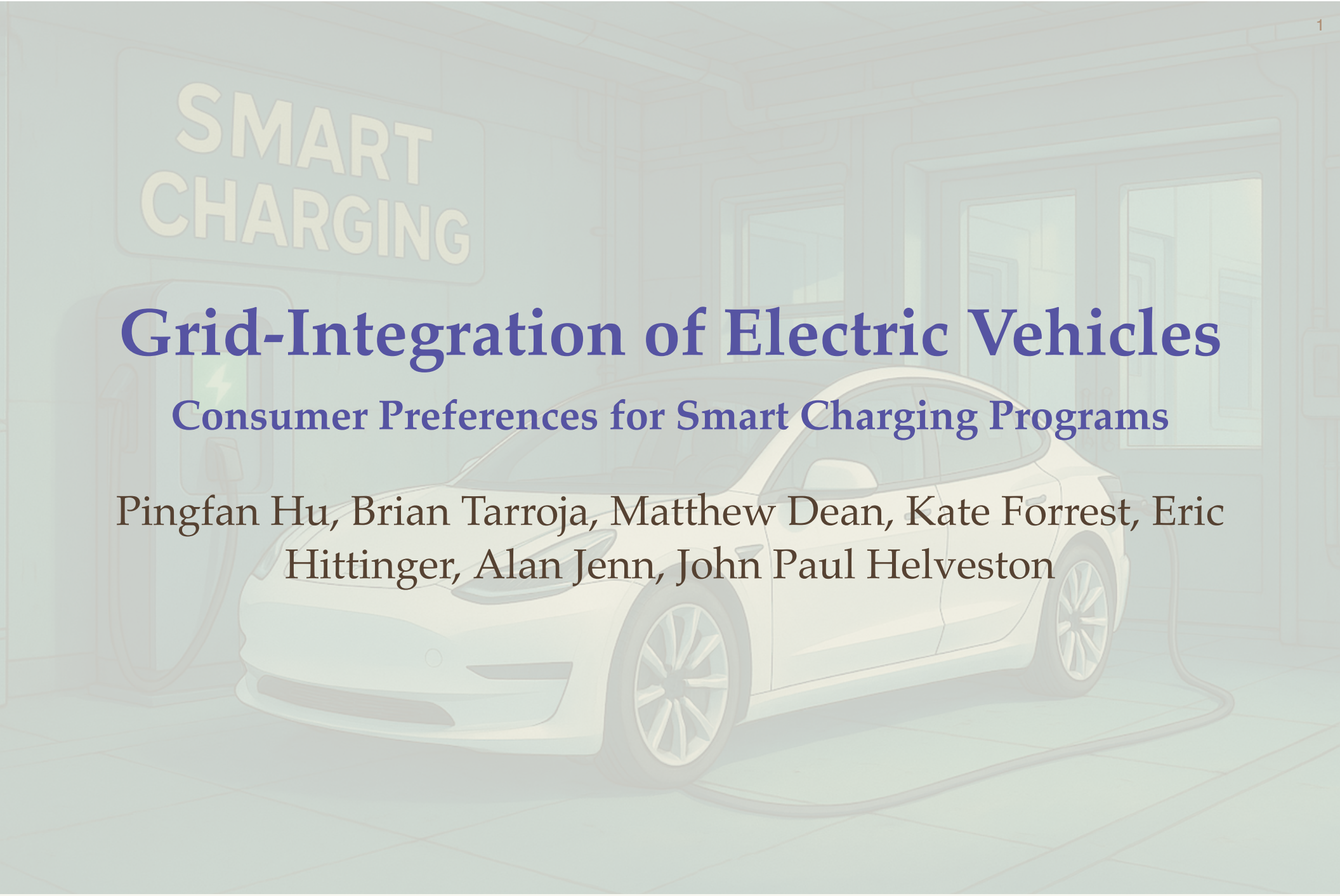


Grid-Integration of Electric Vehicles

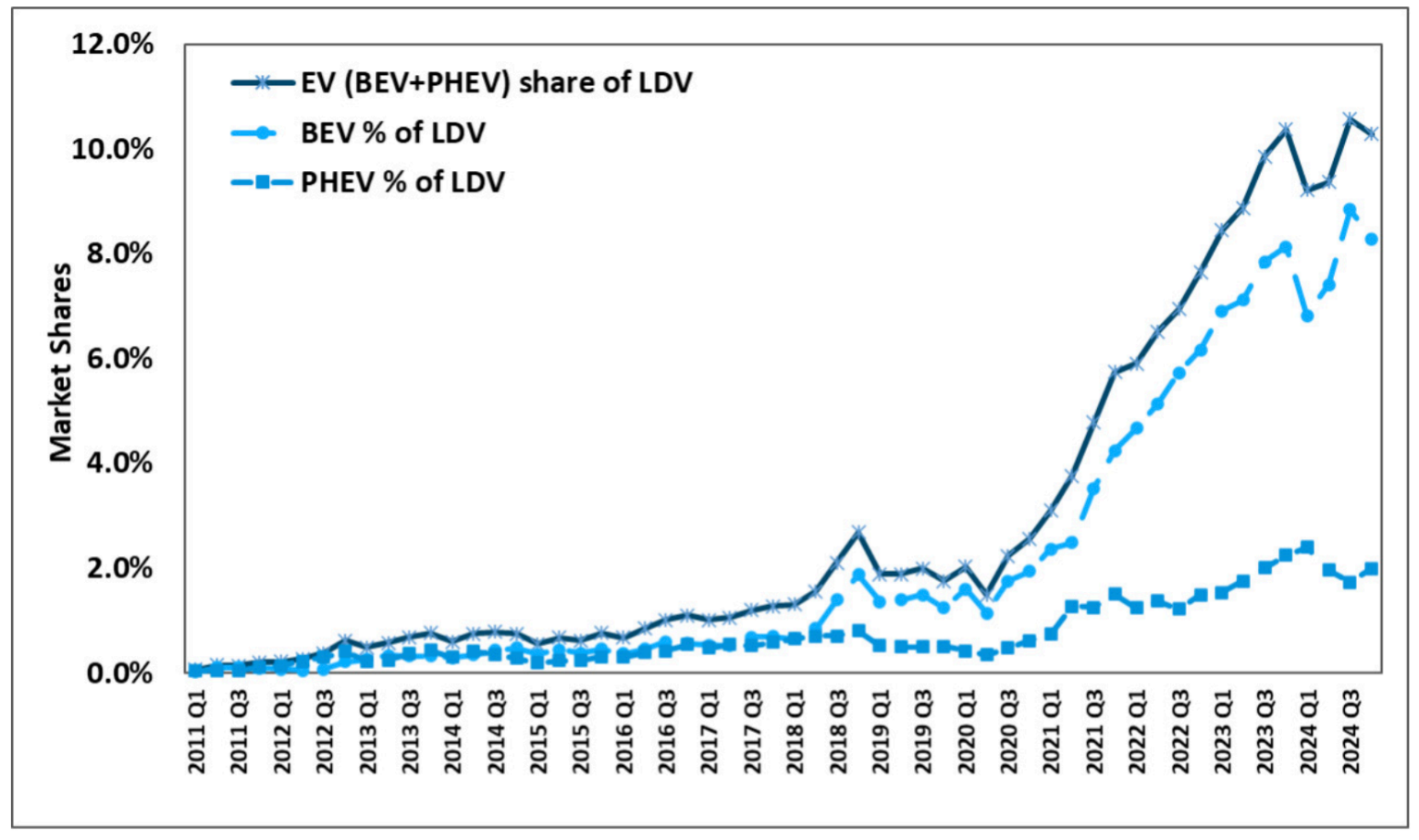
Consumer Preferences for Smart Charging Programs

Pingfan Hu, Brian Tarroja, Matthew Dean, Kate Forrest, Eric Hittinger, Alan Jenn, John Paul Helveston

About Me

- My name is Pingfan Hu, a PhD Candidate at George Washington University, supervised by Dr John Helveston
- Research focuses:
    1. EV grid integration
    2. Consumer behavior
    3. Research software development
- For more infomation, visit pingfanhu.com

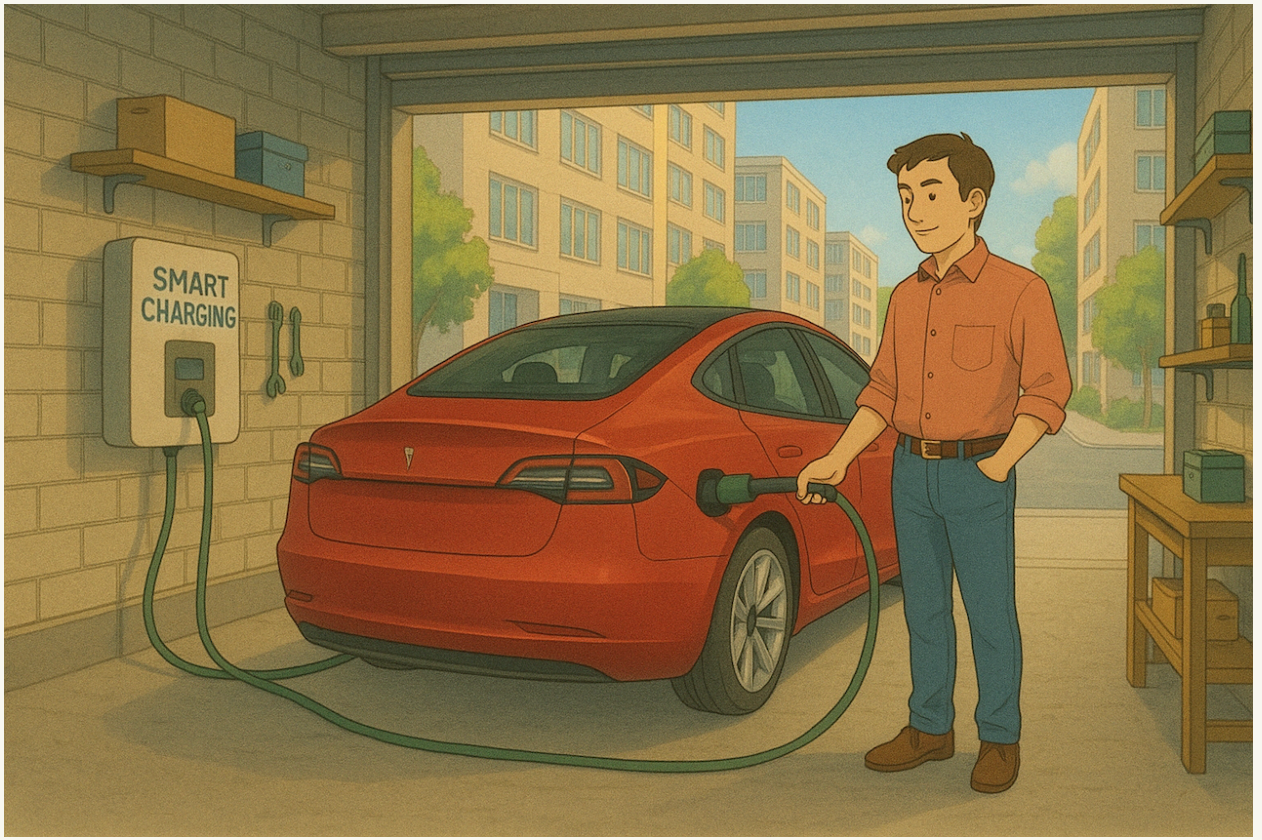
EV sales in US reaching ~10% of sales



Source: Argonne National Lab, www.anl.gov/ev-facts/model-sales

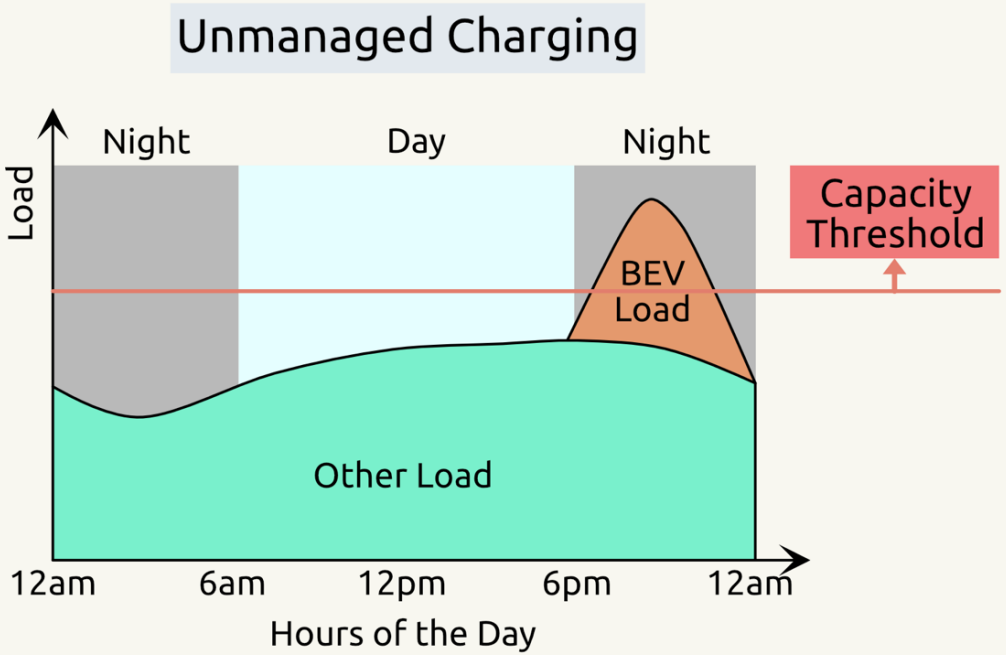
Background

- **Unmanaged** BEV charging is becoming a problem to the grid.
- **Managed** charging is cheaper and smoothes out the grid load.
- **Smart** charging: Supplier-Managed Charging (SMC) and Vehicle-to-Grid (V2G).



SMC - Supplier Managed Charging

- SMC smooths out overnight EV charging demand.
- Electricity demand is controlled below capacity threshold.
- It saves money and reduces pollution.



SMC - Supplier Managed Charging

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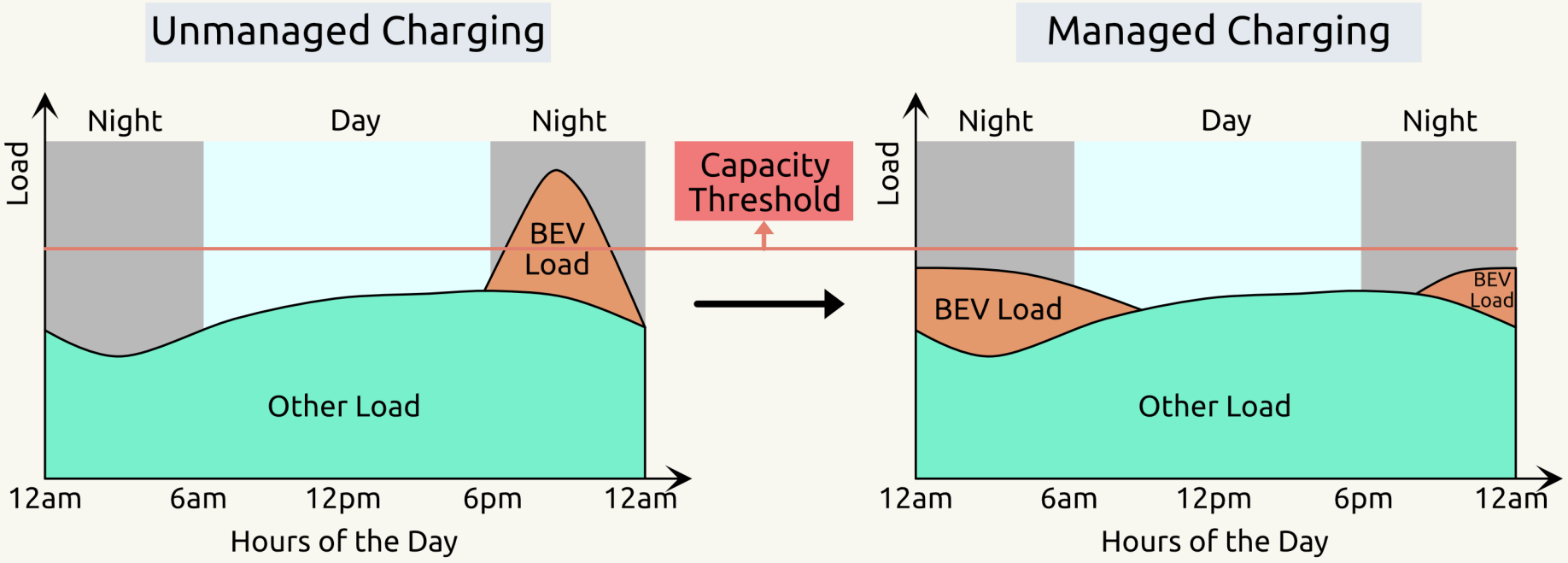


Managed charging avoids overload caused by BEV charging.

V2G - Vehicle-to-Grid

Non-V2G (Single Direction)

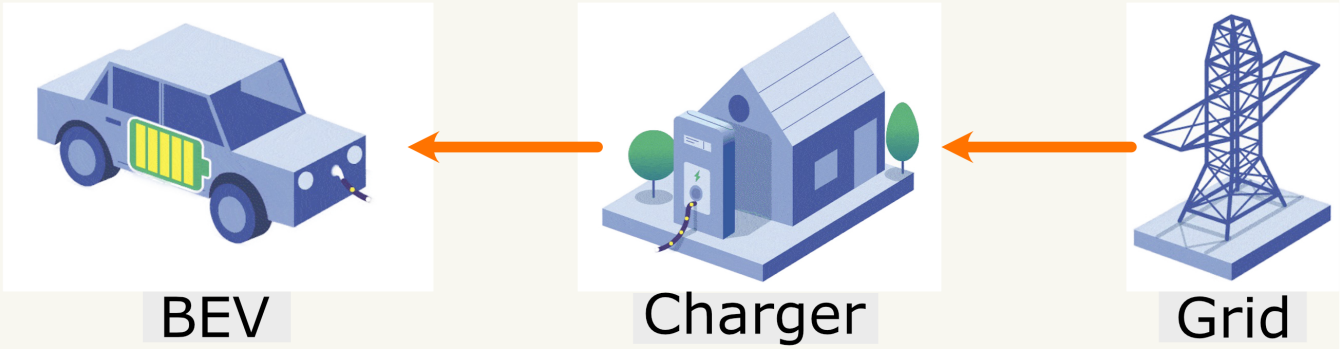
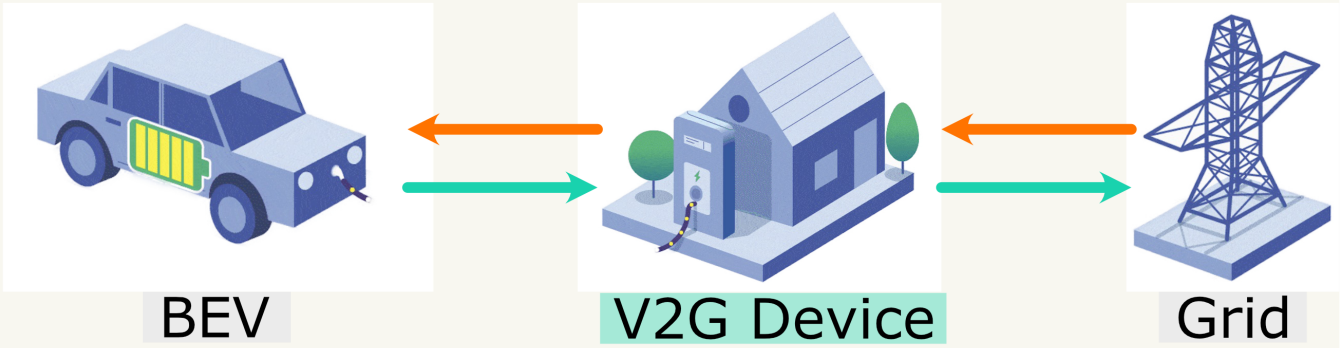


Figure Source: *wri.org*

V2G (Bi-direction)



In a V2G event, BEVs can charge the grid when necessary. BEVs are charged back eventually. Owners earn money.

Smart charging depends on enrollment.

Literature Review

1. A study by Wong et al. (2023) examined **incentives** affect the EV owners' acceptance, but EV ownership is only 19%.
2. A study by Philip and Whitehead (2024) found **range anxiety** matters, but EV ownership is only 1.28%.
3. Another study by Huang et al. (2021) indicates the importance of **fast charging**, but the sample size is only 157.

None of them have demographics data to study heterogeneity.

We need high EV ownership & large sample size, and consider heterogeneity.

Research Questions

1. **Sensitivity**: How do changes in smart charging program **features** influence BEV owners' willingness to opt in?
2. **Enrollment Rate**: Under what **combinations of features** will BEV owners be more willing to opt in to smart charging programs?

Conjoint survey to collect BEV owners' willingness.

Multinomial logit model for utility simulations.

Survey Design with `formr`

Conjoint Questions

1. Monetary Incentives
2. Charging Limitations
3. Flexibility

Demographic Questions

1. BEV Ownership
2. Personal Info
3. Household Info

Conjoint Question Explained

A Sample Conjoint Question

For example, if these were the only apples available, which would you choose? *

Option 1	Option 2	Option 3
		
Type: Fuji **Price**: $ 2 / lb **Freshness**: Average	**Type**: Pink Lady **Price**: $ 1.5 / lb **Freshness**: Excellent	**Type**: Honeycrisp **Price**: $ 2 / lb **Freshness**: Poor

1. Provide respondents with different **sets** of attributes.
2. Observe choices across random sets.
3. Estimate **utility** of each attribute.

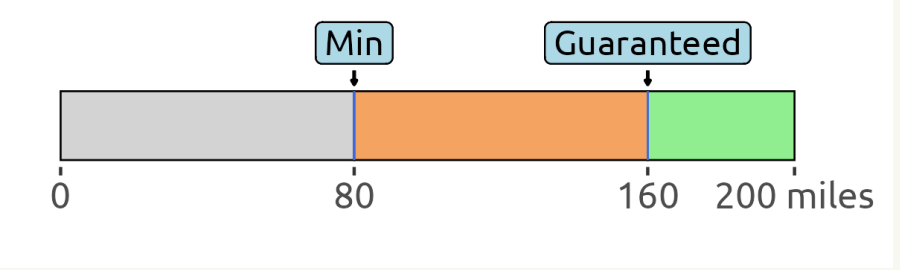
SMC Programs

Attributes

No.	Attributes	Range
1	Enrollment Cash	$50 to $300
2	Monthly Cash	$2 to $20
3	Monthly Override	0 to 5
4	Min Battery	20% to 40%
5	Guaranteed Battery	60% to 80%

Sample Program

Attributes	Values
Enrollment Cash	$300
Monthly Cash	$20
Monthly Override	5



(Range determined by stated vehicle they own)

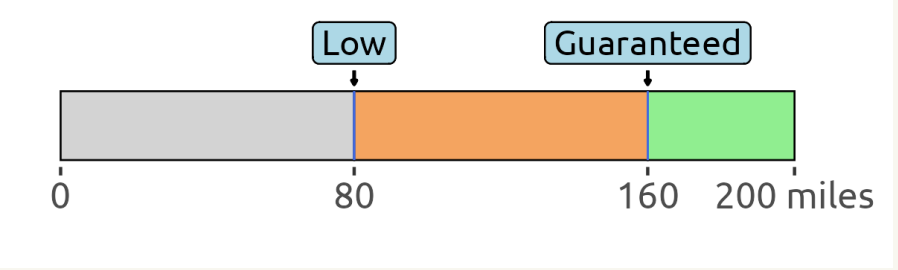
V2G Programs

Attributes

No.	Attributes	Range
1	Enrollment Cash	$50 to $300
2	Occurrence Cash	$2 to $20
3	Monthly Occurrence	1 to 4
4	Lower Bound	20% to 40%
5	Guaranteed Battery	60% to 80%

Sample Program

Attributes	Values
Enrollment Cash	$300
Occurrence Cash	$20
Monthly Occurrence	1

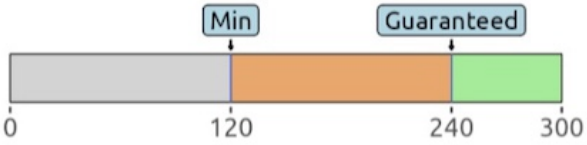


(Range determined by stated vehicle they own)

Sample SMC Question

(1 of 6) If your utility offers you these 2 SMC programs, which one do you prefer?
(Your BEV has maximum range of **300** miles.)

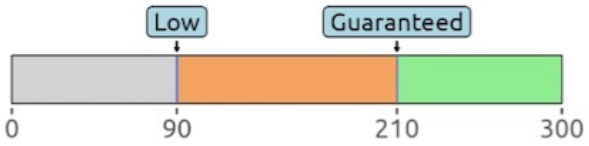
Access the SMC Attributes

Option 1	Option 2	Option 3
Enrollment Cash: $100 Monthly Cash: $20 Override Allowance: 1 per Month	Enrollment Cash: $200 Monthly Cash: $10 Override Allowance: 1 per Month	Not Interested
Battery Thresholds (in Miles): 	Battery Thresholds (in Miles): 	

Sample V2G Question

(1 of 6) If your utility offers you these 2 V2G programs, which one do you prefer?
(Your BEV has maximum range of **300** miles.)

Access the V2G Attributes

Option 1	Option 2	Option 3
Enrollment Cash: $100 Occurrence Cash: $5 Monthly Occurrence: 2 Battery Thresholds (in Miles):  	Enrollment Cash: $100 Occurrence Cash: $20 Monthly Occurrence: 2 Battery Thresholds (in Miles):  	Not Interested

Survey Fielding - 1356 in Total

Meta Ads: Voluntary participants

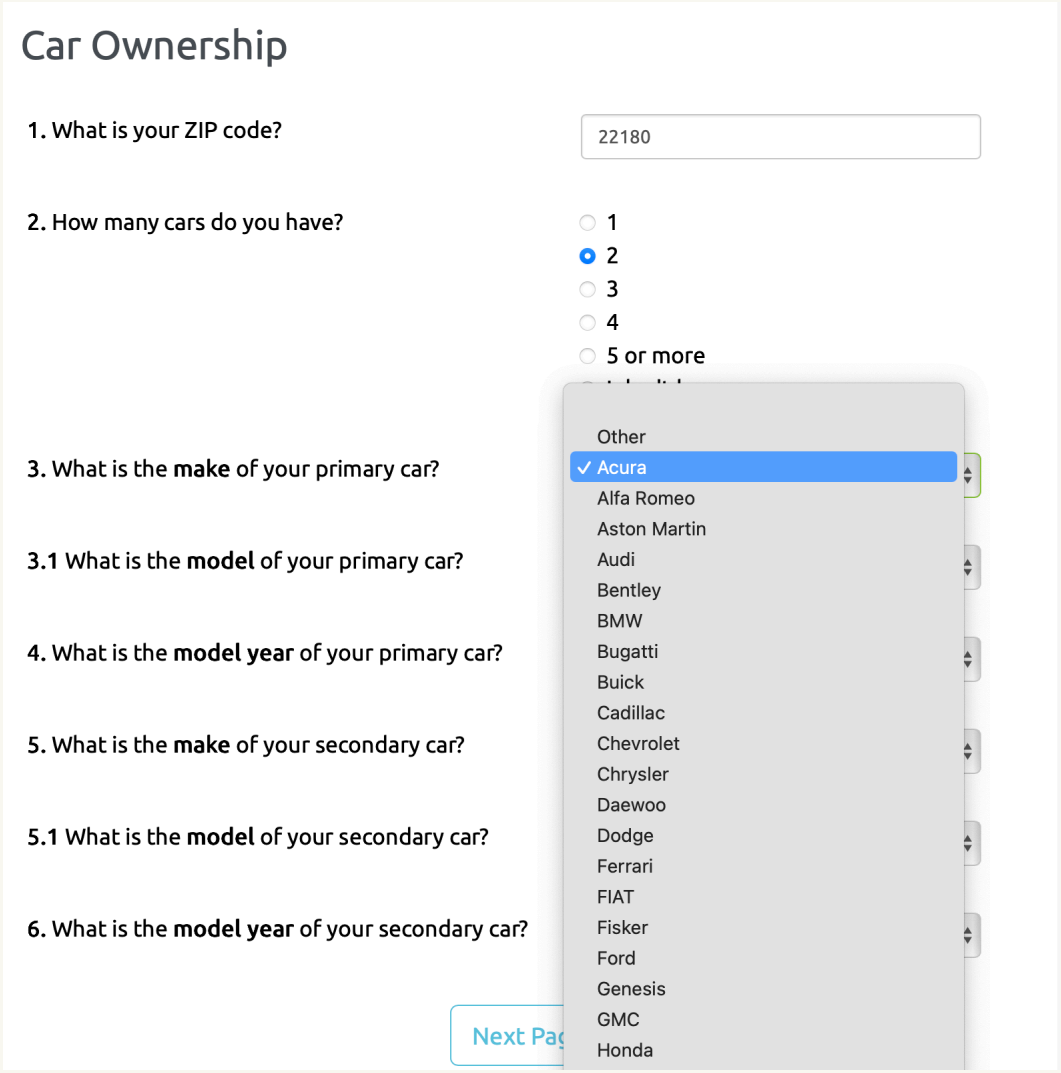
- **803** responses
- March to July in 2024

Dynata Recruitment: Paid survey

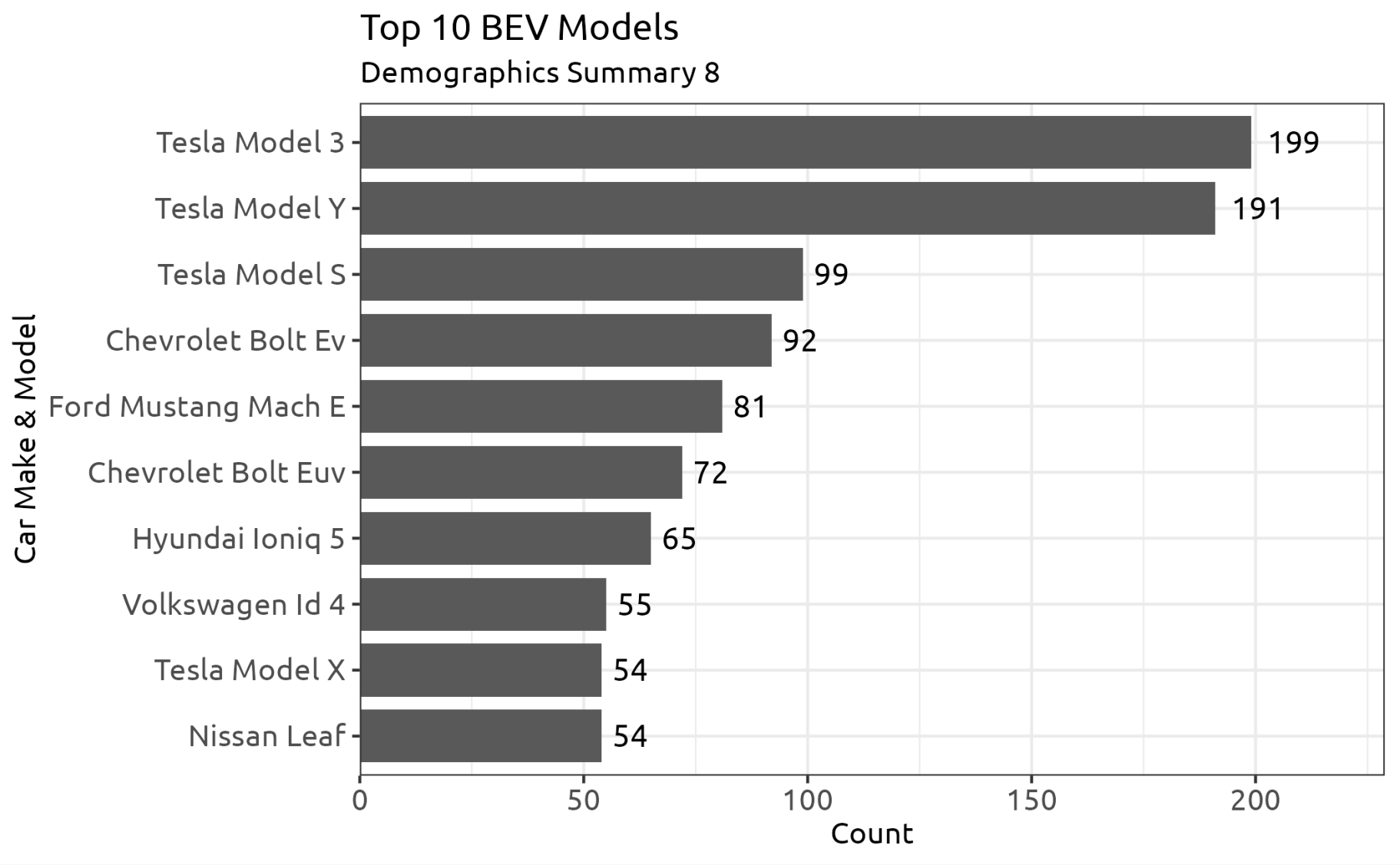
- **553** responses
- September to November in 2024

Facebook Messenger Instagram | dynata

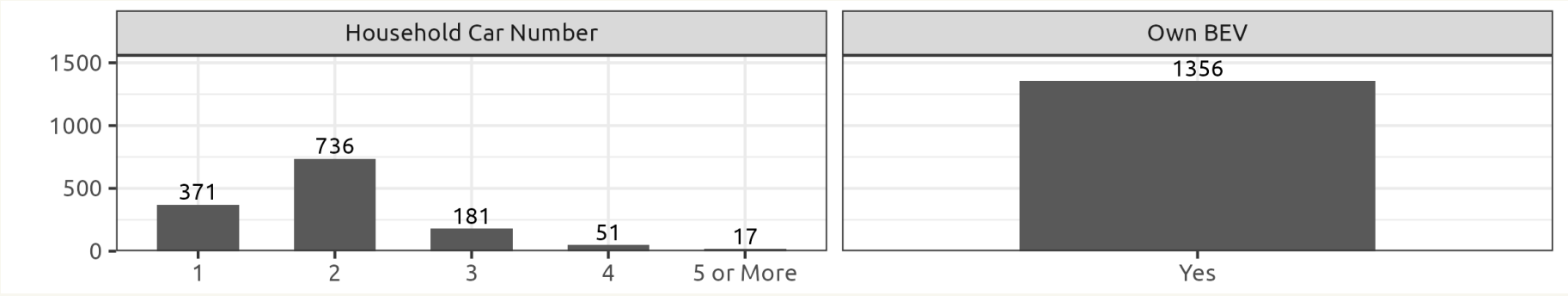
Survey Question - Car Ownership

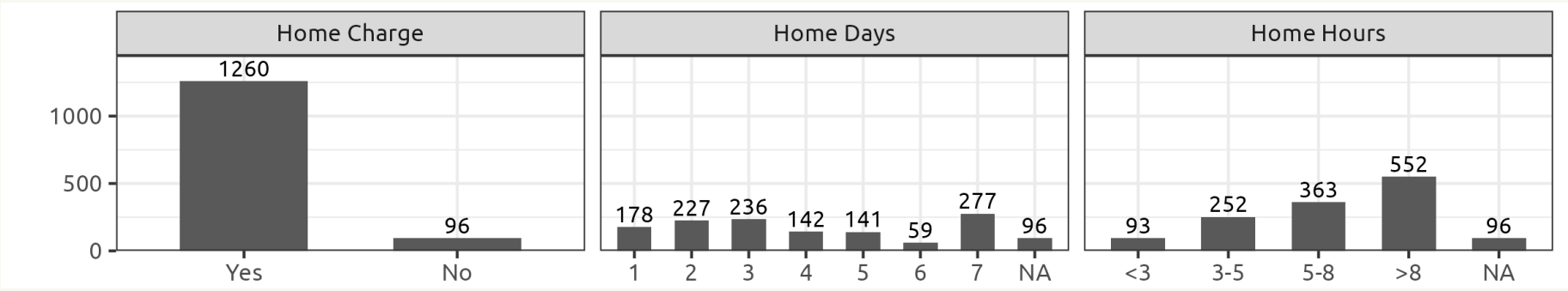


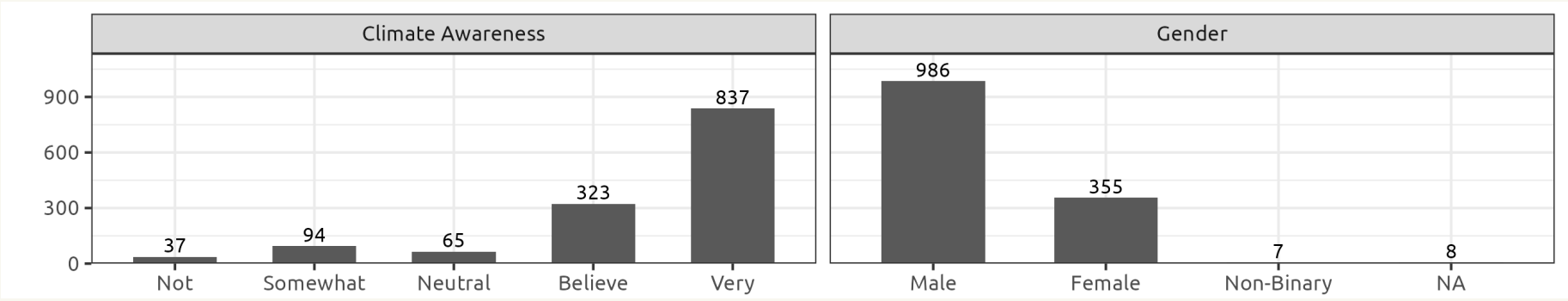
Survey Results - Top 10 BEV



Survey Results - Demographics







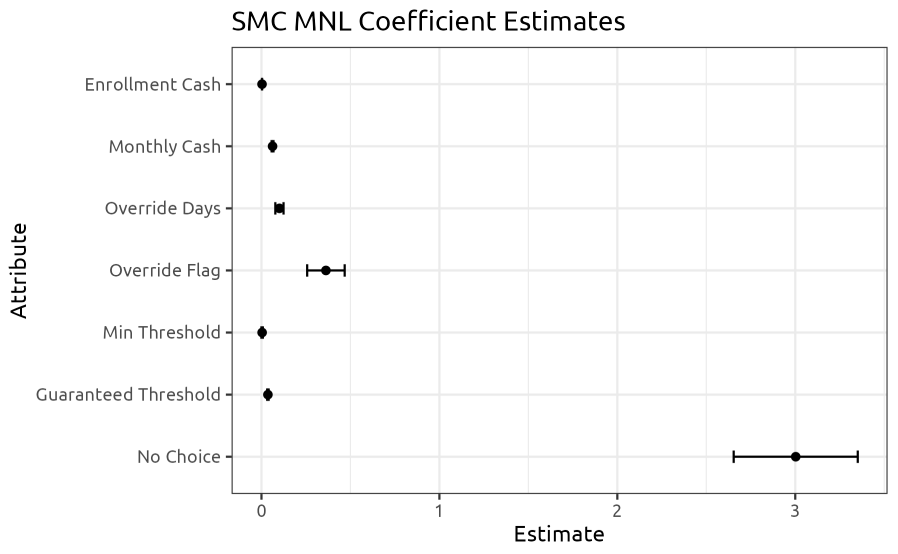
Survey Results - Willingness to Participate

Multinomial Logit Models

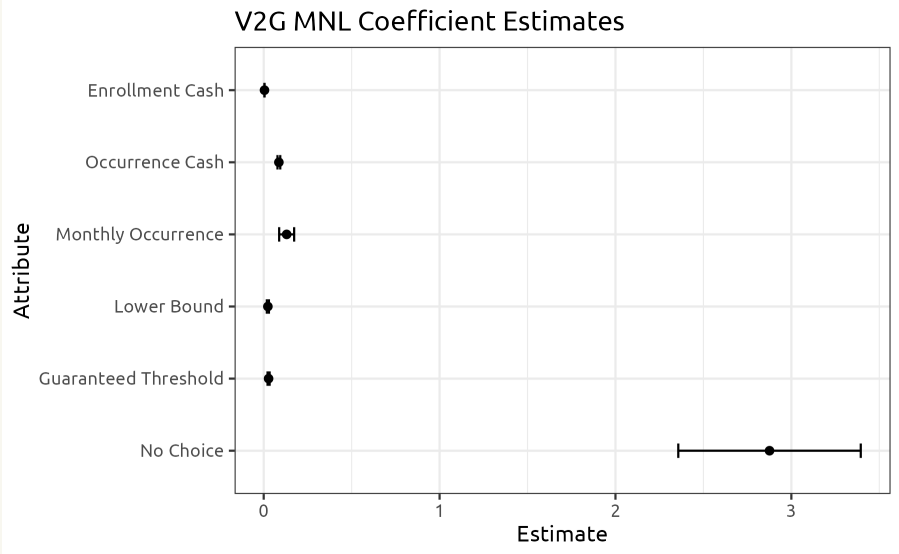
$$u_j = v_j + \epsilon_j = \beta' x + \epsilon_j \qquad P_j = \frac{e^{v_j}}{\sum_{k=1}^{J} e^{v_k}}$$

Utility esimated using maximum likelihood estimation (MLE).

SMC Estimates



V2G Estimates



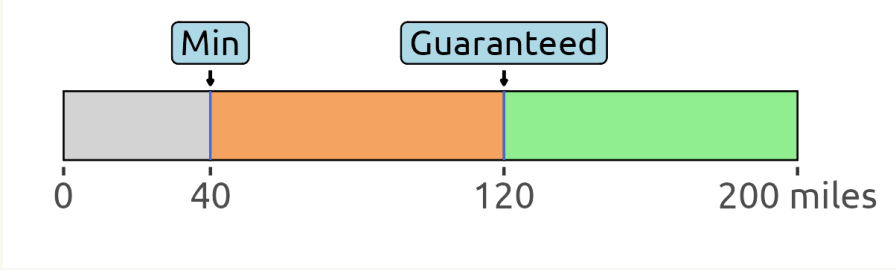
Without compensation, users will not participate.

Enrollment Sensitivity

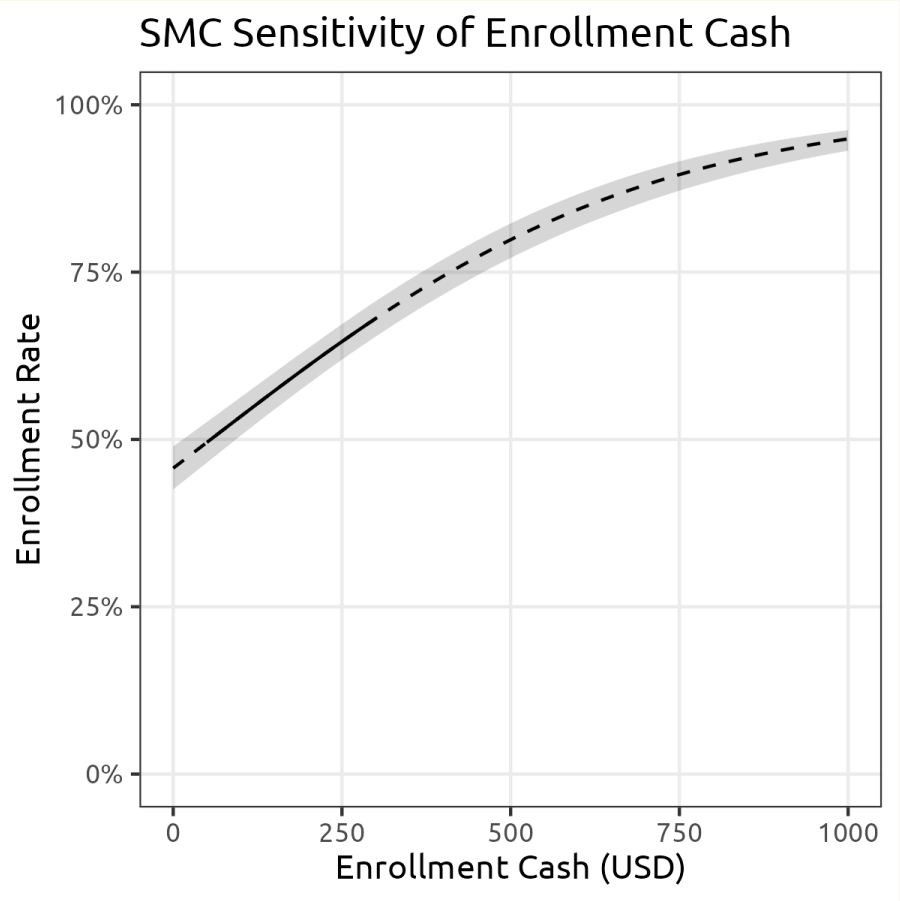
Baseline Simulation

Choice between "None" and this program:

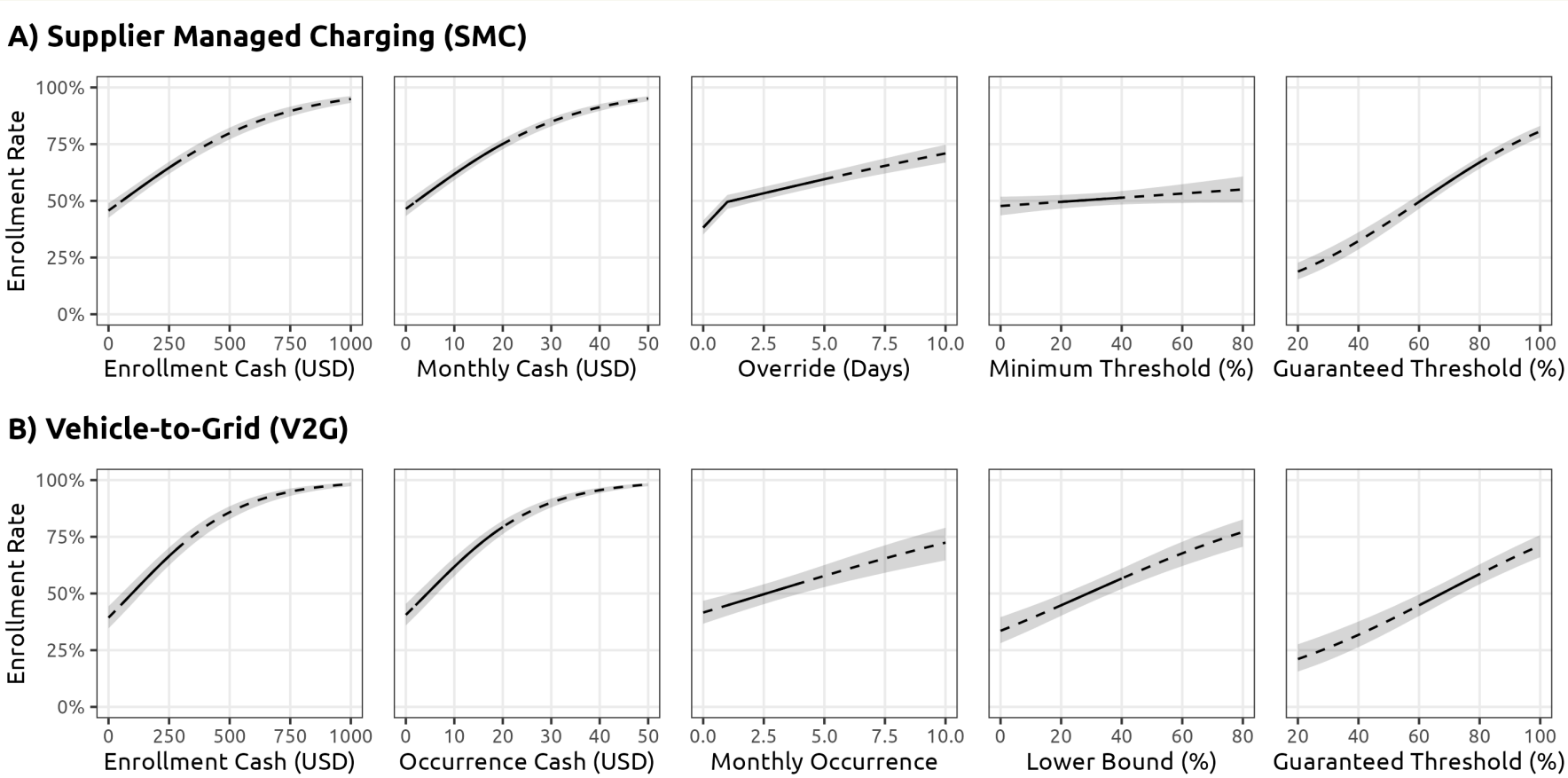
Attributes	Values
Enrollment Cash	$0 - $1000
Monthly Cash	$2
Monthly Override	1



Sensitivity Plot



Enrollment Sensitivity



1. Steeper slope indicates higher sensitivity.
2. Diminishing returns exist.

Equivalencies of 5% Enrollment Increase

SMC

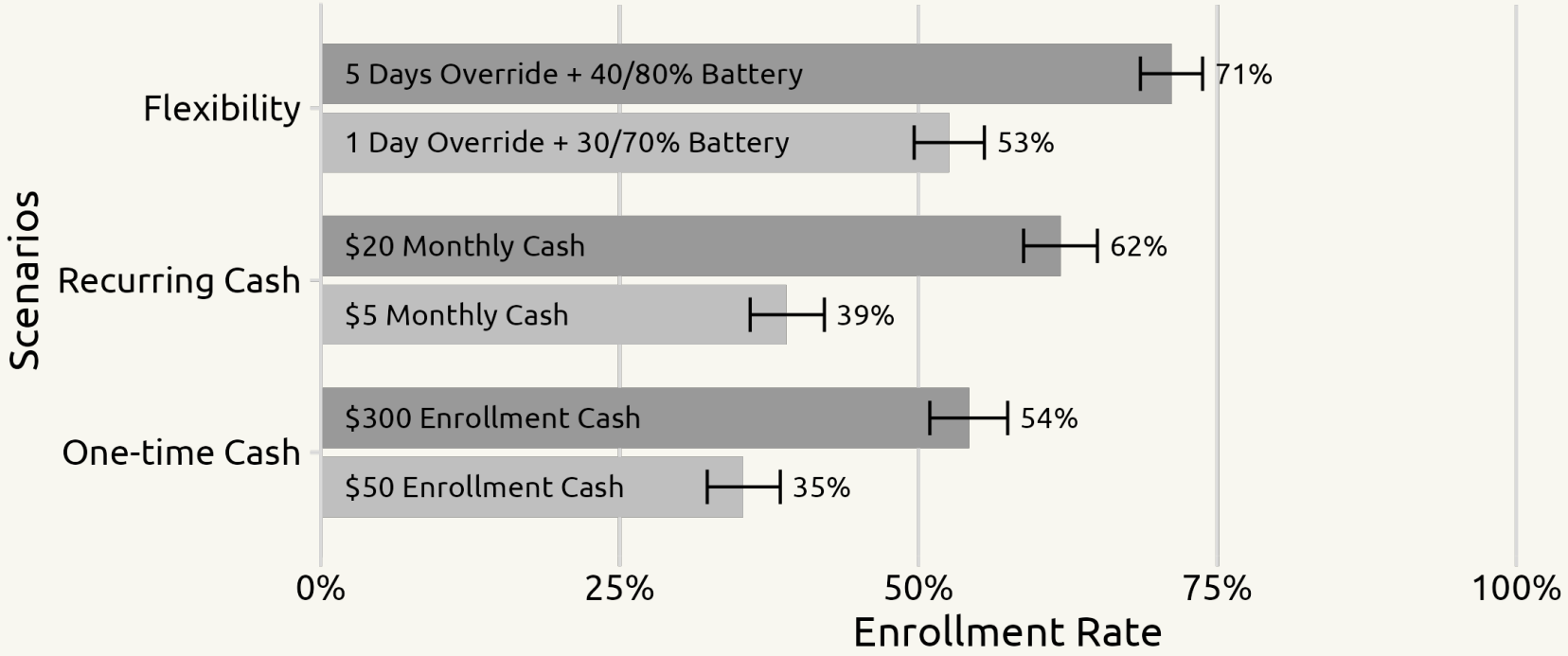
Attribute	Equivalence Value	Unit
Enrollment Cash	64.7	$
Monthly Cash	3.2	$
Override Days	2.0	Days
Minimum Threshold	54.8	%
Guaranteed Threshold	**5.5**	%

V2G

Attribute	Equivalence Value	Unit
Enrollment Cash	**45.0**	**$**
Occurrence Cash	**2.3**	**$**
Monthly Occurrence	1.5	Times
Lower Bound	8.5	%
Guaranteed Threshold	7.2	%

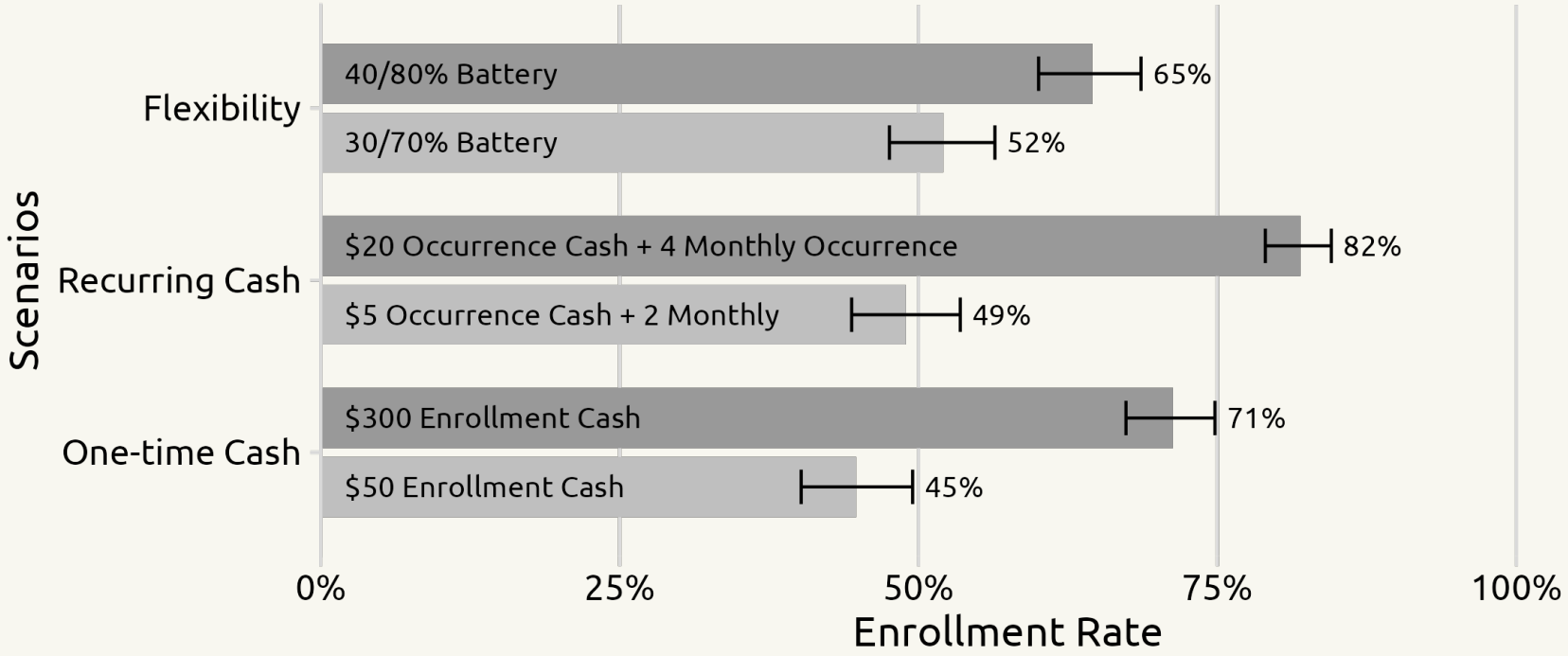
1. **Smaller** value indicates higher efficiency.
2. **Monetary** incentives are valued more in V2G than SMC.
3. **Guaranteed** threshold is more important in SMC than V2G, indicating range anxiety.
4. Attribute equivalencies can be used to inform incentive design.

SMC Scenario Analysis



1. **Flexibility** is highly valued.
2. **Recurring** incentives are more important than one-time.
3. Payment alone is not enough.

V2G Scenario Analysis



1. Still, **recurring** incentives are more important than one-time.
2. But **flexibility** is not as important compared with SMC.
3. Owners are willing to leverage BEV as a source of income.

Smart Charging Enrollment Simulator

Smart Charging Enrollment Simulator | About | SMC (Supplier-Managed Charging) | V2G (Vehicle-to-Grid)

SMC Attributes:

Enrollment Cash ($)

0

Monthly Cash ($)

0

Override Allowance per Month

0

Minimum Threshold (%)

0 20 100

0 10 20 30 40 50 60 70 80 90 100

Guaranteed Threshold (%)

0 60 100

0 10 20 30 40 50 60 70 80 90 100

Reset

Predicted SMC Enrollment Probability:

31.9%

About SMC:

- SMC (Supplier-Managed Charging) allows the utility to monitor, manage, and restrict BEV charging to optimize energy flow during night charging at home.
- By participating in SMC, your BEV will be mostly charged during off-peak periods.

SMC Attributes Explained:

Attribute	Description
Enrollment Cash	The one-time payment you'll receive if you stay for at least 3 months.
Monthly Cash	The recurring monthly payment you'll receive if you don't exceed override allowance.
Override Allowance	The monthly frequency of override to normal charging, effective for 24hrs. If you exceed the limit, no monthly cash for this month.
Minimum Threshold	SMC won't be triggered below this threshold. In the survey it's converted to miles.
Guaranteed Threshold	SMC will give you this much of range by the morning (8 hrs' charging). In the survey it's converted to miles.

Contributions

1. First **large N** study of BEV owners' preferences for smart charging programs.
2. Quantified the **sensitivity** of BEV owners' preferences for smart charging features.
3. Introduced the concept of attribute **equivalencies** to inform incentive design.

Appendix - SMC Logit Model

$$u_j = \beta_1 x_j^{\text{enroll\_cash}} + \beta_2 x_j^{\text{monthly\_cash}} + \beta_3 \delta_j^{\text{override\_allowed}} + \beta_4 x_j^{\text{num\_overrides}} + \beta_5 x_j^{\text{min\_threshold}} + \beta_6 x_j^{\text{guaranteed\_threshold}} + \beta_7 \delta_j^{\text{no\_choice}} + \epsilon_j$$

Attribute	Coef.	Est.	SE	Level	Unit
Enrollment Cash	β_1	0.0031	0.0002	50, 100, 200, 300	USD
Monthly Cash	β_2	0.0623	0.0027	2, 5, 10, 15, 20	USD
Override Days	β_3	0.1010	0.0118	0, 1, 3, 5	Days
Override Flag	β_4	0.3622	0.0538	Yes, No	-
Minimum Threshold	β_5	0.0037	0.0021	20, 30, 40	%
Guaranteed Threshold	β_6	0.0362	0.0021	60, 70, 80	%
No Choice	β_7	3.0026	0.1779	-	-

Appendix - V2G Logit Model

$$u_j = \beta_1 x_j^{\text{enroll\_cash}} + \beta_2 x_j^{\text{occur\_cash}} + \beta_3 x_j^{\text{num\_occurrences}} + \beta_4 x_j^{\text{lower\_threshold}} + \beta_5 x_j^{\text{guaranteed\_threshold}} + \beta_6 \delta_j^{\text{no\_choice}} + \epsilon_j$$

Attribute	Coef.	Est.	SE	Level	Unit
Enrollment Cash	β_1	0.0045	0.0026	50, 100, 200, 300	USD
Occurrence Cash	β_2	0.0863	0.0040	2, 5, 10, 15, 20	USD
Monthly Occurrence	β_3	0.1305	0.0217	1, 2, 3, 4	Times
Lower Threshold	β_4	0.0237	0.0030	20, 30, 40	%
Guaranteed Threshold	β_5	0.0278	0.0030	60, 70, 80	%
No Choice	β_6	2.8759	0.2647	-	-

Reference List

Huang, Bing, Aart Gerard Meijssen, Jan Anne Annema, and Zofia Lukszo. 2021. "Are Electric Vehicle Drivers Willing to Participate in Vehicle-to-Grid Contracts? A Context-Dependent Stated Choice Experiment." *Energy Policy* 156 (September): 112410. https://doi.org/10.1016/j.enpol.2021.112410.

Philip, Thara, and Jake Whitehead. 2024. "Consumer Preferences Towards Electric Vehicle Smart Charging Program Attributes: A Stated Preference Study." Rochester, NY. https://doi.org/10.2139/ssrn.4812923.

Wong, Stephen D., Susan A. Shaheen, Elliot Martin, and Robert Uyeki. 2023. "Do Incentives Make a Difference? Understanding Smart Charging Program Adoption for Electric Vehicles." *Transportation Research Part C: Emerging Technologies* 151 (June): 104123. https://doi.org/10.1016/j.trc.2023.104123.