

**UNDERSTANDING VALUATION OF TRAVEL TIME CHANGES: ARE  
PREFERENCES DIFFERENT UNDER DIFFERENT STATED CHOICE DESIGN  
SETTING?**

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1 **Abstract**

2 Stated Choice (SC) experiments are the most popular method to estimate the value of travel  
3 time changes (VTTC) of a population. In the simplest VTTC experiment, the SC design  
4 variables are time changes and cost changes. The levels of these variables create a particular  
5 setting from which preferences are inferred. This paper tries to answer the question “do  
6 preferences vary with SC settings?”. For this, we investigate the role of the variables used in  
7 the SC experiment on the estimation of the set of VTTC (i.e. mean and covariates). Ideally,  
8 one would like to observe the same individuals completing different SC experiments. Since  
9 that option is not available, an alternative approach is to use a large dataset of responses, and  
10 split it according to different levels of the variable of interest. We refer to this as partial data  
11 analysis. The estimation of the same model on each sub-sample provides insights into  
12 potential effects of the variable of interest. This approach is applied in relation to three design  
13 variables on the data for the last national VTTC study in the UK, using state-of-the-art model  
14 specifications. The results show several ways in which the estimated set of VTTC can be  
15 affected by the levels of SC design variables. We conclude that model estimates (including  
16 the VTTC and covariates) are different in different settings. Hence by focussing the survey  
17 on specific settings, sample level results will be affected accordingly. Our findings have  
18 implications for appraisal and can inform the construction of future SC experiments.

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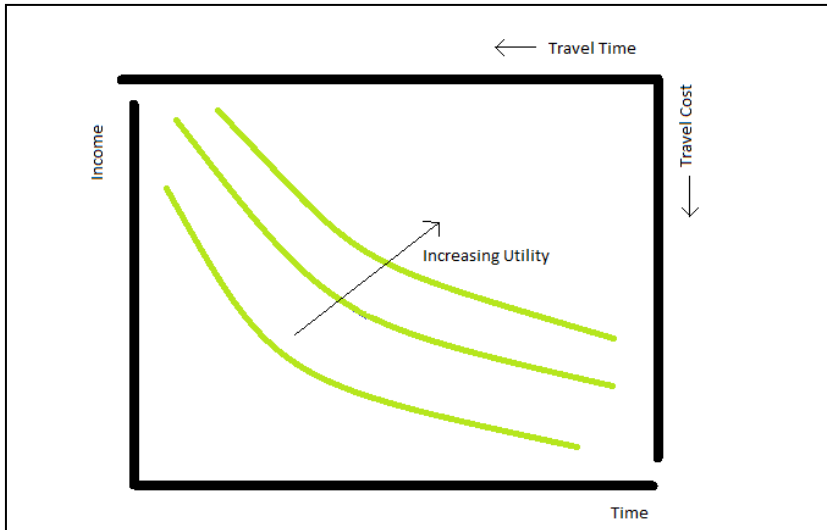
*Keywords:* stated choice, experimental design, value of travel time, cost damping, small time savings, design effects.

# 1 Introduction

2 The value of travel time is a key element in the appraisal of transport projects (Small,  
3 2012; Börjesson and Eliasson, 2014). Big national studies are carried out at somewhat regular  
4 intervals to obtain an estimate of how the population would value changes in travel time. The  
5 objective is therefore a measure of the value of travel time changes (VTTC). Since valuation  
6 is likely to vary across the population and with the trip context, the interest is not placed on  
7 obtaining a single VTTC but an index according to some variables that could explain  
8 travellers' VTTC. Among these variables are individual characteristics (e.g. income) and trip  
9 characteristics (e.g. journey length). The recommended set of VTTC for appraisal has  
10 significant economic implications, and it crucially affects which projects are carried out in a  
11 country. Small (2012) and Daly et al. (2014) concur that our understanding of the VTTC and  
12 its variation should increase in order to maintain the credibility of the VTTC concept. Hence,  
13 it is important to pursue both an unbiased estimate of the VTTC and unbiased estimates of  
14 VTTC elasticities with respect to the variables of interest.

15 The theory of the VTTC has been well rehearsed over the last five decades, based  
16 mainly on the seminal work on time allocation by Becker (1965). DeSerpa (1971) developed  
17 a framework, building upon Becker's work, from which a theoretical definition of the VTTC  
18 is obtained. In short, the VTTC is defined as the marginal rate of substitution between travel  
19 time and money (e.g. travel cost). It is then widely agreed that the VTTC can be found in  
20 individuals' travel choices where they trade-off money and time. Simply imagine a classical  
21 convex indifference curve for the consumption of two goods, time and money, that can be  
22 changed by the allocation of time and money to travelling (as the figure 1 below depicts).

23 **Figure 1. Indifference curves for the money-time trade-off**



24 In this framework, utility increases as the individuals reduce their allocation of time and  
25 income to travelling and the slope of each indifference curve represents the VTTC. While  
26 some data of this nature exist from real travel markets (i.e. revealed preference (RP) data), it  
27 is often very limited: individuals' travel choices are observable, but it is hard to observe the  
28 actual trade-off (if any) that the person faced at the moment of choice. For this reason,  
29 experiments that mimic those necessary trade-offs and choices are typically conducted to  
30 collect data. National VTTC studies typically rely on hypothetical stated choice (SC)  
31 experiments for data collection. Through these methods the researcher has more control over  
32 the variables of interest, time and cost, and can generate trade-offs. Discrete choice models  
33 grounded in traditional microeconomic theory are then employed to estimate the VTTC from  
34

1 the data. In this context, the artificial nature of the SC experiments has sometimes generated  
2 doubts on the validity of estimation results (e.g. Daly and Tsang, 2009). For example, Ojeda-  
3 Cabral et al. (2015) found surprisingly similar patterns in the variation of the VTTC with  
4 income and journey length in two different countries (UK and Denmark) which had used the  
5 same SC design. While there is plenty of evidence on how modelling specification can also  
6 affect the estimation results (see also Fosgerau et al., 2007; and Fosgerau and Bierlaire,  
7 2009), we are not aware of any work that shows how the preferences of individuals vary  
8 (reflected by model estimates) across a number of different SC design settings.

9 Our global aim is to increase our understanding of the set of VTTC in a population. In  
10 this paper we do not question the validity of VTTC estimation results using SC experiments.  
11 However, we acknowledge that the variables used in the SC experiments (decided by the  
12 researcher<sup>1</sup>) may influence the estimated set of VTTC, because preferences may be different  
13 under different SC settings. There is a subtle difference here from saying that the survey  
14 influences the behaviour; rather, different survey settings will potentially lead to different  
15 results given that preferences may vary across settings.

16 In the simplest VTTC experiment, the design variables are travel time changes ( $\Delta t$ ) and  
17 travel cost changes ( $\Delta c$ ). The ratio  $\Delta c/\Delta t$  forms a valuation threshold (Boundary VTTC, or  
18 BVTTC). It is essential to understand how SC design variables influence the VTTC and other  
19 estimates in order to improve the construction of SC experiments: if preferences do vary with  
20 the setting, researchers should decide for which particular setting/s they want to infer  
21 preferences.

22 The objective of the paper is therefore to investigate how different (or not) the  
23 preferences of a sample of travellers may be under different SC design settings. Preferences  
24 are represented by the model estimates of the underlying set of VTTC, while the SC design  
25 settings are represented by the levels of the SC design variables. For this, a series of empirical  
26 exercises which we refer to as partial data analysis are conducted. Ideally, one would like to  
27 observe the same individuals completing different SC experiments. However, with the data  
28 currently available, an alternative approach is to use a large dataset of individuals' responses,  
29 and split it according to different levels of the variable of interest. The data can then be  
30 analysed *as if* the design had a restricted range for the variable of interest (e.g. Fosgerau and  
31 Börjesson, 2015), where it is still highly likely by design that a given respondent contributes  
32 to the results in different segments, given the variety in the settings they are faced with.

33 To increase the policy relevance of this work, we use the data for the last published  
34 national VTTC study in the UK (Mackie et al., 2003) and state-of-the-art model  
35 specifications. The data will be split based on the levels of the three design variables:  
36 boundary VTTC,  $\Delta t$  and  $\Delta c$ . The estimation of the same advanced model on each sub-sample  
37 will show preferences for a particular setting (defined by the levels of the variable). This  
38 paper contributes to the literature on the estimation of the value of time by showing how  
39 preferences may (or not) be different under different SC designs, which is important both for  
40 researchers and policy-makers. The VTTC and how it varies across and within people remain  
41 not fully understood, and not enough attention has been paid to the SC designs that define the  
42 choice contexts (e.g. Fosgerau and Börjesson, 2015). Our work will increase our  
43 understanding, will be useful to inform the construction of future SC experiments to estimate  
44 valuations of travel time and will have implications for appraisal.

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<sup>1</sup> The researcher decides which variables (e.g. changes in travel time) and which levels of the variables (e.g. 5, 10 and 15 minutes) to use in a SC experiment to provide respondents with meaningful and realistic choice contexts. Valuation may be different under different contexts.

1 The paper is structured as follows. Section 2 presents some existing evidence on how  
2 the VTTC has been found to vary across and within individuals, which shapes the current  
3 perceptions about the set of VTTC in a population. Section 3 reviews the standard  
4 methodology applied in most European studies to estimate the VTTC, explaining the essence  
5 of SC experiments and the most common discrete choice models in the field. Section 4  
6 introduces the dataset and section 5 describes the empirical work, including all results.  
7 Section 6 concludes.

## 9 **2 Evidence on variation in the VTTC**

10 Empirical evidence strongly suggests that the VTTC varies across individuals and even  
11 for the same person under different circumstances. For VTTC studies, researchers have  
12 always been interested, and found empirical evidence, on how the VTTC varies with certain  
13 observable variables. In this section, we provide a brief review on some of the most recurrent  
14 sources of variation: current trip conditions, personal income and the size and sign of the  
15 changes (in time and cost) considered. There may be other important variables explaining the  
16 VTTC, but this paper will focus on those mentioned above. For appraisal purposes, current  
17 trip conditions and income are particularly important: these are key drivers of the VTTC of a  
18 given population, before any survey is conducted. The others are related to the choice context  
19 presented in a SC survey (or, if Revealed Preference methods were used, to the choice  
20 context the traveller faced before making his real life choice). In principle, the only certainty  
21 is that one should at least try to explain and control for the effects of the choice context  
22 attributes.

23 In the world we live, income is supposed to affect positively the VTTC, while the  
24 relationship between current conditions and VTTC is less obvious and not even  
25 unidirectional. Current trip conditions, in a simple context, can be understood as the current  
26 travel time and current travel cost an individual is facing on the given trip of interest. *Ceteris*  
27 *paribus*, current time and current cost can affect the VTTC, but also the other way around  
28 (e.g. when a person selects his/her current trip conditions based on his/her VTTC).  
29 Irrespectively of the direction and sign of the relationships, there is a distribution of the  
30 VTTC in a population based on these two variables. In other words, assuming a given trip for  
31 each person, there is one VTTC per person in the population. Data and models for VTTC  
32 estimation are aimed at picking up this distribution.

33 Income can be interpreted as personal or household income, and there is evidence  
34 showing that the VTTC increases with income (e.g. Small, 2012). The impact of current time  
35 and current cost is sometimes referred to as “journey length effect” (e.g. Mackie et al., 2003),  
36 although the correspondence between current time/cost and distance is not precise. This  
37 approximation is, however, practical for appraisal purposes (see e.g. Börjesson and Eliasson,  
38 2014). Many empirical applications on the VTTC report the so-called “cost damping”  
39 phenomenon, by which the sensitivity towards travel cost decreases as current cost increases  
40 (Daly, 2010). Analogously, some works also report “time damping”, where time sensitivity  
41 decreases as current travel time increases. Across individuals, cost damping and time  
42 damping are reasonable especially if we understand that the VTTC can affect the travellers’  
43 current trip conditions (e.g. if a person is choosing an expensive trip in real life, this is likely  
44 to be driven by a low sensitivity to cost; *idem* for time). Several empirical works have found  
45 that the damping effect on the cost domain is greater than on the time domain, and

1 consequently the VTTC increases with journey length (e.g. Mackie et al., 2003; Börjesson  
2 and Eliasson, 2014).

3 The VTTC can also vary for a given individual, depending on the choice context. This  
4 creates controversies for appraisal, since ideally the aim is to pick up one unique VTTC per  
5 person. For example, the VTTC may be different depending on the sign of the changes  
6 considered. Due to diminishing marginal utility, losses would be weighted more than gains  
7 (Tversky and Kahneman, 1991; De Borger and Fosgerau, 2008). Consequently people may  
8 value a given saving of 10 minutes at a lower rate than a loss of 10 minutes (this is known as  
9 loss aversion). Analogously, loss aversion can also be found for the cost attribute. Overall,  
10 this translates into a gap between (low) willingness-to-pay measures and (high) willingness-  
11 to-accept measures. These effects seem undesirable for appraisal purposes (projects are  
12 evaluated with a long-term horizon, where a short-term concept such as loss aversion on a  
13 travel choice does not apply) and may be, at least partially, caused by the SC design (e.g. De  
14 Borger and Fosgerau, 2008; Daly et al., 2014). How to fully remove the choice context  
15 effects is unclear, but current consensus is that models should at least control for them  
16 (Borjeson and Elliason, 2014). For practical purposes, De Borger and Fosgerau (2008)  
17 suggest a formula to obtain one measure of a “reference-free” VTTC.

18 Also at the level of intra-individual valuation heterogeneity, another source of VTTC  
19 heterogeneity (perhaps the most controversial) is the size of the changes considered. Again,  
20 this is a choice context effect and may apply in both time and cost domains. Facing two travel  
21 options, the difference in travel time between them may be, for example, 5, 10, 15 or 20  
22 minutes. How the individual values one minute of travel time may vary depending on  
23 whether he is considering a bundle of 5,10,15 or 20 minutes. This is often referred to as “size  
24 effects”. Welch and Williams (1997) claimed that small travel time changes (typically below  
25 10 minutes) should be valued at a lower rate based on SC empirical evidence. The argument  
26 is usually supported by signs that individuals may even neglect small time changes (e.g.  
27 Mackie et al., 2003). Daly et al. (2014) review this issue, pointing out that although many  
28 studies in fact report low valuation of small time changes, the implementation of this finding  
29 is controversial and therefore rare. There are certain suspicions that the existing SC methods  
30 may not be suitable to accurately estimate this effect due to their artificial nature (Daly et al.,  
31 2014). In particular, the difference between two alternatives in a binary survey may have  
32 different behavioural implications than the difference between two schemes over time in real  
33 world behaviour. Furthermore, other recent studies (Significance, 2013; Ojeda-Cabral, 2014)  
34 recall that there may also be size effects on the cost domain: i.e. VTTC varies with the size of  
35 the travel cost change. Börjesson and Eliasson (2014, p.157) conclude that the interpretation  
36 and treatment of size effects is “perhaps the outstanding unresolved issue in SC valuation”.

37 These different ways in which the VTTC has been found to vary empirically have been  
38 the object of debate for many years. The empirical work conducted for this paper will shed  
39 light on the role of the levels of the SC variables on the estimation of the VTTC, and on how  
40 the VTTC varies (e.g. estimation of elasticities).

41

## 42 **3 Methodology to estimate the VTTC**

### 43 **3.1 Data collection: Stated Choice experiments**

44 The underlying assumption is that the VTTC can be inferred from individuals’ travel  
45 choices where there is a trade-off between travel time ( $t$ ) and travel cost ( $c$ ). SC experiments

1 are the most common method to obtain data on this kind of choices. In most European  
 2 national studies for the VTTC, a binary choice setting is employed. The simplicity of such  
 3 setting makes it very useful for the purposes of this paper. Each traveller is asked to choose  
 4 between two travel options: the *fast and expensive* option and the *slow and cheap* option. For  
 5 ease of exposition, the subscript 1 will always refer to the slow and cheap option, such that:  
 6  $t_1 > t_2$  and  $c_1 < c_2$ ; in actual surveys, the order of these is obviously randomized across choices.  
 7 In each choice scenario, there is always a difference in travel time ( $\Delta t$ ) and a difference in  
 8 travel cost ( $\Delta c$ ) between the two alternatives. The ratio  $\Delta c / \Delta t$  constitutes the BVTTC, an  
 9 implicit “price of travel time”:

$$11 \quad BVTTC = \frac{-(c_2 - c_1)}{(t_2 - t_1)} = -\frac{\Delta c}{\Delta t} \quad (1)$$

12  
 13 In essence, the respondent choosing the fast and expensive (slow and cheap) option  
 14 would reveal a VTTC higher (lower) than the BVTTC. The BVTTC acts as a valuation  
 15 threshold. When researchers design a SC experiment, there is always an expectation  
 16 regarding the range in which the true VTTC will be. This expectation is normally  
 17 transformed into some kind of “target VTTC” (e.g. Fosgerau and Borjesson, 2015), and SC  
 18 designs are constructed accordingly to be able to pick up the true VTTC. The distribution of  
 19 the BVTTC presented in the survey defines the *target VTTC*. The importance of the target  
 20 VTTC was acknowledged early on by Fowkes and Wardman (1988), Fowkes (1996) and  
 21 Clark and Toner (1997).

### 22 23 **3.2 Estimation: Discrete Choice Models**

24 Discrete choice models are used to analyse the data from SC experiments. These  
 25 models are grounded in microeconomic theory. For many years, the random utility (RU)  
 26 model has been commonly used (including all European VTTC studies up to 2007; see e.g.  
 27 Daly et al., 2014). The RU model assumes that individuals choose between two travel options  
 28 ( $i=1,2$ ) to maximise their utility. Each travel option  $i$  is assumed to provide the individual  
 29 with certain level of utility. The utility ( $U_i$ ) is a function with an observable component and  
 30 an error (unobservable) component. The error terms in these RU models have typically been  
 31 incorporated in an additive way, although this is not a requirement:

$$33 \quad \begin{cases} U_1 = \beta_t * t_1 + \beta_c * c_1 + \varepsilon_1 \\ U_2 = \beta_t * t_2 + \beta_c * c_2 + \varepsilon_2 \end{cases} \quad (2)$$

34  
 35 Where  $\beta_c$  and  $\beta_t$  are parameters to be estimated. In this basic setting, they represent the  
 36 marginal utilities of travel cost and travel time respectively. The VTTC is defined as the  
 37 marginal rate of substitution between travel time and travel cost, equal to:

$$39 \quad VTTC = \frac{\beta_t}{\beta_c} \quad (3)$$

1 More recently, the random valuation<sup>2</sup> (RV) model has been used for the last VTTC  
 2 studies in Denmark, Sweden and Norway (Fosgerau et al., 2007b; Börjesson and Eliasson,  
 3 2014; Ramjerdi et al., 2010). The intuition of the RV model can be easily seen if the  
 4 deterministic terms in equation (2) are re-arranged (see, e.g. Fosgerau et al., 2007a). If the  
 5 data is re-ordered such that option 1 is always the slow and cheap option, then:

$$7 \quad \begin{cases} V_1 = BVTTC = \frac{-(c_2 - c_1)}{(t_2 - t_1)} \\ V_2 = VTTC = \frac{\beta_t}{\beta_c} \end{cases} \quad (4)$$

8 It can be seen that when the *fast and expensive* option 2 provides greater utility then the  
 9 VTTC is greater than the BVTTC, and vice versa. While the RU model assumes that utility is  
 10 distributed with constant variance (McFadden, 1974) the RV model poses the constant  
 11 variance assumption on the VTTC (Cameron and James, 1987). In all mentioned studies  
 12 using RV model, the error terms were incorporated in a multiplicative way (again noting that  
 13 this is not an inherent requirement of the RV approach, just as additive is not a requirement  
 14 for RU), which in practice translates to the specification of the utility functions in logarithms  
 15 (see Bierlaire and Fosgerau, 2009) as follows:

$$17 \quad \begin{cases} U_1 = \mu * \ln(BVTTC) + \varepsilon_1 = \mu * \ln\left(-\frac{\Delta c}{\Delta t}\right) + \varepsilon_1' \\ U_2 = \mu * \ln(VTTC) + \varepsilon_2 = \mu * \ln\left(\frac{\beta_t}{\beta_c}\right) + \varepsilon_2' \end{cases} \quad (5)$$

18  
 19 With:

$$20 \quad VTTC = \frac{\beta_t}{\beta_c} = e^{\beta_0} \quad (6)$$

21  
 22 Where:

23  $\beta_0$  is a parameter to be estimated (the exponential function simply ensures positivity of  
 24 the argument of the logarithm and does not affect the results), and  $\mu$  is a scale parameter to be  
 25 estimated associated with  $\varepsilon_i'$  (we use  $\varepsilon_i'$  to note that the type-I GEV distributed error terms in  
 26 Equation (5) are not necessarily the same than those from Equation (2) above). Models can be  
 27 coded to estimate directly VTTC measures (i.e.  $e^{\beta_0}$ ).

28 The latest Danish and Swedish national VTTC studies (e.g. Fosgerau et al., 2007;  
 29 Börjesson and Eliasson, 2014) employed the RV model, arguing that it was superior to RU.  
 30 In another paper using the UK national VTTC study data, we show that, for several model  
 31 specifications, the RV model always performs better than the RU counterpart (Ojeda-Cabral  
 32 et al.; 2015). Consequently, we conduct our analysis using also RV models.

### 34 3.2.1 Observed and unobserved heterogeneity

35 Additionally, regardless of the approach selected (i.e. RU or RV), observed and  
 36 unobserved heterogeneity on the VTTC are generally taken into account. This is done

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<sup>2</sup> This terminology is used by Hultkrantz et al., (1996) and Ojeda-Cabral et al., (2015)



1 extending the definition of the VTTC in (2) or (6). To account for observed heterogeneity,  
 2 interactions between the  $X_j$  variables of interest (i.e. those likely to affect the VTTC) and the  
 3 VTTC are introduced. These interaction terms can modify the VTTC directly. To account for  
 4 unobserved (or random) heterogeneity, a random parameter  $u$  is introduced in the VTTC. For  
 5 example,  $u$  can be assumed to follow a normal distribution:  $u \sim N(0, \sigma^2)$ . In that case, it can  
 6 be seen straightforwardly that the VTTC follows a lognormal distribution across individuals.  
 7 The lognormal distribution has the advantage of restricting the VTTC to positive values and  
 8 has been proven to be convenient in several VTTC applications (see e.g. Börjesson and  
 9 Eliasson, 2014). If these modifications of the VTTC are introduced, the VTTC could be  
 10 extended as follows:

11

$$12 \quad \text{VTTC} = e^{\beta_0 + \beta_{X_j}' X_j + u} \quad (7)$$

13

14 Where:

15  $\beta_{X_j}'$  is a set of parameters to be estimated

16 The mean VTTC, accounting for observed and random heterogeneity, can be calculated  
 17 as:

18

$$19 \quad E(\text{VTTC}) = e^{(\beta_0 + \beta_{X_j}' X_j)} e^{\frac{\sigma^2}{2}} \quad (8)$$

20

21 Under simple cost-time settings in SC experiments, the RV approach (in logarithms)  
 22 and this particular way of introducing observed and unobserved heterogeneity can be  
 23 regarded as part of the state-of-the-art in model estimation for the VTTC (see Börjesson and  
 24 Eliasson, 2014).

25

## 26 **4 Dataset**

27 The dataset used in this paper was collected for the national VTTC study in 1994 by  
 28 Accent and Hague Consulting Group (ACHG, 1996). It contains 12,705 choice observations<sup>3</sup>  
 29 from car travellers for commute and other (i.e. non-business) purposes.

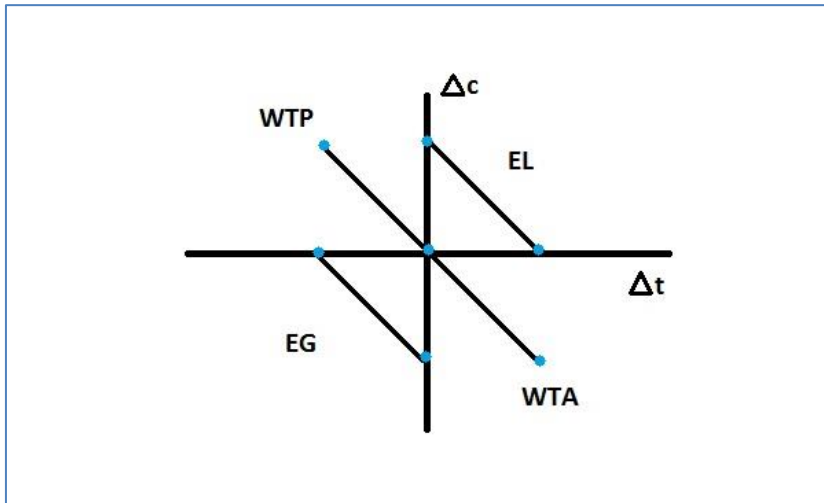
30 The respondents were recruited while travelling and information about a recent trip was  
 31 collected. This trip, defined by current travel time ( $T$ ) and current travel cost ( $C$ ), is used as  
 32 the reference trip throughout the survey. The participants were then presented with eight  
 33 choice scenarios, each with two travel options ( $i=1,2$ ) varying in travel cost ( $c_i$ ) and travel  
 34 time ( $t_i$ ) with levels designed around the reference trip, where  $\Delta t_i = t_i - T$  and  $\Delta c_i = c_i - C$ .  
 35 Travellers were asked to choose their preferred travel alternative. This was a forced choice,  
 36 with no option not to travel. With this basic setup, the SC design of the experiment has some  
 37 interesting properties. Under each scenario, one of each  $\Delta t_i$  and  $\Delta c_i$  are set to zero, so  
 38 travellers are always comparing a given change in time ( $\Delta t$ ) against a given change in cost  
 39 ( $\Delta c$ ). In other words, one of the options always contained  $T$  and one of the options always

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<sup>3</sup> 70 observations were removed due a mistake in the design which offered a negative BVTTC in those cases.

1 contained  $C$ . Those pairwise comparisons are classified into four “types”, based on the four  
 2 quadrants of an indifference curve map (see figure 2 below). The point where the axes  
 3 intersect represents the current trip of the individuals, i.e.  $\Delta t=0, \Delta c=0$ , from which changes in  
 4 time and cost are considered:

5 Figure 2. Four types of choices present in most European VTTC studies.



6  
7

8 1)  $\Delta t < 0, \Delta c > 0$  (current journey vs. faster but more expensive option; willingness to  
 9 pay or WTP)

10 2)  $\Delta t < 0, \Delta c < 0$  (faster option vs. cheaper option; equivalent gain or EG)

11 3)  $\Delta t > 0, \Delta c > 0$  (slower option vs more expensive option; equivalent loss or EL)

12 4)  $\Delta t > 0, \Delta c < 0$  (current journey vs. slower but cheaper option; willingness to accept  
 13 or WTA).

14

15 The lines linked by dots are a representative example of the slope of the indifference  
 16 curve that the design tries to capture in each quadrant. In practice, these slopes do not need to  
 17 be equal for all quadrants; it is theoretically expected (within a Hicksian preference setting)  
 18 and empirically found that the following relationship holds for the slope:  $WTP < \min(EL,$   
 19  $EG) < \max(EL, EG) < WTA$  (see e.g. De Borger and Fosgerau, 2008).

20 Each choice scenario contains an implicit BVTTC. The design includes eight different  
 21 BVTTC (pence/minute), derived from the different combinations of  $(\Delta t, \Delta c)$ . The values used  
 22 in the UK experiment for the BVTTC, as well as the time and cost differences making up the  
 23 BVTTC, are shown in the table 1 below. The eight BVTTC included were considered to  
 24 cover a realistic and sufficient range of VTTC at the time of the study, although recent  
 25 studies (e.g. Börjesson et al., 2012) have suggested that a much larger range of BVTTC is  
 26 required to identify the true mean VTTC over a sample of choices.

27 Table 1. SC design attribute levels

Design variable	Values used for the SC experiment
$\Delta t$ (minutes)	-20, -15, -10, -5, -3, +5, +10, +15, +20
$\Delta c$ (pence)	-300, -250, -225, -150, -140, -125, -105, -100, -75, -70, -50, -35, -30, -25, -20, -15, -10, -5, 5, 10, 15, 20, 25, 30, 35, 50, 70, 75, 100, 105, 125,

	140, 150, 225, 250, 300
<b>Boundary VTTC (pence/minute)</b>	1, 2, 3.5, 5, 7, 10, 15, 25

1

2

In addition to completing the SC tasks, respondents were asked for information on socio-economic characteristics (e.g. income). The work on this data by ITS at the University of Leeds (Mackie et al, 2003) led to the establishment of the current VTTC values officially employed in the UK for appraisal. The analysis carried out in this paper also aims at providing new valuable insights into the results obtained a decade ago, through a focus on the role of the SC design variables.

8

## 9 **5 Empirical work**

10

The *valuation threshold* is the key element of a SC experiment to estimate individuals' valuation if simple time-money trade-offs are employed in the experiment. In the context of the VTTC, this is the BVTTC. A key question is whether it is possible that the BVTTC plays a role on the estimation of the set of VTTC. This is not saying that the survey influences preferences, but that, if preferences (and hence VTTC) are different in different settings, then by focussing the survey on specific settings, our sample level results will be affected accordingly. Fosgerau and Börjesson (2015) analyses the impact of the BVTTC on the estimation of the mean VTTC if basic Random Utility models, with no covariates, are employed. Fosgerau and Börjesson “manipulate” (as they claim) a stated choice survey in order to analyse certain impacts of a design variable, in particular the BVTTC. Their work shows empirically that basing the design of the SC experiment on some target VTTC, defined by the distribution of the BVTTC, will bias the estimated VTTC towards the target (if the VTTC is distributed across the sample). In particular, the “bias” is claimed to be related to model misspecification when a simple Random Utility model (e.g. equation 2 of this paper) is used. Their conclusions simply require that the underlying VTTC in the population vary between individuals (heterogeneity), something which is typically observed in most applications and is therefore acceptable (Fosgerau and Börjesson , 2015).

27

However, much more can be explored. Building upon Fosgerau and Börjesson 's work, our paper will: a) test different modelling specifications in line with the state-of-the-art (based on the RV model described above<sup>4</sup>); b) analyse the impact of BVTTC on the estimation of VTTC heterogeneity, i.e. not only on the mean VTTC; and c) test, in a similar fashion, the impact of the components of the BVTTC, namely the change in travel time ( $\Delta t$ ) and the change in travel cost ( $\Delta c$ ). We assume that estimates are able to reflect preferences, and consequently interpret any differences in estimates as differences in preferences. This empirical work is an attempt to increase our understanding of the role of the design variables in VTTC studies and how inferred preferences can be different depending on the design setting.

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<sup>4</sup> Note that Fosgerau and Börjesson (2015) use a different terminology for the RV model described in this paper: they refer to it as ‘random MRS model’.

## 1 5.1 Partial analysis of the data

2 The series of empirical exercises conducted to investigate our research questions may  
3 be regarded as *partial data analysis*: the term “manipulation” employed by Fosgerau and  
4 Börjesson (2015) might be misleading for our paper. We conduct three exercises, where in  
5 each the dataset of travel choices is split into several sub-samples based on some variable of  
6 interest. In this work, three variables of interest (one per exercise) are investigated: the  
7 BVTTC,  $\Delta c$  and  $\Delta t$ . The levels of these three variables were selected by the researchers when  
8 constructing the SC experiment (AHCG, 1996). In each exercise, the same model will be  
9 estimated on each sub-sample, as well as on the full dataset. The use of this is not to try to  
10 show the inabilities of an inferior (RU) model, but to investigate patterns on the estimation  
11 results across sub-samples, in relation to the VTTC and its covariates.

12 In order to divide the data, Fosgerau and Börjesson (2015) employ the quartiles of the  
13 BVTTC distribution. This gives four sub-datasets of similar size, each with an exclusive  
14 range of BVTTC. Afterwards, the same discrete choice model is estimated on the four sub-  
15 datasets. In our three exercises, we will make use of the same state-of-the-art model  
16 specifications (a logarithmic RV model), in line with equations (5) to (8). The set of  $X$   
17 covariates employed for the definition of the VTTC (equation 8) is the following:

$$18 \beta_{X_j}' X_j = \beta_{BC} \ln\left(\frac{C}{C_0}\right) + \beta_{BT} \ln\left(\frac{T}{T_0}\right) + \beta_I \ln\left(\frac{I}{I_0}\right) + \beta_{\Delta t} \ln\left(\frac{\Delta t}{\Delta t_0}\right) \quad (9)$$

19 where:

20  $C$  = Current travel cost

21  $C_0$  = Reference level of current travel cost (e.g. sample average = 550 pence)

22  $T$  = Current travel time

23  $T_0$  = Reference level of current travel time (e.g. sample average = 70 minutes)

24  $I$  = Income of the individual

25  $I_0$  = Reference level of income (e.g. sample average = £25,000)

26  $\Delta t$  = Change in travel time

27  $\Delta t_0$  = Reference level of change in travel time (e.g. sample average = 7.7 minutes)

28

29 Additionally, the base estimate for the VTTC in equation (8), represented by  $e^{\beta_0}$ , will  
30 be estimated separately for each of the four types of choices (i.e. quadrants) present in the  
31 data. Altogether, this VTTC definition allows us to capture all sources of variation mentioned  
32 in section 2, together with random heterogeneity. Other sources of systematic taste variations  
33 (e.g. age, gender or trip purpose) were tested but found not significant; only main effects  
34 were kept in our models, which is also common practice for models that are then used for  
35 policy (e.g. Mackie et al., 2003). Note that, in a given RV model (and with data using the  
36 design explained above), it is only possible to identify how the VTTC varies with either  $\Delta t$  or  
37  $\Delta c$ . The reason is that the BVTTC,  $\Delta c$  and  $\Delta t$  are multicollinear and the BVTTC is already  
38 part of the model. We have selected  $\Delta t$  as a source of variation, since this is typically a key  
39 factor in VTTC studies and also to comply with current practice.

40 Alongside the VTTC measures by quadrant (four choice quadrants of the indifference  
41 map), the geometric average of the four will also be provided as a measure of the VTTC in  
42 the sample:

1

$$2 \quad VTTC = (VTTC_{WTP} * VTTC_{WTA} * VTTC_{EL} * VTTC_{EG})^{1/4} \quad (10)$$

3

4 This would be an approximation to what De Borger and Fosgerau (2008) suggest as  
 5 “reference-free” VTTC, for this sort of choice settings, through a theoretical derivation. This  
 6 approximation is sufficient for the purposes of this paper, and is certainly better than a mean  
 7 VTTC derived from a model that did not account for the differences across quadrants (De  
 8 Borger and Fosgerau, 2008). In any case, the use of the geometric mean does not affect the  
 9 conclusions of this work, since we would get the same insights by simply looking at the  
 10 specific VTTC by quadrants.

11

### 12 **5.1.1 Exercise 1 - Data split by BVTTC**

13 In the first exercise, the data is split into four based on the quartiles of the BVTTC  
 14 distribution. Two models are estimated on each sub-sample: with and without random  
 15 heterogeneity.

16 For a more complete analysis, the models are also estimated for the full sample. The  
 17 models on the full sample will also be comparable with the models from sections 5.1.2 and  
 18 5.1.3 that will be presented later on. All models have been estimated using Biogeme  
 19 (Bierlaire, 2003).

20 The estimation results are shown in tables 2 and 3, where the former is for a  
 21 Multinomial Logit model and the latter for a Mixed Logit model. In all our models, the panel  
 22 nature of the data was taken into account in the calculation of the robust standard errors. In  
 23 the random coefficients models, the random heterogeneity was specified to be across  
 24 respondents, maintaining homogeneity in sensitivities across the choices for the same person.  
 25 We will look at differences in the VTTC and in the estimation of observed and random  
 26 heterogeneity. On each table, each column defines a sub-sample, showing the available range  
 27 of the design variable for which the model is estimated.

28 The first row shows an estimate of the mean VTTC, at the sample average of the  
 29 covariates. In table 3, where a lognormal distribution is assumed for the VTTC, the mean is  
 30 easily calculated using equation (8) (Fosgerau et al., 2007). In table 2, where the only random  
 31 term in the model is the logistic error, the direct model estimates of the VTTC will  
 32 correspond to the median instead of the mean of the (logistic) distribution<sup>5</sup>. The derivation of  
 33 the mean requires simulation and censoring of the distribution. The mean VTTC can be  
 34 calculated taking the logistic distribution of the error (the difference of two type-I GEV  
 35 distributed error terms follows a logistic distribution) into account as follows (Ojeda-Cabral  
 36 et al., 2015):

$$37 \quad \text{Mean VTTC} = \exp[\ln(e^{\beta_0}) + \frac{1}{\mu}(\varepsilon'_1 - \varepsilon'_2)] \quad (11)$$

38 Where all parameters correspond to the model described in Equations (5) and (6) in  
 39 section 3.2, and hence where  $e^{\beta_0}$  is equal to the median VTTC. Calculation requires  
 40 simulation for the logistic distributions. Additionally, since those distributions are

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<sup>5</sup> The median will coincide with the mean if the logistic error is not part of the preferences. This, however, is contrary to expectations based on empirical evidence (e.g. Börjesson and Eliasson, 2014). If the VTTC follows a distribution and there are not specific random terms to capture it, it can be partially captured by the logistic error.

1 unbounded, it is necessary to make an assumption for the VTTC values which the data does  
2 not support, given mainly by the range of BVTTC (see Börjesson et al., 2012). We use the  
3 approach followed in the Danish VTTC study (Fosgerau et al., 2007b) and censor the  
4 simulated VTTC distribution, restricting it to be close to the BVTTC range. For this, we use a  
5 censor value just above the upper limit of the BVTTC range of the sample ( $1.25 * \text{upper}$   
6  $\text{limit}$ ).

7 Rows below the mean VTTC measure provide the estimates of all coefficients for each  
8 model, including specific VTTC measures by choice context (WTA, WTP, EL and EG). All  
9 VTTC measures are provided in pence per minutes. The standard errors of all estimates are  
10 included in brackets. The last four rows report the number of observations and individuals on  
11 each sub-sample, together with the Log-Likelihood and adjusted rho-squared as model fit  
12 indicators.

13 Overall, coefficients in all models are estimated with the expected sign based on theory  
14 and previous evidence on this dataset (e.g. Mackie et al., 2003; Ojeda-Cabral, 2014), and all  
15 levels of significance are reasonable. The restricted sub-samples caused, in some cases,  
16 identification or correlation problems for estimation due to lack of variability of some  
17 variables. As a result, the models had to be simplified for those samples as will be explained  
18 below. For ease of exposition, the results will be interpreted in several steps as follows.

#### 19 *VTTC estimation (mean/median)*

20 We observe a tendency of the VTTC towards the BVTTC, in line with the exercise  
21 using a basic Random Utility model carried out by Fosgerau and Börjesson (2015). Note that  
22 Fosgerau and Börjesson (2015)'s exercise was also replicated on our dataset, finding the  
23 same tendency when using a RU model<sup>6</sup>. Here we show that the mean VTTC significantly  
24 increases as the BVTTC increases, also with a RV model (only the difference between the  
25 values in columns 3 and 4 is not significant). The differences are also of a relevant size that  
26 would be meaningful if these VTTC were to be recommended for appraisal (e.g. Department  
27 for Transport, 2013). This is an unexpected and important result, as it shows that even a  
28 model that is regarded as a good descriptor of this kind of the data would pick up a positive  
29 relationship between VTTC and BVTTC. The estimated preferences seem to reveal a  
30 valuation that is proportional to the valuation threshold offered. Additionally, the increases in  
31 VTTC with BVTTC seem to be especially driven by WTA and EL choice contexts.

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<sup>6</sup> These results are available from the corresponding author on request.

1 Table 2. Data split by BVTTTC - Estimation results (Standard errors in parentheses)

4 Sub-Samples, each with different BVTTTC range					
	[1,2]	(2,5]	(5,10]	(10,25]	ALL
Mean VTTC (censored max BVTTTC * 1.25)*	1.09	3.52	4.8	6.2	4.89
Median VTTC (p/min)	2.13 (0.61)	4.27 (0.204)	5.2 (1.21)	4.68 (1.74)	3.13 (0.14)
VTTC <sub>EG</sub>	1.88 (0.118)	4.33 (0.163)	5.33 (0.348)	7.52 (1.71)	3.67 (0.244)
VTTC <sub>EL</sub>	1.91 (0.14)	3.82 (0.105)	4.28 (0.397)	3.17 (1.1)	2.07 (0.157)
VTTC <sub>WTA</sub>	4.85 (0.618)	6.03 (0.247)	10.1 (0.477)	10.5 (1.4)	9.97 (0.701)
VTTC <sub>WTP</sub>	1.19 (0.0866)	3.33 (0.117)	3.17 (0.484)	1.91 (0.821)	1.27 (0.105)
$\beta_{BC}$	0.157 (0.052)	0.183 (0.03)	0.21 (0.052)	0.41 (0.15)	0.41 (0.06)
$\beta_{\Delta T}$	NA	NA	NA	NA	0.711 (0.0766)
$\beta_I$	0.28 (0.0484)	0.141 (0.0239)	0.193 (0.0437)	0.387 (0.119)	0.472 (0.0566)
$\beta_{BT}$	-0.025 (0.07)	-0.098 (0.033)	-0.14 (0.054)	-0.188 (0.134)	-0.406 (0.0825)
$\mu$	1.32 (0.116)	2.74 (0.211)	1.72 (0.217)	1.06 (0.2)	0.781 (0.0252)
obs	3382	3328	3100	2420	12230
Indiv.	1776	1769	1673	1399	1804
LL	-2013.35	-1944.49	-1788.274	-935.679	-6708.528
adj. p2	0.138	0.154	0.164	0.437	0.208

2 \* Standard errors could not be calculated for the mean VTTC when it required simulation and censoring.

3 Table 3. Data split by BVTTTC - Estimation results (Standard errors in parentheses) – Random  
4 Heterogeneity

	[1,2]	(2,5]	(5,10]	(10,25]	ALL
Mean VTTC	2.89 (0.25)	4.61 (0.13)	8.62 (1.43)	10.89 (1.19)	7.04 (0.5)
$\beta_{BC}$	0.102 (0.04)	0.22 (0.0324)	0.397 (0.109)	0.436 (0.13)	0.337 (0.057)
$\beta_{\Delta T}$	NA	NA	NA	NA	0.94 (0.058)
$\beta_I$	0.24 (0.04)	0.144 (0.025)	0.321 (0.09)	0.31 (0.09)	0.396 (0.05)
$\beta_{BT}$	-0.023 (0.06)	-0.06 (0.035)	-0.41 (0.124)	-0.016 (0.12)	-0.43 (0.076)
$\mu$	1.95 (0.153)	3.67 (0.3)	1.31 (0.264)	1.96 (0.331)	1.02 (0.0321)
$\beta_0$	0.768 (0.049)	1.41 (0.0222)	1.47 (0.142)	1.49 (0.233)	1.17 (0.0535)
$\sigma$	0.768 (0.07)	0.485 (0.04)	1.17 (0.239)	1.34 (0.22)	1.25 (0.0492)
obs	3382	3328	3100	2420	12230
Indiv.	1776	1769	1673	1399	1804
LL	-2104.241	-1962.843	-1872.23	-938.9	-6636.473
adj. p2	0.1	0.147	0.126	0.437	0.216

1 The VTTC measures by quadrant (WTA, WTP, etc.) show a large gap between WTA and  
2 WTP contexts, in line with findings in the literature (e.g. De Borger and Fosgerau, 2008), but  
3 also between EL and EG.

4 How precise are the VTTC estimates when the SC design setting is limited? Large  
5 standard errors are normal due to sample size reduction, but there are differences across sub-  
6 samples. Most coefficients are much more precise in the second sub-dataset (BVTTC =  
7 (2,5]). The scale of the models ( $\mu$ ) is also greater in the second sub-sample. Interestingly, the  
8 estimated median VTTC in all sub-datasets falls into this range, between 2 and 5  
9 pence/minute. Our interpretation is that offering BVTTC levels that are close to the true  
10 VTTC increases the precision of the estimation. This could also be regarded as a positive  
11 feature of the RV approach, which would be able to approximately recover the underlying  
12 median VTTC in the sample regardless of the BVTTC range presented.

13 It is interesting to compare our estimates with the official work conducted on this data  
14 by Mackie et al. (2003), which led to the national appraisal values that are still used in  
15 practice. For a fair comparison<sup>7</sup>, in Ojeda-Cabral (2015) the replication of the official model  
16 employed by Mackie et al. (2003) led to a VTTC of 5.19 pence/minute. The mean VTTC  
17 estimated from our best model on the full sample (table 3) is almost 2 pence/minute higher,  
18 which would be determinant in the appraisal of projects (Department for Transport, 2013).  
19 By sub-samples, the 5.19 estimate would be closer to the value from the sample with BVTTC  
20 between 2 and 5.

### 21 22 23 *Random heterogeneity*

24 The inclusion of random heterogeneity on top of the models from table 2, through the  
25 assumption of a lognormal distribution for the VTTC, caused problems in estimation, but  
26 only when not all data was used. If all data is used, the same full model was estimated and the  
27 inclusion of random heterogeneity improved model fit considerably. However, when only a  
28 sub-sample is used, the standard deviation ( $\sigma$ ) of the underlying normal distribution assumed  
29 for  $u$  (equation 8) was almost always not significant. These models are not reported here but  
30 are available on request. To be able to estimate models that made use of the lognormal  
31 assumption, several options were tested. A solution was to estimate only one VTTC (not  
32 specific by quadrants) and to omit size effects ( $\beta_{\Delta T} = 0$ ). These problems suggest potential  
33 confounding issues between choice context effects and the assumption of a lognormal  
34 distribution that are discussed below.

35 Crucially, the introduction of random heterogeneity allows us to observe that the  
36 tendency of the mean VTTC towards the BVTTC is statistically significant, even if the RV  
37 model used is believed to represent a more realistic choice process for the data analysed and  
38 hence fits the data better than a RU model (Fosgerau and Borjesson, 2015). The failure to  
39 estimate the full model on sub-samples can be interpreted in two ways. First, as a sign that a  
40 reasonably wide range of BVTTC is necessary in order to capture a distribution (whether  
41 lognormal or other) of the VTTC, while picking up choice context effects simultaneously  
42 (size effects and quadrants effect). On the other hand, another hypothesis might be that the  
43 random heterogeneity that we observe in the model on the full sample is actually an artefact  
44 caused by not fully capturing those choice context effects, including the observed variation

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<sup>7</sup> Mackie et al. (2003) reports VTTC estimates after weighting was applied using National Travel Survey (NTS) data.



1 with the BVTTC across sub-samples. While support for the first hypothesis can be found in  
2 the existing literature (e.g. Börjesson and Eliason, 2014), this does not mean the second  
3 hypothesis might not hold (it would be an interesting objective for further research, e.g. with  
4 the use of simulated data).

5

#### 6 *Covariates*

7 Across the different sub-samples, there are no major variations in the magnitude of  
8 the estimates. Heterogeneity across individuals is found in all cases and estimation is  
9 relatively consistent. Heterogeneity within individuals due to the size of time changes ( $\beta_{\Delta T}$ )  
10 could not be estimated in some sub-samples due to the reduced BVTTC range, and for  
11 comparison purposes we set  $\beta_{\Delta T}=0$  in all sub-samples. In general, a given covariate always  
12 takes the same sign but again the standard errors of coefficients are lower for the sub-sample  
13 with BVTTC between 2 and 5. Hence, the estimation of covariates is also more precise in this  
14 range of the BVTTC.

15 The *income elasticity* ( $\beta_I$ ) is always highly significant around 0.2-0.4, showing that  
16 VTTC is higher the higher the income of the individual. At the same time, the *current time*  
17 *elasticity* ( $\beta_{BT}$ ) is, interestingly, generally about the same magnitude than the *current cost*  
18 *elasticity* ( $\beta_{BC}$ ) but with the opposite sign (i.e. cost damping and time damping effects  
19 approximately compensate each other). In a context (car travel) where current time and cost  
20 are positively correlated and directly related to journey length, this suggests a lack of journey  
21 length effect (opposite to Mackie et al., 2003, who reported a VTTC that increased with  
22 journey length due to cost damping, because their model omitted  $\beta_{BT}$ ). It must be noted that  
23 these elasticities are cross-sectional, and do not necessarily reflect how VTTC would evolve  
24 over time with income and journey length. Their estimated values are in line with other works  
25 (e.g. Mackie et al.,2003; Fosgerau et al.,2007).

26 With respect to the influence of the size of the changes, the estimate of  $\beta_{\Delta T}$  in the full  
27 sample indicates that the VTTC increases with the size of the time changes, in line with most  
28 empirical evidence (e.g. De Borger and Fosgerau, 2008; Hess and Stathopoulos, 2012).  
29 However,  $\beta_{\Delta T}$  was non-significant in some sub-samples, and non-identifiable in others, which  
30 show that the estimation of size effects suffers from some kind of dependency on the range of  
31 BVTTC in the sample.

1 **5.1.2 Exercise 2 – Data split by  $\Delta t$**

2 In exercises 2 and 3, the data will be analysed again partially, but now in relation to the two  
 3 components of the BVTTC separately. In the case of  $\Delta t$ , there are only five levels for this  
 4 variable in absolute terms (3,5,10,15 and 20). Hence, a more interesting analysis is to  
 5 subdivide the data into five sub-samples (one for each level of  $\Delta t$ ), rather than using ranges  
 6 by quartiles. It is worth pointing out that this is possible with a RV model, but not with a RU  
 7 model (in a RU model, estimation requires variability in  $\Delta c$  and  $\Delta t$ ). One advantage of the RV  
 8 approach over RU is that, as long as there is variation in the BVTTC, the model can be  
 9 estimated even if there is no variation in one of its two components (i.e.  $\Delta c$  or  $\Delta t$ ). Results are  
 10 shown in table 4 below.

11 The results show that the VTTC increases consistently with the level of  $\Delta t$ , in line  
 12 with existing literature (e.g. Mackie et al., 2003; Cantillo et al., 2006). However, most of the  
 13 differences are not statistically significant, and only the VTTC when  $\Delta t=3$  is significantly  
 14 lower than the rest at the 90% confidence level. This could be because we are only observing  
 15 the median, but additional models (available on request), show that the VTTC is also  
 16 significantly higher when  $\Delta t=20$ . More importantly, what this exercise shows is the  
 17 identification of a type of choice context which highly drives the VTTC up: WTA scenarios  
 18 with increases in journey time of 15 and 20 minutes. People reveal a very high VTTC when  
 19 asked about extending their typical journey by 15 or 20 minutes. In other words, they would  
 20 ask for a very high monetary compensation in these contexts. Scale, across sub-samples, is  
 21 lower for  $\Delta t=3$  and  $\Delta t=20$ , indicating more uncertainty in those choices. This could reflect  
 22 that choices are more difficult when the changes are too small or too large.

23 Table 4. Data split by  $\Delta t$  - Estimation results (Standard errors in parentheses)

5 Sub-Samples, split by $\Delta t$						
$\Delta t$	3	5	10	15	20	ALL
Mean VTTC (cens. 30p/min)	2.93	4.85	5.23	6.32	6.69	5.14
Median VTTC	1 (0.27)	2.89 (0.39)	3.34 (0.31)	4.54 (1.04)	7.6 (2.41)	3.37 (0.25)
VTTC <sub>EG</sub>	1.83 (0.37)	3.83 (0.42)	4.66 (0.5)	6.79 (1.68)	6.67 (2.12)	3.38 (0.214)
VTTC <sub>EL</sub>	NA	1.63 (0.22)	2.61 (0.22)	2.46 (0.43)	4.55 (1.14)	2.61 (0.176)
VTTC <sub>WTA</sub>	NA	8.38 (0.9)	9.2 (0.858)	17.6 (4.79)	22.6 (6.45)	11.3 (0.757)
VTTC <sub>WTP</sub>	0.55 (0.22)	1.33 (0.19)	1.11 (0.15)	1.44 (0.633)	4.84 (1.32)	1.29 (0.1)
$\beta_{BC}$	0.49 (0.14)	0.37 (0.08)	0.35 (0.09)	0.41 (0.19)	1.38 (0.3)	0.43 (0.06)
$\beta_i$	0.52 (0.15)	0.39 (0.07)	0.5 (0.07)	0.42 (0.14)	0.49 (0.17)	0.45 (0.05)
$\beta_{BT}$	-0.23 (0.19)	-0.27 (0.1)	-0.41 (0.11)	-0.35 (0.24)	-1.38 (0.4)	-0.2 (0.075)
$\mu$	0.65 (0.09)	0.84 (0.05)	0.83 (0.04)	1.16 (0.19)	0.77 (0.1)	0.82 (0.02)
obs	2142	4485	4007	545	1051	12230
Indiv.	1100	1369	1495	228	286	1804
LL	-1067.982	-2419.609	-2277.025	-253.793	-628.896	-6777.606
adj. $\rho^2$	0.277	0.219	0.177	0.307	0.126	0.2

1 However, it must be noted that the sample size is much larger for levels  $\Delta t=5$  and  
 2  $\Delta t=10$ . Only a small part of the respondents observed the higher levels and other effects (e.g.  
 3 personal/trip characteristics) may be at play in determining the higher values when  $\Delta t=15$  and  
 4  $\Delta t=20$ . To control for this, VTTC estimates are always calculated for the same level of  
 5 income and trip characteristics.

6 The estimated covariates suggest that income and journey length effects are similar  
 7 for any level of time changes considered: income elasticity is around 0.4 and the effects of  
 8 current time and current cost on VTTC approximately compensate each other so there is no  
 9 journey length effect overall, in line with exercise 1. Interestingly,  $\beta_{BC}$  and  $\beta_{BT}$  are both much  
 10 greater when  $\Delta t=20$ , and of the same exact magnitude on average but opposite sign. The  
 11 message is that the effect of a trip characteristic may be influenced by the choice scenario, or  
 12 in other words, some VTTC elasticities may not be constant. Also, as in exercise 1, the fact  
 13 that the effects of  $C$  and  $T$  always compensate each other in every sub-sample provides strong  
 14 evidence that journey length effects do not exist in this dataset, regardless of the levels of  
 15 time changes.

### 16 5.1.3 Exercise 3 –Data split by $\Delta c$

17 The data is split based on the quartiles of  $\Delta c$  for the last exercise. The results are shown in  
 18 table 5. The results are close to those observed for exercise 1, where the data was split by  
 19 BVTTC (which makes sense, since  $BVTTC = \Delta c / \Delta t$ ).

20 Table 5. Data split by  $\Delta c$  - Estimation results (Standard errors in parentheses)

4 Sub-Samples, split by $\Delta c$					
$\Delta c$ range	(5-15]	(16-35]	(35-75]	(75-300]	ALL
Mean VTTC (cens. 30p/min)	3.92	5.4	6.82	6.37	4.89
Median VTTC	2.07 (0.85)	3.64 (0.48)	5.2 (1.06)	4.83 (0.87)	3.13 (0.14)
$VTTC_{EG}$	1.72 (0.165)	3.86 (0.278)	5.84 (0.456)	6.78 (0.905)	3.67 (0.244)
$VTTC_{EL}$	1.77 (0.179)	2.99 (0.231)	3.83 (0.27)	3.5 (0.597)	2.07 (0.157)
$VTTC_{WTA}$	5.45 (0.951)	7.39 (0.844)	9.38 (0.585)	12 (0.874)	9.97 (0.701)
$VTTC_{WTP}$	1.11 (0.111)	2.06 (0.194)	3.5 (0.317)	1.9 (0.482)	1.27 (0.105)
$\beta_{BC}$	0.164 (0.062)	0.374 (0.075)	0.267 (0.0618)	0.418 (0.113)	0.406 (0.0635)
$\beta_{\Delta T}$	NA	NA	NA	NA	0.711 (0.0766)
$\beta_i$	0.304 (0.06)	0.381 (0.0631)	0.246 (0.0473)	0.32 (0.0824)	0.472 (0.0566)
$\beta_{BT}$	-0.1 (0.086)	-0.35 (0.083)	-0.25 (0.062)	-0.372 (0.109)	-0.406 (0.0825)
$\mu$	1.09 (0.0853)	1.04 (0.0916)	1.56 (0.132)	1.11 (0.12)	0.781 (0.0252)
obs	3593	3385	2832	2420	12230
Indiv.	1523	1703	1516	1145	1804
LL	-1989.3	-2059.113	-1464.179	-1168.29	-6708.528
adj. $\rho^2$	0.198	0.119	0.25	0.299	0.208

21

1 The mean and median VTTC varies slightly among sub-samples in a similar way than in  
2 exercise 1. The VTTC seems to increase with the level of  $\Delta c$ , but the differences (for the  
3 medians) are not statistically significant. It may be expected to find a positive tendency if the  
4 lognormal assumption was introduced<sup>8</sup>, in line with exercise 1, due to the correlation between  
5 BVTTC and  $\Delta c$ . The sub-sample where  $\Delta c$  is between 35 and 75 pence presents higher scale  
6 and slightly more precise coefficients. As in section 5.1.1, this could happen because this sub-  
7 sample mostly comprises values of the BVTTC which are close to the underlying VTTC of  
8 respondents.

9 Heterogeneity within individuals, i.e. VTTC variation with  $\Delta t$ , could not be estimated  
10 when the range of  $\Delta c$  was reduced. Regarding heterogeneity across individuals, the estimates  
11 of the covariates vary slightly across sub-samples, but again the same patterns are observed.  
12 Income effect is, again, the most stable across sub-samples and  $\beta_{BC}$  and  $\beta_{BT}$  always  
13 compensate each other reflecting lack of journey length effect.

## 15 **6 Discussion and conclusions**

16 This paper has investigated whether and how preferences are different under different  
17 SC design settings. More precisely, we studied the role of the variables used in the SC  
18 experiment on the estimation of the set of VTTC (i.e. mean and covariates). Our aim has been  
19 to increase our understanding of the reality of the distribution of the VTTC in a given  
20 population. For this, we used partial data analysis on data collected with a simple VTTC  
21 experiment, where the design variables are time changes ( $\Delta t$ ), cost changes ( $\Delta c$ ) and the  
22 implied boundary VTTC ( $BVTTC = \Delta c / \Delta t$ ). The motivation was the finding that VTTC tends  
23 to the BVTTC that Fosgerau and Borjesson (2015) report, finding attributed to a model  
24 misspecification. We extended the analysis by using more sophisticated models, observing  
25 not only the mean VTTC but its sources of heterogeneity, and by looking also at other design  
26 variables.

27 The main conclusion is that key model estimates (i.e. VTTC and covariates) are  
28 different in different design settings (where the settings are defined by the levels of the design  
29 variables). In other words, preferences do vary with the SC setting. Hence, if model estimates  
30 are different in different settings, then by focusing the survey on specific settings, our sample  
31 level results will be affected accordingly. We can only reveal preferences for the particular  
32 SC setting that we use, and our results show that the selection of a particular setting can be  
33 crucial. SC designs should be constructed bearing this in mind.

34 The results can be summarized as follows. First, the VTTC varies with the levels of the  
35 design variables. Surprisingly, the BVTTC does have a direct positive impact on the  
36 estimated VTTC even if a model is employed that is commonly used and known to describe  
37 accurately this type of data. The size of cost changes, largely correlated with BVTTC, has a  
38 similar direct impact on the VTTC. The size of time changes affects positively the VTTC, but  
39 this effect was not identifiable or not significant when the range of BVTTC was reduced (i.e.  
40 under some SC design settings). Secondly, more precise estimates (or preferences) are  
41 obtained the closer the levels of BVTTC are to the underlying VTTC. This applies to all  
42 coefficients.

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<sup>8</sup> This and other modelling exercises have been tested, but did not enrich the analysis and would have extended the length of the paper considerably.

1 Third, the introduction of random heterogeneity (through the assumption of lognormal  
2 distribution for the VTTC) showed that a wide range of BVTTC values is needed to capture  
3 the whole VTTC distribution (e.g. Börjesson et al., 2012) while picking up other effects.  
4 Researchers then face a trade-off when designing the experiment: a focus around the  
5 expected VTTC (if known) could bring more precise estimates, but covering a reasonably  
6 wide range can allow capturing a potential VTTC distribution. However, we cannot discard  
7 the hypothesis that the random heterogeneity that we observe in the model on the full sample  
8 may actually be an artefact caused by not fully capturing choice context effects, including the  
9 observed variation with the BVTTC across sub-samples. The test of this confounding  
10 hypothesis, e.g. with the use of simulated data, is suggested as an interesting objective for  
11 further research.

12 Fourth, inter-personal variation of the VTTC is reasonably consistent regardless of the  
13 SC design setting. The estimates of the covariates suggest, quite consistently, that: i) income  
14 effects are always present in a relatively similar magnitude, and ii) journey length effects do  
15 not seem to exist in the data explored, since the VTTC increases with current cost but  
16 decreases with current time always in a similar magnitude, compensating each other. Finally,  
17 some particular SC design settings infer extremely low/high VTTC estimates. The gap  
18 between WTA and WTP is very large, in some cases of a ratio of 5. In general, all WTA  
19 scenarios are associated with higher VTTC, but in particular those WTA scenarios where the  
20 size of the time changes is 15 or 20 minutes.

21 It is known that valuation studies should approach carefully the selection of valuation  
22 thresholds for SC designs, and more generally choice contexts. This paper provides new and  
23 strong evidence that SC design selection involves decisions that are not innocuous, such as  
24 the range and focus of the BVTTC or the inclusion of some WTA scenarios. The good news  
25 is that have also seen how a state-of-the-art model (Random Valuation model), even with a  
26 sample based on a limited SC design setting, is able to provide significant and reasonable  
27 estimates of the VTTC and its main covariates at the inter-individual level (income and  
28 journey length). However, the RV model also provides estimates of the VTTC that tend  
29 towards the range of the BVTTC present in the data.

30 It is not the purpose of this paper to give specific guidelines on how to choose a good  
31 SC design. Every market where valuation information is needed is different, and researchers  
32 would have to make the design selection that they find more appropriate. Our hope is that this  
33 paper raise awareness about the variation of preferences with choice contexts, and hence the  
34 importance of selecting the experiment carefully. Preferences are different under different SC  
35 design settings, and it is the responsibility of the researcher to decide what set of preferences  
36 is wanted.

37

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46

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