paying the national tax was a yearly taxable income of 213 100 Swedish Crowns (SEK) in 1998 and this value is used for all years since all income variables are inflated to the income value of 1998. Although the basic deduction changes with income, these changes occur only for low and medium levels of yearly income so I will use the lowest level of basic deduction of 10 700 SEK in 1998 for all individuals in all years.

The possibility of tax deduction for commuting costs is taken into account by reducing the yearly taxable income by the amount of commuting cost that exceeds 6000 SEK following the 1998 deductibility rules of the tax system. The commuting cost is calculated as 1.5 times "daily commuting distance in kilometers" times 220. Here 1.5 represents the tax deductibility per car commuting kilometer in Sweden for 1998 and 220 is the approximate number of working days per year given full-time working. Finally, the commuting cost is excluded from the net income since this is a part that has to be paid to realize the wage compensation for increased commuting time and, hence, can not be treated as a compensation for commuting time.

The control variables of individual characteristics given in period $t-1$ are the same in all specifications; commuting time, squared commuting time, age, indicator variable of marriage, number of children between 0 and 6 years of age, number of cars in the household coded as 2 if there are 2 or more cars in the household, county of residence and indicator variables of the education level. In addition, several changes in the individual characteristics between $t-1$ and t are also included; change of educational attainment, change of marital status and change of the number of children between 0 and 6 years of age. Job characteristics are captured by indicator variables of both the sector and the industry. When applicable, gender and indicator variables of the time period are also used in the estimations. Finally, a SAMS-specific measure of accessibility to other jobs are defined from the following formula

$$\text{Accessibility}_{jt} = \sum_{k=1}^{K} e^{-c_{jkt}}(X_{kt}), \tag{12}$$

where c_{jkt} is the commuting time between SAMS area j and k in t and X_{kt} is the number of jobs in area k in t.

3.2.2 Sample restrictions

All different estimation samples are at first restricted in several identical ways to make it possible to estimate the income elasticity of VTT in a credible way. A lower threshold value of the yearly income is set to exclude part-time workers. Since the income change between two observation years is used to compute the VTT-variable, it is necessary that the income change is not driven by a change in working hours. However, the income variable in data is given on a yearly basis without any information about the number of working hours.

From data of Statistics Sweden, the fraction of all employed individuals that usually worked less than 35 hours per week was 22.5 percent in 1998, 24.9 percent in 1993 and 23.3 percent in 1990. For 1986, there is no value obtainable so instead I use the mean value of the fractions in 1985 and 1987 which is calculated to 24.7 percent. By assuming that these fractions of the workers in each year are part-time workers and by using a within-sample truncation, the threshold value is set to a yearly pre-tax income of 75 700 SEK in 1986, 120 300 SEK in 1990, 134 700 in 1993 and 157 100 SEK in 1998. Furthermore, as described in subsection 3.2.1, only job changers are included in the estimations. By imposing the definition based on individuals that are coded to another establishment in t compared to in $t-1$, the remaining sample consists of 140 929 observations.

For some individuals, the commuting time variable takes values that are totally unrealistic for daily commuters. Some people commute weekly, have double residences, are distance working or are registered to an establishment that is not their actual place of working. Hence an upper threshold value of commuting time is used to minimize the probability that the workers do not commute this distance every working day. This threshold is set to 1.5 hours per one-way trip between the residence and the establishment. After this sample restriction procedure 131 144 observations are still remaining.

Apart from changing jobs, there is another way of adjusting the commuting time, namely by moving to another residence. A change of residence may not directly affect the wage and would therefore result in a distortion of the VTT-variable as defined in this paper. Hence all workers that change residence, defined as living in another SAMS in period t compared to in period $t-1$, are excluded from the sample. 43 418 observations are excluded for this reason leading to 87 726 remaining observations. There is also a possibility that individuals move within a SAMS. Recall, however, that these areas are relatively small and moving in this way is most likely not motivated by a desire to adjust the commuting time.

There are also some workers that change jobs but still work in the same SAMS. In these cases, the change in commuting time is calculated to zero so the VTT-variable is not defined and consequently these observations can not be included in the estimations. For some establishments, the SAMS code is not given in the data and, hence, it has to be imputed by using the SAMS in the given municipality where the central point of population is located. Also observations where the SAMS code of the establishment is missing have to be excluded if the workers change jobs within the municipality. 75 849 observations are remaining after this procedure.

As mentioned in section 3.1, $\overline{VTT}$ in equation (3) is not observed for individuals where this definition lead to a negative estimate. From this restriction of the sample, a fraction of 49.6 percent of the remaining observations is excluded from the sample. Of these excluded observations, a fraction of 41.5 percent is an improvement of both commuting time and wage when the job changing occurs whereas the other observations are deteriorations in both commuting time and wage.

In addition, some individuals will experience very large income differences when they have changed jobs. Due to outlier problems, these observations may have an unreasonable large influence on the estimations. Hence, these outliers are excluded from the estimation sample with the cut-off points set at the upper and lower percentile of the income change distribution respectively. These cut-off points imply that individuals with a net income increase of more than 113 453 SEK and individuals with a net income decrease of more than 121 607 SEK are excluded from the estimations.

The sample remaining after imposing all restrictions described above consists of 37 618 observations and is the base sample used in the estimation. This sample is restricted in further ways to check the sensitivity and robustness of the result. The sample restrictions are also making it important to devote a subsection to the problem of sample selection and the opportunities to deal with this problem.

3.3 Sample selection problems

Sample restrictions, as described above, arise in several different steps that cause a substantial loss of observations. Problems with sample selection will occur if there are systematic differences between the individuals that are included in the estimation sample and the excluded individuals.

Table 1 contains summary statistics for the sample divided into two subgroups, namely the base estimation sample as described in subsection 3.2.2 and the sample of all excluded observations in the steps after imposing the restrictions of part-time working and unreasonable high daily commuting time. There is a decrease in the number of observations from 381 749 to 37 618 when these restrictions are imposed. When testing the hypothesis of equal variable means across the groups by t-tests, the results are strongly significant in all cases. These tests are not given in the tables but can be provided by the author upon request. The net income, the commuting time, the dummy for being married, the number of children aged 0 to 6 and the number of cars in the household all have higher means in the basic estimation sample. These results are, presumably, related since high-earning workers usually have the longest commuting time. Furthermore, married individuals, individuals with more children aged 0 to 6 and individuals with a high income should have more cars in the household. More cars in the household may also imply fewer restrictions in the commuting opportunities and hence be important for the length of the commuting.

The mean $\overline{VTT}$ in the base sample is 247 SEK (approximately 26.3 EUR) per hour, which is a high estimate compared to the values used in CBA in Sweden and other comparable countries. However, high estimates of VTT are found in Isacsson and Swärdh (2007) and Vredin Johansson et al. (2006) where the former estimates VTT on the same data as this study but uses a duration analysis approach whereas the latter uses another Swedish revealed preference data on commuting mode choice.

[Insert table 1 about here]

A set of various sample and model specifications is used for sensitivity analyses to empirically check the consequences of the sample restrictions and the definitions of the variables. One of them is a Heckman selection model that takes the sample selection problem explicitly into account and produces consistent estimates given that the model is correctly specified. The procedure for this model is to first estimate the selection equation, i.e. the probability of being included in the base sample, by a probit model, and then the outcome equation using the inverse of Mill's ratio from the selection equation as an independent variable (see e.g. Cameron and Trivedi, 2005). Since no guidance is given in economic theory, the same variables will be used in the selection equation as in the second step outcome equation. An approach like this may seem to induce identification problems, but the model is identified by assuming normally distributed errors (Cameron and Trivedi, 2005). Although the Heckman selection model is sensitive to functional form assumptions, it may still shed some light on how important sample selection problems are in this application.

All estimations are performed by the stochastic cost frontier procedure in Stata assuming a half-normal inefficiency parameter, except the Heckman selection model that is estimated by the Heckman procedure in Stata. Also, the results of the Heckman selection model are based on robust standard errors.

4 Results

The estimated results of the model described in equation (10) on the base sample defined in subsection 3.2.2 are presented in the left column of table 2. The income elasticity is estimated to about 1.14, which is significantly higher than one since the p-value of such a test is about 0.01. However, there is a possibility that the income elasticity changes with income, so including a quadratic income term in the estimation is tested and the model corresponding to equation (9) will in this case be formulated as

$$\overline{VTT_{it}} = \rho w_{i,t-1}^{\sigma} \tau_{i,t-1}^{\beta} \exp(\alpha(\ln w_{i,t-1})^2 + \mathbf{z}_{i,t-1}\gamma' + \epsilon_{it})\eta_{it}, \quad (13)$$

where the intertemporal income elasticity of VTT is given by $\sigma + 2\alpha(\ln w_{i,t-1})$.

The results of estimating equation (13) in its logarithmic form on the base sample are found in the right column of table 2. First, a likelihood ratio test of the hypothesis that the model including a quadratic income variable does not add any additional information to the linear model is significantly rejected. The test statistic is asymptotically χ^2-distributed with one degree of freedom and is calculated to $\chi^2 = -2(-78\ 803 - (-78\ 758)) = 90$, which leads to a p-value $\ll 0.001$ (See e.g. Ben-Akiwa and Lerman, 1985, p. 28 for a description of this test). This result makes me conclude that the model including a quadratic term as given in equation (13) performs better than the model with linear income and thus will be used throughout the paper. Furthermore, in all estimations the income elasticity is the average elasticity evaluated at the average income within each estimation sample.

[Insert table 2 about here]

The results of the right column of table 2 also show that the estimated income elasticity is about 0.93, which is not significantly different from one with a p-value of about 0.23. The effect on VTT of commuting time is increasing at low values, reaches its maximum at the commuting time of 6.7 minutes per trip, calculated by $\exp(1.607/(2 \times 0.422))$, and then starts to decline. When looking at different time periods, VTT is found to be highest in period 1993-1998 and lowest in period 1986-1990. Furthermore, age and accessibility to other jobs have a negative impact on VTT. Increasing the number of children under age 6 between period $t-1$ and t have a positive impact on VTT, while VTT is higher for women than for men. The effect of number of children is also positive but significant only at the ten percent level. All other control variables presented in the table are non-significant. The estimation also includes indicator variables for education, county of residence, sector and industry, which for simplicity are not included in the tables. These coefficients can, however, be provided by the author upon request.

By imposing more restrictions on the base estimation sample, the estimated results regarding the control variables are in most cases similar to the results in the model estimated on the base sample and, hence, only noteworthy differences are pointed out in the following.

In table 3, the results of estimation on the base sample restricted to include only the period 1993-1998 are given. The reason for this exercise is to check the sensitivity of using the post-reform tax rates to calculate the net income variable in 1986 and 1990, i.e. prior to the tax reform. This sample restriction leads to an estimated elasticity about 1.03 which is higher than the elasticity estimated on all time periods. Nevertheless, this elasticity is not significantly different from one with a p-value of about 0.76 and, hence, there is no reason to believe that the results are driven by the use of post-reform tax rates for incomes in years before the tax reform.

Another possible objection to the definition of the base estimation sample is that individuals do not value small commuting time changes (see e.g. Cantillo et al., 2006; Welch and Williams, 1997). To test for this effect, I have restricted the basic model to also exclude individuals who have an absolute change in commuting time smaller than 10 minutes per commuting trip between $t-1$ and t. This sample restriction, whose results are found in table 3, leads to an estimated elasticity of about 0.94, which is not significantly different from one. Another different result in this estimation is that none of the period dummies are significantly positive. Instead, the period of 1990-1993 is negatively significant meaning that VTT was lower between 1990 and 1993 than between 1986 and 1990.

[Insert table 3 about here]

In table 4, the results where the estimation sample is restricted to include only men who have at least one car in the household are presented. This exercise aims to control for the effect that measurement errors in the commuting time variable based on car routes may have on the result. The argument for using only men is that they are more likely to commute by car than women, which is an argument that is empirically supported in, inter alia, Transek (2006). The estimated elasticity of about 1.28 is in this case significantly higher than one at the one-percent level. Note, however, that this estimation sample has a higher average income than the base estimation sample. If the income elasticity instead is evaluated at the mean of the base estimation sample, the result is a lower elasticity estimate of about 1.19. The significance level is also reduced and the p-value is now about 0.023.

Another way of testing the sensitivity of the results with respect to the probability of car commuting is to exclude workers living in the county of Stockholm, since public transport is more commonly used in this region than in the rest of Sweden. Also these estimated results are given in table 4 and the estimated elasticity is about 1.01, which is not significantly different from one.

[Insert table 4 about here]

The estimation results of the sample restriction to exclude individuals whose establishment in $t-1$ was closed in t, and of the further restriction to also exclude individuals whose establishment decreased the number of employees between $t-1$ and t are presented in table 5. Both of these estimation sample restrictions, however, result in an income elasticity that is not significantly different from unity.

[Insert table 5 about here]

Finally, in table 6, the results of the Heckman selection model are given. The estimated lambda parameter, i.e. the inverse of Mill's ratio, is positive and significant. Hence, there is a selectivity effect in the estimation on the base sample, and when correcting for this effect the estimated income elasticity increases to about 0.99 which is obviously still not significantly different from one. Some control variables are different in this model compared to most other specifications. For instance, the effect of both marital status and the number of children aged 0 to 6 is now positive and significant. Getting divorced or a widow(er) has a negative and significant effect, while the effect of more children aged 0 to 6 changes sign from positive to negative. Finally, the commuting time for which VTT reaches its maximum is increased to 10.2 minutes per commuting trip in this model.

[Insert table 6 about here]

5 Conclusions

The purpose of this paper is to estimate the intertemporal income elasticity of the value of travel time (VTT) on Swedish revealed preference data and test whether it differs from one. For all job changers a rather simple estimate of the individual VTT, based on the theory of compensating wage differentials, is used as dependent variable in the analysis. Furthermore, the base estimation sample that is used has to be restricted in several ways. This method may cause sample selection problems which my objective is to deal with throughout the paper.

The estimated results show no support of an intertemporal income elasticity of VTT that is different from one. Only one out of eight different estimation sample specifications of the preferred model results in an estimated elasticity that is different from one and this estimate is larger than one. The overall conclusion is that there is no evidence at all of an elasticity lower than one, which is a result in contrast to most previous empirical studies. Hence, this paper corroborates the findings of Fosgerau (2005) and supports his argument that using net income in a progressive tax system will imply an income elasticity of VTT that is not distinguishable from one.

Finally, an argument against an intertemporal income elasticity of VTT that is different from one is given as a comment by Kenneth A. Small in Hensher and Goodwin (2004). He claims that a constant elasticity that is lower than one implies that travel time will become completely unimportant relatively to other considerations in just a few decades of growth. Furthermore, if the elasticity has been constant and lower than one for the last century, travel time must have been enormously important a century ago.

This strong argument in favor of unit intertemporal income elasticity indicates that previous studies probably either suffer from methodological problems or have found some downward shift in the value of travel time.

Finally, the policy implication of result of this paper is that there is no reason to adopt an intertemporal income elasticity of the value of travel time that is lower than one in cost-benefit analysis.

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Table 1
Descriptive statistics of the sample with restrictions imposed on part-time working and unreasonable high daily commuting time divided into base estimation sample and observations excluded by other motivations described in subsection 3.2.2

Variable	Excluded		Base sample	
	Mean	(Std. Dev.)	Mean	(Std. Dev.)
Net income in SEK/year	160 549	(52 507)	162 369	(46 945)
Commuting time in min/trip	10.52	(10.70)	13.37	(12.29)
Age	34.9	(9.29)	35.3	(8.56)
Married	0.54		0.60	
No of children aged 0 to 6	0.30	(0.63)	0.36	(0.68)
Cars in household	0.95	(0.61)	0.98	(0.63)
Accessibility	6.52	(1.87)	6.39	(1.89)
Education changed	0.06		0.06	
Getting married	0.07		0.05	
Getting divorced/widow(er)	0.03		0.02	
More children aged 0 to 6	0.12		0.09	
Fewer children aged 0 to 6	0.13		0.16	
Female	0.37		0.40	
$\overline{\text{VTT}}$ in SEK/hour			247	(3168)
No of observations	344 131		37 618	

Note: Standard deviations are not shown for the dummy variables since they are determined by the mean according to $\sqrt{\mu(1-\mu)}$, where μ is the mean. Cars in household is the number of cars in the household but defined as 2 if the actual number is 2 or more.

Table 2
Estimation results of base estimation sample with linear income and quadratic income respectively

Variable	Linear		Quadratic	
	Coeff.	(Std. Dev.)	Coeff.	(Std. Dev.)
ln Net income	1.144**	(0.054)	-22.15**	(2.414)
(ln Net income)^2			0.965**	(0.100)
ln Commuting time	1.584**	(0.041)	1.607**	(0.041)
(ln Commuting time)^2	-0.413**	(0.009)	-0.422**	(0.009)
Period 90-93	0.364**	(0.054)	0.362**	(0.054)
Period 93-98	0.610**	(0.080)	0.612**	(0.080)
Age	-0.006**	(0.002)	-0.006**	(0.002)
Married	-0.002	(0.026)	-0.005	(0.026)
No of children aged 0 to 6	0.037	(0.024)	0.039†	(0.024)
Cars in household	-0.011	(0.018)	-0.006	(0.018)
Accessibility	-0.035**	(0.006)	-0.033**	(0.006)
Education changed	-0.003	(0.047)	0.007	(0.047)
Getting married	0.034	(0.049)	0.034	(0.049)
Getting divorced/widow(er)	-0.057	(0.068)	-0.056	(0.068)
More children aged 0 to 6	0.104**	(0.039)	0.112**	(0.039)
Fewer children aged 0 to 6	-0.023	(0.042)	-0.026	(0.042)
Female	0.115**	(0.026)	0.098**	(0.026)
Intercept	-14.08**	(0.660)	126.5**	(14.58)
Estimated elasticity	1.144		0.930	
P-value of elasticity = 1	0.008		0.233	
No of observations	37 618		37 618	
Log likelihood	-78 803		-78 758	

Note: The models are estimated with a stochastic cost frontier model assuming a half-normal inefficiency parameter. The estimation also includes indicator variables for education, working sector, working business and county of residence. **, * and † denote significance at the one- five- and ten-percent level respectively. Cars in household is the number of cars in the household but defined as 2 if the actual number is 2 or more. For the quadratic specification, the estimated elasticity is evaluated at the mean net income of the estimation sample. The calculated p-value of this estimated elasticity is based on the delta method.

Table 3
Base estimation sample restricted to only include time period 93-98 and restricted to exclude those with a absolute change in commuting time smaller than 10 minutes per trip between $t-1$ and t respectively

Variable	93-98		Commuting restr.	
	Coeff.	(Std. Dev.)	Coeff.	(Std. Dev.)
ln Net income	-21.44**	(4.447)	-2.867	(2.775)
(ln Net income)^2	0.936**	(0.184)	0.159	(0.115)
ln Commuting time	1.619**	(0.072)	0.351**	(0.039)
(ln Commuting time)^2	-0.409**	(0.016)	-0.082**	(0.009)
Period 90-93			-0.159*	(0.067)
Period 93-98			-0.124	(0.102)
Age	-0.004†	(0.003)	-0.010**	(0.002)
Married	-0.029	(0.042)	0.014	(0.033)
No of children aged 0 to 6	-0.003	(0.043)	0.088**	(0.028)
Cars in household	0.017	(0.030)	0.050*	(0.023)
Accessibility	-0.047**	(0.011)	-0.015*	(0.007)
Education changed	0.067	(0.133)	-0.021	(0.055)
Getting married	0.062	(0.087)	0.041	(0.058)
Getting divorced/widow(er)	0.046	(0.103)	0.091	(0.082)
More children aged 0 to 6	0.142†	(0.074)	0.137**	(0.046)
Fewer children aged 0 to 6	0.047	(0.075)	-0.074	(0.052)
Female	0.059	(0.043)	0.097**	(0.034)
Intercept	122.1**	(26.93)	12.43	(16.74)
Estimated elasticity	1.031		0.937	
P-value of elasticity = 1	0.757		0.360	
No of observations	14 975		9224	
Log likelihood	-32 326		-14 854	

Note: The models are estimated with a stochastic cost frontier model assuming a half-normal inefficiency parameter. The estimation also includes indicator variables for education, working sector, working business and county of residence. **, * and † denote significance at the one- five- and ten-percent level respectively. Cars in household is the number of cars in the household but defined as 2 if the actual number is 2 or more. The estimated elasticities are evaluated at the mean net income of the respective estimation sample. The calculated p-values of the estimated elasticities are based on the delta method.

Table 4
Base estimation sample restricted to only include men with at least one car in the household and to only include workers living in the county of Stockholm respectively

Variable	Men with car		Stockholm excluded	
	Coeff.	(Std. Dev.)	Coeff.	(Std. Dev.)
ln Net income	-15.93**	(3.527)	-22.29**	(3.355)
(ln Net income)^2	0.716**	(0.143)	0.976**	(0.139)
ln Commuting time	1.632**	(0.060)	1.655**	(0.047)
(ln Commuting time)^2	-0.418**	(0.013)	-0.441**	(0.011)
Period 90-93	0.511**	(0.072)	0.545**	(0.068)
Period 93-98	0.831**	(0.114)	0.729**	(0.102)
Age	-0.004	(0.002)	-0.007**	(0.002)
Married	-0.126**	(0.038)	-0.010	(0.032)
No of children aged 0 to 6	0.052†	(0.031)	0.029	(0.029)
Cars in household	0.023	(0.036)	0.011	(0.023)
Accessibility	-0.028**	(0.009)	-0.045**	(0.007)
Education changed	0.053	(0.076)	-0.048	(0.059)
Getting married	0.014	(0.071)	0.039	(0.060)
Getting divorced/widow(er)	-0.017	(0.111)	-0.057	(0.086)
More children aged 0 to 6	0.045	(0.053)	0.115*	(0.047)
Fewer children aged 0 to 6	-0.053	(0.056)	0.008	(0.051)
Female			0.115**	(0.033)
Intercept	87.22**	(21.39)	126.6**	(20.19)
Estimated elasticity	1.276		1.008	
P-value of elasticity = 1	0.001		0.914	
No of observations	17 962		25 575	
Log likelihood	-37 716		-53 851	

Note: The models are estimated with a stochastic cost frontier model assuming a half-normal inefficiency parameter. The estimation also includes indicator variables for education, working sector, working business and county of residence. **, * and † denote significance at the one- five- and ten-percent level respectively. Cars in household is the number of cars in the household but defined as 2 if the actual number is 2 or more. The estimated elasticities are evaluated at the mean net income of the respective estimation sample. The calculated *p*-values of the estimated elasticities are based on the delta method.

Table 5
Base estimation sample restricted to exclude workers whose establishment in $t-1$ did not exist in t and restricted to exclude all workers whose establishment has decreased its employment during the time period respectively

Variable	Excl. closed establ.		Excl. decreasing establ.	
	Coeff.	(Std. Dev.)	Coeff.	(Std. Dev.)
ln Net income	-19.43**	(2.881)	-19.72**	(4.721)
(ln Net income)^2	0.852**	(0.119)	0.860**	(0.195)
ln Commuting time	1.604**	(0.052)	1.557**	(0.088)
(ln Commuting time)^2	-0.429**	(0.011)	-0.419**	(0.020)
Period 90-93	0.424**	(0.064)	0.350**	(0.122)
Period 93-98	0.709**	(0.093)	1.061**	(0.179)
Age	-0.007**	(0.002)	-0.005†	(0.003)
Married	-0.020	(0.030)	-0.017	(0.051)
No of children aged 0 to 6	0.005	(0.028)	0.003	(0.048)
Cars in household	-0.018	(0.021)	-0.034	(0.036)
Accessibility	-0.041**	(0.007)	-0.037**	(0.012)
Education changed	0.012	(0.053)	-0.131	(0.086)
Getting married	0.055	(0.055)	-0.014	(0.088)
Getting divorced/widow(er)	-0.044	(0.081)	-0.007	(0.132)
More children aged 0 to 6	0.072	(0.044)	0.084	(0.072)
Fewer children aged 0 to 6	0.010	(0.050)	-0.042	(0.085)
Female	0.088**	(0.030)	0.124*	(0.051)
Intercept	110.8**	(17.42)	113.8**	(28.59)
Estimated elasticity	0.958		0.907	
P-value of elasticity = 1	0.538		0.417	
No of observations	26 607		8834	
Log likelihood	-55 283		-18 110	

Note: The models are estimated with a stochastic cost frontier model assuming a half-normal inefficiency parameter. The estimation also includes indicator variables for education, working sector, working business and county of residence. **, * and † denote significance at the one- five- and ten-percent level respectively. Cars in household is the number of cars in the household but defined as 2 if the actual number is 2 or more. The estimated elasticities are evaluated at the mean net income of the respective estimation sample. The calculated p-values of the estimated elasticities are based on the delta method.

Table 6
Heckman selection estimation

Variable	Heckman	
	Coeff.	(Std. Dev.)
ln Net income	-7.843**	(2.969)
(ln Net income)^2	0.370**	(0.123)
ln Commuting time	2.075**	(0.045)
(ln Commuting time)^2	-0.447**	(0.010)
Period 90-93	0.229**	(0.062)
Period 93-98	0.797**	(0.095)
Age	-0.003†	(0.002)
Married	0.227**	(0.031)
No of children aged 0 to 6	0.121**	(0.028)
Cars in household	0.028	(0.022)
Accessibility	-0.030**	(0.008)
Education changed	0.196**	(0.055)
Getting married	-0.069	(0.056)
Getting divorced/widow(er)	-0.706**	(0.080)
More children aged 0 to 6	-0.118**	(0.045)
Fewer children aged 0 to 6	0.042	(0.050)
Female	0.148**	(0.031)
Intercept	36.93*	(17.96)
lambda	2.711**	(0.051)
Estimated elasticity	0.992	
P-value of elasticity = 1	0.909	
No of observations	381 749	
Log pseudolikelihood	-196 484	

Note: The estimation also includes indicator variables for education, working sector, working business and county of residence. **, * and † denote significance at the one- five- and ten-percent level respectively. Cars in household is the number of cars in the household but defined as 2 if the actual number is 2 or more. The estimated elasticity is evaluated at the mean net income of the estimation sample. The calculated p-value of the estimated elasticity is based on the delta method. Results from the selection equation of the Heckman procedure are provided by the author upon request.