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Estimating Individual Values of Time in Stated Preference Surveys

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1. Background

The levels of usage of a toll-road are dependent on three major factors:

- The Level of Service (travel times, costs and other factors) on the Toll Road;
- The Level of Service (travel times, costs and other factors) on competing roads; and
- The values placed on these Level of Service variables by the travelling public.

A conventional assumption is that the major factors affecting Level of Service are the travel time and the travel cost, although clearly other factors (such as reliability of travel time) could also be important under various circumstances. However, most models used for predicting toll-road patronage use travel time and cost as the major explanatory variables.

It is assumed that some travellers will be willing to pay tolls in order to take advantage of the reduced travel times normally obtainable on toll roads. In this situation, it is important to understand how different market segments have different Willingness-to-Pay (WTP) for travel time savings by means of the payment of tolls.

One means of obtaining quantitative estimates of this WTP is by means of Stated Preference (SP) surveys, wherein survey respondents are asked to choose between different scenarios describing different Levels of Service on the toll-road and an alternative route. Typically, the scenarios involve a reduction of travel time in conjunction with an increase in toll. The willingness to pay tolls to obtain reductions in travel time is characterised by the Value of Time (VoT) for a respondent, which is defined as the ratio of the marginal utility of money divided by the marginal utility of travel time.

2. Survey Design

There are a number of survey methods that could be used for the conduct of SP surveys. In most situations, SP surveys are conducted by means of a face-to-face survey, often involving the use of a lap-top computer. This enables the SP questions to be customised to the needs of the individual respondent (by matching the attribute levels used in the SP questions to the characteristics of a trip actually made by the respondent). For example, the Singapore VoT study was conducted using face-to-face interviews and lap-top computers to administer an Adaptive Stated Preference survey (Richardson, 2002, 2003).

However, recent SP studies conducted for toll-road projects in Sydney, Melbourne and New Zealand were conducted by means of a phone survey, using a variation of the Adaptive Stated Preference survey, entitled the Semi-Adaptive Boundary-Value SP (SABVSP) survey method. The phone call asked screening, trip and demographic questions, and was also used to ask the SP questions.

The screening questions sought to establish whether any vehicles and drivers were available at that phone number, and whether a trip had been made through the study area corridor in the past month. Negative answers to these questions led to a question about whether anyone in the household/company had made a trip through the study area. Depending on the answers to these screening questions, the respondent was placed into one of various quota categories, or else the interview was terminated.

Once a respondent had been selected for interview, they were then asked about the most recent trip where they had driven through the study area corridor in a specific direction. Respondents with even ID numbers were asked about a trip going in one direction, while respondents with odd ID numbers were asked about a trip going in the other direction. For this trip, they were asked for information about the following:

- The purpose of the trip
- The town/suburb in which the trip started;
- The town/suburb in which the trip ended;
- How long ago the trip was made;
- The day of the week on which they trip was made;
- Whether the trip started or ended at home;
- The time of day that the trip started;
- The length (travel time) of the trip;
- The number of people in the vehicle;
- The type of vehicle used (passenger or freight).

The respondent then proceeded to answer the SP questions (to be described in more detail in the next section), which were based on the trip described by the respondent through the study area corridor.

Following the completion of the SP questions, the respondent was asked some questions about themselves and their household.

The person questions covered:

- The age and sex of the tripmaker;
- Their employment status;
- Their activity status (employed etc);
- Their personal income.

The household questions covered:

- The number of people in the household;
- The number of vehicles in the household;
- The social structure of the household.

3. The Semi-Adaptive Boundary-Value Stated Preference Survey

The Semi-Adaptive Boundary-Value SP (SABVSP) survey is somewhat different to the conventional orthogonal design SP survey, in which each respondent answers a fixed set of questions trading off one parameter against another (e.g. travel time savings against tolls) or choosing between options which contain different levels of many variables (such as travel time, cost, reliability, comfort, safety etc).

The essential feature of the SABVSP method is that the questions search for the boundary-values (or points of indifference) between travel time savings and tolls. The SP questions are framed as "difference questions", whereby the tolls and travel times are presented to respondents as differences, rather than as absolute values (thus, a trip travel time saving of 10 minutes is presented to the respondent, rather than one option being 20 minutes and the other being 30 minutes). The SP questions are customised to the respondent's own trip through the corridor as they have reported to us on the phone. The SP questions are drawn from a matrix of toll differences and travel time differences. The format of the SP questions is as shown in Figure 1.

SP QUESTIONS

I would now like to ask you some questions about toll-roads.

By a toll-road I mean a divided, multi-lane toll-road,
where no delay is incurred in the payment of the toll charge.

Thinking about your trip from A to B at [time of day] on a [day of week]
for the purpose of [trip purpose],

QUESTION	ANSWER
if you had a choice between a free road and a toll road which took Y1 minutes less and cost C1, which road would you choose?	Free Road Toll Road
What if the toll road took Y2 minutes less and cost C2, which road would you choose?	Free Road Toll Road
What if the toll road took Y3 minutes less and cost C3, which road would you choose?	Free Road Toll Road
etc etc as many times as needed (approximately 10 times)	

Figure 1 The Structure of the SABVSP Questions

The primary parameter of interest in these projects was the Value of Time for each individual (and hence the average and distribution of VoT for each market segment). Other factors affecting usage of toll roads were considered (such as the value of travel time reliability), but it was decided not to estimate these values explicitly. To make partial allowance for the effect of these other variables, it was decided to estimate a "toll-road constant" (TRC) which was defined as the "premium" which drivers would be willing to pay (or would need to be paid) in order for them to use the toll road in situations where there was no travel time saving using the toll road, compared to the next best alternative. From previous research, this "premium" was expected to be positive, since toll roads generally offer advantages other than reduced travel times (such as improved reliability, less traffic signals, less hassle etc). However, negative values of TRC could also be encountered where the respondents were biased against the use of a toll-road.

To estimate the Value of Time (VoT) and the "toll-road constant" (TRC) with reasonable precision requires a large matrix of options to ensure that the upper and lower ranges of the distribution of expected values of TRC and the VoT could be identified. For these studies, therefore, a matrix of 10 tolls and 5 travel time savings were used. The tolls were chosen with a minimum base toll (of 10¢) plus increments based on the length of the respondent's trip under consideration (up to a maximum toll of about $5.50). The travel time savings were based on the length of the respondent's trip under consideration, and ranged from about 10% of the trip travel time up to about 50% of the trip travel time. The values of time saving and tolls are entirely customisable to the needs of a specific project situation.

Combinations of these ranges cover the range of most VoTs and TRCs likely to be encountered in the field. However, rather than ask the respondent to evaluate all fifty

combinations of toll and time saving, the SABVSP method "learns" from the respondent's early answers, and omits later questions which have already been effectively answered by the respondent (this process will be explained in more detail below). Thus, 50% of respondents answer between 8 and 14 of these questions, with 25% each answering more or less questions (up to a maximum of about 20 questions). The average number of questions answered is about twelve, which takes about 4-5 minutes in a CATI interview.

As an example of how the SABVSP works in practice, consider a respondent who has reported that their current trip is 30 minutes in duration. Their SP questions would be drawn from the matrix of options shown in Table 1.

Table 1 SP Options for a Respondent with a 30 Minute Trip

	Time Savings (Minutes)				
Toll	3	6	9	12	15
$5.50					
$4.90					
$4.30					
$3.70					
$3.10					
$2.50					
$1.90					
$1.30					
$0.70					
$0.10					

Rather than ask the respondent to complete SP questions involving all 50 combinations of the 10 levels each of toll and time saving, the survey only asks the questions necessary to obtain an estimate of the VoT for that respondent (hence the "semi-adaptive" nature of the survey). The first SP game played by the respondent is randomly selected from the above grid, based on the ID number of the respondent (each cell in the above grid is used equally often as the starting game). The sequence of possible following questions is chosen so as to roam through the matrix in an optimal fashion to minimise the number of games played.

For example, the first game played by a respondent with a 30 minute trip might be a trade-off between a time savings of 9 minutes and a toll of $3.10. The question asked of them, using the information provided by them about their most recent trip through the study area corridor, would be phrased as:

"Considering your trip from [starting town] to [ending town] on [day of week] at [starting time] taking [length of trip] minutes, for the purpose of [purpose of trip]:

If you had a choice between a free road and a toll road, where the toll-road was Y1 minutes quicker and had a toll of C1, which road would you choose?"

Before the first SP question was asked, a short introductory statement was read to each respondent to describe what was meant by a toll-road for the purposes of these questions, as follows:

"I would now like to ask you some questions about toll-roads. By a toll-road I mean a divided, multi-lane toll-road, where no delay is incurred in the payment of the road toll charge. "

The next SP question would depend on the answer provided by the respondent to this initial question. For example, suppose they said "Yes" to the first question. Their Answer Table would then appear initially as shown in Table 2.

Table 2 Initial Answer Table for Respondent after Game 1

	Time Savings (Minutes)				
Toll	3	6	9	12	15
$5.50					
$4.90					
$4.30					
$3.70					
$3.10			**Y**		
$2.50					
$1.90					
$1.30					
$0.70					
$0.10					

However, to avoid asking the respondent redundant questions, the survey program proceeds to fill in some of the rest of the Answer Table at this point. For example, if the respondent was willing to pay $3.10 for a 9 minute saving, it is assumed that they would also be willing to pay $3.10 for longer travel time savings. It is also assumed that they would be willing to pay smaller tolls for a 9 minute saving. Their final Answer Table after game 1 would therefore be as shown in Table 3 (their actual answer is shown in **boldface**, while their inferred answers are shown in *italics*.

Table 3 Final Answer Table for Respondent after Game 1

	Time Savings (Minutes)				
Toll	3	6	9	12	15
$5.50					
$4.90					
$4.30					
$3.70					
$3.10			**Y**	*Y*	*Y*
$2.50			*Y*	*Y*	*Y*
$1.90			*Y*	*Y*	*Y*
$1.30			*Y*	*Y*	*Y*
$0.70			*Y*	*Y*	*Y*
$0.10			*Y*	*Y*	*Y*

Therefore, while their second question was originally intended to be "*If the toll-road was 12 minutes quicker than the free road, and had a toll of $1.30, which road would you choose?*", the program skips that question and moves on to the third question which is "*If the toll-road was 6 minutes quicker than the free road, and had a toll of $4.90, which road would you choose?*" Assuming they say "No" to this question, their Answer Table after this question would be as shown in Table 4.

Table 9.4 Final Answer Table for Respondent after Game 2

	Time Savings (Minutes)				
Toll	3	6	9	12	15
$5.50	*N*	*N*			
$4.90	*N*	**N**			
$4.30					
$3.70					
$3.10			**Y**	*Y*	*Y*
$2.50			*Y*	*Y*	*Y*
$1.90			*Y*	*Y*	*Y*
$1.30			*Y*	*Y*	*Y*
$0.70			*Y*	*Y*	*Y*
$0.10			*Y*	*Y*	*Y*

This process would continue until, after game 14 for this respondent, the matrix had been completely filled and would appear as shown in Table 5.

Table 5 Final Answer Table for Respondent after Game 14

	Time Savings (Minutes)				
Toll	3	6	9	12	15
$5.50	N	N	N	N	N
$4.90	N	N	N	N	N
$4.30	N	N	N	N	N
$3.70	N	N	N	Y	Y
$3.10	N	N	Y	Y	Y
$2.50	N	Y	Y	Y	Y
$1.90	Y	Y	Y	Y	Y
$1.30	Y	Y	Y	Y	Y
$0.70	Y	Y	Y	Y	Y
$0.10	Y	Y	Y	Y	Y

It can be seen that in each column of the Answer Table in Table 5, there is a trade-off point where the respondent switches from being unwilling to pay a toll for a specific time saving to being willing to pay a lower toll for the same time saving. For example, this respondent was unwilling to pay $3.10 to save 6 minutes but willing to pay $2.50

to save 6 minutes. Similarly, they were unwilling to pay $4.30 to save 12 minutes but willing to pay $3.70 to save 12 minutes

4. Estimating Values of Time

The question now remains as to how to use the information about the trade-offs in Table 5 to estimate the VoT for this respondent. The method adopted for this study involves plotting the trade-off points and then estimating the slope and intercept of the line-of-best-fit, as shown below in Figure 2. For example, given that this respondent was unwilling to pay $3.10 to save 6 minutes but willing to pay $2.50 to save 6 minutes, we assume that their point of indifference for this travel time saving is a toll of $2.80 (halfway between the $2.50 and the $3.10). Given the five points of indifference (the "boundary values") shown in Figure 2, the line of best fit is y=0.16x + 1.84 (where y = toll paid and x = travel time saving). The constant in this equation is the "toll-road constant" in dollars. That is, if the travel time savings (x) was zero, the respondent would still be willing to pay a toll of $1.84 (for all the other perceived benefits of using the toll-road). The slope of the line (the coefficient attached to x) is the Value of Time (in $/minute). That is, the respondent would be willing to pay an extra $0.16 for every extra minute of travel time saving.

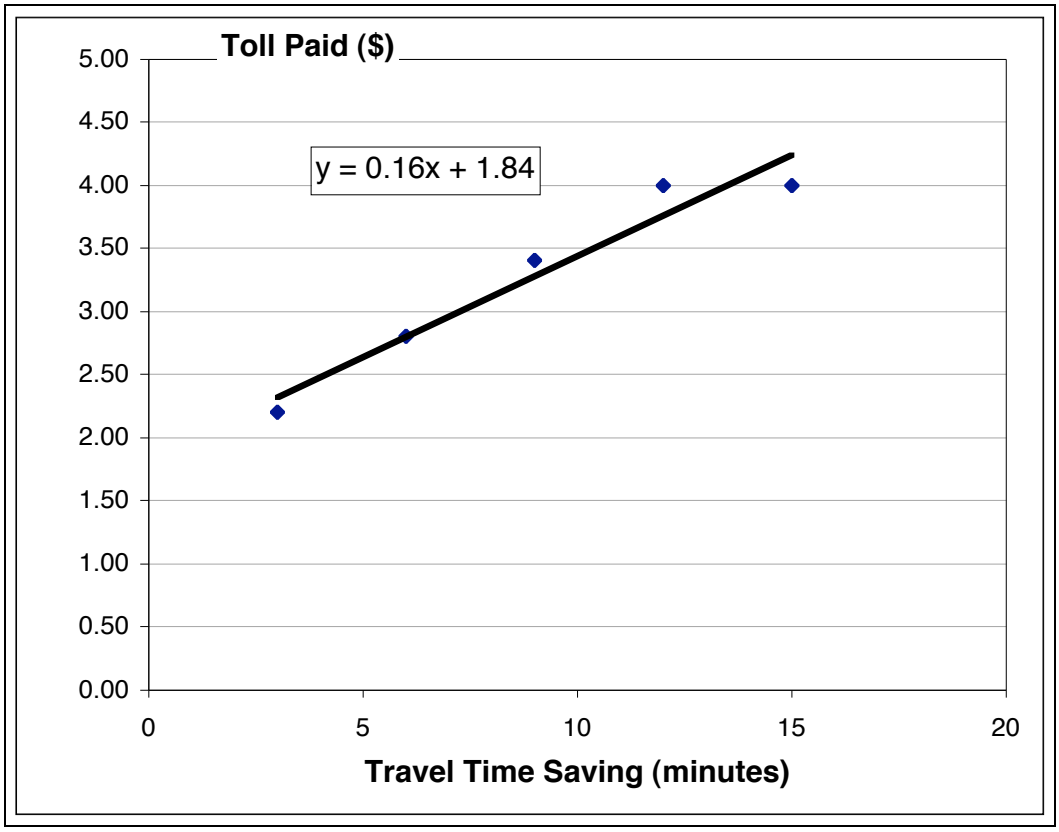

Figure 2 Trade-offs between Time Saved and Toll Paid

5. Simulation Testing of the Boundary-Value SP Survey

To give reassurance about the capabilities of the method, the SABVSP survey design described above has been fully tested via simulation methods (by assuming distributions of trip travel time, VoT and the toll-road constant and then seeing

whether the survey design can reproduce the values of VoT and toll-road constant for each individual).

Each simulation was run for a population of 1000 respondents. For each respondent, a VoT, a toll-road constant and a travel time were sampled independently from the three distributions assumed for the population. The "respondent" was then presented with a sequence of SP games as would occur in the real Semi-Adaptive Boundary-Value SP survey, with time savings and tolls being dependent on their specific trip travel time. The "respondent" would answer each game based on their own VoT and toll-road constant and the values of toll and time saving presented to them. Games were skipped in the same fashion as described above in Section 4. At the end of the games, the VoT and toll-road constant were estimated for each respondent using the line-of-best-fit methods described above. If the respondent made no trade-offs (i.e. they would always choose the toll-road no matter what the toll and time saving or they would never choose the toll-road no matter what the toll and time saving), then their VoT was indeterminate and was excluded from this simulated analysis (these excluded values were either higher than the highest VoT allowed for in the games for that respondent, or lower than the lowest VoT allowed for in the games for that respondent). (Note, however, that in a real study these respondents would be retained and assigned the highest possible VoT from the study design or a VoT of zero).

The estimated values of VoT and toll-road constant were then compared with the actual value of VoT and toll-road constant for that respondent, as sampled from the distribution. A typical comparison for the 1000 respondents in a simulation is shown in Figure 3 for VoT and Figure 4 for toll-road constant. It can be seen that the agreement is generally very good, with no apparent bias and with relatively little scatter around the line of best fit that has a small intercept and a slope close to 1.0 (both regression lines were unconstrained, to test both how close the constant was to zero and how close the slope was to 1.0).

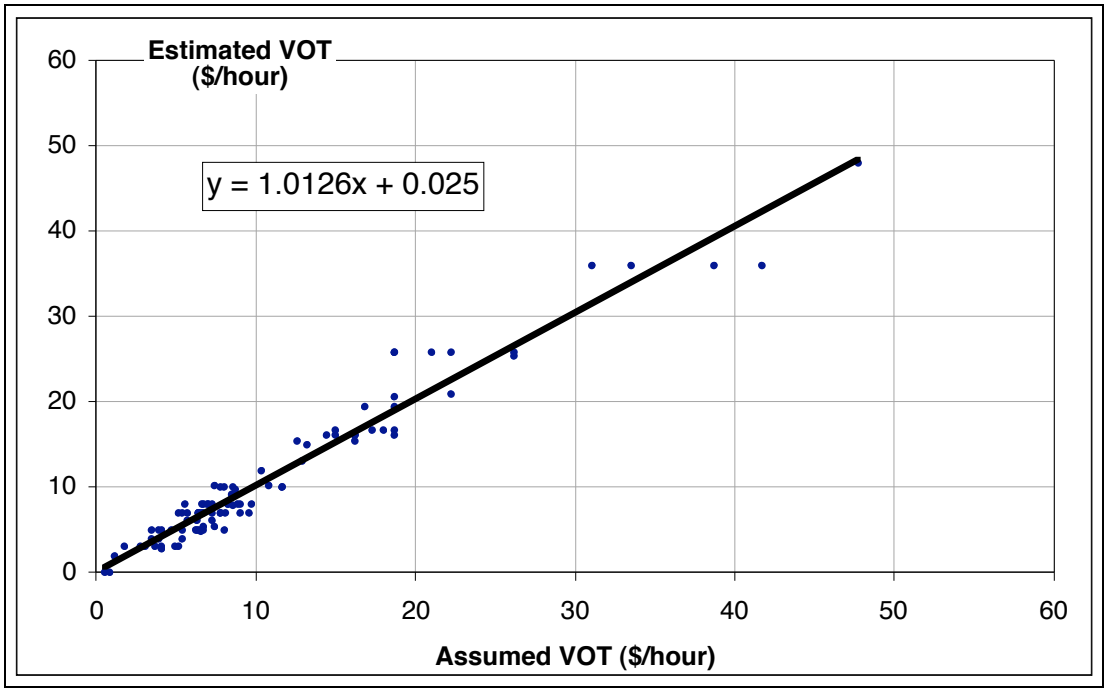

Figure 3 Comparison of Sampled and Estimated VoT

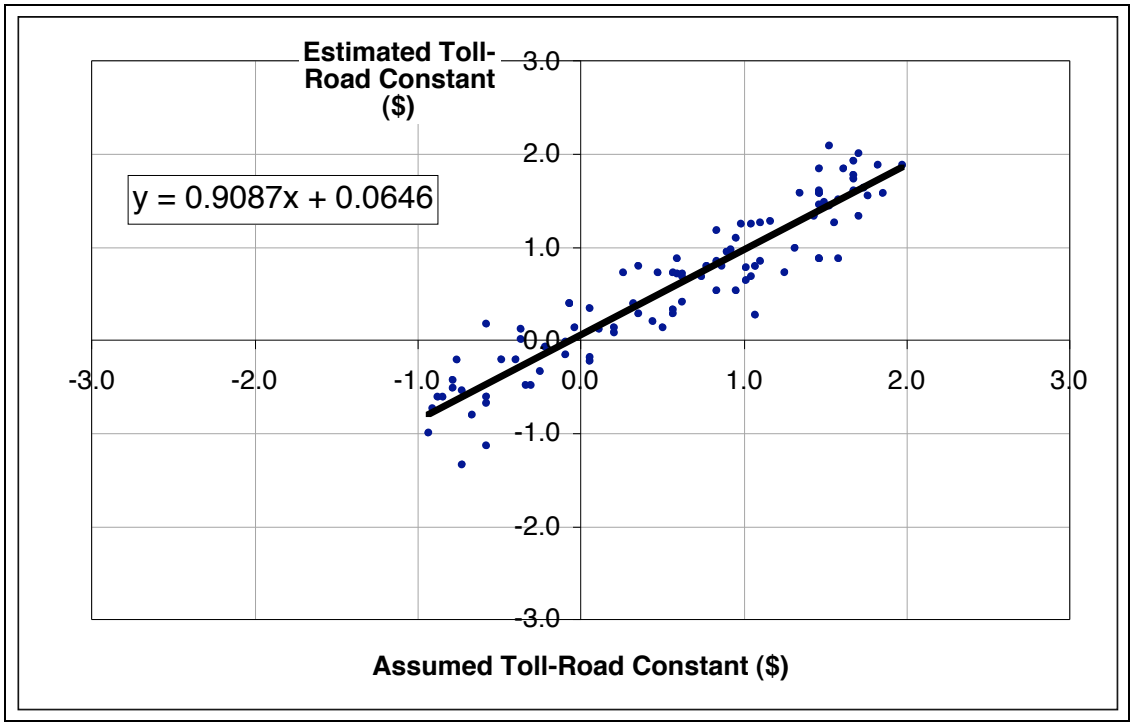

Figure 4 Comparison of Sampled and Estimated Toll-Road Constant

6. Results from a Boundary-Value Stated Preference Survey

For all respondents to the SABVSP questions in a real survey, their individual values of VoT and TRC are estimated as described in Section 4. From this, distributions of VoT and TRC can be derived, from which all the usual statistics (mean, median, mode, variance etc) can be calculated. Because these studies have been conducted for real toll-road projects for private sector clients, the actual results cannot be presented in this paper (for confidentiality reasons). However, examples of the distributions of the VoT and TRC values are shown in Figure 5 and 6 (with scales removed to preserve the confidentiality of the results). It can be seen that approximately 5% of the respondents expressed a zero VoT (i.e they were not willing to pay any more for higher time savings than they were for low time savings), while the VoT distribution has a long tail to the right, indicating a segment of the market who would be willing pay quite high tolls for the time savings on offer.

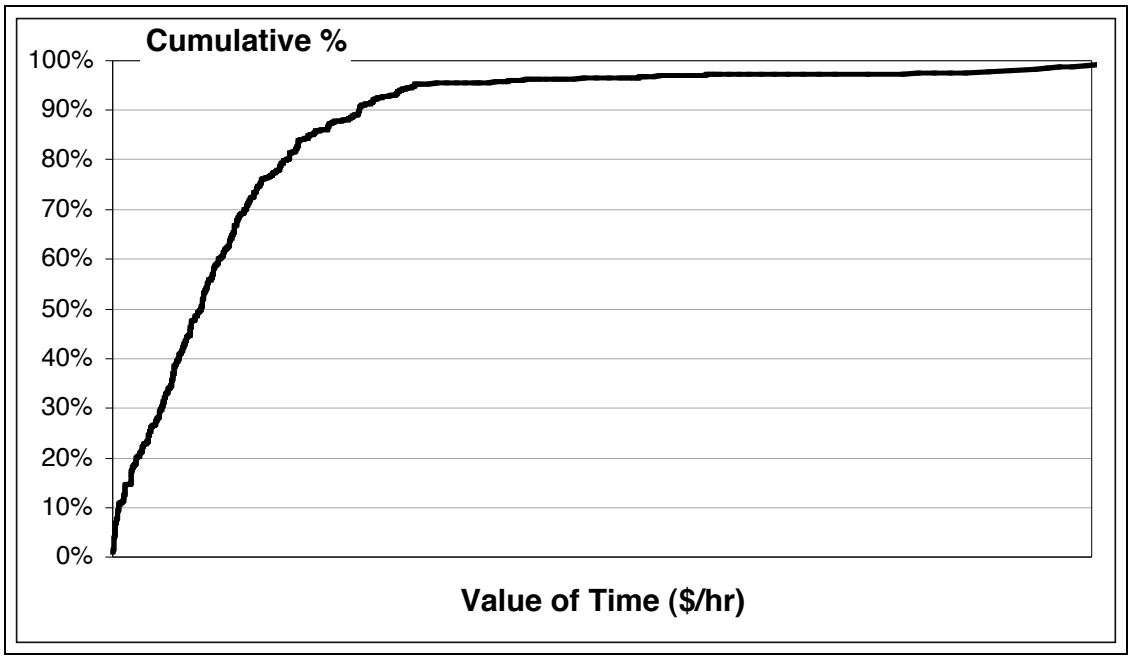

Figure 5 The Distribution of VoT across all Respondents

The distribution of the Toll-Road Constants is shown in Figure 6. In this case, the overall average Toll-Road Constant is slightly negative, indicating a small overall bias against the toll-road. However, about 30% of the respondents had a positive Toll-Road Constant while half had a negative Toll-Road Constant. The remaining 20% had a TRC of effectively zero.

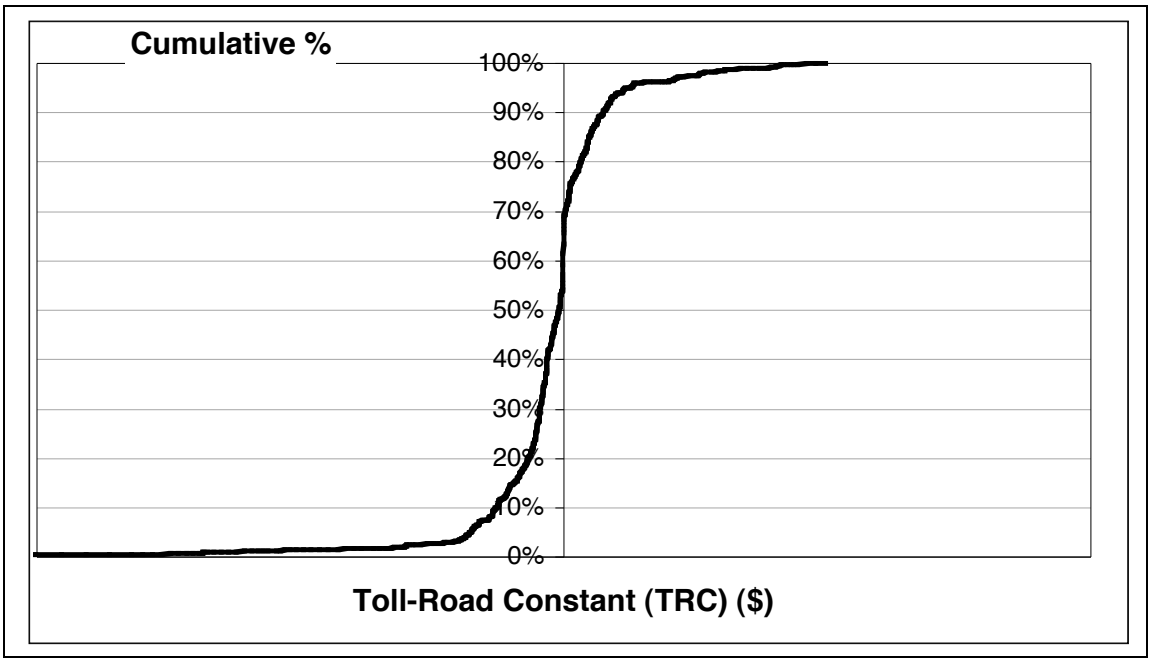

Figure 6 The Distribution of the Toll-Road Constant across all Respondents

The significance of the results shown in Figures 5 and 6 is that the VoT and the TRC exhibit significant variation across respondents. While many previous studies have estimated VoT, they have usually only estimated a mean VoT for the population, or for some limited sub-sets of the population (e.g. peak-period users vs off-peak users). The mean VoT estimated for these groups has often shown some systematic variation between these groups, but has not hinted at the substantial variation in VoT within

these groups. In terms of modelling the usage of toll-roads, this variation is of considerable importance, because toll-roads aim to capture not the driver with the average VoT, but the drivers with the highest values of VoT who will be most willing to pay the tolls. This would suggest that it might be useful to divide the population into three main groups:

- those with high VoT, which would mean that they are essentially "captive" to the toll-road in that they would always be prepared to pay whatever (reasonable) toll is charged;
- those with low VoT, which would mean that they are essentially "captive" to the free road in that they would never be prepared to pay whatever (reasonable) toll is charged; and
- those with intermediate VoT, who would evaluate the time savings and the tolls charged to determine whether the use of the toll-road represented a value-proposition for them on each occasion.

7. Conclusions

This paper has described the methodology and typical results of a Stated Preference survey of drivers, using an SP method used is innovative in that it gives individual values of Value of Time (VoT) and Toll-Road Constant (TRC) for each respondent in the sample. The overall results obtained from the surveys conducted using this method have been shown to be consistent with results obtained from SP surveys conducted using more traditional choice model estimation methodologies. However, the SABVSP method has some advantages in that:

- it provides individual estimates of VoT and TRC for each respondent in the survey, thus enabling post-stratification of the results to identify market segments with specific values of VoT and TRC (e.g. high VoT vs low VoT)
- it produces distributions of VoT and TRC which do not need an a priori assumption about the shape of the distribution
- it uses questions which are simple enough for respondents to fully understand
- it can be administered via a CATI survey, with a total interview time (including screening questions, demographic questions, trip questions and SP question) of about 12 minutes.

8. References

Richardson, A.J. (2002). "A Simulation Study of the Estimation of Individual Specific Values of Time using an Adaptive Stated Preference Survey", Transportation Research Record, 1804, pp.117-125

Richardson, A.J. (2003). "Some Evidence of Travellers with Zero Value of Time", Transportation Research Record, 1854, pp.107-113