Can Vehicle-to-Grid (V2G) Revenues Improve Market for Electric Vehicles?

Michael K. Hidrue
George R. Parsons
Willett Kempton
Meryl P. Gardner

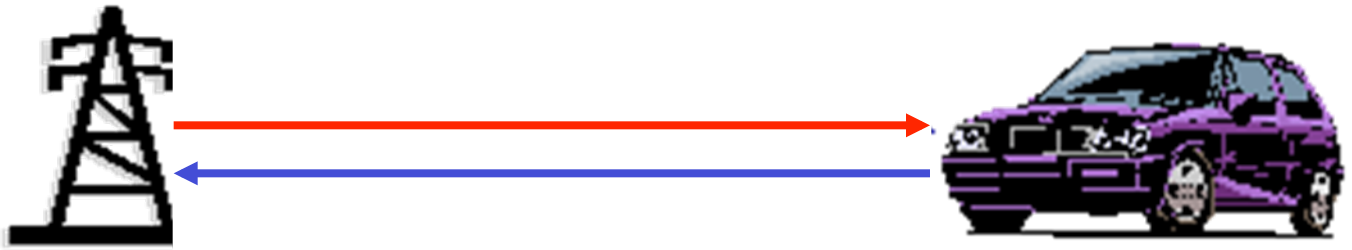
July 7, 2011
International Energy Workshop
Stanford University

Outline

- Background and motivation
- Literature review
- Objectives
- Study design
- Data
- Econometric model
- Estimation results
- Conclusion

Background & Motivation

- What is a V2G Vehicle?



V2G EV

Background & Motivation

- The V2G concept
  - The average US car is parked 95% of the time
  - The power grid requires reserve power
    - Well functioning reserve power market with $12Billion annual market value
  - With a proper design, EVs can provide reserve service to the power grid

UD V2G Vehicle

Background & Motivation

- Advantages of V2G design
  - Payment to EV owners may reduce cost of EVs
    - Kempton and Tomic (2005) estimate upto $2,544 annual payments for an EV owner
  - Improve environmental and energy security benefits of EVs
    - Replace current generators providing reserve service
    - Support renewable sources of energy such as wind and solar energy

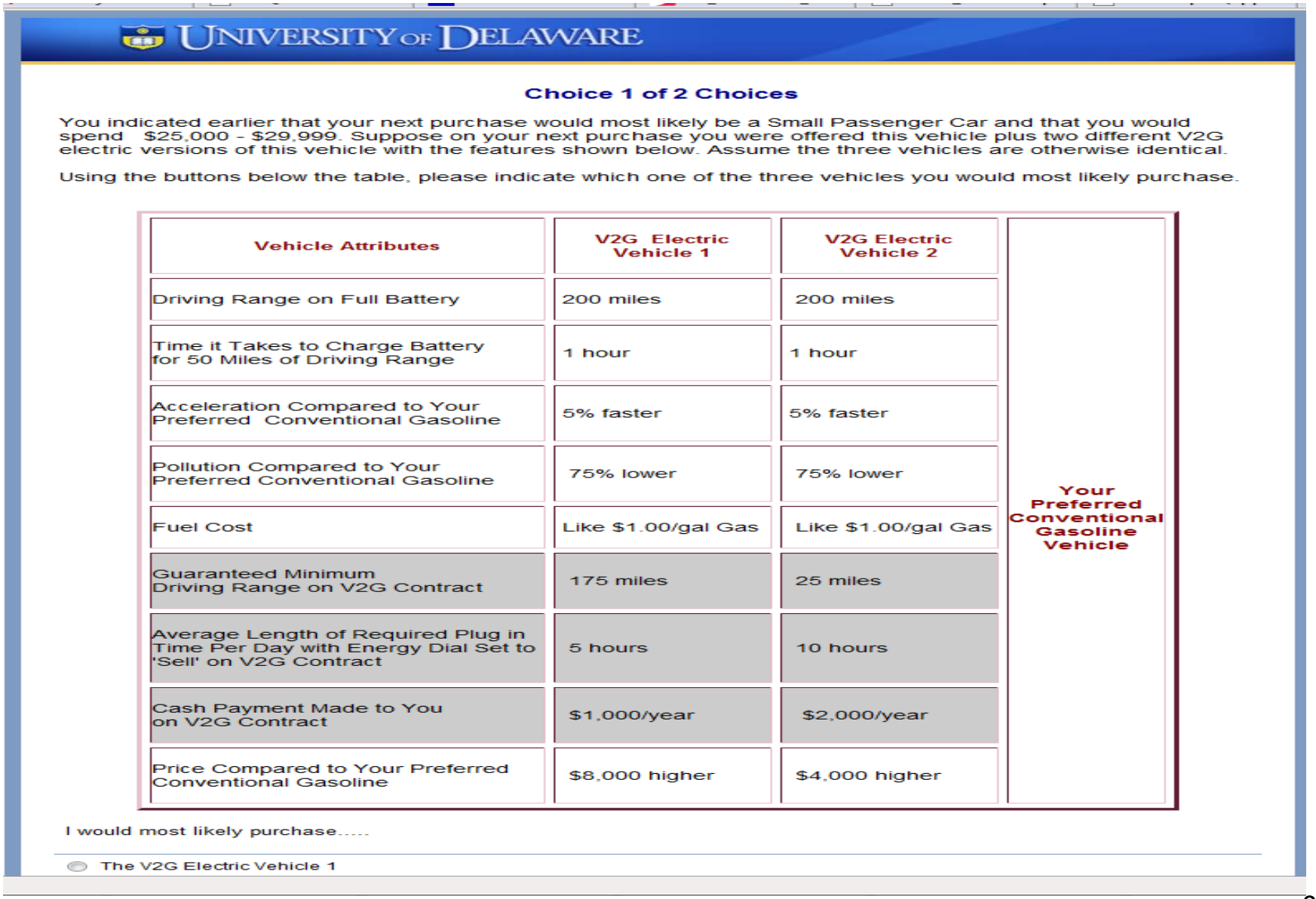
Objectives

- Estimate choice model for V2G vehicles
- Estimate contract prices
- Assess the value of adding V2G on market for EVs

Study Design

- Choice experiment survey to study consumer preference for conventional EVs and V2G vehicles
- The conventional EV survey focused on tradeoff between EV attributes
- The V2G survey focused on tradeoff between V2G contract term attributes

Sample EV Choice Set



UNIVERSITY OF DELAWARE

Choice 1 of 2 Choices

You indicated earlier that your next purchase would most likely be a Small Passenger Car and that you would spend $25,000 - $29,999. Suppose on your next purchase you were offered this vehicle plus two different V2G electric versions of this vehicle with the features shown below. Assume the three vehicles are otherwise identical.

Using the buttons below the table, please indicate which one of the three vehicles you would most likely purchase.

Vehicle Attributes	V2G Electric Vehicle 1	V2G Electric Vehicle 2	Your Preferred Conventional Gasoline Vehicle
Driving Range on Full Battery	200 miles	200 miles	
Time it Takes to Charge Battery for 50 Miles of Driving Range	1 hour	1 hour	
Acceleration Compared to Your Preferred Conventional Gasoline	5% faster	5% faster	
Pollution Compared to Your Preferred Conventional Gasoline	75% lower	75% lower	
Fuel Cost	Like $1.00/gal Gas	Like $1.00/gal Gas	
Guaranteed Minimum Driving Range on V2G Contract	175 miles	25 miles	
Average Length of Required Plug in Time Per Day with Energy Dial Set to 'Sell' on V2G Contract	5 hours	10 hours	
Cash Payment Made to You on V2G Contract	$1,000/year	$2,000/year	
Price Compared to Your Preferred Conventional Gasoline	$8,000 higher	$4,000 higher	

I would most likely purchase.....

The V2G Electric Vehicle 1

Study Design

- V2G contracts
    - Required plug in time (RPT) per day
    - Guaranteed minimum driving range (GMR)
    - Cash back (service payment to EV owners)
    - The higher the RPT and the lower the GMR, the higher the payment

Study Design

- Web based stated preference survey
- Sample drawn from Survey Sampling International (SSI)
- National Survey, N=3029
- Sample resembles national census data

Econometric Model

- Latent class (LC) model
  - Assumes there are S classes of consumers in the population, each with different set of preference
  - Has two sub-models:
    - Class membership model
    - Conditional choice model

Class Membership Model

$$M_{ns} = \theta_s Z_n + \zeta_{ns}$$

Where: M_{ns} is a function relating individual n to class s

Z_n is a vector of individual specific covariates

θ_s is a vector of class specific parameters related to Z_n

ζ_{ns} is an error term

$$Q_{ns} = \frac{\exp(\theta_s Z_n)}{\sum_{s=1}^{S} \exp(\theta_s Z_n)}$$

Where: Q_{ns} is the probability individual n belongs to class s

Conditional RUM Model

$$V_{nj|s} = \beta_s X_{nj} + \varepsilon_{nj|s}$$

Where: $V_{nj|s}$ is individual n's indirect utility function

X_{nj} is vector of vehicle attributes

β_s is class specific vector of parameters

$\varepsilon_{nj|s}$ is an error term

$$\pi_{(nj|s)} = \frac{\exp(\beta_s X_{nj})}{\sum_{j=1}^{J} \exp(\beta_s X_{nj})}$$

Where: $\pi_{(nj|s)}$ is conditional choice probability

Conditional RUM Model

$$V_{nj|s} = \beta_s X_{nj} + \varepsilon_{nj|s}$$

Price
Cash back
GMR
RPT
Yea-saying dummy

Where: $V_{nj|s}$ is individual n's indirect utility function

X_{nj} is vector of vehicle attributes

β_s is class specific vector of parameters

$\varepsilon_{nj|s}$ is an error term

$$\pi_{(nj|s)} = \frac{\exp(\beta_s X_{nj})}{\sum_{j=1}^{J} \exp(\beta_s X_{nj})}$$

Where: $\pi_{(nj|s)}$ is conditional choice probability

Full Model

$$\pi_{nj} = \sum_{s=1}^{S} Q_{ns} * \pi_{(nj|s)}$$

Where: π_{nj} is unconditional choice probability
$\pi_{nj|s}$ is conditional choice probability
Q_{ns} is class membership probability

- π_{nj} allows for taste heterogeneity
- π_{nj} is not restricted by IIA (Swait, 2007; Shonkwiler and Shaw, 2003)
- π_{nj} doesn't allow correlation of choices (Swait, 2007; Greene and Hensher, 2003)

Results: # of Latent Classes

- We estimated the LC model with 2, 3 & 4 classes
- We found 2 class model fit the data better
- …and we labeled the 2 classes as:
  - **Electric Vehicle (EV) class = Highly interested in V2G vehicles**
  - **Gasoline vehicle (GV) class = Less interested in V2G vehicles**
- So who is interested in V2G vehicles and who is less interested in V2G vehicles?

Results: Class Membership Model

Variable	Coefficient	T-stat	Odds ratio
Constant	-2.5	-11.1	0.08
Young (18-35yrs old)	0.65	5.3	1.9
Middle age (36 -55 yrs old)	0.20	1.8	1.2
Having access for installing charger	0.95	9.1	2.6
Expected next vehicle: Hybrid	0.99	9.8	2.7
Tendency to buy new products	0.51	5.8	1.7
Major green	1.01	7.1	2.7
Minor green	0.64	5.4	1.9
Expected gasoline price (in $)	0.05	2.0	1.05
Frequent Long drive	0.25	2.6	1.3

Income, college, vehicle size, multicar, are insignificant in the model

Results: Class Membership Model

- Probability of being in EV class increases with:
  - Young (18-35)
  - Male
  - Being green
  - Hybrid buyer
  - Having access for installing EV charging outlet
  - Like new products
  - Expecting gasoline prices to increase in the coming 5 years
  - Frequent long drive

Results: Class Membership Model

- The following variables have no effect in class membership

- Income
- College education
- Multicar household
- Vehicle size
- Region of the country

Results: Vehicle Choice Model

Attributes	Parameters				Prob. weighted implicit prices
	GV class		EV class		
	Coef.	T-stat.	Coef.	T-stat.	
V2G constant	-2.31	-2.1	2.28	26.6	$12,675
Yea saying	-0.25	-0.95	-0.15	-1.65	
Price (000)	-0.58	-4.0	-0.09	-32.4	
Cash Back (000)	0.42	3.9	-0.35	-9.8	$1.51

Results: Vehicle Choice Model

Attributes	Parameters				Prob. weighted implicit prices
	GV class		EV class		
	Coef.	T-stat.	Coef.	T-stat.	
V2G constant	-2.31	-2.1	2.28	26.6	
	(-$4,414)		**($23,667)**		**$12,675**
Yea saying	-0.25	-0.95	-0.15	-1.65	
Price (000)	-0.58	-4.0	-0.09	-32.4	
Cash Back (000)	0.42	3.9	-0.35	-9.8	
	($0.72)		($2.1)		$1.51

Results: Vehicle Choice Model

Attributes	Parameters				Prob. weighted implicit prices
	GV class		EV class		
	Coef.	T-stat.	Coef.	T-stat.	
V2G constant	-2.31	-2.1	2.28	26.6	
	(-$4,414)		($23,667)		$12,675
Yea saying	-0.25	-0.95	-0.15	-1.65	
Price (000)	-0.58	-4.0	-0.09	-32.4	
Cash Back (000)	0.42	3.9	-0.35	-9.8	
	($0.72)		**($2.1)**		**$1.51**

Results: Vehicle Choice Model (cont.)

Attributes	Parameters				Prob. weighted implicit prices
	GV class		EV class		
	Coef.	T-stat.	Coef.	T-stat.	
Guaranteed Minimum Driving Range (Ref=175 mi)					
125 mi	0.6	0.89	-0.15	3.0	-$500
75 mi	-0.55	-1.3	-0.43	-8.6	-$3,124
25 mi	-1.21	-1.5	-0.77	-13.4	-$5,699
Required Plug-in Time (Ref=5 hrs)					
10 hours	-0.18	-0.22	-0.31	-6.0	-$2,091
15 hours	-1.3	-1.6	-0.51	-9.6	-$4,180
20 hours	-2.9	-4.8	-0.76	-14.4	-$6,950

Results: Vehicle Choice Model (cont.)

Attributes	Parameters				Prob. weighted implicit prices
	GV class		EV class		
	Coef.	T-stat.	Coef.	T-stat.	
Guaranteed Minimum Driving Range (Ref=175 mi)					
125 mi	0.6	0.89	-0.15	-3.0	-$500
75 mi	-0.55	-1.3	-0.43	-8.6	-$3,124
25 mi	-1.21	-1.5	-0.77	-13.4	-$5,699
Required Plug-in Time (Ref=5 hrs)					
10 hours	-0.18	-0.22	-0.31	-6.0	-$2,091
15 hours	-1.3	-1.6	-0.51	-9.6	-$4,180
20 hours	-2.9	-4.8	-0.76	-14.4	-$6,950

Results: Vehicle Choice Model (cont.)

Attributes	Parameters				Prob. weighted implicit prices
	GV class		EV class		
	Coef.	T-stat.	Coef.	T-stat.	
Guaranteed Minimum Driving Range (Ref=175 mi)					
125 mi	0.6	0.89	-0.15	-3.0	-$500
75 mi	-0.55	-1.3	-0.43	-8.6	-$3,124
25 mi	-1.21	-1.5	-0.77	-13.4	-$5,699
Required Plug-in Time (Ref=5 hrs)					
10 hours	-0.18	-0.22	-0.31	-6.0	-$2,091
15 hours	-1.3	-1.6	-0.51	-9.6	-$4,180
20 hours	-2.9	-4.8	-0.76	-14.4	-$6,950

Results: Vehicle Choice Model (cont.)

Attributes	Parameters				Prob. weighted implicit prices
	GV class		EV class		
	Coef.	T-stat.	Coef.	T-stat.	
Guaranteed Minimum Driving Range (Ref=175 mi)					
125 mi	0.6	0.89	-0.15	3.0	-$500
75 mi	-0.55	-1.3	-0.43	-8.6	-$3,124
25 mi	-1.21	-1.5	-0.77	-13.4	-$5,699
Required Plug-in Time (Ref=5 hrs)					
10 hours	-0.18	-0.22	-0.31	-6.0	-$2,091
15 hours	-1.3	-1.6	-0.51	-9.6	-$4,180
20 hours	-2.9	-4.8	-0.76	-14.4	-$6,950

What We Found….

- People discount revenue from V2G contracts heavily
- People associate high inconvenience cost with V2G contracts
- Can revenue from V2G power help improve market for EVs?

The Question…

- People discount revenue from V2G contracts heavily
- People associate high inconvenience cost with V2G contracts
- Can revenue from V2G power help improve market for EVs?

The Question…

- Can power companies pay people more than the perceived inconvenience cost?

- To answer this…
  - We estimate inconvenience cost for different contracts
  - Assess if power companies can pay those costs

Implicit Annual Contract Prices

Contract Scenario	GMR (mi)	RPT (hrs)	Annual Contract Price
A	75	5	$1,850
B	75	10	$3,023
C	75	15	$4,713
D	75	20	$7,106
E	25	5	$3,547
F	25	10	$4,719
G	25	15	$6,408
H	25	20	$8,801

Implicit Annual Contract Prices

Contract Scenario	GMR (mi)	RPT (hrs)	Annual Contract Price
A	75	5	$1,850
B	75	10	$3,023
C	75	15	$4,713
D	75	20	$7,106
E	25	5	$3,547
F	25	10	$4,719
G	25	15	$6,408
H	25	20	$8,801

Can power companies pay these prices?

How much can EVs earn from the power market?

- Kempton and Tomic (2005) estimated the max revenue a Toyota RAV4 EV can earn for 18hrs of RPT and 20 miles of GMR is $2,972

- For a similar contract, our estimates shows consumers will ask $6408

Conclusion

- With a contract, the V2G concept is unlikely to help EVs in the market
- We suggest contracts should be eliminated

Acknowledgment

- U.S. Department of Energy, Office of Electricity
- Sustainable Energy Research Center, Mississippi State University

Thank you

- …and any question