



Charge timing choice behavior of battery electric vehicle users

Xiaohui SUN, Toshiyuki YAMAMOTO and Takayuki MORIKAWA. Nagoya University, Japan

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1. Introduction

Charge timing plays an important role in the effect of charging on electric grid

- Hadley (2006): **nighttime** charging had less impact on peak loads than that occurred in the early evening
- Aksen and Kurani (2010): shifting charging to **off-peak hours** could eliminate the threat to California utilities caused by additional electricity demand

Related researches on charge timing

Research	Objective	Methodology	How to deal with charge timing
Zoepf et al. (2013)	Binary choice as to whether a PHEV was charged or not at the end of a trip	mixed logit model	One explanatory variable
Jabeen et al. (2013)	Multinomial choice as to charging at work, home or public charging stations	multinomial logit model; mixed logit model	One explanatory variable

Objective of this study

- Modeling charge timing choice with indicator for charge timing as dependent variable

2. Focus of this study

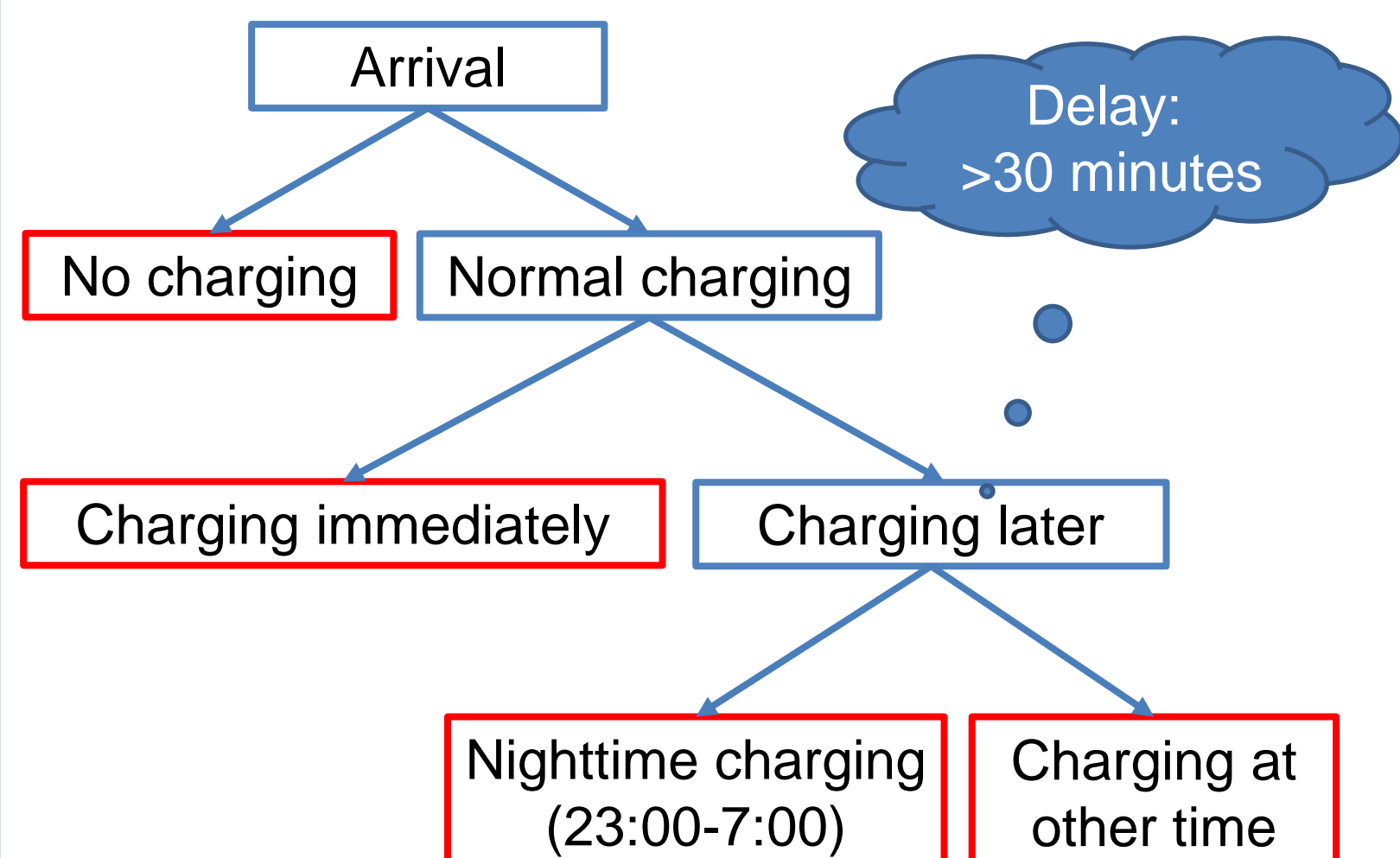
BEV (Battery Electric Vehicle) usage trial in Japan

Behavior related to normal charging at home/company after the last trip of the day

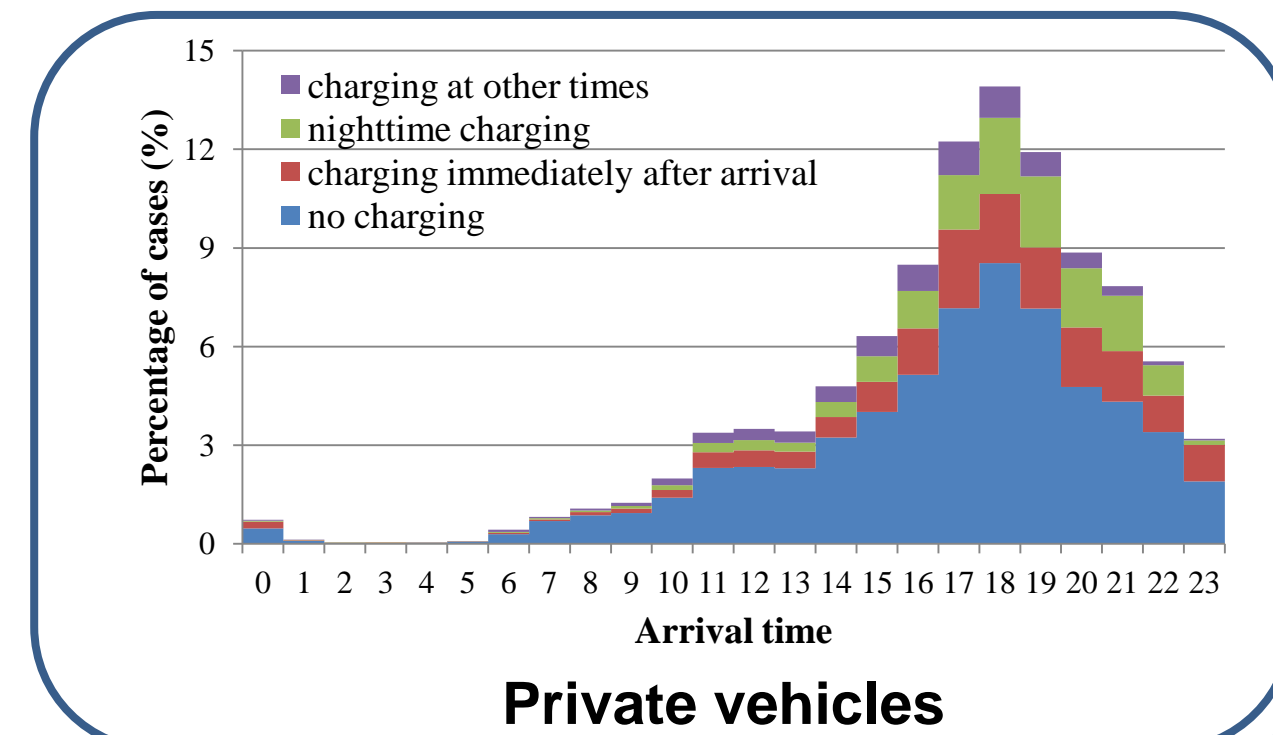
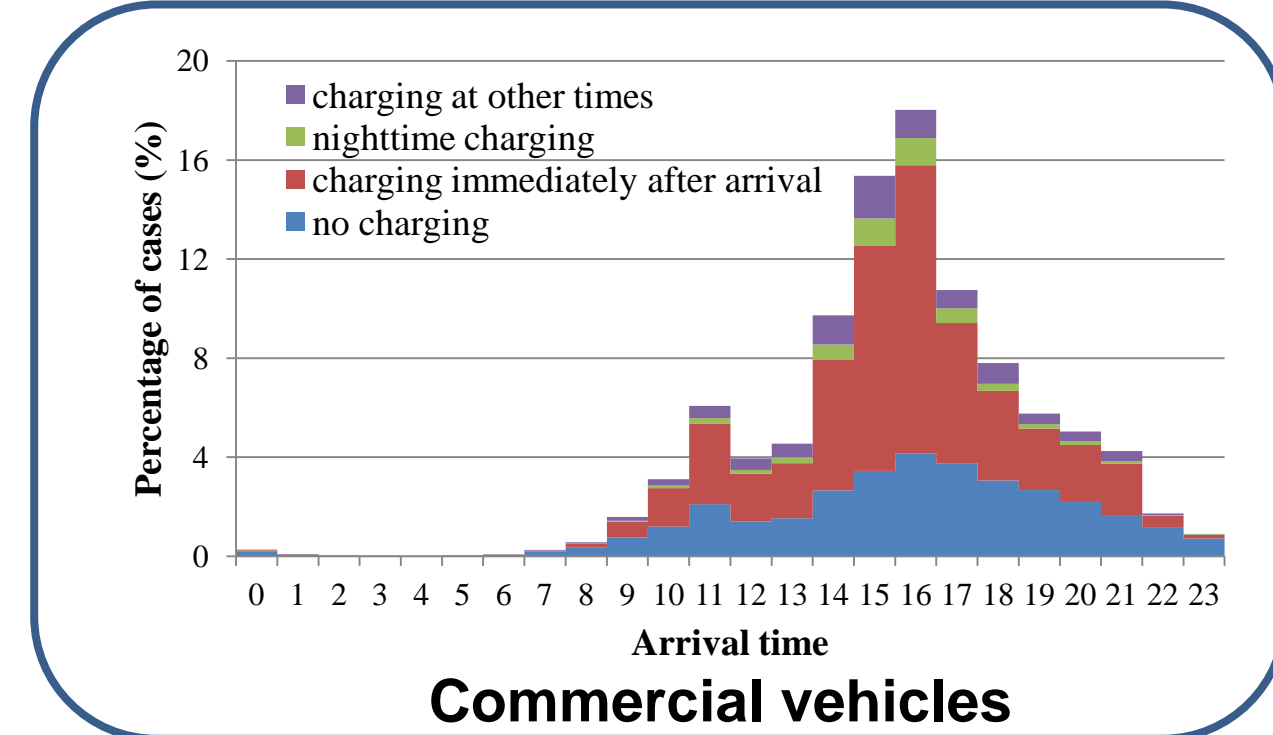
- EVs can be normal-charged without concerns about the availability of chargers at home for private vehicles and at company for commercial vehicles.
- After the last trip of the day, there is plenty of time to make a decision about when to begin normal charging, peak hours or off-peak hours or randomly.

249 commercial vehicles with 51,333 observations and 234 private vehicles with 66,933 observations

3. Alternatives for charge timing choice



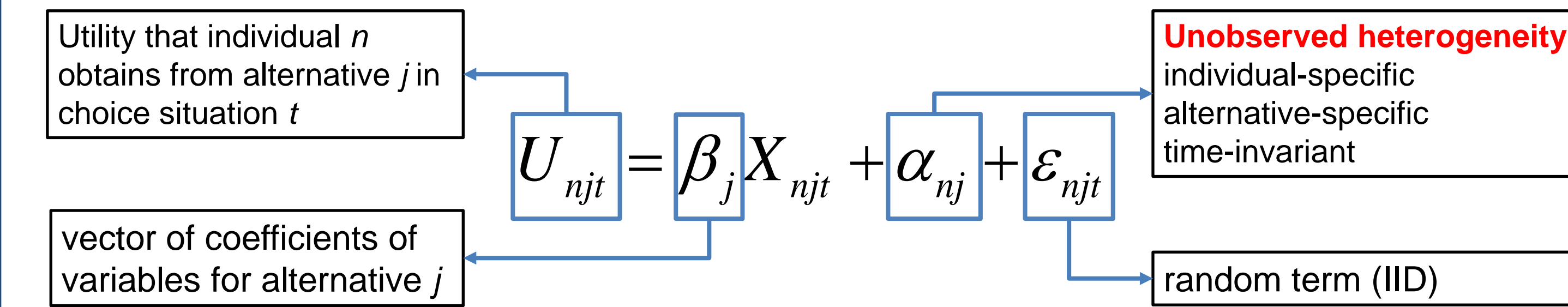
- Most users who delay charging are waiting until 23:00 to begin charging
- One low-price electricity tariff begins at 23:00 and ends at 7:00 in Japan



4. Methodology

Mixed logit model with unobserved heterogeneity

- Repeated observations from an individual tend to be similar
- Differences exist in preference for alternatives within an individual
- Differences exist in preference for alternatives across individuals



Model specification

Assumptions about the unobserved heterogeneity

- Identically and independently distributed over individuals
- Multivariate normal distribution with mean b and variance-covariance matrix W , $\alpha \sim N(b, W)$
- Correlations exist between alternatives within one individual

5. Estimation results

Variable	Commercial vehicles		Private vehicles	
	Coefficient	Std. error	Coefficient	Std. error
SOC × No charging	0.062	0.001***	0.096	0.001***
× Charging immediately	-0.007	0.001***	-0.006	0.001***
× Nighttime charging	-0.0006	0.002	-0.003	0.001**
Interval days before next travel day × No charging	0.057	0.010***	0.018	0.015
× Charging immediately	0.011	0.009	-0.045	0.019**
× Nighttime charging	-0.026	0.021	-0.194	0.025***
VMT on next travel day × No charging	-0.011	0.001***	-0.026	0.001***
× Charging immediately	0.003	0.001**	-0.001	0.001
× Nighttime charging	0.004	0.002**	0.002	0.001***
Experience of fast charging × No charging	0.0002	0.0006	-0.0002	0.0004
× Charging immediately	-0.0005	0.0006	0.001	0.0004***
× Nighttime charging	-0.0003	0.0009	0.0009	0.0004**
Working day (current travel day) × No charging	-0.034	0.062	0.213	0.040***
× Charging immediately	0.112	0.060*	0.036	0.043
× Nighttime charging	0.145	0.132	0.105	0.047**
Working day (next travel day) × No charging	0.025	0.063	0.039	0.040
× Charging immediately	0.014	0.060	0.109	0.043**
× Nighttime charging	-0.107	0.130	0.051	0.047
Nighttime (arrival at home/company premises) × No charging	1.319	0.252***	0.475	0.108***
× Charging immediately	0.370	0.261	1.122	0.108***
× Nighttime charging	0.588	0.415	-0.921	0.141***

To be continued

5. Estimation results (continued)

Variable	Commercial vehicles		Private vehicles	
	Coefficient	Std. error	Coefficient	Std. error
Latter half of trial × No charging	0.033	0.041	-0.085	0.037**
× Charging immediately	0.107	0.037***	-0.052	0.040
× Nighttime charging	1.077	0.074***	0.179	0.043***
Electricity company × No charging	-1.634	0.062***	—	—
× Charging immediately	-0.156	0.065**	—	—
× Nighttime charging	1.796	0.109***	—	—
Alternative specific constant (i.e. Mean)				
No charging	-2.005	0.102***	-3.050	0.081***
Charging immediately	1.602	0.090***	0.417	0.082***
Nighttime charging	-3.506	0.196***	0.709	0.097***
Variance				
No charging	6.745	0.198***	4.977	0.149***
Charging immediately	3.977	0.101***	3.254	0.097***
Nighttime charging	10.456	0.320***	5.222	0.128***
Covariance				
No charging & Charging immediately	1.278	0.099***	-0.669	0.078***
No charging & Nighttime charging	4.672	0.190***	1.720	0.105***
Charging immediately & Nighttime charging	0.391	0.110***	-0.807	0.054***
LL(0) (log likelihood without any coefficients)	-45041.328		-57703.986	
LL (Bc) (log likelihood without correlated coefficients)	-30813.970		-40007.980	
LL (B) (log likelihood with correlated coefficients)	-30531.299		-39780.196	

Experience of fast charging: the total number of fast charging events before the last trip of the current travel day.
 Reference group is: charging at other times
 — Variables not included in the model
 *, **, *** indicate significance at 10%, 5%, and 1% level, respectively

6. Conclusions

- Mixed logit model with unobserved heterogeneity is used to explore choice behavior related to normal-charge timing after the last trip of the day.
- SOC, interval days, VMT, experience of fast charging, travel on working days, arriving at nighttime influence the normal-charge timing choice behavior after the last trip of the day.
- Users tend to charge during the nighttime in the latter half of the trial.
- It is possible to encourage users to take nighttime charging.

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