HOW DO MOTORISTS RESPOND TO COST: EVIDENCE FROM AN INTER-URBAN ROUTE CHOICE CONTEXT

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ABSTRACT

The M6 Toll road (M6T) is the United Kingdom's first toll motorway. The 27 mile (43km) £900m three lane motorway was designed to alleviate traffic congestion on the existing M6 motorway around Birmingham and was built under a public-private partnership scheme. The road was fully opened on 14th December 2004.

This paper reports on research conducted into motorists' route choice for inter-urban journeys. In particular, it examines the extent to which motorists' are prepared to pay a toll to use the M6T and save significant amounts of travel time. A variety of different route choice exercises were employed to examine a wide range of issues, and a large sample of over 3000 motorists was obtained.

We here focus on how motorists' respond to variations in toll charge and fuel costs, as reflected in the parameters of Stated Preference route choice models. The specific hypotheses investigated are:

- To what extent do motorists respond differently to changes in toll and fuel cost?
- To what extent is the fuel cost coefficient moderated by the extent to which motorists consider fuel costs in their route choices?
- How does the sensitivity to cost variation vary with journey length?
- What is the impact of income on the sensitivity to toll charge and fuel cost variations?
- Are there significant random variations in the cost coefficients across motorists?
- Are there significant non-linearities in response to a wide range of toll charges, and are increases and reductions in toll charge regarded the same?
- Does the sensitivity to toll charge depend upon whether the toll is charged on an existing tolled motorway, on an existing free motorway, on an extended tolled motorway or on an entirely new motorway.

Keywords: *Route Choice, Stated Preference, Toll Roads, Cost Sensitivity, Value of Time*

1 INTRODUCTION

The M6 Toll road (M6T) is the United Kingdom's first toll motorway. The 27 mile (43km) £900m three lane motorway was designed to alleviate traffic congestion on the existing M6 motorway around Birmingham and was built under a public-private partnership scheme. The road was fully opened on 14th December 2004 and generated £45 million in revenue in its first full year of operation. On opening, the standard toll for cars was £2 but this had increased significantly to £3.50 by the time of our data collection in November 2006 and to £4 shortly thereafter.

The existence of the M6T provides an appropriate real-world context upon which to base Stated Preference (SP) experiments exploring time and cost trading through route choice. It also allows Revealed Preference (RP) data relating to motorists' actual choices to be collected, although in such instances the toll charge does not vary.

This paper reports on research conducted into motorists' route choices for inter-urban journeys and in particular it examines the extent to which motorists' are prepared to pay a toll to use the M6T and save significant amounts of travel time and how the sensitivity to toll change varies with a range of factors and compared to the sensitivity to fuel cost. A variety of different route choice exercises were employed to examine a wide range of issues, and a large sample of over almost 2500 motorists was obtained.

The specific hypotheses investigated are:

- To what extent do motorists respond differently to changes in toll charge and fuel cost?
- To what extent is the fuel cost coefficient moderated by the extent to which motorists consider fuel costs in their route choices?
- How does the sensitivity to cost variation vary with journey length?
- What is the impact of income on the sensitivity to toll charge and fuel cost variations?
- Is there significant random variation in the sensitivity to cost across motorists?
- Are there significant non-linearities in response to a wide range of toll charges, and are increases and reductions in toll charge regarded the same?
- Does the sensitivity to toll charge depend upon whether the toll is charged on an existing tolled motorway, on an existing free motorway, on an extended tolled motorway or on an entirely new motorway.

The evidence adds to the limited amount of knowledge in this area. The structure of the paper is as follows. Section 2 covers the background to the modelling presented in the paper, in terms of the choice context examined and the SP exercises used, whilst section 3 reports briefly on the data collection. The empirical findings, based on a random parameters logit model estimated to both RP and SP data, are reported in section 4. Section 5 provides concluding remarks.

2 BACKGROUND

The SP exercises were based around a real-world context where, for inter-urban journeys, motorists could pay a toll to use the M6T and save time. There is also the possibility of using A-type roads to avoid the congested section of M6 around Birmingham, an option revealed as realistic in prior focus groups. The choice context is depicted in Figure 1.

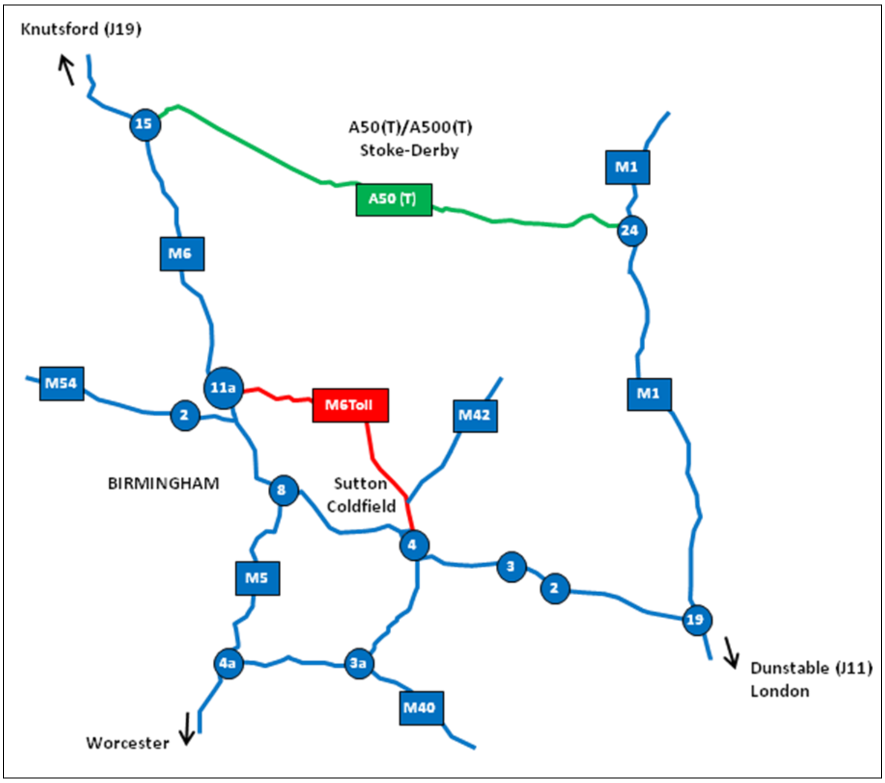

Figure 1. The M6T and Survey Corridor

The SP exercises were based around that portion of an individual's journey through the West Midlands where the M6T offered a time saving opportunity. In order to support a wider range of time-cost trade-offs, different levels of toll and time saving, and realistic variations in fuel cost, three different SP choice contexts were used. In reference to Figure 1, these contexts were as follow:

- A 27 mile M6T corridor between junctions 4 and 11a;
- An 80 mile corridor between M6 Junction 15 (Stoke) and the M1 Junction 19;
- A 150 mile corridor between M6 Junction 19 (Knutsford) and M1 Junction 11 (Dunstable).

The specific SP designs used for each generic choice context and which are made use of in the research reported here are set out in Table 1. Standard orthogonal fractional factorial designs were used and any respondent was offered only eight of the full sixteen.

Table 1. The Stated Preference Exercises

Corridor	Code	Routes	Attributes	Comment
Route Choice Exercises				
Stoke-M1	SP1A-1	M6 v M6T v A50/A500	Time, Toll, Fuel	Absolute times
	SP1A-2	M6 v M6T v A50/A500	Time, Toll, Fuel	Absolute times
	SP1A-3	M6 v M6T v A50/A500	Time, Toll, Fuel	M6T quicker
	SP1A-4	M6 v M6T v A50/A500	Time, Toll, Fuel	M6 slower
	SP1A-5	M6 v M6T v A50/A500	Time, Toll	No fuel
	SP1A-6	M6 v M6T v A50/A500	Time, Toll	No fuel, higher tolls
	SP1C-1	M6 v M6T v A50/A500	Time, Toll, Fuel	Toll on M6
	SP1C-2	M6 v M6T v A50/A500	Time, Toll, Fuel	Toll on M6
	SP2A-1	M6 v M6T v A50/A500	Time, Toll, Fuel	Extended M6T
	SP2A-2	M6 v M6T v A50/A500	Time, Toll, Fuel	Higher toll
	SP2A-3	M6 v M6T	Time. Toll	Omit A Road and fuel
	SP2B	M6 v extended M6Ts	Time, Toll	North and South Extensions
M6T Corridor	SP1B-1	M6 v M6T v A Road	Time, Toll	Absolute times
	SP1B-2	M6 v M6T	Time, Toll	Absolute times
	SP1B-3	M6 v M6T	Time, Toll	M6T quicker
	SP1B-4	M6 v M6T	Time, Toll	M6 slower
	SP1B-5	M6 v M6T	Time, Toll	Different tolls
	SP1B-6	M6 v M6T	Time, Toll, Information	M6 Roadworks
	SP1B-7	M6 v M6T	Time, Toll, Information	M6 Accident
	SP1B-8	M6 v M6T	Time, Toll, Information	M6 Congestion
Knutsford-Dunstable	SP2C	New Motorway v M6 v M6T	Time, Toll	Larger tolls and time savings
Route and Departure Time Choice Exercises				
Stoke-M1	SP3A	M6 v M6 (earlier/later) v M6T v M6T (earlier/later)	Time, Toll, Departure Time Shift	Lower or zero tolls and quicker journey times at different departure time
M6T Corridor	SP3B	M6 v M6 (earlier/later) v M6T v M6T (earlier/later)	Time, Toll, Departure Time Shift	

The choice context in the 27 mile M6T corridor (SP1B) could in principle be applied to all 'in-scope' motorists whatever the length of their journey. However, focussing solely on this would limit the analytical possibilities.

Using the Stoke-M1 corridor choice context makes it realistic to offer the A50(T)/A500(T) as a free alternative to the often highly congested M6 (SP1A, SP1C). Not only does this support a wider range of time-cost trade-offs but, because it is ten miles shorter, it permitted sensible fuel cost differences to be introduced. Using this corridor also allows the evaluation of an M6T option extended over the entire 80 miles offering larger time savings and toll charges (SP2A). A variant upon this (SP2B) offered the existing M6T and possible Northern and Southern extensions, both separately and together, across the corridor, implying choices between the current M6 and 7 alternatives.

The third route choice context, suitable for those making very long journeys, allows a wider set of time-toll trade-offs to be presented as well as evaluating preferences towards an entirely new tolled motorway (SP2C).

For the M6T and Stoke-M1 corridors, we also extended the route choice exercise by introducing a departure time dimension (SP3A, SP3B). Motorists faced the additional possibility of saving time and toll by travelling on either the M6 or M6T at a different time.

One of the issues of interest here was comparing sensitivity to toll and fuel cost. Critical to this is that realistic fuel cost variations are offered. We did not regard it credible to vary fuel costs within a route, although this approach is adopted in some studies, particularly given that there might then be infeasible variations relative to journey time. The fuel cost is held constant on the M6/M6T across all 16 scenarios but varies between two levels on the A road. However, it should be noted that any respondent was only given one level of fuel cost difference (either £10 versus £9 or else £10 versus £7.50) because again it was felt that varying petrol cost would not be plausible. Given that an important aspect of our investigation was the extent to which fuel is considered and its utility weight relative to that for toll, our design exhibits the required variation in fuel cost across designs but is plausible for any particular individual in only offering a single fuel cost difference.

3 DATA COLLECTION

The SP exercises were administered through mail-back self-completion questionnaires distributed in November 2006 to 'in-scope' respondents who were making a journey in the M6T corridor. The overall response rate was 22%.

All respondents were presented with two SP exercises. The first covered an existing route choice context (SP1A, SP1B, SP1C), except for some making sufficiently long journeys who were offered the new motorway design (SP2B). The second exercise was generally one of 'abstract choice' covering issues such as the type of time and various aspects of car journey quality (Wardman et al., 2008) or else it was a route and departure time exercise (SP3A, SP3B) or the extended M6T exercise (SP2A).

Table 2 lists the number of individuals who answered each SP exercise, the number of SP observations yielded and the split of choices across the alternative routes. After accounting for those who did two exercises, we have 29158 SP choice observations from 2495 respondents. In addition, we have 3030 RP observations[1], making a total of 32188 observations in the combined RP-SP model.

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[1] This includes those who did not the other forms of SP but who nonetheless provided the relevant RP route choice information.

Table 2. SP Responses by SP Exercises

Design	Context	Inds	Obs	Choices
SP1A	Stoke-M1 Corridor	991	7652	M6: 1309 (17%) M6T: 4900 (64%) A: 1443 (19%)
SP1B	M6T Corridor	1266	9738	M6: 2726 (28%) M6T: 6486 (67%) A: 526 (5%)
SP1C	Stoke-M1 Corridor	150	1169	M6: 136 (11%) M6T: 757 (65%) A: 276 (24%)
SP2A	Stoke-M1 Extended M6T	422	3210	M6: 498 (16%) M6T: 2137 (66%) A: 575 (18%)
SP2B	Extended M6T in Bits	225	1625	M6: 250 (15%) M6T: 550 (34%) Nth: 82 (5%) Sth: 11 (1%) M6TNth: 262 (16%) M6TSth: 22 (1%) NthSth: 41 (3%) All: 407 (25%)
SP2C	Knutsford-Dunstable NewM6	136	1042	M6: 305 (29%) M6T: 556 (54%) A: 181 (17%)
SP3	Route and Departure Time	627	4722	M6: 522 (11%) M6T: 1855 (39%) M6 Earlier: 82 (2%) M6T Earlier: 1124 (24%) M6 Later: 178 (4%) M6T Later: 961 (20%)

4 EMPIRICAL FINDINGS

The model reported in Table 3 is based on joint RP-SP data and is the multinomial logit form with random parameters specified for toll and the alternative specific constants (ASC). The model was estimated by maximum simulated likelihood (Revelt and Train, 1998) using MATLAB-based code developed by J Nicolás Ibáñez and Richard Connors at ITS University of Leeds. The estimation employed 2500 draws (per individual) that were generated through Marsaglia's ziggurat algorithm (Marsaglia and Tsang, 1984). The total estimation time was 13.05 hours.

Previous analysis (Wardman et al., 2008) had revealed that the SP data from the various exercises had essentially the same scale and hence could be pooled without allowing for scale differences although the RP data had a scale that was around 50% larger. The only reason why we have not considered this different scale for SP and RP data in the random parameters model reported in Table 3 is because the only estimation routine that we were able to use to estimate our model (the MATLAB-based code mentioned above) did not allowed for this possibility, and hence the data from the different SP exercises and the RP data are constrained to have the same scale.

Results based on a standard joint RP-SP model indicated that this constraint does not make a great difference to the coefficient estimates. The RP component of the model, that is, the time and cost attributes describing the three available alternatives (M6, M6T and A-type roads), is based on network data rather than reported data from the motorists that were surveyed.

The overall goodness of fit of the model, denoted by the ρ^2 specified with respect to constants, has a value of 0.37, far exceeding the figures typically achieved in SP models. No doubt the random parameters configuration contributes to this fit but even without them the goodness of fit was a very respectable 0.25 (see Wardman et al., 2008). The model has a number of other sound features, notably the range of right sign and highly significant coefficient estimates. The reported model contains the socio-economic variables that were found to have a significant effect, specified as interactions with the main effects, as well as the main effects themselves of time, toll charge, fuel cost, earlier departure time, later departure time, and information provision. The proportion of heavy goods vehicles (%HGV) and the reliability indicators relate to the existing routes, varying across respondents but not varied within the SP exercises.

Table 3. Random Parameters RP-SP Logit Model

ASC_{M6T-RP}	2.8708 (16.5)	*Adj-HolsSB*	0.0119 (5.4)
ASC_{A-RP}	-0.1487 (1.8)	*Adj-VFR*	0.0076 (5.6)
$ASC_{M6TCorridor}$	1.8276 (13.7)	*Adj-Male*	0.0044 (3.7)
$ASC_{M6TStoke-M1}$	2.1270 (15.1)	M6 delays due to	0.9887 (7.4)
$ASC_{M6TExtended}$	2.0469 (7.8)	Exp 25m delays	2.3632 (15.1)
$ASC_{M6TLong}$	2.0265 (9.6)	No M6 Delays	-0.3966 (3.1)
ASC_{NTH}	-2.4259 (13.3)	*EmpPayToll*	0.0023 (11.0)
ASC_{STH}	-4.0472 (12.3)	*Toll> £3.50*	-0.0011 (8.6)
ASC_{M6TNTH}	1.7666 (14.6)	*Toll New motorway*	0.0019 (6.4)
ASC_{M6TSTH}	-0.5260 (2.3)	*Toll Extended M6T*	0.0007 (2.1)
ASC_{NTHSTH}	-1.2102 (6.9)	FuelYes	-0.0051 (16.1)
ASC_{ALL3}	2.8807 (19.6)	TollDK-Mean	-4.7572 (67.8)
SD-ASC_{M6T}	1.5925 (30.7)	TollDK-SD	0.5403 (15.3)
ASC_{M6T}*Never M6T*	-2.1321 (13.8)	Toll-<£10k-Mean	-4.5456 (35.2)
ASC_{M6T}*Male*	-0.4061 (4.2)	Toll-<£10k-SD	0.4528 (4.8)
ASC_{M6T}*Age65+*	0.7497 (4.3)	Toll-£10-29k-Mean	-4.6418 (80.3)
ASC_{M6T}*Others*	0.4776 (4.7)	Toll-£10-29k-SD	0.5228 (15.7)
ASC_{M6T}*ObjectTolls*	-0.2665 (4.1)	Toll-£30-39k-Mean	-4.7619 (61.2)
Very Reliable	1.3719 (17.0)	Toll-£30-39k-SD	0.5855 (15.2)
Reliable	1.0393 (13.8)	Toll-£40-49k-Mean	-4.7628 (62.0)
Usual/Sometime Rely	0.7021 (15.3)	Toll-£40-49k-SD	0.5473 (14.9)
Unreliable	0.3049 (5.3)	Toll-£50-59k-Mean	-4.7853 (62.3)
%HGV	-0.0014 (1.1)	Toll-£50-59k-SD	0.4837 (12.7)
$Time_{M6}$	-0.0841 (45.0)	Toll-£60-69k-Mean	-4.8107 (59.8)
$Time_{M6T}$	-0.0802 (38.7)	Toll-£60-69k-SD	0.3999 (9.9)
$Time_{A}$	-0.0898 (46.7)	Toll-£70-89k-Mean	-4.8453 (51.4)
$Time_{Bits}$	-0.0532 (19.4)	Toll-£70-89k-SD	0.4595 (10.4)
Time*Acttim**1.1	-0.000014 (2.7)	Toll-£90-99k-Mean	-4.9740 (28.4)
Time-OthAdults	0.0099 (4.6)	Toll-£90-99k-SD	0.4494 (5.8)
Earlier	-0.0377 (29.8)	Toll-£100k+-Mean	-5.0960 (38.8)
Later	-0.0348 (22.5)	Toll-£100k+-SD	0.4648 (7.8)
Later-Business	-0.0040 (2.6)	ρ^2 (constants)	0.375
Later-Commute	-0.0106 (5.8)	Log Likelihood	-19117.9

Notes: The same λ parameter on the actual time interaction of 1.1 was used as provided the best fit in the standard RP-SP logit model. This was estimated using a grid-search.
Incremental effects in italics.
T-ratio values in brackets,

The pattern of piecewise estimation results, where in turn the time, toll, fuel and departure time shift coefficients were allowed to vary across different time bands for the actual journey made, motivated the inclusion of a duration effect solely on the sensitivity to time. We proceeded to fit a continuous function of the form:

$$U_i = \alpha_i T_i + \beta AT^{\lambda} T_i + \gamma C_i + \ldots \qquad (1)$$

where T_i is the SP journey time for route type i, AT is the actual time for the journey made, and C_i is some measure of cost. The marginal utility of travel time (MU_T) is:

$$MU_{T_i} = \frac{\partial U_i}{\partial T_i} = \alpha_i + \beta AT^{\lambda} \qquad (2)$$

and it can increase or decrease with AT or be constant. The value-of-time duration elasticity (η) is:

$$\eta_i = \frac{\partial \ln VOT_i}{\partial \ln AT} = \frac{\beta\lambda}{\gamma VOT_i} AT^{\lambda} \qquad (3)$$

with value-of-time being defined as follows:

$$VOT_i = \frac{MU_{T_i}}{MU_{C_i}} = \frac{\dfrac{\partial U_i}{\partial T_i}}{\dfrac{\partial U_i}{\partial C_i}} = \frac{\alpha_i + \beta AT^{\lambda}}{\gamma}$$

This elasticity η can increase, decrease or be effectively constant according to the values of β and λ. The value of λ was indirectly estimated by an iterative grid search process, in intervals of 0.1, to achieve the best fit.

When it comes to the RP data, AT is not an interaction term but is the independent variable itself. In the pooled RP-SP model, the RP utility functions are specified as:

$$U_i^{RP} = \alpha_i AT + \beta \frac{AT^{\lambda+1}}{\lambda+1} + \ldots \qquad (4)$$

so that the marginal utility of travel time (MU_T) is the same as for the SP utility function (equation 2).

Prior to discussing the results relating to willingness to pay tolls and differential levels of sensitivity we briefly discuss some of the other findings.

4.1 NON COST VARIABLES

The time coefficient is found to increase with the length of the actual journey, although in this combined RP-SP model it is not as strong an effect as for the SP data alone and indeed the duration elasticities are low. Table 4 presents values of time by journey duration for an average household income in the band £50-59k.

For reference, we provide values of time from two sources. These are official Department for Transport valuations that are recommended for use in scheme appraisal (Department for Transport, 2006) and the values implied by a model estimated on a very large data set of British empirical evidence to explain variations in values of time in meta-analysis reported in Wardman (2004).

Table 4. Implied Values of Time (VoT) and Duration Elasticity (η, equation 2)

Distance	VoT	η
30m	9.0 (9.6)	0.01 (0.01)
60m	9.1 (9.7)	0.02 (0.02)
120m	9.2 (9.8)	0.03 (0.03)
180m	9.4 (10.0)	0.05 (0.05)
240m	9.6 (10.2)	0.07 (0.07)
300m	9.7 (10.3)	0.09 (0.08)

Note: Values for time spent on the M6 (A road in brackets) in toll units

The official Department for Transport values of time for quarter 4 2006 prices and incomes are around 43 pence per minute for business travel, 10 pence per minute for commuting and 9 pence per minute for other. Noting that SP exercises do not tend to recover business valuations that reflect the firm's valuation, but would seem to reflect personal valuations, our estimated valuations are in line with official values. However, the latter do not distinguish by, amongst other things, journey length and the cost numeraire. The meta-analysis equation, for values of time in quarter 4 2006 prices and incomes and expressed in toll units is:

$$VoT = 1.16 \times GDP^{0.723} \times D^{0.259} \times \exp\left(-5.114 + 0.498 \times EB + 0.100 \times C - 0.312 \times T\right) \quad (5)$$

VoT denotes the value of time in pence per minute, GDP is gross domestic product per capita, with here an index of 4037, D is distance in miles, EB denotes the journey purpose of employer's business, C is commuting and T represents a toll charge numeraire. The business values represent those typically obtained from SP exercises but which cannot be taken as representative of wage-rate based employers' valuations.

For the average journey durations in our sample, of 2 hours 17 minutes, 1 hour 14 minutes and 3 hours 9 minute for business, commuting and leisure trips, the meta-analysis implied valuations are 12.0, 7.0 and 8.0 pence per minute. Given that business travellers form 36% of the sample, with 14% making commuting trips and 50% leisure trips, the average would be

9.3. The overall values reported in Table 4, which are largely driven by the SP data, are highly consistent with previous British value of time evidence.

The marginal utility of time varies with time, and hence the time valuations of other factors will depend on the journey duration. We report time based valuations in equivalent units of M6 time and for the average journey length of 2 hours 34 minutes. This implies a time coefficient of -0.0877.

The base level of departing earlier is valued at around 43% of journey time on average, being higher for visiting and friends and relatives and highest, at 57% of the time value, for those on holidays or short breaks. Departing later is valued at 40% of travel time, 44% for business travellers, 48% for those visiting friends and relatives, 52% for commuters and 53% for those on holidays or short breaks. Males value departing earlier or later a little over 10% higher. It is not uncommon that studies find little variation between the valuations of departing earlier and later and the valuations obtained here seem very reasonable.

Compared to being perceived to be very unreliable, a very reliable route is valued at almost 16 minutes, falling to 12 minutes for a reliable route and 8 minutes for a usually reliable route.

The information on delay coefficients were specified relative to the M6T. Hence a sign stating that delays of 25 minutes are expected on the M6 would increase the chances of choosing the M6T. Compared to a base of unspecified delays on the M6 in terms of length or cause, no delays is taken to be equivalent to 4.5 minutes. Delays for some specified reason are valued at 11.3 minutes whilst 25 minutes of expected M6 delay has a value of 27 minutes. Thus compared to no delays on the M6, 25 minutes of delay on the M6 is valued at 31.5 minutes. This is reasonable, attaching as it does some premium to the (anticipated) delay.

Few variations in the time coefficients were found by socio-economic and trip related characteristics, with only slight variation by route and journey duration and the sensitivity to time variations around 11% lower when travelling with other adults.

Despite allowing the time coefficients to vary across route types, which can discern variations in route preference that depend on duration, strong alternative specific constants (ASCs) remain. These are specified relative to the existing M6. Generally, there was little difference between the M6 and existing A roads but there were strong preferences for new motorways. For example, the RP constant indicates a preference of nearly 33 minutes for the M6T over the M6. Although varying with the choice context, the SP exercise reveals preferences of 20.8 minutes for the M6T corridor, 24.4 minutes for the Stoke-M1 corridor, and 23.3 minutes for the extended M6T and entirely new M6T.

Variations in the ASCs were discerned with regard to socio-economic and attitudinal factors. Those who stated that they would never use the M6T have an ASC some 24 minutes lower and those who object to paying tolls and males have 3.0 minutes and 4.6 minutes lower

ASCs. Those over 65 and those travelling with others are more likely to choose the M6T, with larger ASCs of 8.5 and 5.4 minutes respectively.

We have allowed the ASC for the M6T to exhibit a normal distribution across the sample, but constrained it to be the same for $ASC_{M6T\text{-}RP}$, $ASC_{M6TCorridor}$, $ASC_{M6TStoke\text{-}M1}$ and $ASC_{M6TExtended}$. The estimated standard deviation is denoted $SD\text{-}ASC_{M6T}$ which is highly significant. There remains considerable random variation in the ASCs. The distribution of the RP ASC ($ASC_{M6T\text{-}RP}$) around its central estimate of 2.87, along with the cumulative distribution, are depicted by Figure 1. The distribution seems reasonable. Although the normal expectation would be for an ASC favouring the M6T, it is not inconceivable that some would not prefer it, and the results show a small proportion having a negative ASC for the M6T.

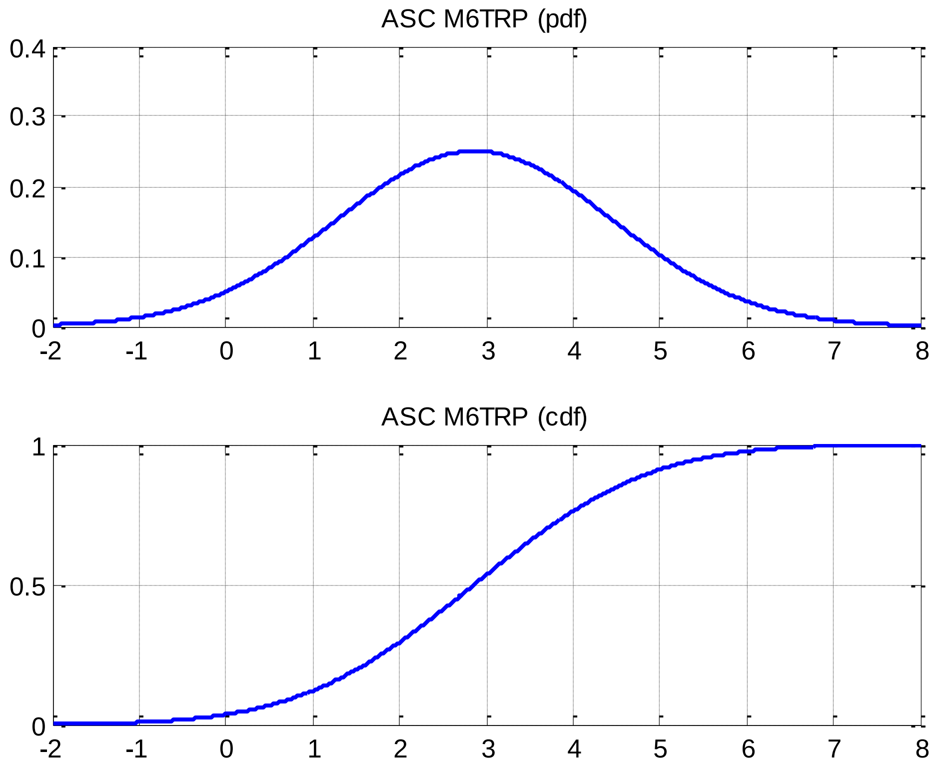

Figure 1: Distributions of M6T ASC for RP Data (ASCM6T-RP)

4.2 THE COST VARIABLES

4.2.1 Response to Toll and Toll Level

A wide range of toll charges were covered across the large number of SP exercises as indicated in Table 5.

The exercises generally cover both gains and losses on the toll charge of £3.50 at the time of the surveys. However, SP1C included tolls on the existing M6, SP2C covers tolls on a new motorway whilst SP2A and SP2B offer some large toll levels to complement those of SP2C and also cover the extension of an existing tolled motorway. The toll is constant at £3.50 in the RP choice context.

Table 5. Toll levels covered in SP Designs

Design	**Toll Levels (pence)**	**Base**	**Comments**
SP1A (Stoke-M1)	200, 350, 500, 750. 100, 200, 400, 500.	200 200	SP1A Designs 1-5 SP1A Design 6
SP1B (M6T Corridor)	200, 350, 500, 750. 100, 200, 400, 500. 150, 250, 400, 650.	200 200 250	SP1B Designs 1-4 SP1B Design 5 SP1B Designs 6-8
SP1C (Stoke-M1)	200, 350, 500, 750. 0, 100, 200.	200 200	Tolls on M6T Tolls on existing M6
SP2A (Extended M6T)	200, 350, 500, 750. 300, 550, 800, 1000.	200 300	SP2A Design 1 SP2A Designs 2-3
SP2B (Extended in Bits)	250, 350, 450. 100, 150, 200, 250. 100, 150, 200, 250. 350, 400, 450, 500, 550, 600, 650, 700. 350, 400, 450, 500, 550, 600, 650, 700. 200, 250, 300, 350, 400, 450, 500. 450, 600, 650, 700, 800, 850.	450 250 250 450 450 450 450	M6T North South M6T and North M6T and South North and South All
SP2C (New motorway)	750, 1000, 1500, 2000. 200, 350, 500, 650.	750 200	New motorway Existing M6T
SP3 (Departure Time)	200, 350, 500, 750. 0, 100, 200.	200 200	Current Depart Time Different Depart Time

The initial modelling of toll effects specified a piecewise model, involving dummy variables to represent each toll level relative to a base. This takes the form:

$$U = \sum_{i=2}^{n} \alpha_i d_i + \ldots.. \quad (6)$$

The d_i are dummy variables for each of n-1 toll levels and their coefficients are interpreted relative to the base (omitted) category, here specified as level 1.

The base levels used in the modelling are specified in Table 5 above, and are repeated in Table 6 containing the results. They were chosen to be as similar as possible to assist interpretation.

Table 6 reports the estimated coefficients for the toll levels along with their t ratios and also the unit effect after 'normalising' for the size of the toll. From the toll coefficients reported in Table 3, a rough benchmark for the unit toll coefficient is around -0.009.

Common parameters are estimated where a common base can be specified. So, for example, SP1A, SP1B, SP1C, SP2A, SP2C, SP3A and SP3B all contain a 200p toll charge which can be used as a base. Nonetheless, we have kept SP2B separate, even though it has a 250p base which also occurs in some SP1B exercises, because of the somewhat different nature of how the toll charge is arrived at, whilst SP1C and SP3 were kept separate where they respectively involved the introduction of tolls on the M6 and lower tolls on the M6T in return for departing at a different time.

The results presented in Table 6 seem to indicate that that there is a diminishing marginal utility of toll charge as the toll increases. This is apparent for design SP2B, with a monotonic reduction in the unit disutility across a large number of tolls in excess of 450p. Diminishing effects are also apparent for SP2A, relative to the 300p base, and also for the SP1, SP2A, SP2C and SP8 designs relative to the current toll of 350p. The results do not provide any clear indication that the marginal utility with respect to toll is greatly different between increases and reductions in toll, as with the comparison of increases versus decreases in SP2B.

Table 6. Piecewise Estimation of Toll Effects

Design/Level	Coeff (t)	Unit Effect	Design/Level	Coeff (t)	Unit Effect
1. SP1,			**6. SP2B**		
SP2A,			200	2.299 (2.5)	0.0092
SP2C, SP8	2.025 (6.1)	0.0203	250	2.095 (6.3)	0.0105
100	-	-	300	1.028 (1.7)	0.0068
200=Base	-0.432 (7.7)	-0.0029	350	1.169 (5.6)	0.0117
350	-1.419 (7.0)	-0.0071	400	0.713 (2.6)	0.0143
400	-1.738 (27.9)	-0.0058	450 = Base	-	-
500	-3.041 (39.3)	-0.0055	500	-0.824 (3.4)	-0.0165
750			550	-1.225 (4.5)	-0.0123
2. SP2C			600	-1.788 (6.1)	-0.0119
750=Base	-	-	650	-2.202 (6.7)	-0.0110
1000	-1.556 (4.1)	-0.0062	700	-2.708 (6.6)	-0.0108
1500	-3.299 (6.1)	-0.0044	800	-3.499 (6.8)	-0.0100
2000	-7.951 (5.5)	-0.0064	850	-3.533 (6.5)	-0.0088
3. SP1B					
150	3.565 (9.9)	0.0356	**7. SP2B**		
250=Base	-	-	100	1.807 (3.9)	0.0120
400	0.5322 (2.1)	0.0036	150	1.178 (2.7)	0.0118
650	-3.144 (16.0)	-0.0079	200	0.8510 (1.9)	0.0170
4. SP2A			250 = Base	-	-
300=Base	-	-	**8. SP3**		
550	-2.263 (13.1)	-0.0091	Free	1.506 (14.8)	0.0075
800	-3.805 (20.8)	-0.0076	100	1.092 (9.6)	0.0109
1000	-4.254 (21.3)	-0.0061	200=Base	-	-
5. SP1C					
Free	-0.5335 (2.9)	-0.0027			
100	-0.5032 (2.3)	-0.0050			
200=Base	-	-			

The pattern of results from this piecewise estimation is not particularly clear, with the possible exception of a diminishing marginal utility as tolls increase. This pattern of results could be due either to some protest or strategic biasing against higher tolls, whereupon the spreading of a fixed disutility across larger tolls even with constant marginal utility would imply diminishing estimated average and marginal effects, or due to a genuine non-linearity.

We now turn to specific formulations of the utility function to test particular hypotheses relating to toll sensitivity as set out above. These are all for utility functions which enter toll (T) in its usual linear-additive form but with additional terms to test these hypotheses. This takes the form:

$$U = \alpha T + \beta d_1 + \lambda\, d_2 T \qquad (7)$$

The dummy variables d_1 and d_2 represent some feature of the toll or the context in which it is charged. Here the dummy variable term d_1 represents a factor that might be expected to have a constant (additive) effect on utility independent of the toll level. This might be a protest against the introduction of tolls on a currently untolled motorway, whereupon we would expect β to be negative. The interaction term composed of dummy variable d_2 allows the utility effect to depend upon the level of toll. We might hypothesise that the sensitivity to toll is different for increases on the current toll level. Thus d_2 would denote tolls in excess of 350p, whereupon the toll coefficient would be $\alpha + \lambda$, otherwise it is α. Additional interactions can be entered as appropriate.

An additive dummy variable was specified simply to denote whether or not a route had a toll. This was found to be far from significant. Nor was there a remotely significant effect when an incremental term was entered to denote the introduction of a toll on an existing free motorway.

An incremental toll effect was specified for increases on the current level of 350p. This was an interaction of a dummy variable denoting an increase in toll and the toll variable itself. A significant negative coefficient was returned, consistent with the results of the piecewise estimation.

The focus groups (Faber Maunsell et al., 2006) seemed to detect a resistance to paying a 500p toll on the existing M6T. If such a threshold did exist, it might not apply to an extended M6T. The results in Table 6 do not suggest that any such threshold exists for the existing M6T covered in SP1A, SP1B, SP1C and SP3. Nonetheless, we specified a threshold interaction effect for tolls £5 or over. The coefficient estimate of -0.00011 was of the right sign, although small relative to the toll coefficient, and far from significant (t=0.83). The incremental effect relating to a toll increase on the current toll of £3.50 was statistically superior.

Through the specification of dummy variable interactions with the toll variable, the toll coefficient was allowed to vary across entire new motorways, as in SP2C, the longer M6T (SP2A) and the Northern and Southern extensions to the M6T (SP2B). The latter was far from significant. However, significant effects were obtained for the toll coefficients for the entirely new motorway and for the extended M6T. These denoted lower toll coefficients in these SP exercises.

We examined whether the response to toll (*T*) was linear or not by specifying a power term to the toll variable. This took the form:

$$U = \alpha T^{\lambda} \tag{8}$$

The linear assumption implies a λ of unity. Specifying this function across all toll levels, we found that any departure from this special case of unitary λ actually led to a worse fit.

Restricting this function to the toll levels beyond the current level, with a separate linear term for other toll levels, it was possible to obtain a better fit by departing from linearity. A λ of 0.70 provided the best fit. However, the dummy variable interaction for tolls greater than £3.50 was not then significant. Of the two formulations, the latter provided the better fit and hence was retained.

Table 3 reports the models containing the significant effects on the toll coefficient that have been detected. These are all interaction terms which impact on the sensitivity to toll.

There was a greater degree of sensitivity to toll charges that were an increase on the then prevailing toll level of £3.50 than for reductions. For the average income level in the band of £50-59K, the mean toll coefficient is -0.0094[2]. The toll coefficient for increases on the current level is therefore is only 12% higher.

As for the more appropriate toll coefficient to use, we would argue that the incremental effect for tolls in excess of 350p should be ignored as discerning protest response.

It could be argued that the incremental effect for toll increases is not detecting a response bias but is only reflecting a widely held view that losses are valued more highly than gains. But it might then be reasonable to expect non-linear effects of a reduced marginal sensitivity for larger toll increases in line with prospect theory or an increasing marginal sensitivity in line with diminishing marginal utility. Whilst the former was detected when tested for, it was not statistically superior to the additive effect relating to all increases on the current level.

4.2.2 Toll Sensitivity and Incentives to Bias

Whilst the incentive to response bias may differ between increases and reductions in toll compared to the existing level, there could be other incentives to bias apparent in the choice contexts offered in our SP exercises.

There might be an even stronger response to introductions of tolls on an existing free motorway than to increases on a currently tolled motorway. This was tested in SP1C where tolls were introduced on the existing toll free M6 motorway. However, no significant differentials were detected.

At the other extreme, there is an incentive to overstate willingness to pay for an entirely new motorway in order to influence the chances that it is built but without any commitment to use it should the toll turn out to be too high. Given that for the new motorway the tolls all exceed 350p, the comparison is with the base toll coefficient and the incremental effect for tolls over 350p. This is, for the average income level, -0.0105. The toll coefficient of -0.0075 is 29% lower, in line with expectations.

When an extension to the M6T is being considered, the incentive to bias is similar to that for a completely new motorway, although perhaps with some disincentive to overstate willingness to pay in case this should translate through to existing toll levels. Here we find that the toll coefficient of -0.0087 is 17% lower. Thus whilst any protest towards tolls may be expected to be tempered by a desire to see new and improved motorways, respondents

[2] The mean toll coefficients is calculated as $\exp\left(mean + 0.5 \times SD^2\right)$.

could be expected to have a stronger desire to see a new motorway than an extension to the M6T. We feel that in these circumstances respondents have an incentive to inflate their stated willingness to pay and we might therefore treat responses to choice experiments which deal with new motorways with some caution.

4.2.3 Toll and Fuel Cost Sensitivity

We made every effort, as described above, to make the fuel variation realistic. Indeed, we feel we have somewhat surpassed what is done in this area where it is common to offer fuel cost variations without any explanation or even consideration of how they might realistically vary.

Respondents were asked whether they took account of fuel costs both in their actual route choice, the RP element, and in response to the SP questions.

In the actual choices, 16% did not consider fuel cost differences whilst in the SP data it was 65% amongst those who were offered the fuel cost differential between the motorways and A roads.

For those who stated that they did not consider fuel, its coefficient was, unsurprisingly, not significant and has not been retained in the reported model. Clearly, we have obtained a highly significant fuel cost coefficient amongst those who did consider fuel cost (FuelYes).

In SP models that estimated a single fuel cost coefficient, without removing the 65% who do not consider fuel costs in their SP responses, the fuel cost coefficient fell by 69%. Surprisingly, when allowance is made for those whose toll charge is paid by the employer, the toll coefficient would be far from zero.

These findings draw into some doubt values of time based either in part or entirely upon a fuel cost numeraire when no account has been made for those who do not consider fuel. However, for forecasting purposes, it is appropriate to use separate coefficients for the two types of motorist.

If we take the toll coefficient for reductions and on the existing M6T as the most appropriate toll coefficient, and at the mean income band of £50-59k, the mean toll coefficient is -0.0094. This is somewhat larger than the fuel cost coefficient of -0.0051. Even in the SP exercises where there is an incentive to be less sensitive to toll variations, motorists would apparently be much less sensitive to fuel cost than toll charge.

Abrantes and Wardman (2009) in a large scale meta-analysis of British value of time evidence found that the value of time based on a fuel cost numeraire is 50% larger than a toll charge numeraire. This implies a toll coefficient 50% larger than the fuel cost coefficient. We find the discrepancy to be much larger here, particularly when it is borne in mind that the meta-analysis will have covered fuel cost coefficients where no attempt was made to isolate those who do not consider fuel.

Whilst we could argue that the toll coefficient is influenced by bias, and this causes the divergence, the values of time obtained using the toll coefficient, and as reported in Table 4, are very reasonable and consistent with other evidence. Using a fuel cost numeraire would lead to values of time almost double and these would seem unreasonable.

We therefore conclude that even in these carefully controlled circumstances, with allowance for those who say that they do not consider fuel costs in decision making, full account of fuel costs is not made in route choice decision making.

4.2.4 Cost sensitivity and Income

The reported model contains separate coefficients for ten income categories, one of which denotes that the income is not known. These coefficients are allowed to follow a lognormal distribution, in order to avoid wrong sign values of time which can occur when normal distributions are specified. No significant and sensible variations in the fuel cost coefficients by income could be obtained.

For each income category, Table 3 reports both a mean and a standard deviation coefficient. In addition to the category representing those for whom the income level is not known (TollDK), there are nine pairs of coefficient estimates, all of which are highly significant. Thus Toll-£30-39k-Mean represents the mean toll coefficient for those with a household income in the range £30-£39k with Toll-£30-39k-SD denoting the standard deviation estimate for the same income group. These are all absolute rather than incremental coefficients

In order to return a monotonic income effect, we have only had to combine income bands to a very limited degree. We have combined the £10-19,000 and £20-29,000 income categories and the £70-79,000 and £80-89,000 income categories.

What is impressive is that we can obtain a monotonic effect across nine income categories. Values of time spent on A-roads (VoTA) and of time spent on the M6T (VoTM6T) for each income band are reported in Table 7. Mean and median values are given, and because the denominator term in the value of time calculation has a lognormal distribution, the mean value of time value still exceeds the median value of time. The relationships are presented graphically in Figure 2.

Whilst the effect of income on the value of time is a well researched theme, we are not aware of previous research that has obtained a pattern of results as clear as those reported here. However, the implied income elasticity is relatively minor, much less than the 0.5 cross-sectional income elasticity typically achieved, which perhaps makes the estimation of such a monotonic effect all the more impressive.

Table 7. Values of Time by Income Band (pence per minute, p/min)

	Median M6T	Median M6	Median A Roads	Mean M6T	Mean M6	Mean A Roads
<£10k	7.86	8.23	8.77	8.71	9.12	9.71
£10-29k	8.66	9.06	9.65	9.92	10.39	11.06
£30-39k	9.76	10.22	10.88	11.58	12.13	12.92
£40-49k	9.77	10.22	10.89	11.35	11.88	12.65
£50-59k	9.99	10.46	11.14	11.23	11.76	12.52
£60-69k	10.25	10.73	11.43	11.10	11.62	12.38
£70-89k	10.61	11.10	11.83	11.79	12.34	13.15
£90-99k	12.07	12.63	13.45	13.35	13.97	14.88
£100k+	13.63	14.27	15.20	15.19	15.90	16.93

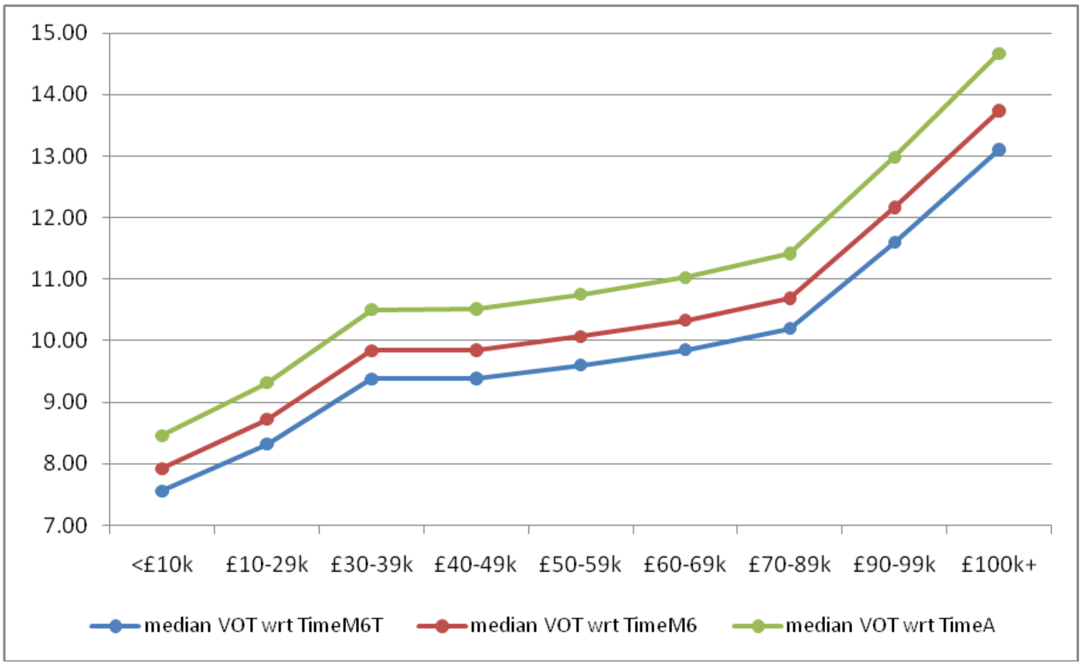

Figure 2: Values of Time by Income Band (p/min)

The degree of taste variation in the value of time is illustrated in Figure 3. The probability density function and cumulative distribution are reported for the value of time on the M6T for the £40-50,000 income group. Not only are the mean values broadly in line with previous empirical evidence, as discussed above, but the distribution of values across individuals seems reasonable. Note however that some of the incremental toll effects are lower in absolute than in a previous model that did not specify random parameters even when most other coefficients are larger due to the lower residual variation. It is an unfortunate consequence if important insights obtained through the specification of dummy variable interaction terms which are themselves discerning taste variation are weakened or else lose statistical significance when random coefficient variation is permitted.

The extent of taste variation would seem to be plausible and these variations in parameters will imply somewhat different propensities to use a toll road across the sample. Indeed, the random taste variation is large relative to the limited systematic variation that we could detect in the ASC and particularly the toll coefficient according to socio-economic factors and trip characteristics. However, the two distributions of preferences are assumed to be independent of each other when in fact those with a stronger ASC in favour of the tolled road might also tend to have a lower sensitivity to toll.

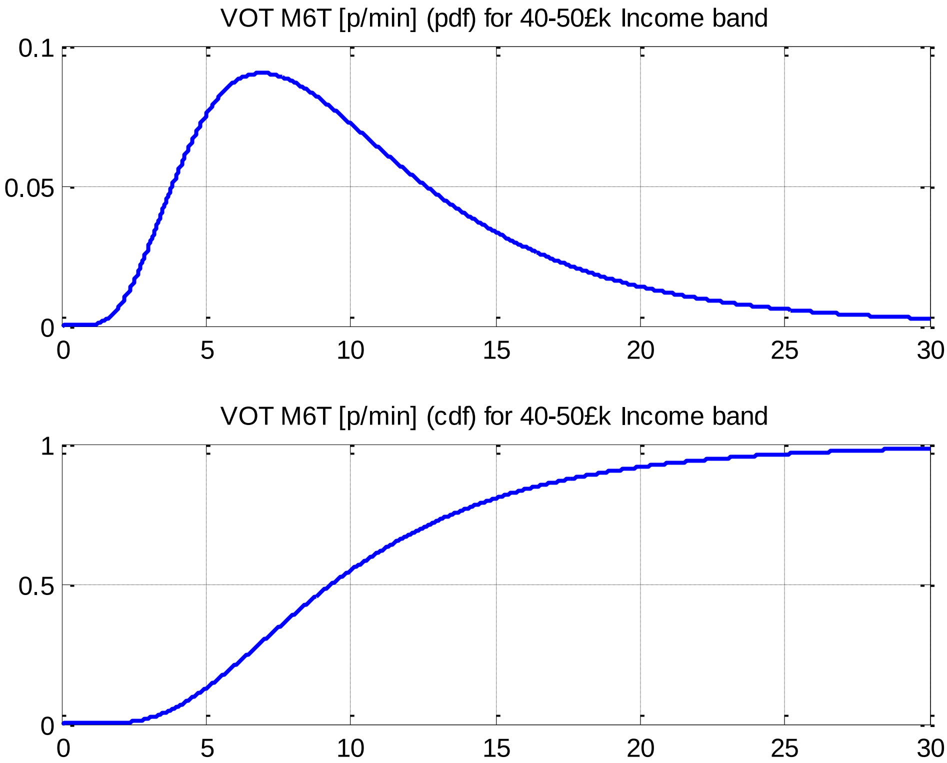

Figure 3: Distributions of Value of Time (time spent on M6T for £40-50k Income Group)

4.2.5 Toll and Duration

Whilst it is widely accepted that the value of time increases with distance, and the meta-analysis reported by Abrantes and Wardman (2009) contains a very precisely estimated distance elasticity for car travel of around 0.2, there is a common view that this is because the marginal utility of money falls with journey length and there is no offsetting effects from the marginal utility of time. Conventional economic theory would imply that the marginal utility of time increases with journey time and that the marginal utility of money would increase as monetary outlay increases. For the value of time to increase with distance would require the marginal utility rate to increase at a faster rate than the marginal utility of money.

What we have here reported is a slight increase in the marginal utility of time with journey duration, although as we have previously stated some purely SP models did exhibit somewhat stronger effects and the piecewise estimation did find a strong relationship between the marginal utility of time and actual time band when freely estimated through this piecewise configuration.

The time categories were: 45 minutes or less (1); 46-75 minutes (2); 76-120 minutes (3); 121-180 minutes (4); 181-240 minutes (5); 241-360 minutes (6); over 360 minutes (7), and where the actual journey time was not known (8). There was an almost monotonic relationship between the marginal utility of time and the reported time category.

This same piecewise process was pursued, independently, with regard to the sensitivity to toll variations. We were also able to detect an effect of journey duration on the sensitivity to toll and as the journey duration increased respondents were less sensitive to toll. This was apparent using both piecewise estimation and subsequently using a single continuous function. Nonetheless, the effects were minor. For example, the strongest effects, for both reported and network data, were for journeys over 6 hours where the toll coefficient was only about 20% lower than for journeys of 45 minutes or less.

5 CONCLUSIONS

Despite the predominance of car travel in the transport market, relatively little is known about motorists' sensitivity to costs when making inter-urban journeys. The research reported here, based around the possibilities to save time by paying a toll to use the UK's first toll motorway, adds a number of new findings to the empirical evidence in this area. The models developed seem robust, with highly significant coefficients and values of time that are consistent with other evidence.

In response to the various hypotheses we set out to test, which are listed in the introduction, we make the following conclusions

- There is a greater sensitivity to toll increases than reductions, which we attribute to response bias. However, the difference is not large.

- The variations in the toll coefficient according to whether a new or extended motorway is being considered is consistent with incentives to response bias. We conclude that SP responses to toll variations based on possible new tolled motorways should be treated with some caution.

- Even after account is taken of those who stated that they did not consider fuel costs in their SP choices, the fuel coefficient is very much lower than the toll coefficient. Given the latter yields much more plausible values of time, and after selecting the toll coefficient least suspect to bias, we conclude that fuel is not fully accounted for even amongst those who did not ignore it. We would also cast doubt on values of time derived from fuel cost coefficients when no allowance has been made for whether it influences choices although of course any such coefficient would remain valid for forecasting

- We have recovered, as far as we are aware, one of the most impressive freely estimated relationships between cost coefficients and income bands. A monotonic relationship between the value of time and nine income groups was obtained whilst there was plausible random variation within any particular income group and highly significant mean and standard deviation parameter estimates. However, in this particular market we note that the implied income elasticity is small, lower than the commonly estimated cross-sectional income elasticity of around 0.5.

- The variation in the toll charge, and indeed fuel cost, coefficients with respect to journey duration category were minor.

Further evidence is needed on motorists' sensitivity to cost variations for inter-urban journeys. In particular, the incentives to bias against toll charges in different circumstances needs more thorough investigation as does the relative sensitivity to fuel costs and toll charge and indeed other costs such as parking. Such research would be significant since it is fundamental to the evaluation of investment in road schemes, particularly those involving tolls, whilst values of time based around fuel costs would seem to be suspect. Qualitative research as well as judiciously selected RP exercises can make a useful contribution alongside tightly controlled SP experiments.

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