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Abstract

The value given by commuters to the variability of travel times is empirically analysed using stated preference data from Barcelona (Spain). Respondents are asked to choose between alternatives that differ in terms of cost, average travel time, variability of travel times and departure time. Different specifications of a scheduling choice model are used to measure the influence of various socioeconomic characteristics. Our results show that travel time variability is valued 2.4 times more than travel time savings. Heterogeneity among commuters, both in terms of restrictions about the starting work time and the use of the trip to undertake other activities, are shown to have significant effects on the value of travel time variability.

Keywords: travel time variability, value of time, commuting, stated preference.

JEL codes: D12, R41

1. Introduction

Travel time savings are the main component of benefits generated by investments in transport projects. However, the valuation of such savings using standard procedures only takes into account the consequences that a project may have on average travel times, disregarding its consequences on time variability. This fact may result in projects that contribute to a reduction in the dispersion of travel times, without significantly reducing their average values, not being chosen when compared to others that have the opposite effects. For instance, a project that provides information in advance with respect to the trip conditions, may not have a significant impact on average travel times, but may be very useful to avoid unexpected delays in exceptional circumstances.

This issue is of particular relevance to the transport system of all large urban areas, where unexpected situations that affect travel times are more likely to occur than in intercity traffic. The large levels of traffic density observed at peak times in all urban areas make travel times very vulnerable to incidents that constraint available capacity, such as accidents, or circumstances that increase transport demand and lead to increased delays. Despite this, transport policy in most urban areas continues to place a great emphasis on the provision of more capacity, usually at a high cost, while the development of tools that reduce travel times variability, such as precise information about the location and duration of incidents that would affect travel times, have been given much lower attention.

One of the reasons for the absence of travel time variability impacts from standard evaluation procedures is the relative lack of evidence about its precise economic value. Despite the fact that the transport economics literature has acknowledged its importance for a long time, the efforts devoted to the estimation of its value are much less common than those given to travel time savings, for which a large number of results exist for different countries, trip motives and other characteristics. In the case of travel time variability, the difficulties associated with appropriately measuring its economic value explain why there is still a lack of knowledge about the influence of different socioeconomic attributes or trip characteristics. Given that trips in urban areas have very diverse motives and characteristics, better understanding how such heterogeneity influences the values of variability of travel times is an unavoidable step for a better evaluation of transport policies in urban contexts.

Although some estimations from European contexts are available, most empirical analyses of the values of travel time variability for car commuters have been obtained in the US, while in Europe there has been a relatively larger interest on public transport users (particularly in the

UK). In this paper we estimate the economic value of travel time variability by commuters in a European city (Barcelona) and analyse the role that individual characteristics and trip circumstances have on such value.

Our results are consistent with the approach found in most empirical literature regarding commuters' valuation of travel time variability. We find that variability is not valued *per se,* but due to the impact that it may have in provoking early or late arrivals. Therefore, its economic valuation depends on the values given to the magnitude of early or delayed arrivals. We find that delay time is valued at more than twice the savings of average travel times, although the precise value depends on working time flexibility and on whether the trip is used to carry out other activities.

The paper is structured as follows. In section 2 we discuss the different implications of alternative approaches used to estimate the value of travel time variability. Then, section 3 explains the stated preference experiment that we carry out to obtain the data and summarises the main characteristics of the sample. Our results are presented and discussed in section 4, while section 5 concludes. An appendix provides additional details about the design of the questionnaire.

2. Modelling travel time variability.

The concept of travel time variability refers to the commuter's inability to forecast how long his trip will last. Following Bates (2001), we define travel time as being variable when random factors may have an impact on the duration of the trip in such a way that actual arrival time does not coincide with the desired one. This definition implies that travel times that vary in a way that is anticipated by the commuter before he starts the trip, such as frequent delays due to congestion at regular times, cannot be considered as 'variable'.

Travel time variability is usually modelled in one of two ways, depending on the assumption made about the reasons why it is valued. If it is assumed that individuals merely dislike the possibility of being early, or late, so that travel time variability is valued *per se*, then it is enough to include in the individual's indirect utility function a measure of travel time variability together with the usual components of travel costs. Alternatively, it can be assumed that travel time variability is valued according to the consequences of being early or late. In this case its modelling should consider the consequences on the time restrictions of the individuals, such as early or late arrivals with respect to the desired arrival time. However, as it will be pointed out below, both interpretations are not mutually incompatible.

Small (1982) provides the most used framework to model the impact of travel time variability on arrival times. He develops a model where, taking into account the consequences of arriving to destination earlier or later than desired, individuals choose the time at which they depart. In this model, commuters adapt their behaviour to the presence of variable travel times by choosing earlier departure times.

Noland and Small (1995) further develop this idea through a more explicit modelling of the components of travel time variability. Given an exogenously determined preferred arrival time to his destination, the commuter chooses a departure time in order to minimise a cost function that, as well as the costs generated by total travel time, includes those due to arriving earlier or later than desired. Such function can be postulated as follows:

$$C_s = \alpha\, T + \beta\, (SDE) + \gamma\, (SDL) + \phi\, D_L \tag{1}$$

where T is total travel time, SDE (schedule delay early) and SDL (schedule delay late) are respectively the time margins with which arrival takes place earlier or later than desired. If t_w is the (exogenously determined) desired arrival time and t_h is the chosen departure time, SDE can be expressed as Max $(0, t_w-(t_h+T))$, and SDL as Max$(0, (t_h+T)-t_w)$. Noland and Small (1995) add the additional dummy variable D_L, which would take a value of one if SDL>1, to account for the extra cost due to arriving late, irrespectively of how much. They explicitly introduce randomness by distinguishing three components of T:

·T_f, which stands for travel time in free flow conditions, and is assumed to be constant for a given trip.

·T_x, which is the extra travel time due to recurrent congestion, which is known by the commuter before he starts the trip. If such congestion depends on departure time, then $T_x(t_h)$.

·T_r is the extra time due to unexpected congestion, accidents, or any other causes that are not anticipated by the commuter. It is this component that causes travel time to be variable and is defined as a random variable whose distribution can be assumed to depend on t_h.

With random travel times, arrival times cannot be known with certainty, and a probability of late arrival $P_L(t_h)$ can be defined. A late arrival will take place if

$$t_h + T_f + T_x(t_h) + T_r(t_h) > t_w \tag{2}$$

The choice of departure time can now be set in expected utility maximisation terms: the commuter maximises his expected utility and chooses a departure time that includes a 'headstart' time (Gaver, 1968), defined as the extra advance in departure time to take into

account the effects of variable travel times. Using (1) and the explained decomposition of travel times, expected utility can be expressed as

$$E[U(t_h)] = \alpha\, E[T(t_h)] + \beta\, E[SDE(t_h)] + \gamma\, E[SDL(t_h)] + \phi\, P_L(t_h) \qquad (3)$$

As shown by Bates (2001), a common simplification of (3) assumes that the parameters that define the distribution of travel time variability are not time dependent, recurrent congestion is independent of departure time and there is no lateness penalty. In this case, taking departure time to be continuous, the standard deviation of T_r approximates the sum of the schedule delay early and late components of travel time at the optimal departure time t_h. Such simplification justifies the direct inclusion of the standard deviation of travel time in the utility function, leading to a model where choice depends on the mean and the standard deviation of travel times. This mean-variance model corresponds to the interpretation of travel time variability having and impact *per se* on the individual's utility, which would be captured by the coefficient of the standard deviation of travel time.

At the optimal departure time, the expected utility level can be expressed as a linear function of expected travel time, the expected margins of early or late arrival and the probability of arriving late (Noland and Small, 1995):

$$EU^* = \alpha\, (T) + \beta\, E(SDE) + \gamma\, E(SDL) + \theta\, P_L^* \qquad (4)$$

This expression can be used to postulate a choice model of route choice, where each alternative is characterized by different degrees of travel time variability and departure times. The choice process is based on an implicit valuation of average travel times, the possible delays or advances with respect to the desired arrival time, as well as of the fact of being late by itself. In order to obtain estimates of those values it is necessary to assume a distribution of variable travel times in each route[1].

There are a growing number of studies that empirically estimate the value given to travel time variability. Although work has been done for public and freight transport (see Bates (2001), Wardman (2001), Noland and Polak (2002) and de Jong et al (2004)), most of the research effort has focused on the variability of travel times experienced by users of private car.

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[1] An area where little research has been carried out is the analysis of factors that explain variability from the supply side. Ideally, an equilibrium model of supply and demand that takes into account variability from both sides should be specified. Noland et al. (1998) combine the results obtained in the estimation of a demand model with a simulation model of traffic conditions that allows for variability, making it possible to endogenously evaluate the impact of different transport policies on expected travel times and costs.

Almost all empirical work has relied on data obtained with stated preference techniques. This can be explained by the difficulties associated with measuring travel time variability, both in real terms and in the way that it is perceived by transport users. The only papers that, to our knowledge, use revealed preference data are those by Lam and Small (2001) and Small et al. (2005). They observe route choices between an uncongested tolled route and an untolled one subject to delays in the SR91 corridor in Los Angeles, and build a variable that captures variability in travel times for each case.

Black and Towriss (1993), Senna (1994), Abdel-Aty et al (1995) and Copley et al (2002) estimate mean-variance models. The main result that is obtained from these models is the 'reliability ratio', that is, the marginal utility of a reduction of the standard deviation of travel time over that of average travel time. The papers by Noland et al (1998) and Small et al (1999), surveyed by Noland and Polak (2002), are the best examples of the schedule delay function approach. They are therefore able to estimate the values given to early and late arrivals, and compare them to that of in-vehicle travel time. In section 6 we make reference to some results of these papers, when explaining our estimation results.

3. The stated preference experiment

Given the lack of available measurements of travel time variability in the context that we study, our empirical analysis uses data from a stated preference experiment. The choice experiment focuses on private car users, who are asked to choose between two alternative routes for their home-to-work trip. The design of our experiment follows that reported by Small et al (1999) in their analysis of valuation of travel time variability in California. The origin of this type of analysis can be traced back to previous work by the same authors (Noland et al. 1998) and Black and Towriss (1993).

The geographical context where we carry the empirical work is the Maresme corridor, north of Barcelona city, in Spain. The corridor is formed by two parallel routes (the untolled national road A-2 and the tolled highway C-32) which connect Barcelona with northeastern suburbs and small towns. Both the national road and the motorway, which has been open to traffic since 1969, are frequently used by residents in the area and experience congestion at different times of the day. Besides having its own employment centres, the Maresme region has been subject to intense suburbanisation from Barcelona city, resulting in heavy commuter traffic through the corridor. Most of the population is therefore familiar with choosing between alternative routes characterised by different monetary costs, travel times and possible delays (due to accidents or

heavy traffic resulting in unexpected congestion, for instance). By choosing this corridor for our analysis we minimise the impact of the main problem of stated preference surveys, namely that respondents not familiar with the type of hypothetical choices that they are asked to make may not properly assess the variables used to characterize the alternatives. On the other hand, it is possible that respondents to the survey try to justify their actual choices, or use the survey to complain against the existence of tolled routes (a long-standing political argument in some areas of Spain). In order to avoid the biases that may result from this, we use different methods, such as unlabelled alternatives to characterise each route, a random ordering of the questions in the choice set and a definition of monetary costs than never shows one alternative to be free.

We analyse route choices in the context of home-to-work commuting trips. Given the importance of being on time for these trips, variability in travel times is more relevant than in trips due to other reasons, such as leisure. The larger degree of homogeneity in the determinants of commuting trips makes it possible to focus on the role that socioeconomic characteristics of the commuter or trip constraints may have in explaining heterogeneity in the valuation of travel time variability.

As mentioned above, the choice set is composed of two routes, each one of them defined in terms of monetary cost (vehicle operation costs plus the toll in the case of the motorway) average travel time (the time that would usually be required to drive from home to the workplace, which would be the result of free flow time plus the time due to recurrent congestion) and a measure of travel time variability due to unexpected congestion[2]. As shown in the previous section, the schedule function approach assumes that the individual may modify his departure time in order to take possible delays into account. Thus, an additional variable that characterises the alternatives is the advance with which the commuter leaves home with respect to the required departure time if travel times were not subject to variability. The alternatives are therefore defined by four attributes: average travel time, variability in travel times, monetary cost and advance in departure time.

The stated preference survey, consisting of a set of nine choice questions and a socioeconomic questionnaire together with an introductory letter and a set of instructions, was delivered at different petrol stations used by commuters accessing the road or motorway, during the autumn of 2005. Respondents were asked to fill it in at home and return it by post using a stamped addressed envelope.

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[2] Further details about the construction of this variable and its presentation, as well as a sample of the questionnaire used, are provided in the appendix.

As a result of the stated preference sampling exercise described in the previous section, 259 valid questionnaires were obtained from individuals who use the corridor for their commuting trips, implying a response rate of 10%. The number of available observations to estimate the choice model is therefore 2331. Most (86%) respondents commute on a daily basis using the corridor, and 60% choose the tolled alternative. Two thirds of respondents are men, with an average age of 40. A majority of respondents (63%) pay the full cost of their trips, while 29% declare that their employers pay all or part of them. A slight majority have no children (54%) and almost a quarter have two (18.9%) or more (5.5%).

The questionnaire included two questions that allow the identification of different restrictions that individuals may face in their commuting trips. The first one is defined along the lines of Small et al (1999) as the maximum delay with which commuters may arrive to their workplace without it having negative consequences on their wages or job position. The aim of this variable is to identify the effect of travel times being variable on the possibility of not only arriving late, but doing so too late. The second question asks if other activities, such as taking children to school or shopping, are carried out during commuting trips. It is expected that commuters that undertake such activities would place a higher value on travel times being less variable. Table 1 summarises the responses given to these questions.

Table 1. Restrictions during commuting trips

Maximum possible delay of arrival at workplace without penalty			Other activities during the trip		
	cases	%		cases	%
Less than 5 minutes	58	22.4	Yes	107	41.3
5 to 9 minutes	47	18.2	No	125	48.3
10 to 14 minutes	33	12.7			
15 to 19 minutes	8	3.1			
20 or more minutes	32	12.4			
No fixed entry time	59	22.8			
No answer	22	8.5	No answer	27	10.4
Total	259	100.0	Total	259	100.0

Table 2 shows the reported household gross monthly incomes and the education level of the main income providers. There is a high share of commuters belonging to household whose main income provider has a university degree. Even though self-reported household incomes are likely to be biased, the values reported are above those of the geographical area of reference. Moreover, more than ¾ of them have two or more occupied members, which is a large figure for Spanish standards. All this information permits to describe the sample as relatively well off.

Table 2. Sample characteristics: education and income

Education level of main income provider			Household gross monthly income		
Categories:	cases	%	Euros:	cases	%
Primary	15	5.8	Under 1000	7	2.7
Secondary (compulsory)	24	9.3	1001-1500	28	10.8
Secondary (post-compulsory)	37	14.3	1501-2000	34	13.1
Professional (basic)	14	5.4	2001-2500	42	16.2
Professional (higher)	30	11.6	2501-3000	35	13.5
University (diploma)	50	19.3	3001-4000	38	14.7
University (B.A. or more)	87	33.6	4001-5000	23	8.9
			5001-7000	15	5.8
			7001-9000	5	1.9
			Over 9000	14	5.4
No answer	2	0.8	No answer	18	7.0
Total	259	100	Total	259	100

4. Model estimation and results.

We specify the route choice decision process with a logit model. Under random utility theory assumptions, the deterministic component of the indirect utility function for individual i when choosing alternative j is based on the schedule delay function discussed in section 2, and can be expressed as

$$V_{ij} = V(T_{ij}, SDL_{tj}, SDE_{ij}, P_{Lij}, M_{ij}) = \beta_T E(T_{ij}) + \beta_L E(SDL_{tj}) + \beta_E E(SDE_{ij}) + \beta_P P_{Lij} + \beta_M M_{ij} \qquad (5)$$

where T_{ij}, SDE_{ij} and SDL_{ij} are defined as in (1) and M_{ij} is the monetary cost of the alternative. The expectation operator $E(\cdot)$ is applied to the five scenarios that characterize each alternative, whose design is explained in the appendix. $E(T_{ij})$, the average travel time, is easily calculated. However, $E(SDL_{ij})$ and $E(SDE_{ij})$ only take into account the cases in which a late or early arrival takes place, respectively. As shown by Small et al (1999), it is variability in travel times what generates the values of those variables. Thus, the costs due to the existence of variability can be captured through the costs of expected early or late arrival times. The more variable travel times, the larger the values of those expected values. Finally, P_{Lij} captures the additional impact on utility of the probability of arriving late, independently of the magnitude of the delay. It is empirically defined as the proportion of times in which a late arrival would take place.

We use a binomial logit specification to estimate the empirical discrete choice models, where the dependent variable takes the value 1 when the tolled motorway alternative is chosen. All explanatory variables are expressed as the difference between their values in the motorway and the national road alternatives. The specification strategy followed focuses first on the selection between the mean-variance and the schedule delay function approaches to the modelling of

travel time variability. The results of following each approach are shown in models 1 to 3 (table 3).

Table 3. Estimation results.

Variable	Model 1 Coefficient	t Stat	Model 2 Coefficient	t Stat	Model 3 Coefficient	t Stat
Constant (1=motorway)	-0.8291	-4.698	-0.8663	-5.006	-0.8169	-4.664
Cost	-0.3932	-4.592	-0.4042	-4.747	-0.3905	-4.571
Travel time	-0.0970	-7.778	-0.1023	-8.565	-0.0954	-7.891
SDL	-0.1770	-1.950			-0.2234	-10.367
SDE	-0.0266	-0.680			-0.0459	-3.350
Standard deviation	-0.0239	-0.527	-0.1002	-9.720		
Observations	2331		2331		2331	
Obs with road choice	1273		1273		1273	
Obs with motorway choice	1058		1058		1058	
Regression St. Error	0.473		0.475		0.473	
Residual sum of squares	520.597		523.922		520.651	
Log likelihood	-1486.93		-1494.54		-1487.07	
Schwarz criterion	1.296		1.296		1.293	

We initially estimate a broad specification that incorporates all the variables that capture the impact of travel variability according to both approaches: schedule delay early, schedule delay late and the standard deviation of travel times (model 1)[3]. The cost and travel time coefficients take the expected signs and are statistically significant, but only one of the variability measures (SDL) is marginally significant.

Model 2 corresponds to the mean-variance approach, where only the standard deviation of travel time captures the effect of variability. This model allows for the calculation of the ratio between the coefficients of the standard deviation and the average travel time, usually known as 'reliability ratio'. Our value of 0.98 is in line with the literature. Although Black and Towriss (1993) found a value of just 0.55, more recent work has estimated ratios above unity: Noland et al (1998) find a value of 1.27 for commuting trips in Los Angeles, and Copley et al (2002) obtain a ratio of 1.3 in a model estimated with Manchester data. According to Bates (2001), a typical value for the reliability ratio would be 1.1.

Model 3 captures the effects of travel time variability through the early or late scheduled delays. The estimates of the cost and travel time coefficients are very stable with respect to the previous models, while statistically significant estimates are now obtained for both SDE and SDL. These

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[3] The variable P_L that captures the probability of late arrival is omitted since its coefficient was not significantly different from zero in any of the preliminary estimations. Given the way in which they are defined, the variables SDL and P_L are strongly correlated, and their estimation is therefore difficult.

estimates show that more importance is attached to delay than to travel time, which in turn is more valued than early arrival time[4]. These are expected results and coincide with those of Noland et al (1998) or Small et al (1999).

Model 1 clearly shows that it is not possible to simultaneously use both approaches to capture the impact of travel time variability on the choice process. We therefore need to choose between model 2 and model 3. Applying a likelihood ratio test to the alternative exclusion of the standard deviation or the SDE and SDL variables yields clear results[5] in favour of model 3. Therefore, similarly to what was found by Small et al (1995), Noland et al (1998) and Small et al (1999), our estimations offer evidence favourable to the schedule function approach to analysing the role played by variable travel times.

The estimates of the cost and time variables in the previous models are robust with respect to the alternative specifications. This stability makes it possible to deal with one frequent problem in stated preference experiments, such as whether respondents correctly understand the choices they are asked to make. One way of evaluating *ex post* the magnitude of this problem is to analyse the coherence of the estimation results, which can be done by computing the price and travel time demand elasticities for the average values in the sample. We obtain elasticities of -0.26 and -0.48, respectively, which are close to what could be expected in a corridor with relatively congested traffic[6].

A key issue when analysing the valuation of travel time variability is the existence of heterogeneity among commuters. Such heterogeneity may be captured by different socioeconomic and trip characteristics, and may affect choice in two ways: it can have an influence on the absolute preference for the alternatives or it may modify the relative valuation of the attributes that characterize each alternative. In the first case, the characteristic is included in the utility function as an additional explanatory variable, and therefore has a direct impact on the constant term. In the second case, it interacts with the attributes that characterize the alternatives and therefore modifies the estimated slope coefficients.

When including in the model the socioeconomic variables that capture individual heterogeneity, equation (5) may be rewritten as:

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[4] Small et al (1999) suggest the inclusion in a quadratic way of SDL and SDE, with the aim of capturing non linear effects. However, in our case such specification did not provide results significantly different from the one reported.

[5] Testing model 2 against model 1 provides a LR statistic of 15.22 (5% critical value=5.99). However, the test of model 3 against model 1 shows a LR value of 0.28 (5% critical value=3.84), so that the null cannot be rejected.

[6] The authors have estimated short and long run price elasticities of -0.21 and -0.33 for the same corridor using aggregate data (Asensio and Matas, 2005).

$$V_{ij} = \alpha_j + \beta_{iT}T_j + \beta_{iL}SDL_j + \beta_{iE}SDE_j + \beta_{iP}P_{lj} + \beta_{iM}M_j + \gamma Z_i \tag{6}$$

where Z_i are the characteristics that modify the constant term, and coefficients' estimations may include interactions with other attributes.

In our next specification stage we estimate different models of the form (6) to include heterogeneity in the model, taking as a starting point the specification in model 3. The decision about which variables are directly included in the indirect utility function (as Z_i) and which are used to segment the sample is up to a certain point arbitrary. Ideally, an equation should be specified for each type of individual (whereby heterogeneity would influence both the constant and the variables' coefficients) and the equality of coefficients across types of individuals would be tested. However, the number of available observations makes such strategy unfeasible. Therefore, a priori assumptions were required based on literature results and some preliminary estimations. In model 4 we assume that commuter's age, sex and the number of children in the household modify the constant term. Estimation results show that men and commuters with more children are more likely to choose the tolled alternative. Since age is included non-linearly it shows that it has an increasing influence on the probability of choosing the more expensive alternative until the commuter is 47 years old. The coefficients of all other variables are very stable with respect to model 3, providing evidence about the robustness of the estimation.

Table 4. Estimation results. Model 4.

Variable	Coefficient	t Stat
Constant (1=motorway)	1.7816	3.292
Cost	-0.4002	-4.628
Travel time	-0.0978	-7.976
SDL	-0.2296	-10.493
SDE	-0.0469	-3.381
Sex (male=1)	0.3374	3.522
Age	-0.1377	-5.500
Age2	0.0015	5.090
Number of children under 16	0.2128	4.412
Observations	2331	
Obs with road choice	1273	
Obs with motorway choice	1058	
Regression St. Error	0.4679	
Residual sum of squares	508.359	
Log likelihood	-1459.544	
Schwarz criterion	1.2822	

Although in our survey we included variables that made it possible to approximate income in three ways (self-reported income, educational level and job category), none of them led to

significant results when used to segment the time or cost variables. This result may be due to the fact that the sample used belongs to a population of relatively high incomes and educational levels.

We next deal with the characteristics of the trip that may influence commuters' preferences. These variables are used to segment in different ways the estimates in model 4. We first analyze whether the personal experience of the commuter about the duration of his/her trip influences the valuation of the alternatives' attributes. Model 5 shows that commuters with trips lasting more than 40 minutes have a marginal valuation of delay time that is half of that of the rest (the average reported commuting time of respondents to the survey is 36 minutes, although the most numerous groups are those that take 16 to 30 minutes and 46 to 60). This result is in line with the findings of Wardman (2001), who after reviewing various studies concludes that trip distance is negatively related to the value given to delay time. It can be interpreted that shorter trips are subject to more strict restrictions, while being late can be considered less important for longer trips. The estimates of other coefficients are fairly similar to those of model 4, although they are not strictly comparable given the reduction in the number of available observations.

Table 5. Estimation results. Model 5.

Variable	Coefficient	t Stat
Constant (1=motorway)	1.6775	2.970
Cost	-0.4067	-4.502
Travel time	-0.0866	-6.765
SDL* trip shorter than 40 mins	-0.2775	-10.129
SDL* trip longer than 40 mins	-0.1516	-4.307
SDE	-0.0427	-2.974
Sex (male=1)	0.3881	3.865
Age	-0.1231	-4.692
Age2	0.0012	4.081
Number of children under 16	0.2003	3.952
Observations	2142	
Obs with road choice	1165	
Obs with motorway choice	977	
Regression St. Error	0.468	
Residual sum of squares	465.947	
Log likelihood	-1476.460	
Schwarz criterion	1.287	

In model 6 we test the role of different restrictions on arrival times to the workplace. We differentiate between commuters that can start at any time and those that have a fixed entry time, further distinguishing according to their maximum allowed delay. The results show that having a maximum allowed delay of 10 minutes or less implies valuing each minute late almost

2.4 times more than what commuters with higher allowed delays or flexible entry times do. For the latter we estimate a value of early arrival time that is not significantly different from zero. No significant results were obtained when attempting to obtain different estimates for the cost or average travel time coefficients.

Table 6. Estimation results. Model 6

Variable	Coefficient	t Stat
Constant (1=motorway)	1.9231	3.094
Cost	-0.4061	-4.453
Travel time	-0.0959	-7.406
SDL * delay<10 min.	-0.3462	-9.744
SDL * delay ≥ 10 min.	-0.1448	-3.984
SDL * no fixed entry time	-0.1447	-3.577
SDE * fixed entry time	-0.0605	-3.602
SDE * no fixed entry time	-0.0015	-0.053
Sex (male=1)	0.3760	3.706
Age	-0.1433	-4.865
Age2	0.0015	4.469
Number of children under 16	0.2092	4.071
Observations	2115	
Obs with road choice	1143	
Obs with motorway choice	972	
Regression St. Error	0.467	
Residual sum of squares	458.660	
Log likelihood	-1459.086	
Schwarz criterion	1.290	

Finally, model 7 shows that commuters that use their trips for activities such as taking children to school or shopping have a slightly higher value for delay time, although the difference is not statistically significant.

An interesting feature of discrete choice models is that they make it possible to obtain values given to travel time savings as the ratio between estimated coefficients for time and monetary cost. We now present and discuss the values of time savings that result from the previous models. From model 4 a value of travel time savings of 14.7 €/hour is obtained. Although this value may be regarded as a relatively high estimate, two issues should be borne in mind. First, average travel time includes a component of time spent in congestion, which is valued at a higher rate than time spent in free flow situations. Besides, this is an estimate corresponding to daily commuter trips of individuals with relatively high incomes and educational levels[7].

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[7] In order to put the sample characteristics into perspective, note that 52% of sampled individuals have higher education, while the corresponding figure for the whole Spanish population is 22.4%. Completing three years of higher education yields gross wages 40% above the national average, while five years increase that figure up to 80%.

Table 7. Estimation results. Model 7.

Variable	Coefficient	t Stat
Constant (1=motorway)	2.1955	3.541
Cost	-0.4194	-4.596
Travel time	-0.0945	-7.292
SDL * activities	-0.2605	-7.917
SDL * no activities	-0.1918	-6.631
SDE	-0.0472	-3.235
Sex (male=1)	0.3491	3.456
Age	-0.1526	-5.165
Age2	0.0016	4.697
Number of children under 16	0.2057	3.996
Observations	2088	
Obs with road choice	1134	
Obs with motorway choice	954	
Regression St. Error	0.470	
Residual sum of squares	457.631	
Log likelihood	-1311.702	
Schwarz criterion	1.293	

The models also make it possible to obtain estimates of the values of savings in early or late arrival times, as these are the ways in which the consequences of variability of travel times are captured. When no trip characteristics are taken into account, late arrival time is valued at 34.4 €/hour, a value 2.3 times over that of travel time, while savings in early arrival time are valued at just 7 €/hour, or 48% of travel time ones. These results are similar to the findings of other authors, such as Small (1982), who obtains ratios of 2.41 and 0.61, or Noland et al (1998), whose model without extra penalty for late arrival shows ratios of 2.18 and 0.75, respectively.

Table 8. Values of average travel times and travel time variability (€/hour)

Value of average travel time	
Full sample	14.7
Value of delayed arrival time	
Full sample	34.4
Fixed start time (possible delay up to 10 min.)	51.1
Fixed start time (possible delay of more than 10 min.)	21.4
No fixed start time	21.4
Value of early arrival time	
Full sample	7.0
Fixed start time	8.9
No fixed start time	n.s.

Trip restrictions in the form of maximum allowed delay at work entry imply very different valuations of savings of late and early arrival times. Commuters with low delay allowances value delays almost three times as much as travel times, while those with more flexibility value delay time just 50% above travel time. On the other hand, only those commuters with fixed

work starting times give a positive value to savings in early arrival times. These results stress the need of taking into account individual and trip characteristics when valuing travel time variability.

5. Conclusions

In this paper new estimations of the value given to the variability of travel times in an urban context have been provided. This issue is of particular relevance for the more precise evaluation of policies that may impact on travel times, given that the empirical analysis carried out for commuter trips shows that the value placed on time variability is well above that of average travel time. Our results show that individuals value travel time variability because of the consequences of being early or late with respect the desired arrival time. Consistently with this result, the value of time variability highly depends on the time restrictions faced by the individual. In particular, restrictions related to work starting times (entry flexibility and maximum allowed delays) have been shown to have very significant impacts on such valuations.

The estimated value of average travel time savings is 14.7 €/h, while late arrival is valued at 34.4 €/h, or 2.3 times more. However, when working time restrictions are taken into account, the value of late arrival reaches 51€/h for those commuters who cannot arrive more than 10 minutes late, whereas the ones with more flexible start times value it at 21.4 €/h. Savings on early arrival time are only relevant for those with fixed entry times, who value them at 9€/h.

The high value given to travel time variability has implications for transport policy, both in terms of decision taking with respect to new investment in infrastructure and optimal pricing of its use. Cost-Benefit Analysis should include valuations of the impact on travel time variability as an additional issue in order to improve the results of project evaluation. Moreover, any policy aimed at setting charges for the use of congested infrastructures should take into account the valuation of variability in travel times, as well as the observed heterogeneity in such valuation according to the trip characteristics.

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Appendix. The stated preference questionnaire.

This appendix provides details about the stated preference experiment which was used to obtain the data needed to estimate the different models. A pilot survey was followed by the main survey, both carried out during the fourth quarter of 2005. Commuters were contacted at different petrol stations in the national road and tolled motorway, where after some screening questions an envelope containing the survey and an introductory letter with instructions was distributed. Commuters were asked to complete the survey at home and return it by mail with pre-stamped envelopes that were provided.

Each choice was formed by two alternatives, characterized by four variables: average travel time, variability of travel time, early departure time and monetary cost. For each variable, three possible values are considered. However, in order to reduce the number of possible scenarios that would result from the combination of all the variables' levels, the values of the monetary cost and average travel time variables were defined in difference terms. Costs and travel times are also related by the fact that in every choice scenario presented in the questionnaire, the quickest alternative is also the most expensive. In this way, besides avoiding dominance problems, choices are made more similar to the actual ones faced by commuters in their daily trips.

Each variable may take three possible values. Average travel times and monetary costs were calculated by simulation of trip characteristics form the Maresme area to Barcelona's city centre under standard travel time conditions at peak times. The values thus obtained of the difference of travel time and cost between each routes were used to define the central level, which was then modified upwards and downwards to calculate the other two required levels. The construction of the variable that captures the variability of travel time is based on the methodology of Small et al (1999). Following Black and Towriss (1993), the distributions of variable travel times are presented as five possible travel times which are equally likely to occur[8]. Each possible distribution of variable travel times is summarised by a set of five coefficients which, once multiplied by the average travel time of the alternative, yield the five possible travel times. The three possible distributions capturing different degrees of variability can then be combined with each average travel time. In the case of departure times, one value is that which would result in punctual arrival if there was no variability of travel times, while the other two imply advancing departure 5 and 8 minutes, respectively.

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[8] See Bates et al (2001) for a discussion of the difficulties associated to the presentation of variability of travel times in SP questionnaires.

The full factorial of a stated preference experiment designed in this way has 3^6 scenarios which can be reduced to a fractional factorial of 18 scenarios (Louvière et al, 2000). However, that is still a large number to guarantee that no fatigue effects appear. Therefore, two groups of questionnaires of 9 scenarios each were created and each surveyed commuter was asked to make the choices of all the scenarios of only one group. Table A1 shows the levels of all variables used in the choices for each group. Although, as previously explained, the differences between alternatives in terms of average travel times and monetary costs only take three possible values, absolute values were used in the presentation of the characteristics of each alternative to avoid complexity.

Table A1. Scenarios used in the questionnaires.

First group		Cost	Average time	Departure advance	Distribution of possible travel times				
Scenario 1	A	3,25	40	8	36	38	40	42	46
	B	2,5	46	5	39	42	46	50	60
Scenario 2	A	2,75	45	5	41	43	45	47	52
	B	1,25	55	5	50	52	55	58	63
Scenario 3	A	3,25	45	5	38	41	45	49	59
	B	2,5	55	8	47	51	55	59	72
Scenario 4	A	3,25	35	5	26	30	35	39	51
	B	2,5	50	8	45	48	50	53	58
Scenario 5	A	2,75	35	0	32	33	35	37	40
	B	1,25	50	8	43	46	50	54	65
Scenario 6	A	2,75	40	5	34	37	40	43	52
	B	1,25	46	5	35	39	46	52	67
Scenario 7	A	4	35	0	30	32	35	38	46
	B	2	50	5	45	48	50	53	58
Scenario 8	A	4	40	5	30	34	40	45	58
	B	2	46	0	39	42	46	50	60
Scenario 9	A	4	45	0	34	38	45	50	65
	B	2	55	5	47	51	55	59	72

Second group		Cost	Average time	Departure advance	Distribution of possible travel times				
Scenario 1	A	4	35	5	32	33	35	37	40
	B	2	50	0	38	43	50	56	73
Scenario 2	A	2,75	40	0	30	34	40	45	58
	B	1,25	46	8	35	39	46	52	67
Scenario 3	A	3,25	40	0	36	38	40	42	46
	B	2,5	46	0	41	44	46	48	53
Scenario 4	A	3,25	45	0	38	41	45	49	59
	B	2,5	55	0	41	47	55	62	80
Scenario 5	A	2,75	45	8	34	38	45	50	65
	B	1,25	55	0	50	52	55	58	63
Scenario 6	A	3,25	35	8	26	30	35	39	51
	B	2,5	50	5	38	43	50	56	73
Scenario 7	A	4	45	8	41	43	45	47	52
	B	2	55	8	41	47	55	62	80
Scenario 8	A	2,75	35	8	30	32	35	38	46
	B	1,25	50	0	43	46	50	54	65
Scenario 9	A	4	40	8	34	37	40	43	52
	B	2	46	8	41	44	46	48	53

It is possible that political opposition to tolls by some respondents would bias their declared choices against the alternative that characterises the tolled motorway. In order to avoid such problem, alternatives are unlabelled and randomly ordered in the presentation of choice sets. Given that operation costs are also considered in the definition of monetary costs, no alternative presents zero costs.

Small et al (1999) discuss whether the full implications of choices of this type can be correctly understood in a stated preference experiment, given that each alternative is characterised by four relatively complex characteristics. In their pilot survey they test two alternative presentations that aggregate the values of two variables, so that the choice is simplified. One way is to add departure time and the distribution of possible travel times into a distribution of possible arrival times to destination. The second option aggregates the average travel time and the departure time into a variable that defines departure in terms of minutes with respect to the desired arrival time to destination. They choose the first method, since the results of the pilot survey show that the latter specification is not correctly understood by most respondents, while the first is. We also used our pilot survey to compare both types of simplifications and obtained the same conclusion. Although Wardman (2001) argues that such aggregations of variables may result in individuals not interpreting in a correct way the information presented, the alternative risk is that too much information is used to characterise each alternative and the details about the variability of travel times are not fully taken into account. Therefore, our questionnaire mimics that of Small et al (1999). An example of the choice presented for one scenario is shown in table A2.

Table A2. Example of choice question

Please, choose **OPTION A** or **OPTION B**

OPTION -A-	OPTION -B-
Average travel time: 40 minutes	Average travel time: 46 minutes
You have the same probabilities of arriving:	You have the same probability of arriving:
10 minutes before your desired arrival time	20 minutes before your desired arrival time
6 minutes before your desired arrival time	15 minutes before your desired arrival time
At the desired arrival time	8 minutes before your desired arrival time
5 minutes after your desired arrival time	2 minutes after your desired arrival time
18 minutes after your desired arrival time	13 minutes after your desired arrival time
The cost of the trip is 2.75 euros	The cost of the trip is 1.25 euros
A ☐	B ☐

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