Australasian Transport Research Forum 2013 Proceedings
2 - 4October 2013, Brisbane, Australia
Publication website: http://www.patrec.org/atrf.aspx

ELECTRIC VEHICLE BATTERY CHARGING BEHAVIOUR: FINDINGS FROM A DRIVER SURVEY

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Abstract

This study explores drivers' charging preferences in the Western Australia Electric Vehicle trial. Drivers in this trial have experience of planning trips using plug in electric vehicles (EV). There are trade-offs between charging options in terms of cost and time. In this study each driver was given a set of four stated choice experiments; they picked their best and worst options for charging EV from each experiment. Labelled experiments contained mainly three choices: work, home and public with different values of charging cost, duration, and time of day. Drivers were given assumptions before doing the experiments, for example: that they are planning a trip for their next working day. The findings of this study give several insights into drivers' charging behaviour: drivers preferred to charge EV at home or work rather than at a public charging station; drivers having solar panels at home prefer to charge EV at home; people having travel commitments involving other family members do not like to charge EV at home but generally prefer to use a public charging station. Members of the Australian Electric Vehicle Association, one of the partners in the WA EV trial, preferred to charge at home. Drivers were in general sensitive to cost and showed a strong preference for low cost EV charging.

Key words: *Electric vehicle, stated-choice analysis, drivers' EV Charging behaviour.*

1 Introduction

A major operation with plug in electric vehicles (EV) is battery charging. Potential benefits include green impact on the environment (Ma *et al*., 2012), home-charging (Kurani *et al*., 1996) and low travel cost (Chan, 2007). An electric vehicle battery can be recharged by plugging into a battery charging station or unit, this battery charging operation can be done at home, which is convenient as it can be recharged overnight. Battery charging can also be done at public charging stations or specific bays provided at workplaces. Depending on battery status, requirement for a trip, or charging cost, it might be more convenient to charge at work or at a public charging station. Charging at work may not be free and usually the number of bays with charging facilities is limited. Public charging stations are provided only at certain locations and using them may require careful planning. Nevertheless, the public stations provide quick charging and are located in places of wide interest (shopping centres, hotels, transport hubs), offering additionally the privilege of a reserved/free parking bay.

In this way, there is a trade-off between the generalised cost (including the electricity price and the duration of charging) and the convenience of charging an EV. For example charging at home might be convenient, but the cost of electricity at home during on-peak hours (evening or a few hours in the morning) is different from the off-peak hours (at night or in the middle of the day, as discussed in the next section). For the purpose of this study we made a set of assumptions: drivers privately own a new electric vehicle and they have a charging facility at home or at work with a free parking bay or at a public charging station located within their daily itinerary. They are planning their next working day, the EV is the principal car at home, and their vehicle's current battery status is 30% full. The reason for these assumptions is that this study aims to determine drivers' preferences for EV battery charging with a full access to charging infrastructure at work, at a public facility, and at home. As the charging infrastructure is not well established yet in Perth, the EV drivers participating in the trial have limited options for charging. Therefore, this study explores drivers' preferences for charging at work, home or public charging stations through stated choice experiments, where drivers indicate their best and worst choice for charging an EV in hypothetical scenarios.

The next section gives more detailed information about battery charging options, with their time and cost, and home charging with solar panels; this is followed by a an introduction to the WA EV Trial, and then discussion of data and methodology is given in section 3. Section 4 presents the findings about the drivers' battery charging choices; results of this stated preference experiment provide useful insights which are further elaborated in the discussion section.

2 Electric Vehicle Battery Charging

Home charging differs from charging at work or at a public charging station both in terms of charging duration and cost. People with solar panels at home can use solar energy for EV charging during the daylight hours. Considering these variations in charging options, respondents were given a set of assumptions before starting the experiment – as presented in next section.

2.1 Battery Charging Levels: Time and Cost

Battery charging cost depends on the charging station Level (fast and expensive or slow and inexpensive), the time of the day, and the place. Level II and Level III are fast charging stations, while Level I represents a slow charging station. Accordingly, the cost of Level I charging is less than the cost of Level II, which in turn is cheaper than Level III. A Level I charging unit (usually installed at home) recharges a battery from empty to full in 6-8 hours. Level I is ideal for home use as it uses 120 V circuits providing AC power to the vehicle (National Research Council, 2013). A Level II charging station provides faster charging by using 240 V AC power, reducing

charging time to 2-4 hours. Level III is also called a DC charging station because it converts AC voltage power to DC (National Research Council, 2013) and charges the EV battery at a fast speed of 10-30 mins for a full recharge. This DC charging station is ideal for public charging because of its speed.
The price of electricity is based on the time of day: peak rate (morning/late afternoon and evening) is most expensive, while off-peak (usually during the night) has the lowest rate (Table 1). The price also differs between home and business (work/public).

Table 1: Electricity Rate Synergy Home Plan effective from July 2012 (Synergy, 2012a)

Time*	Rate
Peak	45.87 cents per kWh
Off-peak	13.97 cents per kWh
Shoulder	24.44 cents per kWh
*These timings vary during summer and winter hours	

There are two power suppliers in WA: Synergy mainly supplies the metropolitan area while Horizon Power covers the rest. An overview of the on-peak and off-peak home rates is given in Table 1 as accessed from a WA power supplier website (Synergy, 2012a). These values were used in designing the stated choice experiment.

2.2 Home charging with solar panels

Solar energy systems allow their owners to generate surplus electricity during the day, thus offering zero cost daytime charging for EV at home. The photovoltaic power generation systems with benign impact on the environment (Tsoutsos *et al.*, 2005) can be ideal for EV charging, when compared to conventional energy generation sources. The cost of EV charging depends on the type of solar panel and the electricity supplier. Synergy offers a buyback price for surplus energy during the day at a fixed rate of 8.4 cents/kWh, but during night hours households have to buy at the standard rates (Synergy, 2012b). The buyback rate by Horizon Power varies across different rural areas in WA from 10 cents/kWh to 50 cents/kWh (Horizon Power, 2012).

2.3 Charging Behaviour: Previous Studies

Yilmaz, and Krein (2013) reviewed the current status of battery chargers for plug-in EV, and plug-in hybrid vehicles; no defined international standards for battery charging infrastructure exist yet. A number of studies investigated battery charging behaviour from different perspectives. For example, Peterson, and Michelek (2013) assessed the cost effectiveness of charging infrastructure, and suggest using plug in hybrid electric vehicles to reduce petrol consumption in the US. Schroeder, and Traber (2012) linked the cost of establishing the charging infrastructure with the adoption of electric vehicles. Through simple valuation methods in Germany, they found that the return on investment of a Level III charging station depends on its demand and thus relies on EV adoption at a large scale; fleet operations were suggested as one solution to increase the requirement for fast charging.

Axsen and Kurani (2012) analysed residential access to vehicle charging in order to develop an understanding of plug-in electric vehicle demand, use and energy impacts. Their findings from two different experiments were i) about half of the US population had Level I home charging access, ii) one third of the population of San Diego County had access to Level II home charging while another 20% were willing to pay the costs required for Level II installation. A higher percentage of samples having home charging access desired to have an EV as their next vehicle, compared to those who had no access. Their study did not cover all regions in the USA, however they suggested a relationship between EV charging access and EV adoption.

3 The WA EV Trial

A limited number of EVs are being driven in Perth as part of the Western Australia Electric Vehicle trial. The trial monitors the performance, benefits, infrastructure and practical implications of the EV fleet. This trial consists of eleven participant organizations, where each organization owns a number of EVs. The survey explores battery charging preferences for the drivers in the trial and how EV drivers plan their trip considering the limited range of an EV. However, these drivers experienced driving an EV that is owned by an organization and EVs are plugged-in for charging while they are parked. Though these drivers do not own an EV, for the purpose of this study drivers were given conditions before participating in the survey such as "*assume that you own an electric car*". The main objective of these assumptions was to determine preferences for charging time, charging location, and duration of charging, for EV drivers in Perth.

3.1 Conditions applying for this Study

In addition to the assumption of privately owning a new EV, drivers were asked to consider that they are planning their trip for the next working day, indicated as "tomorrow". EV drivers were given the following scenario:

- *"You own a new Electric Vehicle with a charging facility at your home; Level-I charging units are installed at home (Level I charging units are slower as compared to Level II or Level III). The cost of re-charging the EV will be added to your electricity bill, however if you have solar panels at home it will reduce the cost to zero.*
- *Suppose the requirement for your EV battery charging is from Empty (30%) to Full (100%), that is currently your battery status is 30% full.*
- *Your workplace provides free parking space for your car and you can book a bay to recharge your car if needed (Level II and Level III fast charging units are provided). There is however a price for charging at work (you are charged at the rate shown in each combination of options).*
- *A public charging station is available en route between home and work and there is a max 10 mins queuing time. However these public charging bays are located close to attractions (like coffee shop, a mall or a kid's play area). You are charged at the rate shown in each combination, and Level II and Level III fast charging units are provided.*
- *You are planning your activities and travel for tomorrow, which is a working day.*
- *Your new EV is the principal vehicle in your household."*

4 A Stated Preference Inquiry into the Choice of Charging Location

4.1 The Design of the Stated Preference Experiment

The choice tasks in the stated preference (SP) discrete choice experiment were set up with the objective of testing drivers' charging preferences. Several factors were identified as relevant to this decision: the time of day, the duration of charging, and the cost of electricity. As indicated earlier, the duration of charging depends on the type of charging station, with Level I or slow charging stations installed at home, while Level II and III stations are installed at parking bays at work or at public places.

Table 2: Attribute Levels for Experimental Design

Attribute levels for Work/Public	
Attributes	**Attribute levels**
When	8:00 AM, 1:00 PM
How Long	10 minutes, 20 minutes, 30 minutes
Cost/kWh	$0.22, $0.44
Attribute levels for Home	
Attributes	**Attribute levels**
When	8:00 AM, 1:00 PM, 9:00 PM
How Long	6 hours, 7hours, 8hours
Cost/kWh	$0.12, $0.30

The attribute levels are shown in Table 2. An orthogonal experimental design was generated using statistical software package (SPSS). Choice combinations deemed infeasible or with dominance were removed. A set of 4 scenarios was given to each respondent in one treatment with each scenario containing three options/alternatives. In designing this experiment, five different sets were generated, each containing four scenarios with three options. These five blocks (A, B, C, D, E) were randomised in that each respondent was randomly given one or more blocks to complete. In this way each respondent provided answers for at least four scenarios.

Table 3: An Example of a Choice Scenario

EV_Drivers'Survey_II

Opportunities for Recharging Your Electric Vehicle [Set-C]

6. Charging at

	WORK	*HOME*	*PUBLIC*
	When : 1:00PM **How Long :** 10 mins **Cost/kWh :** $0.44	**When:** 8:00AM **How Long:** 6 hrs **Cost/kWh:** $0.12	**When:** 8:00AM **How Long:** 20 mins **Cost/kWh:** $0.22
Most Preferred	○	○	○
Least Preferred	○	○	○

An example of a scenario with labelled alternatives is given in Table 3. Respondents were asked to indicate the most preferred and the least preferred options. There are advantages in allowing the respondent to choose best/worst (Finn and Louviere, 1992) options, primarily more information being obtained from one scenario. For example, with a set of three alternatives a complete ranking of four scenarios provides 8 choice situations, even though the respondent looks at only four scenarios.

4.2 Information about respondents

An invitation to participate in the survey was sent out on 24 Sep 2012, to the eleven participant organisations in the WA EV Trial. Given that the Australian Electric Vehicle Association (AEVA) is one of the partner organisations in WA EV Trial, a large number of respondents in this survey were from AEVA (Table 4).

Table 4: WA EV Trial Sample

Organization	Out of Total 67	Out of the 54 Completed Surveys
AEVA	54	32
Non AEVA	23	22

A total of 67 respondents participated in the survey with 54 complete sets of responses. Many of these drivers had participated in an earlier survey of the acceptability of electric vehicles (Jabeen *et al* 2012).This second driver survey included two sections: 1) background questions and 2) scenarios for EV charging at work/home/public points. A summary of the sample's socio-demographic characteristics is given in Table 5.

Table 5: Sample Information

Variable	%	Count (Total=54)
Gender		
Male	79.6	43
Female	20.4	11
Age		
<29	11.1	6
30-49	48.1	26
50-59	13.0	7
60+	27.8	15
What is your highest level of education?		
Year 12	13.0	7
College/Professional qualification	20.4	11
University Bachelor Degree	40.7	22
Masters or PhD	25.9	14
Do you usually have travel commitments involving other family members (e.g., pick-up/drop-off)?		
Yes	44.4	24
No	55.6	30
Do you have solar panels on your roof top?		
Yes	44.4	24
No	55.6	30

The sample was dominated by male respondents (79.6%), reflecting closely the population of EV users in Perth. Approximately half of the respondents (48.1%) were in the 30-49 years age group, 27.8% were above 60 years of age, and only 11.1% were young (<29 years). Thirty six (66.6%) of the respondents had university education. In addition to these socio-demographics, respondents were also asked about their travel commitments - involving other family members - and about having solar panels at home. From the data set it was observed that the majority (61%) of AEVA members had solar panels at home.

5 Drivers' Battery Charging Behaviour

Each respondent indicated their best and worst choices for charging at a particular place in each choice set. For the purpose of analysis, the Econometric Software NLOGIT 5.0 was used. By using a most preferred-least preferred design, an exploded choice set was generated, with multiple observations from one respondent. After data cleaning a total of 900 observations was obtained from 54 complete sets of responses. Each respondent indicated their best and worst option this is the reason that a large number of observations were achieved.

5.1 Multinomial Logit Model Estimation

The analysis of drivers' preferences for charging EV, at work, home, or public, started with the simplest discrete choice model – the multinomial logit (MNL).This model remains the starting point for empirical investigations of data such as preliminary data checks before applying advanced discrete choice models (Louviere *et al.*, 2000).

MNL Model Specifications: The systematic component of the utility functions tested for this MNL model with the model fit are given below (Table 6) and the parameter estimates obtained from three MNL models are given in Table 7. The model was also tested with variables reflecting personal characteristics (age, gender, and income), but they were not significant.

Table 6: MNL Model Specifications

$$V_{home} = \beta_{morning}X_1 + \beta_{night}X_2 + \beta_{howlong}X_3 + \beta_{cost}X_4 + \beta_{solar}X_5$$

$$V_{work} = \alpha_{work} + \beta_{morning}X_1 + \beta_{lunch}X_2 + \beta_{howlong}X_3 + \beta_{cost}X_4 + \beta_{AEVA}X_5$$

$$V_{Public} = \alpha_{Public} + \beta_{morning}X_1 + \beta_{lunch}X_2 + \beta_{howlong}X_3 + \beta_{cost}X_4 + \beta_{fam\_com}X_5$$

Model fit: The log likelihood function of the MNL model with the best fit, model M3 gives log-likelihood (LL) value= -627.81, and Chi-squared value with 8 degrees of freedom equals 669.79 (Table 7). With constants only, LL = -749.49.Table 7 also shows the pseudo-R^2 calculated for each model using equation (1).

$$\boldsymbol{\rho^2 = 1 - \frac{LL_{Estimated\ Model}}{LL_{Base\ Model}}} \qquad \textbf{(1)}$$

Parameter estimates: The first model M1, tests the preferences for EV charging at a place, time of day, cost, and duration of charging. The alternative specific constants with a negative sign for work and public in model M1 and model M2 indicate that drivers showed a preference to charge their EV at home or at work instead of public charging stations (Table 7).

Table 7: Multinomial logit model estimates

	M 1		M2		M 3	
	Beta	z	Beta	z	Beta	z
Charging at public	-3.37***	-5.24	-3.52***	-5.16	-0.50	-0.60
Charging at work#	-2.12***	-3.33	-1.39**	-2.07	1.7**	2.04
Time of Day	0.43***	5.18	0.48***	5.53		
MORNING	Time of day				0.09	0.39
LUNCH TIME					0.13	0.49
NIGHT					1.96***	7.38
Cost ($)	-4.35***	-7.76	-4.79***	-8.17	-3.75***	-6.13
HowLong (Duration in Mins)	-0.007***	-4.75	-0.008***	-5.11	-0.001	-0.72
Solar Panels At Home			0.97***	5.48	1.01***	5.45
Family Commitments wrt Home Charging			0.32*	1.81	0.34*	1.88
AEVA Members charging at work			-1.06***	-5.89	-1.17***	-6.20
Number of parameters (K)	5		8		10	
Log likelihood	-695.207		-655.168		-627.811	
AIC	1400.4		1326.3		1275.5	
ρ^2 (*Mc Fadden*)	0.07		0.12		0.16	
Log likelihood With constants only	-749.489					

#Home is reference; *****, **, * indicate Significance at 1%, 5%, and 10% level respectively**

The time of day variable was coded in ordinal form to represent morning, lunch time, and night hours as -1, 0, and 1 respectively. Positive parameters for this variable in M1, and M2 indicated that drivers preferred to charge their EV during night hours. In M3, the time of day variable was coded using dummy variables; their respective parameter estimates clearly indicate higher preference for charging at night (β=1.96, z=7.38), and lower preference for charging during the day times. Drivers are sensitive to the time taken to charge EV, and even more sensitive about EV charging cost, as shown by the parameter values in M2 (β=-4.79,z= -8.17).

Covariates: Drivers having solar panels at home preferred to charge their EV at home; this is indicated by significant parameter estimates in M2 and M3 for the solar panels at home covariate in Table 7. This preference for charging EV at home might be due to the savings in cost for charging EV using solar panels, and/or because of the convenience of charging EV at home. As mentioned above, almost 61% of AEVA members who participated in this survey had solar panels at home; thus there was overlap between these two groups, that is, AEVA members showing a strong preference for charging at home and drivers having solar panels at home. AEVA members preferred not to charge their EV at work, with negative coefficients in both M2 and M3. Drivers having travel commitments involving other family members showed a preference for charging their EV at a public charging station during the day (10% significance level).

5.2 Random Parameters Logit Model Estimation

Random parameters or mixed logit model (RPL/ML) is an advanced model used for exploring the behavioural output, elasticity of choice, and valuation of attributes (Louviere *et al.*, 2000).Revelt and Train (1998) suggested that the RPL interpretation is useful when considering models with repeated choice, RPL*'...allows efficient estimation when there are repeated choices by the same customer (*decision maker*)*". Although the ML model is also termed the error components model (Hensher, and Greene, 2003), due to the multiple observations/respondents, i.e. panel data, we used the random parameters logit model along with error component model (ECM) specifications. Standard Halton sequence draws (SHS) were used in drawing random parameters because SHS is an intelligent draw method that can obtain good results with a small fraction of the total number of draws required by other methods, and is designed to sample the entire parameter space (Baht, 2001;Train, 2003).

A total of 459 experiment situations were used in this analysis. There were 18 instances where respondents indicated only their most preferred choice but did not answer their least preferred option, which resulted in a total of 900 valid observations.

Model Structure: Assuming that each sampled driver q is given J=3 alternatives, in each of choice situation, the number of choice situations given to each respondent was variable (T=4, 8, 12, 16, or 20). A utility expression of general form for a discrete choice model is given as following:

$$\boldsymbol{U_{jtq}} = \sum_{k=1}^{K} \boldsymbol{\beta_{qk} x_{jtqk}} + \boldsymbol{\varepsilon_{jtq}}$$

$$= \boldsymbol{\beta'_q x_{jtq}} + \boldsymbol{\varepsilon_{jtq}} \quad \textbf{(2)}$$

where, j= 1,.., 3 alternatives,

t= 4, 8, 12, 16, or 20 choice situations,

q=1,....., 54 respondents

x_{jtqk} is the full vector of explanatory variables including attributes such as time of day, duration, and cost of charging against each alternative, and choice task itself in choice situation *t*.

In this experiment more than one observation from each respondent was collected for T choice situations in time-period i = {i1, ...iT}. The probability conditional on β that a respondent makes this sequence of choices is the product of logit formulas (Train, 2003) given in equation (3).

$$\boldsymbol{L_{qi}(\beta)} = \prod_{t=1}^{T} \left[\frac{e^{\beta'_q x_{qi_t t}}}{\sum_j e^{\beta'_q x_{qjt}}} \right] \quad \textbf{(3)}$$

As mentioned above, each driver in this survey was given a different number of choice situations; thus analysed using the RPL/ECM model with repeated choices, the unconditional probability is the integral of this product over all values of β, as given below:

$$\boldsymbol{P_{qi}} = \int \boldsymbol{L_{qi}(\beta) f(\beta) d\beta} \quad \textbf{(4)}$$

Table 8: Mixed logit/Error Component Model Parameter Estimates

Non-random parameters in utility functions		
	Beta	**z**
Charging at public#	-0.06	-0.04
Long Duration (Hours)	-0.001	-0.32
Short Duration (Mins)	-0.04	-1.6
NIGHT	3.67***	12.95
Random parameters in utility functions		
Cost for Charging at home/work	-9.83***	-11.06
Cost for Charging at public stations	-7.33***	-4.58
Charging at work	2.6*	1.67
Heterogeneity in mean variable: parameter		
Work: Solar Panels	-1.75**	-2.27
Work: Family Commitments	1.3	1.6
Work: AEVA Members	-1.9***	-2.6
Cost: Solar Panels	-8.05***	-3.17
Cost: Family Commitments	6.06**	2.56
Cost: AEVA Members	-3.17	-1.41
Derived standard deviations of parameter distributions		
Cost for Charging at home/work	5.9***	11.06
Cost for Charging a public stations	4.4***	4.58
Charging at work	3.6***	4.74
Error Components		
Work, Public	2.49***	5.23
Model Fit		
Number of parameters (K)	16	
Log likelihood	-467.05	
AIC	966.1	
$\boldsymbol{\rho^2}$	0.37	
Adjusted $\boldsymbol{\rho^2}$	0.527	

#Home is reference *****, **, * indicate Significance at 1%, 5%, and 10% level respectively**

The specified random parameters in the RPL/ECM model were for charging at work, and charging costs. Adding a random parameter for charging time caused an insignificant improvement in overall fit, thus it was kept as a non-random parameter (Table 8).

In this model specification, Halton sequence draws were used to estimate random parameters with two normal distributions, and one triangular distribution. The normal distributions were used for the cost of charging at home/work, and the cost of charging at public stations, and the one triangular distribution was used for the alternative specific for charging at work. SHS is an efficient drawing method that reduces the chance of drawing parameters from a particular part of the distribution (Baht, 2001); thus to give good results 100 intelligent Halton draws for β were used. Other parameters not specified as random were interpreted similarly to the parameter estimates in the MNL. The parameter estimates using the RPL/ECM model are given in Table 8.

Model fit: With the same 900 observations from 54 respondents, the LL value of the RPL/ECM model has improved on the MNL models in Table 7 with log-likelihood = -467.05 (as given in

Table 8). The Chi-squared value with 16 degrees of freedom for this model equals 1,043.38. Using equation (1), the pseudo R^2 for this model is 0.37 which is approximately equivalent to $R^2 \approx 0.71$ for a linear regression model (Hensher *et al*., 2005; p.338).

Preference Heterogeneity: The random parameters logit model allows preference heterogeneity around the means of random variables that can be used to test interaction effects. Statistically significant parameter estimates for *derived standard deviations of random parameters* indicate that there is *heterogeneity in the parameter estimates over the sampled population around the mean parameter estimate* (Hensher *et al.*, 2005; p.633). Variables that were covariates in the MNL model earlier (Table 7) are explored here for their interaction effects. Using the RPL model the preference for charging at home while having solar panels at home, and having travel commitments with family members were tested for interactions. This provided useful insights into the drivers' charging behaviour and their preferences for charging at home, and their preferences with respect to charging cost. The results in Table 8 indicate the following:

- In general drivers had a preference for charging their EV during night hours, and they were sensitive to cost and duration of charging.
- Drivers who were AEVA members did not favour charging at work but were marginally sensitive to charging cost at public charging stations.
- Similarly, drivers having solar panel at home did not like to charge EV at work, and they also showed a negative reaction to the cost of charging at public stations.
- Drivers having travel commitments with family were prepared to pay a high cost for EV charging. This behaviour indicates the importance of charging infrastructure.

5.3 Charging Price and Duration Elastiticities

Results from the RPL/ECM model indicated the sensitivity to duration and cost of charging. Choice elasticity with respect to charging cost and with respect to duration of charging are presented in Table 9 and Table 10 respectively. The own elasticity for charging at work of -0.57 indicates that a 10% increase in the cost of charging at work results in a 5.7% decrease in the preference for charging at work, all else being equal. The own elasticities for home, and public are -0.40, and -0.52 respectively. As an example of an (off-diagonal) cross-elasticity, a 10% increase in the cost of charging at home would result in a3.8% increase in the preference for charging at public charging stations, ceteris paribus (Table 9). These values for choice elasticity with respect to charging cost indicate that all three charging alternatives are fairly close substitutes. This is further supported by the beta weights for (*Work, Public*) error components where work and public showed strong correlation values in Table 8.

Table 9: Choice Elasticity with respect to the Charging Cost Attribute

Preference for	Cost at Work	Cost at Home	Cost at Public
Charging at Work	**- 0.569**	0.148	0.208
Charging at Home	0.175	**-0.401**	0.182
Charging at Public	0.464	0.380	**-0.517**

The direct charging duration elasticity for charging at public charging stations of -0.2 indicates that 10% increase in public charging duration will result in 2% decrease in the preference for charging at public charging stations all else being unchanged (Table 10). For cross elasticities, a 10% increase in charging duration at public stations results in less than a 1% increase in the preference for charging at home or for charging at work, all else being equal.

Table 10: Choice Elasticity for Charging with respect to Charging Duration at Public Charging Stations

Preference for	With respect to charging duration at public stations
Work	0.078
Home	0.073
Public	**- 0.200**

5.4 Willingness to Pay (WTP) for reducing Charging Duration

WTP measures were calculated in a similar manner as for MNL except that through the RPL model, a WTP Matrix containing the willingness to pay measure for each observation was calculated *as a ratio of the coefficient of charging duration in minutes to the coefficient for charging cost in dollars*.

$$\boldsymbol{WTP_q = \left(\frac{\beta_{time_q}}{\beta_{cost_q}}\right) \times 24} \quad (5)$$

The WTP measure for each respondent *q*, was calculated in the WTP Matrix on a kWh basis. It takes 24kWh to charge an EV from zero to full (National Research Council, 2013). Hence, to get the cost for a full charge this value was multiplied by 24. By taking an average of the resulting values, drivers in the WA EV trial were willing to pay $1.17 extra for a 10 minute reduction in charging time. This value, though small, is comparable to the existing cost of charging electric vehicles. The willingness to pay measures for charging convenience was also calculated in a similar manner, but it did not reveal any additional meaningful results.

6 Discussion and Future Research

Home-charging remains one of the advantages of EV as drivers had a preference for the convenience of charging overnight or during the day at home. Drivers having solar panels preferred to charge at home, this preference being explained by the saving in cost and also the convenience. Average daily travel distance requirements of 25-30 kms in Australia (*BITRE*, 2010) are supported by a comment from one of the drivers in this survey: "..... *4 months ago we purchased the all-electric car Nissan LEAF. So far this has nearly always been solar charged at home.*.......", showing that current EV range is sufficient for household travel requirements in this part of Australia. An argument for daytime home charging is that the cost of overnight charging EV while having solar panels at home is determined by the buy-back rate provided by the power supplier. As mentioned earlier Synergy offers 8.4 cents/kWh, while Horizon Power offers10 cents/kWh to 50 cents/kWh in different rural areas/suburbs of Western Australia (WA). For this reason households may experience various costs for charging at night.

AEVA members preferred not to charge their EV at work as many had solar panels at home. In the RPL model AEVA members were not sensitive to price at public stations, and their preference for home charging reflects their enthusiasm for using renewable energy. Another factor is convenience, indicated by drivers' comments, as exemplified here: "*I would insist on charging at home no matter the cost.*"

Drivers having travel commitments involving other family members showed a stronger preference for charging EV at public stations. This could be due to the requirement for their long trip, involving a pickup/drop of a family member or some household chores. One of the respondents who had travel commitments involving other family members made a comment that: "*Public charging facilities, e.g. at shopping centres and in city centre would definitely be useful.*" This indicates that it is convenient for people to plug-in their EV and effectively use the charging time for other activities, therefore public charging stations installed near places of interest are appealing.

Charging at public charging stations is different from charging at home or at work. The convenience of overnight or during the day differentiates home-charging from public charging. For charging at work, the convenient location, less effort and convenient timing makes it different from charging at public stations. The cross elasticities with respect to charging duration in Table 10of about 0.07 indicate that the time to charge at a public station has a small impact on the probability of charging at home or work. It is a matter of trip length that leads drivers to charge at public charging stations during the day. In general, drivers were sensitive to charging cost, but convenience was also important, as pointed out by one of respondents: "*I think if your battery capacity permits, you will charge wherever it is both cheap and convenient. If not one, you will go for the other*."

The main aim of this experiment was to test WA EV Trial drivers' preferences for EV charging. The study has several limitations, with *i)* reduced number of respondents and *ii)* lack of a charging infrastructure being the most evident. At the time when this study was conducted the charging stations in WA were in their infancy but the drivers in the trial had ample experience of EV charging.

7 Conclusion

This paper explores the drivers' preferences for charging at work, at home, and at public charging station. With ~~a~~ limited availability of charging infrastructure, stated choice experiments were used to analyse driver's charging preferences. Advanced discrete choice models were used to analyse panel data. Main observations from this study are that drivers' in most instances preferred to charge EV at home/work, and they were sensitive to charging cost and duration. Among the drivers in the WA EV trial, people having solar panel at home were generally enthusiasts who preferred to use the renewable energy to charge their EV at home.
Overall drivers were sensitive to charging cost, and duration, but people having travel commitments with family were prepared to take the time required to charge at public charging stations.

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