Travel using managed lanes: An application of a stated choice model for Houston, Texas

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A R T I C L E   I N F O

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Managed lanes
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A B S T R A C T

Managed lane (ML) travel adds flexibility, but also complexity, to travel choices. Stated choice models (SCMs) are often used for modeling complex transportation choices such as these in an effort to predict demand for these travel options. The design methods for SCMs have evolved from simple orthogonal designs to more sophisticated designs such as D-efficient design that can increase efficiency in estimation. We used three different survey design strategies to produce the stated preference portion of surveys, which were used to elicit travel choices for a sample of Houston travelers. Apart from the D-efficient design we also used random and adaptive random designs to generate attribute levels. There were observable differences in choice behavior depending on what design strategy was used. These differences appear to influence estimates of the value of travel time savings (VTTS) obtained from the random parameter logit (RPL) models estimated using these data. This, in turn, would greatly impact the percentage of travelers predicted to use the MLs.

The adaptive random strategy was superior to the other design methods in several categories, and it had similar efficiency to the D-efficient design. However, the mean of VTTS estimate obtained from a D-efficient design was closer to what is typically found in the literature. The difference was considerable and could greatly influence traffic and revenue estimates for the MLs, illustrating the importance of the survey design strategy.

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1. Introduction

Houston, Texas is the fourth largest city in the United States with a 2007 US Census population estimate of over 5.7 million people living in the Houston metropolitan area (USCB, 2007). Despite the significant investment in the transportation infrastructure, the Houston metropolitan area remains the seventh most congested area for automobile traffic in the US. The average traffic delay per driver for the year 2005 was about 56 h (Schrank and Lomax, 2007).

In a recent effort to reduce this congestion, the Katy Freeway was expanded. The expansion included the addition of four managed lanes (MLs) in the center of the freeway designed to better manage congestion by using peak-period pricing and preferential treatment for High Occupancy Vehicles (HOVs). The MLs opened to travelers in November 2008, operating as HOV lanes where carpools (2 or more occupants) motorcycles and buses were allowed to travel for free. Single Occupant Vehicles (SOVs) were not allowed on the MLs at that time. Later, in April 2009, the MLs began to allow SOVs on for a toll – operating as High Occupancy Toll (HOT) lanes. Note that HOVs also pay a toll in the off-peak period.

The underlying economic concept associated with MLs is that as congestion increases in general purpose lanes (GPLs), more travelers will be willing to pay to use the MLs to save more travel time. Ideally, to keep the MLs operating at high speeds the toll must increase during periods of peak traffic demand. Priced too high, and travelers will not use the MLs. Priced too low, and the ML itself becomes congested, defeating the purpose of its construction.

This research used the Katy Freeway expansion as an opportunity to study recent advances in stated preference (SP) survey design in estimating the mode choice of travelers where they have managed lane options. This research effort collected data during the period when the managed lanes were operating as HOV lanes and did not allow SOVs. SP surveys can be used to estimate the preferences that travelers have using hypothetical scenarios in which a traveler is asked to choose between various alternatives (travel modes) described using relevant factors (such as toll and travel time). In this

research, travelers were asked about their potential use of the MLs as a toll-paying SOV prior to that option being available.

One of the limitations of the SP studies is that people may not actually do what they say they will do, and this issue is generally known in the SP literature as potential hypothetical bias (see Little and Berrens, 2004; Murphy et al., 2005 and references within both). However, the SP approach is one of the few ways to estimate reaction to a potential new travel option (such as SOVs being able to use MLs by paying the toll), guiding transportation planning and travel demand management. SP responses can be compared with revealed preferences based on actual decisions, i.e. those corresponding to real world decisions (see Ben-Akiva and Morikawa, 1990; the later studies by Adamowicz et al., 1994; Dosman and Adamowicz, 2006).

In some cases hypothetical bias has led to SP-based probabilities being larger than those corresponding to field or laboratory choices with payments and this has been explored in stated choice models (SCMs) (see Ready et al., 2010). It can also lead to larger implied willingness to pay than the willingness to pay (WTP) based on actual behaviors, and actual payments (e.g. Lusk and Schroeder, 2004). However, a carefully constructed and designed stated choice model can indeed shed light on real-world behaviors and values that individuals have for goods and services (see Louviere et al., 1999). In the context here, MLs can be extremely capital intensive and developing the appropriate toll rate is a key to efficient operation and estimating the costs and benefits of the MLs. Therefore, advanced information regarding travelers’ willingness to pay for the MLs based on stated preferences is especially valuable.

Many SCM applications involve purely hypothetical alternatives. However, in this application many of the survey respondents were expected to be familiar with most of the Katy Freeway travel alternatives except for paying a toll to use the MLs as an SOV. This is because at the time the survey was conducted Katy Freeway travelers faced the actual choice of GPLs versus MLs, but the latter were only operating as HOV lanes. Three versions of the SP survey were based on three different design strategies. The design primarily influences the levels of the attributes that respondents see when they make their choices. The key attributes, travel time and tolls, varied to gauge the sensitivity of travelers to these key attributes of their travel. Analysis of the collected data provides valuable information regarding the traveler’s value of travel time savings (VTTS), which can be used for estimating the toll rates for a socially efficient or desirable operation of the MLs on the Katy Freeway. The main objective of the analysis in this paper is to investigate the influence of these three survey design techniques on the estimation of VTTS on Katy Freeway managed lanes.

The remainder of the paper begins with additional background information regarding the Katy Freeway. Next, material related to the survey and data collection (details of the survey and survey designs used) is presented. In Section 3, we discuss the descriptive analysis carried out for samples corresponding to each of the design strategies. Specifically we look at whether the respondents vary their choices in the same fashion across the different designs. In Section 4, we present model estimation results for each design strategy, as the estimated parameters influence the implied VTTS. In the final section, some conclusions based on the estimation results and descriptive analysis are offered and discussed.

2. Survey development and administration

2.1. Study location

Houston is one of the fastest growing cities in the US. The Katy Freeway is a 23 mile stretch of Interstate-10 connecting the cities of Katy (to the west) and Houston. This freeway currently serves more than 219,000 vehicles a day (TxDOT, 2009). Before the expansion in 2008 it had 3 to 4 lanes along with 1 to 2 frontage road lanes in each direction plus one reversible HOT lane in the center. The expansion project began in 2003 and was completed in 2008, with the project costing approximately 2.7 billion dollars (US) (TxDOT, 2009). The expanded facility first opened in October 2008 with a minimum of four continuous through-lanes in each direction and as many as eight lanes at key connecting points, entrance and exit ramp locations. The new expanded facility also has four (two in each direction) MLs. The MLs on the Katy Freeway are separated from the general purpose lanes by flexible “candelstick” barriers. The MLs are free to use for METRO buses at all times of day and also are free to HOV2+ (with 2 or more people in a vehicle) vehicles and motorcycles during the peak traffic periods. From October 2008 until March 2009, SOVs were not permitted on the MLs. Beginning in April 2009, single occupant vehicle drivers willing to pay a toll could also use the MLs. The toll rate was set to vary by time of day ($4, $2, $1 for peak, shoulder and off-peak times, respectively, for the 12 mile stretch), with HOVs and motorcycles paying only during off-peak hours. The toll can only be paid by electronic toll collection (ETag or TTag) (HCTRA, 2009). As mentioned above, we had the advantage over purely hypothetical SCM contexts, of collecting our choice data just at the time when the Katy Freeway MLs opened and most of the travel modes in the survey were available to travelers. The surveys were conducted in the November of 2008 using a sample of travelers who live near, and use the freeway. The survey data were collected via the internet and are described below.

2.2. The internet survey

An internet survey naturally requires that the sample members have at least some temporary, if not permanent access to a computer to take the survey. In the year 2007 about 75% of all US households had an internet broadband connection, which was a large increase of 21% as compared to the previous year (Legatt, 2007). Not every traveler has access to internet, introducing potential sampling bias. However, a recent study focused on this issue of sampling bias in toll road SP studies using data collected from six regions in the USA between 2007 and 2008 (Smith and Spitz, 2010). Smith and Spitz (2010) concluded that “collecting data only from those with internet access is unlikely to lead to significant coverage error in a travel survey where driving in the study area is required”. Further, all survey and sampling approaches have potential biases except in the rare case where 100% of a relevant population is surveyed with perfect completion of all parts of the questionnaire. For example, mail surveys and telephone surveys using landlines often suffer from poor response rates. Telephone surveys have also become increasingly problematic as cellular phones have become the only type of telephone that some homes have. Listings of cell-phone numbers are available but random digit dial approaches for cell phones are met with poor response rates.

In addition, claiming that one has an unbiased sample for any implementation approach requires belief that the sample that self-selects to partially or fully participate is not significantly different than those potential respondents who opt out of the entire survey. Stated choice surveys can involve complex tasks. The more complex the task, the less likely some types of respondents will be to complete the survey, or participate at all. The use of computers is actually quite desirable for implementing the choice survey because the computerized survey can provide visual additions that facilitate communication of key concepts, and because they can control the sequence of presentation, as well as block the respondent from moving on in the survey questionnaire before a question is answered. One way to use the computer is to physically hand a subject a laptop, and stand near them while they do the survey. Another is to post the survey on the internet and broadcast its existence to the relevant target population.
which is the approach taken here. Note that while owning a computer with internet access facilitates participation greatly, some people who do not own one can use publicly available computers, such as those found at libraries, churches, and schools.

Internet survey techniques were employed here in an effort to obtain a reasonable response rate with lower costs of data collection (in-person surveys using trained personnel are often the most expensive option) while minimizing confusion in the presentation of alternatives. The internet survey was also designed such that several consistency checks on responses were built in. Thus, while not every household in the Houston area has access to the internet, we believe the advantages more than offset underlying potential biases.

2.3. Data collection/survey administration

The sampling strategy for the data collection targeted travelers who used the Katy Freeway regularly, or who had at least used it once in the week before they were surveyed.

People living in proximity to the Katy Freeway were encouraged by several means of communication to take the survey online. The availability of the survey and the web location of it (www.katysurvey.org) were publicized through radio, news websites and by sending e-mails to randomly selected travelers in Harris County who owned an electronic toll transponder (E-mail addresses were available because of this). In order to increase the survey participation, two awards of $250 gasoline cards, with the recipient to be selected by a lottery, were advertised for those who completed the survey. Incentives to participate such as this are often used in recruiting respondents to take all types of surveys.

A large sample of commuters and other travelers initially got involved in this internet survey. A total of 6312 respondents took at least some portion of it online. Of these, more than half (3990 respondents) fully completed the survey.

The survey questionnaire was designed to most optimally use information obtained from travelers who were traveling by car (either alone or as carpooler), but 119 respondents who traveled by motorcycle or bus also took the survey. Their responses were not used, to allow focus on the automobile mode. Additionally, 973 respondents were discarded as their survey design was different than others: it did not follow any of the three key design strategies outlined below. Thus, the choice model estimation is performed on a total of 2898 respondents.

Ideally, each respondent used in estimation should have responded to all questions. However, a question that many respondents refuse to answer pertains to their personal or household income. Because income is often a key variable in determining response rates in surveys and for the use of toll roads/MLs, we performed a check to see whether we have a biased group in this regard. The underlying thought is that income may serve as a proxy for an individual’s time available to take surveys, or perhaps ability (and in this case, lower income groups may contain lower percentages of households which own computers).

We compared our survey sample with:

- the sample of Katy Freeway travelers from a 2003 survey. This previous survey recorded license plates of travelers on the Katy Freeway and then mailed a mail survey to their address. The previous survey had over 850 Katy Freeway respondents for a 24% response rate. Based on this sample we suspect it is representative of travelers on this freeway, despite the fact their incomes were considerably different from:
- the population of people living near the freeway. The population was defined as people living in the traffic analysis zones (TAZ) along the Katy Freeway and information on this population was based on the latest household travel survey performed for the Houston-Galveston Council of Governments. We considered the TAZs which are not just adjacent to the Katy freeway but also those which are closer to the Katy freeway than other corridors parallel to the Katy Freeway.

Our sampling strategy did oversample from the higher income group in the population (68% in our survey versus 57% of the population living near the freeway have annual incomes over $75,000), and it under-samples from the low income group (under $25,000) (see Table 1). The current internet based survey sample is not very different from the previous (2003) study sample. Thus we were encouraged that our sample was similar to one that was comprised of travelers observed on the freeway, but are aware of factors that influence the applicability of results to the more general population. To the extent that VTTS relates to income (either because of direct non-random or indirect random connections), we caution that our results best pertain to a more affluent segment of the population.

2.4. The survey questions

The survey questionnaire begins by asking the respondent questions about their most recent trip on the Katy Freeway. These questions were followed by questions regarding the respondent’s general travel behavior on the Katy Freeway, then an introduction to the managed lanes concept is provided. Next, there were questions regarding the respondents’ feelings towards this ML concept, stated preference questions, and finally key socio-economic questions.

In the fifth section of the survey questionnaire the respondents were presented with three SP questions, each with two parts. Each question first asked the respondent about their choice of travel mode for a trip under an ordinary travel situation and secondly for an out of the ordinary travel scenario. In each of the two parts, the respondent can choose from among four alternatives that feature different modes of travel, and other key attributes of the alternatives. The travel time and toll (if any) related to the trip were the key attributes that defined the alternatives in each SP scenario in such a way that allows the estimation of travelers’ VTTS. This paper focuses exclusively on the data corresponding to the ordinary case travel scenarios, leaving analysis of out of ordinary trips to another research paper. A typical presentation of the SP question presented in the survey questionnaire is shown in Fig. 1.

Table 1
Income distribution in the sample and population.
Source: Houston-Galveston Council of Governments.

<table>
<thead>
<tr>
<th>Income category</th>
<th>Katy Freeway survey 2008 (sample includes all designs) (%)</th>
<th>Along Katy Freeway corridor (population) (%)</th>
<th>Katy Freeway survey 2003 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual household income</td>
<td>3</td>
<td>11</td>
<td>3.8</td>
</tr>
<tr>
<td>&lt; $25000</td>
<td>29</td>
<td>32</td>
<td>33.1</td>
</tr>
<tr>
<td>$25000 to $75000</td>
<td>68</td>
<td>57</td>
<td>63.1</td>
</tr>
<tr>
<td>&gt; $75000</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A simple specification of the variables used to characterize the alternatives was chosen for the choice model. A parsimonious specification was used: only two key specific attributes of the travel choices, the travel time and toll which were presented in the SP questions. The specific levels or values of travel time and toll to be presented in the SP questions were determined for each survey version, using one of the three corresponding experimental designs. Alternative-specific constant (ASC) terms were used in the model to capture unobservable, but non-random attributes of the alternatives. The specific experimental designs are discussed in more detail in the next section.

2.5. Details of the survey designs

A wide range of travel options is actually available to many, if not all, potential users of managed lanes. However, the number of alternatives that can be presented to a survey respondent is typically limited to a subset of all possible alternatives to reduce the cognitive demands of the survey-taking task on the respondent and to decrease the chances of the respondent abandoning the survey altogether. We used a total of five alternatives to reduce the complexity of this survey. Fig. 1 shows that each respondent compares four alternatives when making a choice. Efficiently choosing the alternatives and corresponding attribute levels to present in the choice experiment is a challenge. One of the objectives of this research was to examine if the design of the SP portion of the survey influenced travelers’ VTTS. Therefore, three specific survey designs were used. These designs were used to determine the specific levels of travel time and toll to be presented in the SP questions. In all three of these design methods the respondents were presented with four out of five travel options (design alternatives) as follows:

- Driving alone on the general purpose lanes (DA-GPL),
- Carpooling on the general purpose lanes (CP-GPL),
- Driving alone on the managed lanes (DA-ML),
- Carpooling with one other person on the managed lanes (HOV2-ML),
- Carpooling with three or more people on the managed lanes (HOV3+-ML).

The travel time and toll were presented as the key attributes in the SP questions, describing each alternative. The total ML toll
that was presented to the survey respondents was developed by estimating a per-mile toll rate and multiplying that rate by the miles of ML travel for that respondent. The per-mile toll rate was developed using one of the three design methods described in Sections 2.5.1, 2.5.2, and 2.5.3. The miles traveled on the ML were calculated using the Katy Freeway entry and exit ramp the respondent reported that he or she used. The total travel time was derived in a similar manner. The average travel speed was developed using one of the three design methods outlined below. Using the calculated distances, a total travel time was calculated and that time, along with the toll, was presented to the respondent. Note that the respondent could select entry and exit locations beyond the total 12 mile length of the Katy ML. If that occurred, a travel speed of approximately 60 miles per hour was used for those additional miles traveled, at a zero toll charge.

The travel alternatives that involved the GPLs were presented with a zero toll charge and with longer travel times than the ML travel alternatives (MLs with variable pricing are operated such that they provide a faster and more reliable travel option than the GPLs). The specific levels used for speed and toll rate are described along with the respective survey design/approach discussed in the next sections. Survey respondents were selected at random to receive SP questions developed using one of these three designs.

2.5.1. D-efficient design

D-efficiency is based on minimizing the D-error, which is calculated by taking the determinant of the asymptotic variance covariance matrix and scaling this according to the number of parameters (see, Johnson et al., 2007; Rose and Bliemer, 2008 for details). The first design approach simply assumed a linear model when developing the D-efficient design, as the macros for searching this type of design are readily available in SAS software (Kuhfeld, 2005).

Accordingly, survey design of 24 runs/treatments (24 questions in eight blocks of three ordinary situation questions) was obtained by running the MkTex macro of SAS. Thus, unlike the other two design methods below, this method used a fixed number of runs and attribute levels to construct and present a choice task.

As mentioned earlier, four alternatives were presented in each choice task; however, randomly choosing four out of five alternatives is likely to create a significant number of choice tasks, which did not contain respondent’s current travel mode. Hence, to make the choice tasks more realistic, and at the same time to be able to search for an efficient design, we fixed one alternative in all the choice sets. Thus each SP question in this version of the survey (with D-efficient design) contained the alternative of driving alone on the general purpose lanes: DA-GPLs, which was travel mode used by most (63%) of the respondents.

Thus, this survey design was structured to present only three out of the remaining four travel alternatives to each respondent. An additional level to indicate unavailability of the alternative was used in the attribute speed. The attributes and levels used for this design for peak period travelers are given in Table 2. Higher speeds on GPLs and lower toll rates on the MLs were used for the off-peak period travelers.

2.5.2. Random attribute level generation (random)

In the random attribute level generation approach the choice alternatives and attribute levels were generated in a different manner than by using the D-efficient design approach. Every respondent was presented with two fixed travel alternatives; their current actual travel mode (DA or CP) on the GPLs and the same mode on the MLs. Thus, this method was constructed to use the respondent specific information obtained in the earlier part of the survey to select a subset of alternatives. The other two

### Table 2

<table>
<thead>
<tr>
<th>Alternative (travel mode)</th>
<th>Attributes</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive alone on the GPLsa</td>
<td>Speed (mph)</td>
<td>25, 35, 45</td>
</tr>
<tr>
<td></td>
<td>Toll rate (cents/mile)</td>
<td>0</td>
</tr>
<tr>
<td>Carpool on the GPLs</td>
<td>Speed (mph)</td>
<td>25, 35, 45, NAb</td>
</tr>
<tr>
<td></td>
<td>Toll rate (cents/mile)</td>
<td>0</td>
</tr>
<tr>
<td>Drive alone on the MLs</td>
<td>Speed (mph)</td>
<td>55, 60, 65, NAb</td>
</tr>
<tr>
<td></td>
<td>Toll rate (cents/mile)</td>
<td>0</td>
</tr>
<tr>
<td>Carpool with one other person on the MLs</td>
<td>Speed (mph)</td>
<td>55, 60, 65, NAb</td>
</tr>
<tr>
<td></td>
<td>Toll rate (cents/mile)</td>
<td>0, 5, 10</td>
</tr>
<tr>
<td>Carpool with three or more people on the MLs</td>
<td>Speed (mph)</td>
<td>55, 60, 65, NAb</td>
</tr>
<tr>
<td></td>
<td>Toll rate (cents/mile)</td>
<td>0, 5, 10</td>
</tr>
</tbody>
</table>

a Fixed alternative in the choice set,
b NA indicates the mode was not offered as a choice. In developing the D-efficient design this is how we developed the design to show each respondent only 4 modes and not all 5.

alternatives presented to each respondent were randomly chosen from the remaining three travel modes. For example, if the respondent’s current actual travel mode was DA-GPL, he or she was always presented with the two modes: DA-GPL and DA-ML, when making a choice. In the case where the respondent’s current actual travel mode was CP-GPL (first fixed alternative for the respondent) the respondent was always presented with HOV2-ML (50% of the time) or HOV3+-ML (50% of the time) as the second fixed alternative. This approach of choosing the four alternatives out of five as described above made it possible to make use of respondent’s RP information and make the choice set more realistic for each respondent.

No fixed numbers of experimental design runs/rows or attribute levels were used in this approach (and in the third design approach described below); instead the attribute levels were generated randomly within the range of values for each attribute as specified in Table 2.

2.5.3. Adaptive random experiment

In the third design approach, called an Adaptive Random Experiment, the alternatives presented were generated in the same way as they were in the random design approach described above. For the first choice question the attribute levels were chosen randomly. In the second and third questions the speed levels (and the resulting travel times shown on the survey) were again chosen randomly. The toll rates increased (up to 75%) or decreased (up to 50%) if the choice made in the previous question was a tolled or a toll free travel mode, respectively. Thus, the VTTs offered for a similar travel mode on the MLs was increased or decreased (adaptive) depending on the choice made in the previous question.

This third approach slightly differs from the computer adaptive designs as it does not search for an attribute level combination (run) from an efficient design after every question. Hence, it does not take as much time as other approaches do to generate the SP attribute levels to be presented in next question.

3. Descriptive analysis of the respondents

The description of the sample data and responses corresponding to each survey design approach are presented in this section (see Table 3). There were no major differences in the samples corresponding to each of the design approaches except for the sample size and the frequency of alternatives presented in the SP questions (which are as planned prior to the survey).

Basic statistical results (means, variances, and parameter estimates) may vary depending on the design. If they do not,
Table 3
Descriptive analysis of responses by design strategies.

<table>
<thead>
<tr>
<th>Data characteristic</th>
<th>D-efficient</th>
<th>Random</th>
<th>Adaptive random</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of respondents</td>
<td>1240</td>
<td>1303</td>
<td>355</td>
</tr>
<tr>
<td>Peak period travelers</td>
<td>50%</td>
<td>51%</td>
<td>57%</td>
</tr>
<tr>
<td>Morning peak travelers</td>
<td>30%</td>
<td>29%</td>
<td>32%</td>
</tr>
<tr>
<td>Evening peak travelers</td>
<td>20%</td>
<td>22%</td>
<td>25%</td>
</tr>
<tr>
<td>Average trip length (miles)</td>
<td>11.7</td>
<td>11.9</td>
<td>12.2</td>
</tr>
<tr>
<td>Trip purpose as commute/work</td>
<td>57%</td>
<td>54%</td>
<td>61%</td>
</tr>
<tr>
<td>Male respondents</td>
<td>57%</td>
<td>57%</td>
<td>59%</td>
</tr>
<tr>
<td>Carpoolers</td>
<td>36%</td>
<td>36%</td>
<td>36%</td>
</tr>
<tr>
<td>Traveling towards downtown</td>
<td>47%</td>
<td>48%</td>
<td>48%</td>
</tr>
<tr>
<td>Age &lt; 25 years</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Age 25–65 years</td>
<td>91%</td>
<td>91%</td>
<td>91%</td>
</tr>
<tr>
<td>Age &gt; 65 years</td>
<td>7%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>Annual household income ≤ $25000</td>
<td>3%</td>
<td>3%</td>
<td>4%</td>
</tr>
<tr>
<td>Annual household income &gt; $25000 $75000</td>
<td>29%</td>
<td>29%</td>
<td>28%</td>
</tr>
<tr>
<td>% of times alternative DA-ML</td>
<td>18%</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>% of times alternative HOV2-ML presented</td>
<td>19%</td>
<td>18%</td>
<td>19%</td>
</tr>
<tr>
<td>% of times alternative HOV3+-.ML presented</td>
<td>19%</td>
<td>18%</td>
<td>17%</td>
</tr>
</tbody>
</table>

Non-trading and Lexicographic Behavior

<table>
<thead>
<tr>
<th></th>
<th>Non-trading</th>
<th>Always choosing fastest alternative</th>
<th>Always choosing cheapest alternative</th>
<th>Always choosing alternative with lowest occupancy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>33.9%</td>
<td>2.2%</td>
<td>36.6%</td>
<td>62.7%</td>
</tr>
<tr>
<td></td>
<td>30.8%</td>
<td>3.4%</td>
<td>32.1%</td>
<td>60.4%</td>
</tr>
<tr>
<td></td>
<td>22.6%</td>
<td>3.2%</td>
<td>24.0%</td>
<td>60.0%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. The model and estimation results

The samples corresponding to each design approach were used to estimate the travel mode choice models. A random parameter logit (RPL) model specification was used for each. The RPL is one of the model specifications increasingly used in travel demand modeling and is derived from a theory of individual utility maximization. An individual is assumed to choose the alternative with the maximum utility for them. Various explanatory variables, such as travel time and toll along with the characteristics of individual and travel enter the systematic part of the utility. The RPL allows for the possibility of heterogeneity in the parameters of some or all of these variables for each individual. This heterogeneity may be desirable in an investigation of the value of an individual's time saved.

A conventional functional form for the utility function is linear, and it assumes that the cost (the toll) and time (T) variables enter separately. We divide the toll for the alternative by the individual's wage rate to yield cost (C). For the RPL specification the key part of deterministic utility function (V) for traveler n, alternative j and the choice situation t is typically given by Eq. (1), as follows, noting that often the researcher may introduce a constant term, or alternative-specific constants. The implied marginal VTTS for this specification is simply the ratio of $\beta_{2n}$ and $\beta_{1n}$, which are scaled coefficients.

$$V_{nt} = \beta_{1n} C_{nt} + \beta_{2n} T_{nt}$$

(1)

where $\beta_{2n}$ and $\beta_{1n}$ vary randomly over travelers.

Further, in our application we estimate the RPL models in willingness to pay (WTP) space. This approach offers significant advantages in the estimation of the VTTS over the usual RPL models corresponding to Eq. (1) (see discussion in Train and Weeks, 2005; and more recently in Scarpa et al., 2008). Accordingly, Eq. (1) is re-parameterized to yield Eq. (2), which is a non-linear-in-the-parameters form. The implied marginal VTTS for this specification is directly estimated by the scale free term below, w_n.

$$V_{nt} = \beta_{1n} C_{nt} + \beta_{2n} w_n T_{nt}$$

(2)

where $w_n = \beta_{2n}/\beta_{1n}$.

Note that by definition of $w_n$, the parameter $\beta_{1n}$ essentially cancels out algebraically, but the form in Eq. (2) allows for a clean interpretation of the VTTS. In addition, the WTP space approach conveniently allows for some or all of the parameters to be normalized to include estimation of the scale parameter (which is the standard deviation of unobserved utility), which again can vary across individuals, implying an individual-specific variance term (Scarpa et al., 2008). The scale parameter was assumed to be constant across the travelers in this study.

For the RPL models a distribution must be chosen for the parameters, and the usual choices are limited to the normal, log-normal, and triangular distributions. For our RPL $\beta_{1n}$ was assumed to be distributed normally and $w_n$ (VTTS) was assumed to be log-normally distributed. While assuming a log-normal distribution for the VTTS ensures positive values, it has the drawback of getting some extreme values. In all the models the mode – DA-GPL – was set as the base alternative. The RPL models were estimated assuming uncorrelated coefficients and using 1000 draws generated using modified Latin hypercube sample procedure proposed by Hess et al. (2006). The software BIOGEME was used for the estimation (Bierlaire, 2003).

The main study goal of this study was examining how the SP survey designs (D-efficient, Random, and Adaptive Random) impact the estimated VTTS of travelers. Therefore, we used the same variables in each model. All utility functions contained the alternate specific constants and a few other variables found to be the best predictors of mode choice plus those variables given in Eq. (2). The hourly wage rate was calculated as annual household income divided by 2000 (approximate number of work hours in a year).

After estimating the RPL models for samples corresponding to each design approach we calculated the D-error for each using the estimated parameters and corresponding sample sizes. The model
estimation results and estimated VTTS are summarized in Table 4. The log-likelihood value and adjusted $\rho^2$ are also reported for each model (see Eq. (3)):

$$\text{Adjusted } \rho^2 = 1 - \frac{LL(\hat{\beta}) - K}{LL(C) - K}$$  \hspace{1cm} (3)$$

where, $LL(\hat{\beta})$ is the log-likelihood for the estimated model, $LL(C)$ is the log-likelihood for the constants-only model, $K$ is the number of parameters in the estimated model, and $K$ is the number of parameters in a constants-only model. Comparing the adjusted $\rho^2$, the model corresponding to the adaptive random strategy provides a better fit than other models despite a smaller sample size.

The resulting model did add ASC terms along with several other variables (see Table 4) to the basic form of the model shown in Eq. (2). The ASCs are treated as fixed variables in our RPL specifications. These help capture unobservable, but non-random features of each alternative that individuals might care about. As will be seen below, these have signs (direction of influence on the choices) as consistent with intuitive a-priori expectations. Holding other factors constant, we can easily imagine that most travelers would simply prefer to drive alone in a lane that did not require a toll to be paid. Next we discuss the estimated results.

### 5. Results

Table 4 provides the estimated parameters and goodness of fit results. To begin, we compare the success of each model in predicting actual choices by the travelers (see the “percent correct” rows at the bottom of each table). Both the random attribute level generation and adaptive random strategies’ models are predicting the market share of the less popular modes much more accurately than D-efficient design model. Note that the managed lane modes and CP-GPL mode have smaller trip shares (DA-GPL is the most popular mode), hence a model/design approach, which predicts these modes more accurately is more useful to transportation policy makers. This difference in prediction success may be attributed to the way four alternatives (to be presented in a stated choice question) were selected from the global choice set. This underlines the importance of a strategy to select alternatives from the global choice set.

Examination of the in ASCs the top rows of the Table 4 reveals that when compared to the mode for DA-GPL, almost all other modes have negative ASCs, and hence are less attractive than this mode (which is as expected), other things being equal. In all models HOV3+-ML appears to be the least attractive mode to these travelers. This is consistent with the added inconvenience travelers face in terms of coordinating a carpool with multiple parties. The effect of fixing the mode DA-GPL in the all choice sets in the D-efficient design was visible as the magnitudes of ASCs for other modes were larger negative values in the D-efficient design.

The estimated Toll and Time coefficients are treated as fixed variables in our RPL specifications. These help capture unobservable, but non-random features of each alternative that individuals might care about. As will be seen below, these have signs (direction of influence on the choices) as consistent with intuitive a-priori expectations. Holding other factors constant, we can easily imagine that most travelers would simply prefer to drive alone in a lane that did not require a toll to be paid. Next we discuss the estimated results.
from zero, which indicates their importance in the choice models. Also, the VTTS (as percentage of wage rate) is estimated directly because the models were specified in WTP space. The mean of VTTS estimated was estimated to be 21%, 23%, and 38% of the wage rate (see Table 4) for the adaptive random, random, and D-efficient designs, respectively. In order to test if the means of these three RPL models were significantly different we also estimated a RPL model on pooled data by combining the three datasets corresponding to each design. The mean of parameter $w_a$ in the pooled model was specified to have heterogeneity with respect to each design. The heterogeneity parameters were estimated significantly indicating that the means are different for each design. A market segmentation test on the log-likelihood of the pooled model ($-7534.18$) also confirmed that the pooled model is not better than three separate models for each design.

Further, we compared the distributions of the VTTS obtained from RPL models corresponding to each design. Recall that the VTTS was assumed to be distributed with a log-normal distribution in the RPL models, hence it inherits the feature of having potentially fat tails or exceptionally large values (see pdf plots in Fig. 2). The standard deviation of VTTS is an indicator of proportion of these very large values in the distribution. The standard deviation of VTTS for D-efficient design model is larger, indicating poor fit to the population considering that the mean of distribution is also larger compared to other designs. Thus, the percent of values above wage rate as estimated by D-efficient design were 10% whereas the same estimated by the random and adjusting random designs were 2% and close to 0%, respectively (refer to cdf plots in Fig. 2). However, the standard deviation of VTTS for adaptive random model was not significant, which calls for further investigation with different distributional assumptions or making it a fixed parameter if it is still insignificant. Thus the underlying survey design clearly affected the VTTS estimated.

An earlier study conducted for the VTTS of Katy Freeway travelers (data collected in 2003) estimated the value as 39% of the wage rate (Burris and Patil, 2006). The mean results here are somewhat lower than this estimate and are in the lower end of the range found in the literature. Although the mean D-efficient result was extremely close to the prior estimate and closer to what is commonly found in the literature. If the range of the VTTS is examined, 53% of D-efficient results were between 25% and 75% of the wage rate. This dropped to 42% for the random design and 37% for the adaptive random design.

These results may be, in part, to our own definition of “wage rate”. The survey asked the respondents for their annual household income or hourly wage rate. Of those answering this question, almost all respondents chose to enter a household income. Since this income could be comprised of multiple wage earners and income from sources other than wages it is likely the true hourly wage rate is lower than our estimate, resulting in a higher VTTS than we estimated. Another possible confounding influence of the design results pertains to sample sizes for the surveys, which are unequal.

Our final comparison of the models focuses on the D-error. Comparison of the D-errors indicates that all three strategies yield designs of similar efficiency when developing the alternative levels for the time and toll factors.

6. Conclusions

The main purpose of this study was to investigate how survey design strategies impact the prediction of stated preference choice behavior and estimation of VTTS for the travelers of managed lanes with congestion pricing. The study used three different experimental designs in a single survey: a D-efficient design searched assuming a linear model, a random attribute level generation strategy (random), and an adaptive random attribute level generation strategy based on VTTS and the respondent’s answer to the previous SP question.

The choice behaviors such as non-trading and lexicographic behaviors were significantly different for respondents receiving the different survey design strategies. This is consistent with the view that the design strategy can influence stated choices. For the large sample sizes used in this study we found that the adaptive random attribute level generation strategy was less susceptible to the non-trading behavior than the D-efficient and random designs. The adaptive random strategy was also found to perform better in comparison to the D-efficient design with respect to the lexicographic behavior criteria of the respondent always choosing the cheapest alternative. The efficiency of parameter estimation (measured by D-efficiency) was found to be similar for all three designs, possibly due to large sample sizes of each design. The adaptive random strategy produced a better model fit (with larger adjusted $R^2$) as compared to the D-efficient and random strategy for the estimated RPL models.

With the assumed log-normal distribution for the implied marginal VTTS the adaptive random strategy produced fewer extreme values of VTTS. The means of the distribution estimated for all designs were in the range from 20% to 40% of the wage rate and were close to the expected values obtained from previous studies for Katy Freeway. The D-efficient design produced results closest to previous Katy Freeway study and the literature.

Our key finding is that survey design has significant impact on results. The adaptive random strategy appears to be the best overall – and even has similar efficiency as the D-efficient-for-linear-model design. Based on the choice of survey design, the difference in estimation of VTTS is considerable and would greatly influence traffic and revenue estimates. In future research we will attempt to use Katy Freeway RP data to determine which VTTS estimate is closer to what travelers are actually doing.

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