THE CONSEQUENCES OF THE PRODUCTIVE USE OF TRAVEL TIME:
REVISITING THE GOODS-LEISURE TRADEOFF IN THE ERA OF
PERVASIVE ICT

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Abstract:

The valuation of travel time savings plays a fundamental role on transport modelling and appraisal. The theoretical foundation for placing a value on travel time savings rests on models of time allocation. Although many alternative time allocation models exist, for many years, this area of theoretical debate was regarded as relatively uncontroversial, with several well-established theories providing a justification for conventional demand modelling practices. In recent years however, the adequacy of these frameworks has begun to be questioned. For example, a number of authors have reported both qualitative and quantitative results which they interpret as indicating that in certain circumstances there can be a positive utility associated with increasing travel time. Other authors have noted that developments in ICT have blurred the classical distinction between activities and travel, enabling some types of activities to be conducted during the course of travel.

In the light of these developments, this paper argues that there is an urgent need to revisit some of the fundamental assumptions underlying classical time allocation models. In particular, we argue that all existing models share a critical weakness in that they assume that a given quantum of time can be used for one and only one activity (or for travel). Drawing on evidence from time use surveys from a number of contexts, we argue that this is a highly unrealistic and limiting assumption, especially in an era of pervasive ICT enabled activities. We argue that failure to explicitly accommodate this type of simultaneous activity engagement underlies a number of the apparently anomalous results recently reported in the literature.

Building off this conceptual position, the paper presents a new framework for modelling time allocation which explicitly accommodates multiple simultaneous activities. This framework is based on an extension of the Goods-Leisure framework of Train and McFadden and the more recent work of Jara-Dias and colleagues (itself drawing on ideas from the earlier work of Evans and De Serpa). We demonstrate how this framework generalises earlier work and provides new insights into the impact of simultaneous activities on the valuation of travel time savings.

As an exercise in the application of this framework, we examine the consequences for the estimation of the value of travel time savings of accommodating various degrees of productive use of time spent travelling, and the consequences of mis-specifying this productivity. This is done by means of a simulation study in which the extended Goods-Leisure framework is used to generate synthetic choice data which are then modelled within a random utility framework using various specifications that omit or mis-specify the impact of the productive use of travel time. The paper discusses the implications of the results for demand modelling and project appraisal.
1. INTRODUCTION

The value placed on savings (and losses) of travel time plays a fundamental role both in the analysis and prediction of travel demand and in the appraisal of transport policy measures. The theoretical foundation for placing a value on travel time savings rests on models of time allocation, originally developed by Becker (1965) and subsequently extended by many authors. Although many alternative time allocation models exist, and debates for many years, this area of theoretical debate was regarded as relatively uncontroversial, with several well-established theories providing a justification for conventional demand modelling practices.

In recent years however, the adequacy of these frameworks has begun to be questioned. For example, a number of authors have reported both qualitative and quantitative results which they interpret as indicating that in certain circumstances there can be a positive utility associated with increasing travel time (e.g., Mokhtarian and Salomon, 2001; Redmond and Mokhtarian, 2001; Salomon and Mokhtarian, 1998). Other authors have noted that developments in ICT have blurred the classical distinction between activities and travel, enabling some types of activities to be conducted during the course of travel (e.g., Lyons and Urry, 2005).

In the light of these developments, this paper argues that there is an urgent need to revisit some of the fundamental assumptions underlying classical time allocation models. In particular, we argue that all existing models share a critical weakness in that they assume that a given quantum of time can be used for one and only one activity (or for travel). Drawing on evidence from time use surveys from a number of contexts, we argue that this is a highly unrealistic and limiting assumption, especially in an era of pervasive ICT enabled activities. We present an extended version of the classical Goods-Leisure framework (McFadden and Train, 1978) which can accommodate multiple simultaneous activities and explore the implications of this new model for the valuation of travel time savings, at both a theoretical and an empirical level.

The structure of the paper is as follows. The next section provides a brief overview of the development of approaches to the valuation of travel time savings. Following this, the third section presents the extended Goods-Leisure framework and demonstrates how this framework generalises earlier work and provides new insights into the impact of simultaneous activities on the valuation of travel time savings. The fourth section describes a Monte Carlo study using simulated data that applies this extended framework to explore the consequences for the estimation of the value of travel time savings of accommodating various degrees of productive use of time spent travelling, and the consequences of mis-specifying this productivity. The extended Goods-Leisure framework is used to generate synthetic choice data which are then modelled within a random utility framework using various specifications that omit or mis-specify the impact of the productive use of travel time. The fifth section describes the results of this study and the sixth section discusses
the implications for demand modelling and project appraisal. The final section summarises the overall conclusions.

2. ESTIMATION OF THE VALUE OF TRAVEL TIME SAVINGS: THE CURRENT STATE OF PRACTICE

The valuation of travel time savings has been an important component of transport investment appraisal and public policy analysis since the early 1950s. In the UK, for example, travel time savings have accounted for about 80% of the monetised benefits within the cost benefit analysis of major road schemes (Mackie et al., 2003). We owe our current understanding of the value of travel time savings (VTTS) to the seminal models of time allocation developed by Becker (1965), Oort (1969), de Serpa (1971) and others, which conceptualise how individuals allocate time among alternate activities, goods and services, and travel. These models are based on the formulation of a direct utility function which is assumed to depend on the consumption of goods and services and also on the time spent in different activities, including travel. The direct utility function is maximised subject to constraints such as time and money budgets.

These models suggest different ways of theoretically valuing time. The resource VOT is derived by treating time as a resource, since the total amount of time available for allocation to all activities is fixed by the total time constraint. This is the ratio of the marginal utility of total time to the marginal utility of income. The value of time as a commodity is derived by viewing time itself as a potential source of utility i.e. not just as a factor contributing to the production of other goods. This is derived as the rate of substitution between the activity that time is spent on and money, and would be equal to the resource value of time only if the individual assigns more time to the activity than the minimum required i.e. only for leisure activities. The third way of valuing time is the value of saving time in a particular activity (e.g. value of travel time savings) based on technical constraints on the minimum amount of time that must be allocated to particular activities (e.g. minimum time for a trip, though this is a constraint that could be relaxed to account for activities such as telecommuting). This is the algebraic value of the difference between the value of time assigned to an alternative use (such as the value of leisure) and the value of time as a commodity.

Several researchers have also demonstrated the link between these theories of time allocation and the discrete choice modelling framework (see Truong and Hensher, 1985; Bates, 1987; Jara-Diaz, 2000) through the construction of indirect utility functions in models of travel behaviour. These provide an empirical means of estimating the values of time from observed (revealed preference) data and/or data from state choice experiments. The VOT in these models is implicit and is extracted from observed sensitivities of individuals to travel times and costs. In the simplest case, with linear utility functions, the VOT is given by the ratio of parameters of travel time and cost.

The current practice of the value of travel time savings in the UK dates back to the National VOT studies that were commissioned in the UK in the early
This was the beginning of the use of stated preference (SP) surveys for the estimations of VTTS in the UK. This was followed by a further study commissioned in 1994 (AHCG, 1996). The currently used values and practice of VTTS derives largely from these two ‘market research’ type studies and is documented in detail in the Department for Transport’s website for Transport Analysis Guidance. Mackie et al. (2003) provide a detailed history of studies of VTTS in the UK, undertakes a meta-analysis of VOT survey data and makes general recommendations for practice. There has recently emerged significant interest in the heterogeneity of VTTS. For example, Cirillo and Axhausen (2004) examine random taste heterogeneity in the marginal utility of travel time, Hess et al. (2005) discuss the implications of alternative specifications of mixed logit models for estimating VTTS, and Lapparent and de Palma (2002) analyse non-linearities in VOT estimates.

Over the course of this development, a number of issues have attracted debate: resource vs behavioural valuations; the arguments for and against the valuation of small travel time savings; the implication of income effects and so on. A number of these are reviewed by Wardman (1998) and Mackie et al., (2001). However, the key structural assumptions of the time allocation framework have not been challenged. One of these key assumptions is that a given quantum of time can be used for only a single activity.

The time use literature has long acknowledged the presence of simultaneous use of time for multiple activities, use such as watching TV while making a social phone call (Sullivan, 1997; Sullivan and Gershuny, 2001; Floro and Miles, 2003). A particularly important instance of simultaneous activities is productive activities carried out during travel. Gripsrud and Hjorthol (2008) and Lyons et al. (2007) argue that for as long as we have been travelling our time has been filled with a range of activities. Depending on the context of travel, such as the mode of transport, travel time, travel company, accessible equipment, and so on, these activities can be recreational (sleeping, thinking, staring out the window), productive (such as paid work), socialising (conversation, caring for children etc), or private or combinations thereof. Whilst it has always been the case that people have sought ways to use travel time productively, the issue has taken on new importance with the growth in pervasive ICT and a number of researchers have explored conceptual aspects of this issue. For example, Mokhtarian and Salomon (2001) put forward the idea that travelling has a positive component comprising three elements: (i) activities conducted at the destination, (ii) activities that can be conducted while travelling, and (iii) the activity of travelling itself and they argue that it is important to know the relative weight of the different elements in order to be able to predict the effects of different transport schemes. Laurier (2004) has studied the car as a mobile office and Lyons and Urry (2005) have explored the same issue for rail travel. Hu and Polak (2008) proposed an activity production framework to characterise the impact of ICT technologies on activity scheduling behaviour. The empirical evidence (though far from extensive) suggests that the productive use of travel time is widespread, especially in rail travel. For example, Lyons et al. (2007) found that only 18% of participants agreed with the statement: “My time spent on this train
today is wasted time”. Mobile work or nomadic work is a key concept of several studies (Axtell et al., 2008; Sørensen, 2002), the hypothesis being that new ICTs and communication networks prepare us for a “nomadic” way of moving and working.

Transport scheme appraisal relies heavily on the assumption that travel time is unproductive, wasted time. Accordingly travel time savings typically represent a substantial proportion of the benefits of a scheme, benefits that are used to justify capital and operating costs. In this paper we challenge this assumption and test the effects of a simultaneous time use model on VTTS, a model that allows the productive use of travel time through ICT use.

3. AN EXTENDED GOODS-LEISURE TRADE-OFF MODEL

While numerous assumptions underlying time allocation frameworks were questioned, the summative form of time constraint implying no possibility of time-sharing (simultaneous) activities has proved to be particularly resilient to reformulations. The issue was only recently addressed by Pawlak and Polak who provided a reformulated version of a generalised time constraint allowing any number of activities being performed at the same time (Pawlak and Polak, 2010). Below we present a revisited version of Goods-Leisure framework, originally proposed by Train and McFadden (1978). Such utility-maximising approach enables derivation of an indirect utility function conditional on the choice of a transport mode and as well as traveller’s characteristics. The modified utility maximisation problem of an individual can be defined as:

$$\text{Max}_{W, L, T, N} U(G, L, T) \quad U = K + \sqrt[3]{G} + \beta \sqrt[3]{L} + \gamma \sqrt{T}$$  \hspace{1cm} (1)

subject to:

$$G + c_i = w(W + p_i N) + E$$ \hspace{1cm} (2)

$$W + L + t_i = D$$ \hspace{1cm} (3)

$$N + T = t_i$$ \hspace{1cm} (4)

and

$$G, W, L, T, > 0$$ \hspace{1cm} (6)

$$N \geq 0$$ \hspace{1cm} (7)

$$\beta, \gamma > 0$$ \hspace{1cm} (8)

$$0 < p_i < 1$$ \hspace{1cm} (9)

where

$$W$$ time allocated to work  \hspace{1cm} $$c_i$$ monetary cost of travel with mode $$i$$

$$L$$ time allocated to leisure  \hspace{1cm} $$t_i$$ travel time on mode $$i$$

$$T$$ travel time allocated to leisure  \hspace{1cm} $$p_i$$ productivity on mode $$i$$, relative (as fraction) to usual office conditions

$$N$$ travel time allocated to work  \hspace{1cm} $$w$$ wage rate of an individual

$$G$$ monetary value of consumption  \hspace{1cm} $$D$$ total endowment of time (assumed
preference for leisure in relation to goods consumption as 960 minutes, i.e. 16 hours)

\[ \gamma \] parameter describing preference for travel leisure in relation to goods consumption

\[ E \] unearned income

\[ K \] constant

The particular choice of the utility function was dictated by its concavity property as well as the fact that the resulting conditional indirect utility function is analytically tractable. Such a formulation is handled more easily by estimating codes than highly non-linear and exponents-including formulation resulting from, e.g. Cobb-Douglas class functions. Substituting the constraints \((2-4)\) results in \((1)\) an expression of utility in terms of work time \(W\), work on travel time \(N\) and exogenously given parameters:

\[
U = K + \sqrt{w(W + p_i N)} + E - c_i + \beta \sqrt{D - W - t_i} - \gamma \sqrt{t_i - N} \tag{10}
\]

Optimising individual will choose their work and work on travel time as to maximise their utility which can be expressed as the first order conditions, also forming simultaneous equations:

\[
\frac{\partial U}{\partial W} = 0 \tag{11}
\]

\[
\frac{\partial U}{\partial N} = 0 \tag{12}
\]

Solving these equations results in expressions for optimal work \(W^*\) and work on travel time \(N^*\):

\[
W^* = \frac{1}{w(\beta^2 + w)} (w D - w^2 t_i - \beta^2 E + \beta^2 c_i - \beta^2 w p_i (\beta^2 w p_i^2 t_i + w^2 p_i^2 t_i - \gamma^2 w D + \gamma^2 w t_i - \gamma^2 E + \gamma^2 c_i)) \tag{13}
\]

\[
N^* = \frac{\beta^2 w p_i^2 t_i + w^2 p_i^2 t_i - \gamma^2 w D + \gamma^2 w t_i - \gamma^2 E + \gamma^2 c_i}{\beta^2 w p_i^2 + w^2 p_i^2 + \gamma^2 w p_i} \tag{14}
\]

Substituting these into \((10)\) results in an expression:

\[
\hat{V}_i = \frac{\sqrt{w D + w p_i t_i - w t_i + E - c_i \sqrt{\beta^2 p_i^2 + w p_i + \gamma^2}}}{\sqrt{w p_i}} \tag{15}
\]

Since all terms of the function are non-negative, a positive monotonic transformation of squaring both sides can be applied resulting in the final formula for indirect utility function conditional on exogenous parameters
describing individual’s and transport mode’s characteristics, including the newly introduced terms of productivity and parameter $\gamma$:

$$V_i = \frac{(wD + wp_i t_i - wt_i + E - c_i)(\beta^2 p_i^2 + wp_i + \gamma^2)}{wp_i}$$ (16)

This function can form the deterministic component of the utility function in the random utility models (Ben-Akiva and Lerman, 1985). The final step is calculation of the monetary value at which individuals would be willing to trade (one unit of) their travel time, i.e. value of travel time savings (VTTS). In optimum, this could be defined as a derivative of travel cost with respect to travel time which on the other hand can be written as a ration of the respective marginal utilities:

$$\frac{\partial c_i}{\partial t_i} = \frac{\partial U}{\partial t_i} = \frac{MU_{t_i}}{MU_{c_i}}$$ (17)

Using (10) in conjunction with the constraints, one can reformulate the utility function to obtain the following expression:

$$U = K + \sqrt{w(D - L - t_i + p_i(t_i - T)) + E - c_i +}$$

$$+ \beta\sqrt{D - W - t_i - \gamma\sqrt{t_i - N}}$$ (18)

From that it follows that value of one unit of travel time saving is equal:

$$\frac{\partial c_i}{\partial t_i} = w(1 - p_i) + \frac{MU_T}{MU_G} - \frac{MU_T}{MU_G}$$ (19)

Hence expression for calculating VTTS in the presence of travel activities is:

$$VTTS_{TAct} = \frac{\partial c_i}{\partial t_i} = w(1 - p_i) + \frac{\beta \sqrt{G}}{\sqrt{L}} - \frac{\gamma \sqrt{G}}{\sqrt{L}}$$ (20)

The interpretation of this expression is the following. How much value one puts into possibility of reducing travel time depends positively on the wage relative level of and preference between leisure and goods consumption as expressed by the first term, and the wage rate. This is, however, discounted by the productivity on the way as well as the level of and preference for leisure during travel as compared to goods consumption. If the initial framework is reduced to a form not allowing for productive nor leisure use of travel time ($p$ and $\gamma$ constrained to zero), the resulting expression for the VTTS is:
The difference between the two is thus:

\[
VTTS_{NoTAct} - VTTS_{TAct} = w p_l + \frac{MU_T}{MU_G}
\]  

This means that inclusion of the possibility of productive and leisure use of travel time can lead to reduced value of travel time savings. This is especially the case for individuals with high travel productivity as well as those for whom the marginal utility of leisure time during travel is positive. The constrained expression is also consistent with the current practice of valuing savings in travel time during the course of work at the wage rate (Mackie et al., 2003). This is because in such a case, individual’s marginal utility of consumption can be assumed quite high as compared to leisure (because individual chooses to work) and also because \( \beta \), as is shown later, should be of absolute magnitude less than one. This makes the product small, and hence the VTTS can be assumed approximately equal to the wage rate. Given the above theoretical consideration, the following section discusses the research design used to evaluate the extent to which not acknowledging the existence of productive and leisure use of time may influence estimation of the VTTS.

4. RESEARCH DESIGN

To the best of authors’ knowledge, so far no dataset has been compiled which would include standard travel diary information supplemented with information on individual’s productivity during that journey conditional on the transport mode. While there exist empirical studies investigating the issue of productive use of travel time (Floro and Miles, 2003; Lyons et al., 2007; Gripsrud and Hjorthol, 2009; Pawlak and Polak, 2010), these have largely been confined to one mode of transport (usually train) while productivity has been assessed using very general measures, e.g. categories such as ‘not productive’ and ‘productive’. While these papers could provide basis for investigating factors affecting productivity during travel, such a research question remains beyond the scope of this study. Given the nonlinear character of the indirect utility function resulting from the proposed goods-leisure framework along with the very limited treatment of productivity issue in the existing travel datasets, it was decided to make use of the synthetic data. Such an approach allows for a great degree of flexibility in terms of obtaining large datasets containing information necessary for estimating the newly proposed frameworks and which are not available from the empirical data (Garrow et al., 2010).

For the purpose of this paper, we generated a sample of 30,000 individuals, each of whom reported one journey only using the correlation kernel (Williams and Ortuzar, 1982) derived from London Annual Travel Survey LATS 2001 (LATS, 2001). Particular variables of interest were generated as follows:

- Gender – generated randomly with possible outcomes of male and female;
• Age – generated as random variable with log-normal distribution bounded between 16 and 85 years, with mode at 34 years:

\[ Age = X - 25 \]
\[ X \sim \text{LogN}(4.1, 0.154) \]  

(23)

• Trip origin and destination – drawn randomly from the set of 15 possible locations (number of sectors in the LATS dataset);

• Wage \( w \) – generated as random variable uniformly distributed within interval defined by individual’s random allocation to household income groups defined in LATS dataset, and subsequently converted to per capita income using average household size of 2.3 (ONS, 2011).

• Unearned income \( E \) – was generated so as to ensure the range of a few pounds, and remote association with the wage rate:

\[ E = 6XY \cdot Wage \]
\[ X \sim U(0,1) \]
\[ Y = \text{randomly drawn integer from} < 1,12 > \]

(24)

• Possessed equipment – dummy variables describing whether an individual has had certain pieces of equipment with them during travel, usually based on a seed number \( U \) randomly generated for each item:
  
o Mobile phone, Paperwork – generated as

\[ \delta_{\text{MOB/PPW}} = 1 \text{ (possesses of the item) if } U \sim (0,1) > 0.9 \] \[ \delta_{\text{MOB/PPW}} = 0 \text{ Otherwise} \]

(25)

• Tablet/Pad – generated by assuming that possession of tablets is conditional on age and household income \( (w_H) \), with middle-age and young people from richer households being more likely to possess tablet computers:

\[ \delta_{\text{TAB}} = 1 \text{ if } \left( \frac{-\left(\text{Age}^2 + 60 \cdot \text{Age} + 2700\right)}{3600} \right) \cdot X \cdot \frac{w_H}{1 + e^{1+w_H^2}} > 0.5 \]

\[ \delta_{\text{TAB}} = 0 \text{ Otherwise} \]
\[ X \sim U(0,1) \]

(26)

• Laptop – generated similarly to tablet possession, but if individual already has had a tablet with them, the probability of having laptop may have been lower:

\[ \delta_{\text{TAB}} = 1 \text{ if } \left( \frac{-\left(\text{Age}^2 + 105 \cdot \text{Age} - 1350\right)}{1406} \right) \cdot \delta_{\text{TAB}} \cdot X \cdot \frac{w_H}{1 + e^{1+w_H^2}} > 0.5 \]

(27)
Travel time $t$ – generated as random draw from a triangular distribution bounded by 25 and 75 percentiles of the values observed in the LATS. Where data were missing, Wald estimator was used to approximate by referring to car travel times since these were available for all zone combinations (Blundell et al., 1998; Cameron and Trivedi, 2005).

Travel cost $c$
- Car – defined as sum of fuel and parking cost
  - Fuel cost, assuming average speed randomised between 15 and 40 km/h, fuel consumption between 5 and 15 litres per 100 km and fuel price between £1.20 and £1.50 per litre:

$$c_{\text{fuel}} = t \times \text{speed}_{\text{average}} \times \text{fuel consumption} \times \text{price}$$  \hspace{1cm} (28)

  - Parking cost, randomised between 0 and £10;
- Train – generated as depending on the journey time, so that 120 min journey multiplies the price by a factor of two, and discount of 30% would apply to younger people:

$$c = \delta_{<21} \times X \times t^{0.144783}; \quad X \sim U(£0.5, £10)$$ \hspace{1cm} (29)

$$\delta_{<21} = 0.7 \text{ if } \text{AGE} < 21, \quad 1 \text{ otherwise}$$

- Bus – similar to train cost, but with lower pricing band:

$$c = \delta_{<21} \times X \times t^{0.144783}; \quad X \sim U(£0.2, £1.5)$$ \hspace{1cm} (30)

$$\delta_{<21} = 0.7 \text{ if } \text{AGE} < 21, \quad 1 \text{ otherwise}$$

- Walk – monetary cost of walking constrained to zero.

Productivity – defined as depending on trip duration (through function $f_i(t_i)$) and equipment possession parameter obtained from inverse normal distribution centred at the product of the mode-specific vector $\theta$ of feasibility of equipment use (with dummies equal to 1 if a device can be used on the mode $i$) and equipment possession vector $EQP$:

$$p_i = \frac{e^{\theta_i' EQP, 1}}{1 + e^{\theta_i' EQP, 1}} \times \frac{e^{f_i(t_i)}}{1 + e^{f_i(t_i)}} \hspace{1cm} (31)$$
The multiplicative form of the function ensures that for high productivity, neither of the terms can be small, e.g. very short journey may prevent productive work despite equipment possession. The specific functions for the considered travel modes are presented in Table 1 below:

<table>
<thead>
<tr>
<th>Mode</th>
<th>Feasible ICT</th>
<th>$\theta_i$</th>
<th>Impact of journey duration on productivity (assumed)</th>
<th>$t_i(t_i)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car</td>
<td>Mobile phone</td>
<td>(0.5, 0, 0)</td>
<td>As duration increases, the productivity lowers due to exhaustion (need to focus on driving).</td>
<td>$5 - 0.32 \times X^\dagger \times t_i$</td>
</tr>
<tr>
<td>Train</td>
<td>Mobile phone</td>
<td>(0.5, 1, 1)</td>
<td>As duration increases, the productivity increases concavely (focusing on the job).</td>
<td>$-4 + 0.24 \times X^\dagger \times t_i$</td>
</tr>
<tr>
<td></td>
<td>Laptop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tablet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paperwork</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bus</td>
<td>Mobile phone</td>
<td>(0.5, 0, 1)</td>
<td>As duration increases, the productivity increases concavely (focusing on the job).</td>
<td>$-4 + 0.09 \times X^\dagger \times t_i$</td>
</tr>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paperwork</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walk</td>
<td>Mobile phone</td>
<td>(0.5, 0, 0)</td>
<td>As duration increases, productivity lowers due to physical exhaustion.</td>
<td>$2 - 0.08 \times X^\dagger \times t_i$</td>
</tr>
</tbody>
</table>

$\dagger X \sim U(0,1)$

Given the above design, the dataset consisting of 30,000 trips has been created. Using that dataset, the values of utilities associated with each modal alternative on every trip were calculated using the indirect utility function specified in section 3. The parameters $\beta$ and $\gamma$ of the function were chosen so that both the average value of the optimal work time among individuals was around 480 minutes (8 hours), and for some trips individuals would engage in work as well as leisure activities during travel. Subsequently, probabilities associated with each mode were calculated using multinomial logit (MNL), and choice for each trip was generated in a Monte Carlo simulation thus obtaining complete dataset needed for comparative analysis.
4.1 COMPARATIVE ANALYSIS WITH THE MIS-SPECIFIED MODELLING FRAMEWORKS

Different specifications of models which were compared to the ‘true value’ of the VTTS as obtained from the original framework are summarised in table 2. It was chosen to fix initially the parameters $\beta$ and $\gamma$ at 0.4 and 0.03 respectively and subsequently to vary them by an increment ($\beta$ to 0.5 and $\gamma$ to 0.04) to investigate the sensitivity of the results. In terms of the model specifications for comparison, the reasons for choosing particular formulations for comparison were as follows:

- Original model with parameters retrieved from the data, to prove that utility function of this form can be estimated and that the simulated data are reliable for investigation;
- Original model without work or leisure (degraded original framework), to assess the extent to which productivity and leisure, ceteris paribus, impact the VTTS in such an utility optimisation framework;
- Simple linear framework, to assess the extent to which the most basic formulation, often used in VTTS studies as a point for reference, e.g. Mackie et al. (2003), mis-specify the VTTS;
- Quasi-linear formulation with productivity term, to examine whether inclusion of productivity term in the linear specification could improve the valuation and make the estimate more similar to the ‘true value’.

While the expressions for the VTTS have their source in the underlying utility optimisation framework, for linear and quasi-linear specification such expressions can be obtained by taking the ratio of derivatives of the modal utility functions with respect to cost and time. This in fact is the usual practice for measuring the value that individuals attach to saving one minute of travel time. However, such a measure cannot be computed for walking which inherently is a monetary-cost-free mode. Due to this difficulty, in such a case the value of VTTS was fixed at the wage rate and product of wage rate and productivity for linear and quasi-linear specifications respectively.

All estimations and testing for parameter significance were done using BIOGEME software (Bierlaire, 2003). The threshold for parameter significance was assumed at the usual 95% level. The results of these estimations are presented in the section below.

<table>
<thead>
<tr>
<th>Model</th>
<th>Utility function $V$ for mode $i$</th>
<th>VTTS expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original model</td>
<td>$(wD + wpt_i - wt_i + E - c_i)(\beta^2p_i^2 + wp_i + \gamma^2)$</td>
<td>$wp_i$</td>
</tr>
<tr>
<td>Original model with parameters retrieved from the data</td>
<td>$w(1 - p_i) + \frac{\beta \sqrt{D}}{\sqrt{L}} - \frac{\gamma \sqrt{D}}{\sqrt{L}}$</td>
<td></td>
</tr>
<tr>
<td>Original model without travel work or leisure</td>
<td>$(wD - wt_i + E - c_i)(\beta^2 + w)$</td>
<td>$w + \frac{\beta \sqrt{D}}{\sqrt{L}}$</td>
</tr>
</tbody>
</table>
5. FINDINGS

The results of estimating the models are presented in Table 3. Not surprisingly, the best fits were achieved by estimations aiming at retrieving the initial parameters. The degraded framework performed poorly as compared to much simpler specifications. On the other hand, quasi-linear specification supplemented with productivity and wage term, achieved quite a good fit as compared to the original and degraded framework, especially in light of its relative simplicity. Table 4 and Figure 1 present comparatively mean estimated VTTS, overall and disaggregated by mode. Various mean values were tested for their difference from the original mean using Z-test at 95% level of confidence. While the parameters estimated from the data using original specification resulted in estimated virtually the same as original values, the degraded model consistently overestimates VTTS with the

### Table 3. Results of estimating the tested model specifications

<table>
<thead>
<tr>
<th>Parameter combination for data generation</th>
<th>Model</th>
<th>Log-likelihood</th>
<th>$\rho^2$</th>
<th>Log-likelihood</th>
<th>$\rho^2$</th>
<th>Log-likelihood</th>
<th>$\rho^2$</th>
<th>Log-likelihood</th>
<th>$\rho^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original model with parameters retrieved from the data</td>
<td>-22646</td>
<td>0.455</td>
<td>-16209</td>
<td>0.610</td>
<td>-22161</td>
<td>0.467</td>
<td>-15946</td>
<td>0.617</td>
<td></td>
</tr>
<tr>
<td>Model Description</td>
<td>VTTS Estimate 1</td>
<td>VTTS Estimate 2</td>
<td>VTTS Estimate 3</td>
<td>VTTS Estimate 4</td>
<td>VTTS Estimate 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td>-----------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Original model without travel work or leisure (degraded model)</td>
<td>-37887</td>
<td>0.089</td>
<td>-38567</td>
<td>0.073</td>
<td>-36464</td>
<td>0.123</td>
<td>-37810</td>
<td>0.091</td>
<td></td>
</tr>
<tr>
<td>Simple linear formulation</td>
<td>-37693</td>
<td>0.153</td>
<td>-37509</td>
<td>0.153</td>
<td>-37140</td>
<td>0.107</td>
<td>-37225</td>
<td>0.105</td>
<td></td>
</tr>
<tr>
<td>Quasi-linear formulation with productivity term included</td>
<td>-33382</td>
<td>0.197</td>
<td>-30791</td>
<td>0.260</td>
<td>-32787</td>
<td>0.212</td>
<td>-30865</td>
<td>0.258</td>
<td></td>
</tr>
</tbody>
</table>

Greatest differences reported for car and train users. Linear and quasi-linear models, on the other hand, usually lead to underestimated VTTS. However, for such models also negative values of a significant size have been reported for car and train users, thus also affecting the overall mean. Interestingly, in general it turns out that simpler specification excluding productivity term results in VTTS estimates closer to the true value than quasi-linear specification. In terms of initial $\beta$ and $\gamma$ parameters variation, their incremental change does affect discrepancy between original, retrieved and resulting from degraded model values, but influences linear and quasi-linear.

Another interesting feature is the impact of productivity on the discrepancy between true and estimated values. Figure 2 presents plots of differences between true values and resulting from the models, against productivity of the chosen mode. For the retrieved parameters (top row of the graphs) this difference is practically non-existent. In case of the degraded model, the discrepancy increases in line with productivity with some notable large differences also reported for low productivity levels, probably due to high disproportion between marginal utilities of travel leisure and consumption. In case of the linear formulation, there lower productivity seems to be associated with is a greater range of discrepancies, while for higher VTTS becomes consistently overestimated (negative difference). Finally, in case of the quasi-linear formulation, the observed discrepancy is similar to the case of linear model for low values of productivity. For values of productivity above 0.3, however, the resulting discrepancies between true and estimated VTTS are not only more spread, but also more negative suggesting overestimated VTTS. However, given the mean values for such model being lower than for
### Table 4. Mean estimated values of VTTS for different modes and parameters (in GBP)

<table>
<thead>
<tr>
<th></th>
<th>Original model</th>
<th>Estimated original</th>
<th>Degraded model</th>
<th>Linear simple</th>
<th>Quasi-linear</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>β=0.04 γ=0.03</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall mean</td>
<td>0.201±0.001</td>
<td>0.201±0.001</td>
<td>0.281±0.001*</td>
<td>0.087±0.001*</td>
<td>0.060±0.001*</td>
</tr>
<tr>
<td>Car users</td>
<td>0.261±0.002</td>
<td>0.260±0.002</td>
<td>0.360±0.003*</td>
<td>0.160±0.000*</td>
<td>0.181±0.004*</td>
</tr>
<tr>
<td>Train users</td>
<td>0.149±0.004</td>
<td>0.149±0.004</td>
<td>0.456±0.006*</td>
<td>0.039±0.000*</td>
<td>-0.017±0.000*</td>
</tr>
<tr>
<td>Bus users</td>
<td>0.193±0.002</td>
<td>0.193±0.002</td>
<td>0.234±0.002*</td>
<td>0.013±0.000*</td>
<td>0.003±0.000*</td>
</tr>
<tr>
<td>Walkers</td>
<td>0.166±0.002</td>
<td>0.166±0.002</td>
<td>0.195±0.002*</td>
<td>0.098±0.001*</td>
<td>0.016±0.000*</td>
</tr>
</tbody>
</table>

| **β=0.04 γ=0.04** |                |                   |                |               |              |
| Overall mean     | 0.221±0.001    | 0.218±0.001*      | 0.328±0.002*   | -0.32±0.001*  | 0.334±0.009* |
| Car users        | 0.283±0.002    | 0.279±0.002       | 0.466±0.003*   | -0.231±0.000* | 1.069±0.027* |
| Train users      | 0.186±0.004    | 0.183±0.004       | 0.549±0.006*   | 0.047±0.000*  | 0.094±0.003* |
| Bus users        | 0.201±0.002    | 0.199±0.002       | 0.251±0.002*   | 0.016±0.000*  | 0.004±0.000* |
| Walkers          | 0.188±0.002    | 0.185±0.002       | 0.205±0.002*   | 0.103±0.001*  | 0.013±0.000* |

| **β=0.05 γ=0.03** |                |                   |                |               |              |
| Overall mean     | 0.196±0.001    | 0.195±0.001       | 0.267±0.001*   | 0.069±0.001*  | 0.038±0.001* |
| Car users        | 0.265±0.002    | 0.264±0.002       | 0.334±0.003*   | 0.100±0.000*  | 0.116±0.002* |
| Train users      | 0.136±0.003    | 0.136±0.003       | 0.451±0.005*   | 0.045±0.000*  | -0.029±0.001*|
| Bus users        | 0.200±0.002    | 0.199±0.002       | 0.240±0.002*   | 0.015±0.000*  | 0.003±0.000* |
| Walkers          | 0.151±0.001    | 0.151±0.001       | 0.179±0.002*   | 0.089±0.001*  | 0.016±0.000* |

| **β=0.05 γ=0.04** |                |                   |                |               |              |
| Overall mean     | 0.220±0.001    | 0.219±0.001       | 0.291±0.002*   | -3.409±0.031* | 0.113±0.003* |
| Car users        | 0.286±0.002    | 0.284±0.002       | 0.394±0.003*   | -11.679±0.000*| 0.363±0.009* |
| Train users      | 0.182±0.004    | 0.181±0.004       | 0.458±0.007*   | 0.045±0.000*  | 0.006±0.000* |
| Bus users        | 0.208±0.002    | 0.207±0.002       | 0.243±0.002*   | 0.017±0.000*  | 0.003±0.000* |
| Walkers          | 0.178±0.002    | 0.176±0.002       | 0.195±0.002*   | 0.098±0.001*  | 0.013±0.000* |

*Difference from the mean obtained from the original model significant at 95% level
Figure 1. Comparison of mean estimated values of VTTS for different modes and parameters (in GBP)
Figure 2. Differences between true value and different model specifications depending on productivity of the chosen mode (in GBP)
original values (see Figure 1), such cases seem to be more than balanced out by underestimated values for travellers with low productivities. Interestingly, in both linear and quasi-linear formulations, the VTTS for walking assumed equal to wage rate and wage rate multiplied by productivity respectively, display similar discrepancies to the values calculated for the remaining modes (ratio of cost- and time-associated parameters).
In terms of undertaking work activities, it turns out that the impact of productivity on the proportion of travel devoted to working differs depending on the mode (Figure 3). In case of bus and train, there appears to be a concave-like relationship, with proportion of travel devoted to work rising rapidly if productivity reaches 0.3. Such a relationship is weaker for car and almost non-existent in case of walking.

![Figure 3. Proportion of travel time spent on work-related activities as depending on productivity of the mode](image)

6. IMPLICATIONS FOR DEMAND MODELLING AND PROJECT APPRAISAL

The findings suggest that if individuals are indeed able to make productive use of travel time, the value they will place on travel time saving will be different than that implied by conventional analyses. While small deviations of the productivity parameters from their true values do not lead to significant
distortions in VTTS estimation, neglecting the possibility of productive time use altogether or treating it in an overly simplistic manner may result in significant over- or underestimation of VTTS. Whereas the degraded model overestimates VTTS because of the neglected productivity and leisure value of travel time (see equation 22), the linear and quasi-linear specifications lead to underestimations probably due to poor fit (underlying specification is strongly non-linear) and ignoring the effect of other factors such heterogeneity in marginal utilities of time and consumption. In some cases the resulting negative values would mean that individuals would be keen to pay to travel for longer time. While this could be true in certain circumstances such as sightseeing trips or driving for pleasure when the utility of travel itself can be deemed positive (Mokhtarian and Salomon, 2001), it is unlikely that at a more aggregated level this is the case. Thus the observed negative VTTS above should be attributed to the inability of to recover fully the underlying preferences, perhaps due to simplistic treatment of the relationships between the parameters.

Within the proposed framework, the most important driver of the discrepancies between true and estimated VTTS is the presence of productivity effects. For the degraded model, the higher the productivity, the bigger the overestimation as related to the true value which would indicate that conditional on continuing ICT development stimulating travel productivity, bias resulting from ignorance of that feature will increase. Interestingly, the effect is opposite for the linear specification where lower productivity is associated with greater range of discrepancies while higher lead to comparatively small (around £0.1) although consistent underestimation. This is because true VTTS being generally lower for high productivities and thus closer to generally underestimated linear valuations. Such a pattern is partially broken in quasi-linear formulation (bottom row in Figure 2) where low levels of productivity are associated with underestimation (due to the effect observed in linear model) while high productivities lead to overestimation, probably due to insufficient weight given to the role of productivity in time valuation. This demonstrates that inadequate specification may lead to equally significant distortions as complete neglect of the issue.

In the current model, productivity specification is constant with a mode. However, Lyons and Urry (2005) speculate that productivity may vary between individuals and journey contexts within a given mode, and that these patterns of heterogeneity may themselves vary between modes. If this is correct, it would mean that also the difference between true and estimated VTTS may differ for different transport modes, potentially making existing appraisal methodology implicitly inconsistent across modes. The issue is even more profound, since potential inclusion of productivity in VTTS estimation would paradoxically make investments improving ‘productive’ transport modes such as trains look less beneficial than those favouring, e.g. cars. Indeed, in an increasingly connected and nomadic world, policy makers would be better advised to focus attention not only on travel time savings per se also on the change in the productive output (be it leisure or monetary) one can generate during travel. The conclusions of earlier work by Hu and Polak (2008) reinforce this point.
7. CONCLUSIONS

In judging the significance of these results, it must of course be noted that the data used for these numerical experiments are synthetic (albeit based on an RP kernel) and that the utility-maximising framework (1-9) ignores issues such as heterogeneity in preferences for leisure and consumption or institutional or scheduling constraints (Small, 1986; Jara-Díaz, 2007). However, our purpose is not to develop a perfect predictive model but rather to shed light on an issue that is of growing significant but which has to date been largely ignored by the travel demand modelling community.

Our results indicate that ignoring the productive potential of travel time for work and leisure activities can lead to biases in VOT and VTTS estimation, and consequent misallocation of resources. In particular, there will be a tendency for over-investment in increasing the speed of already productive modes and under-investment in improving the speed and productive environments provided by other modes.

The possibility of undertaking simultaneous activities is widespread in time allocation decisions, but is not acknowledged in conventional time allocation frameworks. The modelling framework we have proposed generalises existing time allocation approaches, is consistent with empirical research on activities undertaken simultaneously with travel and provides a novel and exciting new channel through which the effects of ICT can enter transport modelling.

8. REFERENCES


