Assessing Consumer Preferences for Alternative Fuel Vehicles and Autonomous Driving Technology

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Outline

- Assessment of consumer preferences for alternative fuel vehicles (AFVs) and autonomous driving technology
  - Plug-in hybrid (PHEV), electric (EV) & fuel cell (FCV), hybrid (HEV), clean diesel (CDV)
  - Autonomous driving and driving assistance (Levels 0 - 3)
  - Factors affecting consumers' purchase decision
- Best—Worst Scaling (BWS)
  - Choice modeling with Best & Worst choices
  - Multi-profile case (Case 3)

AFV Policies in Japan

- Pricing policies: One-time reduction
  - Clean energy vehicles (CEV) subsidy
    - FCV (2 million yen), EV (0.4 million yen), plug-in hybrid (0.2 million yen)
  - Local governments subsidy for CEV
    - EV: 0.05 million yen by the city of Yokosuka
  - Eco-car tax exemption
    - 0.15 million yen
- Infrastructure subsidy
  - Charging facilities and station of electricity and hydrogen

Deployment of Hydrogen Station

- 134 stations operating in Japan, as of January 1, 2021
  - Hokkaido (2), Tohoku (5), Hokuriku (2), Kanto (51), Chubu (35), Kinki (18), Chu-Shikoku (8), Kyushu (13)
  - Government goal: By 2025, 320 stations
  - In 2018, self-service refueling approved
  - In March 2020, unmanned hydrogen station to open
- Optimum deployment of hydrogen station (Itaoka, et al., 2019)
  - 200: Tokyo, Nagoya, Osaka + prefectural capital
  - 400: 100 - 200 thousand population cities
  - 2500: Difficult to achieve refueling convenience comparable to ICEVs
- Hydrogen station and business hours
  - Average business hours: 34.3 hours/week, 4.9 hours/day
  - Less operation on weekends, holidays, and evenings, low convenience for individual users

Current Status and Issues of Fuel Cell Vehicles

- Passenger vehicle
  - Toyota: In 2014, launch of MIRAI. Total sales about 10,000. New model released in Dec. 2020
  - Honda: In 2016, launch of CLARITY Fuel Cell. Total sales (lease only) 1,600
  - Hyundai: By 2018, sold about 1,000. In 2020, more than 10,000
  - Nissan, Ford, Daimler. In 2017, suspension of joint development plan
- Commercial vehicle/truck/bus
  - Toyota & Hino: In 2018, launch of a bus, "SORA." Total sales about dozens. Partnership with China and U.S. companies
  - Isuzu & Honda: Joint development of FC truck
  - Mitsubishi Fuso: Concept car of a small truck was released
- Electric vehicles (EV), plug-in hybrid (PHEV), fuel cell vehicles (FCV)
  - Nissan Leaf 3.32 mil., Toyota PRIUS PHV 3.23 mil., Toyota MIRAI 7.4 mil., Honda Clarity Fuel Cell 7.83 mil., Honda Clarity PHEV 5.98 mil.
  - Japan (as of Sep. 2019): quick charge (7,800), normal charge (22,500) + home
  - CEV subsidy: FCV (2 mil. Yen), PHEV (200,000 yen), EV (56,000 – 400,000 yen)
  - Charging, fueling place and time, brand availability, fuel cost, CO_2 emissions

Choice Modeling and Valuation

- Best–worst scaling study of AFV is a new modeling approach to assess consumer preferences
- Discrete choice experiments (DCEs)
  - Choose the most important profile (goods) with several attributes and levels
  - Most of the AFV valuation studies applied DCEs
    - Liao et al. (2017) reviewed 26 choice modeling studies and considered the factors affecting consumer preferences
- Best–Worst Scaling: BWS
  - Pick the best & worst options
  - Advantages when facing usual (possible) and unusual (impossible) choice scenario
  - Analyzing the data from a best–worst exercise for analysis is less straightforward than that in traditional DCEs

Model Specification of Multi-Profile Case

- Combination of Best and Worst
  - J (J-1) = 4×3 = 12
  - J = 4 (traditional DCE)
- Probability to choose *i* as Best, and *i'* *as* Worst ($i \neq i'$)
- $$P_{BW}(ii'|X) = \frac{\exp \beta'(x_i - x_{i'})}{\sum_{\substack{j,j' \in X \\ j' \neq j}} \exp \beta'(x_j - x_{j'})}$$

Data Collection

- Online questionnaire survey in Japan
- Samples: 2,096 monitors with a valid driver's license
- Survey in March 2019
- Male and female 50%
- Age groups: teens (16.0%), 20s (16.8%), 30s (16.8%), 40s (16.8%), 50s (16.8%), and 60s and older (16.8%).
- Car owner (80.3%), non-user (18.3%), car sharing (1.3%)
- Regions in which respondents live
  - Tokyo (10.6%), Osaka (8.2%), Kanagawa (7.0%), Saitama (5.8%), Aichi (5.8%), Hyogo (5.4%)

Survey Design: Attributes

- Overview of financial, technical and infrastructure attributes of valuation studies (Liao et al. 2017)
  - Purchase price
  - Operation cost (price per 100 km, gasoline)
  - Driving range (range after full charge, weather condition)
  - Charging/refueling time (normal and quick charge)
  - Engine power, acceleration time, maximum speed
  - Reduction of CO_2 and pollutants emission
  - Brand
  - Brand diversity (number of brands available)
  - Warranty (battery)
  - Charging availability (distance, congestion)

Survey Design

- The orthogonal fractional factorial designs. 16 choice sets, each comprising four profile types with five attributes and four levels
- Each respondent was given eight different choice sets and one common profile that had the same price level for each profile
- Attributes of the profile are engine and/or motor type, reduction of CO_2 emissions, purchase price, operation cost (fuel/electricity) per 100 km, and maximum driving distance after filling up or at full charge
- Engine types were gasoline, HEV, CDV, PHEV, EV, and FCV
- Respondents to bear an additional financial burden to purchase AFVs compared with purchasing a conventional gasoline car, which has the lowest purchase price
- The purchase price of AFVs was established at up to 1.1 mil. yen

Survey Design (Attribute)

- When a respondent buy a passenger car, there are four types of cars that have six different engine/motor. The respondent choose the best and worst car among four alternatives (profiles)
- ① Engine/motor
  - Gasoline, FCV, EV, PHEV, CDV, HEV
- ② Purchase price (gasoline + _XX_yen higher)
  - Based on gasoline cars, let respondents assume the desired price, and set other models to be more expensive than the gasoline cars
- ③ Autonomous driving level (+additional cost)
  - Levels 0, 1, 2, and 3. Level 1(+80 thousand yen), Level 2 (+200 thousand yen), Level 3 (+800 thousand yen)
- ④ Fuel/electricity (operation) cost (100km drive)
- ⑤ Maximum driving range
- ⑥CO_2 emissions (compared with a normal gasoline car)
- Four levels for each attribute: Purchase price, operation cost, driving range, CO_2 emissions

Attributes and Levels

	Level	1	2	3	4	5
Engine/motor		FCV	EV	PHEV	CDV	HEV
Purchase	FCV	110	140	170	200	
price	EV	50	70	90	110	
(+10 thousand yen)	PHV	50	70	90	110	
	CDV	20	30	40	50	
	HEV	20	30	40	50	
Operation cost	FCV	600	800	1000	1200	
(yen/100km)	EV	100	200	300	400	
	PHV	400	500	600	700	
	CDV	600	700	800	900	
	HEV	500	600	700	800	

Attributes and Levels (cont.)

	Level	1	2	3	4
Driving range	FCV	750	700	650	600
(km)	EV	550	450	350	250
	PHV	1150	1050	950	850
	CDV	900	800	700	600
	HEV	1100	1000	900	800
CO_2	FCV	80	60	40	20
(% reduction)	EV	90	80	70	60
	PHV	70	60	50	40
	CDV	10	5	0	-5
	HEV	50	40	30	20
Autonomous		Level 0	Level 1	Level 2	Level 3

SAE Automation Levels

Level	Who does what, when
0	No automation
1	Driver assistance (hands on)
2	Partial automation (hands off)
3	Conditional automation (eyes off)
4	High automation (mind off)
5	Full automation (steering wheel optional)

Note: Society of Automotive Engineers (SAE)

Levels of Driving Automation
(Society of Automotive Engineers (SAE))

- Level 0 (no automation): Zero autonomy; the driver performs all driving tasks
- Level 1 (driver assistance): Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design
- Level 2 (partial automation): Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all the times
- Level 3 (conditional automation): Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice
- Level 4 (high automation): The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle
- Level 5 (full automation): The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle

Benefits of Driving Automation for a Driver

- Level 0 (no automation): The human driver does all the driving.
- Level 1 (driver assistance): An advanced driver assistance system (ADAS) on the vehicle can sometimes assist the human driver with either steering or braking/accelerating, but not both simultaneously
- Level 2 (partial automation): An advanced driver assistance system (ADAS) on the vehicle can itself actually control both steering and braking/accelerating simultaneously under some circumstances. The human driver must continue to pay full attention ("monitor the driving environment") at all times and perform the rest of the driving task
- Level 3 (conditional automation): An Automated Driving System (ADS) on the vehicle can itself perform all aspects of the driving task under some circumstances. In those circumstances, the human driver must be ready to take back control at any time when the ADS requests the human driver to do so. In all other circumstances, the human driver performs the driving task
- Level 4 (high automation): An Automated Driving System (ADS) on the vehicle can itself perform all driving tasks and monitor the driving environment – essentially, do all the driving – in certain circumstances. The human need not pay attention in those circumstances
- Level 5 (full automation): An Automated Driving System (ADS) on the vehicle can do all the driving in all circumstances. The human occupants are just passengers and need never be involved in driving

Respondent Awareness of Autonomous Driving Technology

Interest in autonomous driving technology

	persons	(%)
Very interested	207	(9.9%)
Interested	391	(18.7%)
Somewhat interested	589	(28.1%)
Neutral	350	(16.7%)
Not so interested	298	(14.2%)
Not interested	107	(5.1%)
Not interested at all	154	(7.3%)

} 56.7%

Awareness of Autonomous Driving from Level 0 to 5

If you use a self-driving car, answer the level you want at the present time without considering the cost, purchase price, etc.

Level	Persons	(%)
0 No automation	296	(14.1%)
1 Driver assistance	459	(21.9%)
2 Partial automation	461	(22.0%)
3 Conditional automation	265	(12.6%)
4 High automation	266	(12.7%)
5 Full automation	341	(16.3%)

Summary of Crosstab Results of Autonomous Driving

- Gender: Male respondents are likely to be significantly higher than female respondents, regarding reliability and interests
- Age group: Different preferences for different age groups
  - Response rate for level 2 and level 3 was higher than those of other generations in their 60s or older
  - For teens, levels 0 to 2 tend to be higher and level 5 lower
  - The proportion of respondents at all levels in their 30s was nearly uniform compared to other generations
  - Households that do not own a car tend to be more interested in autonomous driving

BWS Multi-Profile Case

"There are four types of engines (/motors) as well as a conventional gasoline engine sold by a certain automobile manufacturer. Which are the most attractive and the most unattractive vehicles when you consider buying? Please select one by one. There are eight different questions."

Attribute	Car A	Car B	Car C	Car D
Engine/motor	Gasoline	EV	PHEV	FCV
Fuel/electricity	Gasoline	Electricity	Gasoline & Electricity	Hydrogen
Purchase price (+ thousand yen)	Asking price	+700	+300	+2000
Operation cost (yen/100km)	1,200	300	800	1200
Autonomous level	Level 0	Level 3	Level 1	Level 2
Driving range	600 km	250 km	800 km	600 km
CO_2 emissions (reduction)	0%	70%	40%	20%

I am most likely to choose				✓
I am least likely to choose	✓			

BWS Multi-Profile Case: RPL Estimation Results

Variable	With autonomous		w/o autonomous	
	mean	std.dev.	mean	std.dev.
Dummy_FCV	0.00269	0.0304	0.0819	0.0182
Dummy_EV	0.304***	0.0414	0.514***	0.100
Dummy_PHEV	0.229**	0.0479	0.413***	0.0275
Dummy_CDV	-0.180***	0.0014	-0.0308	0.0217
Dummy_HEV	0.593***	0.372***	0.735***	0.577***
Purchase price	-0.00655***	0.00669***	-0.00730***	0.00620***
Autonomous: Level 1	0.154***	0.0105	–	–
Autonomous: Level 2	0.0977***	0.210***	–	–
Autonomous: Level 3	0.0811***	0.161	–	–
Fuel/electricity cost	-0.00024***	0.00051***	-0.00014*	0.00090***
Driving range	0.00063***	0.000064	0.00067***	0.00037
CO_2 reduction	0.00038	0.0013	0.00098	0.01145***
Pseudo R^2	0.0676		0.0731	

Note: n=8384. ***, **, * denote statistical significance at 1%, 5%, and 10%, respectively.

Marginal Willingness to Pay (MWTP)

(thousand yen)

Attribute	With autonomous	w/o autonomous
	MWTP [95% C.I.]	MWTP [95% C.I.]
FCV	4.1 [-289.5, 297.7]	112.2 [-160.5, 384.8]
EV	464.5 [169.7, 759.2]	704.1 [438.7, 969.4]
PHEV	349.8 [83.1, 616.6]	566.1 [324.0, 808.1]
CDV	-274.9 [-470.0, -79.7]	-42.3 [-206.1, 121.6]
HEV	904.8 [686.1, 1123.5]	1007.7 [804.0, 1211.5]
Autonomous: Level 1	235.1 [144.4, 325.7]	-
Autonomous: Level 2	149.0 [65.1, 233.0]	-
Autonomous: Level 3	123.7 [35.0, 212.5]	-
Fuel/electricity cost	-0.36 [-0.62, -0.11]	-0.19 [-0.43, 0.05]
Driving range	0.96 [0.62, 1.29]	0.91 [0.61, 1.22]
Reduction of CO_2	0.59 [-1.68,2.85]	1.34 [-0.78, 3.47]

Note: 95% Confidence Interval [lower bound, upper bound].

Latent Class Model Results

		With autonomous			w/o autonomous		
		Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
Choice	FCV	-0.674***	-0.0398	1.727***	-2.507***	-0.00838	1.331***
	EV	-0.387	0.312	2.241***	-1.233	0.368**	2.092***
	PHEV	-0.165	-0.336	2.411***	-0.768	0.242*	1.821***
	CDV	-0.481***	-0.145	0.533**	-1.390**	-0.0322	0.577**
	HEV	0.0148	0.567***	2.357***	0.745	0.431***	2.324***
	Purchase price	-0.00918***	-0.00310***	-0.00930***	-0.0155***	-0.00543***	-0.00749***
	Autonomous: Level 1	0.0953	0.140***	0.458***	–	–	–
	Autonomous: Level 2	0.0860***	0.0694	0.185*	–	–	–
	Autonomous: Level 3	-0.0625***	0.0987*	0.315***	–	–	–
	Fuel/electricity cost (yen/100km)	0.00014	-0.00032**	-0.00079**	0.00123*	0.0000269	-0.00082**
	Driving range (km)	0.00021	0.00097***	0.00063*	-0.00168*	0.00076***	0.00072*
	Reduction of CO_2 emissions (%)	0.00045	-0.00035	0.00103	-0.00207	-0.00077	0.00943***
Respondent	Constant.	0.428	6.483***	–	-1.302***	1.268***	–
	Gender (male)	1.721***	0.393	–	1.063***	0.767***	–
	Age	-0.0364***	-0.134***	–	0.0237***	-0.0361***	–
	Household income	-0.00079***	0.00000171	–	-0.00137***	0.00014	–
	Detached own house	0.0407	0.199	–	-0.366**	0.0478	–
	Inconvenient public transportation	-0.0835	-0.00289	–	0.544**	0.0710	–
	Owner of next-generation vehicles	-2.367***	0.646	–	-11.111	-2.354***	–
	Car owner	2.342***	-0.0232	–	2.619***	1.746***	–
	Car price more than 5 million yen	1.792***	-3.881	–	62.103	61.352	–
	Interest in autonomous driving technology	-0.612***	0.935***	–	–	–	–
	Preference for autonomous Level 4 & 5	-1.022***	-0.177	–	–	–	–
	Will buy a light car	0.412***	-0.454*	–	-0.0113	-0.119	–
	Expected price for the experiment	0.0000415	-0.00201**	–	-0.0107***	-0.00017	–
Class probability		0.381	0.435	0.184	0.103	0.691	0.207
# of observations		8384			8384		
Log likelihood		-18785.5			-18797.8		

Note: ***, **, * denote statistical significance at 1%, 5%, and 10%, respectively.

Latent Class Model Results (Excerpt)

	With autonomous		
	Class 1	Class 2	Class 3
Constant.	0.428	6.483***	–
Gender (male)	1.721***	0.393	–
Age	-0.0364***	-0.134***	–
Household income	-0.00079***	0.00000171	–
Detached own house	0.0407	0.199	–
Inconvenient public transportation	-0.0835	-0.00289	–
Owner of next-generation vehicles	-2.367***	0.646	–
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Car price more than 5 million yen	1.792***	-3.881	–
Interest in autonomous driving technology	-0.612***	0.935***	–
Preference for autonomous Level 4 & 5	-1.022***	-0.177	–
Will buy a light car	0.412***	-0.454*	–
Expected price for the experiment	0.0000415	-0.00201**	–
Class probability	0.381	0.435	0.184
# of observations	8384		
Log likelihood	-18785.5		

Note: ***, **, * denote statistical significance at 1%, 5%, and 10%, respectively.

BWS Multi-Profile Case: Interaction Terms

Variable	With autonomous	w/o autonomous
Dummy_FCV	-0.0720	-0.0333
Dummy_EV	0.327***	0.487***
Dummy_PHEV	0.230**	0.349***
Dummy_CDV	-0.162***	-0.0228
Dummy_HEV	0.583***	0.637***
Purchase price	-0.00545***	-0.00552***
Autonomous: Level 1	0.155***	-
Autonomous: Level 2	0.0936***	-
Autonomous: Level 3	-0.00633	-
Fuel/electricity cost	-0.131*	-0.0000247
Driving range	0.000560***	0.000585***
CO_2 Reduction	0.00884***	0.00598***

Note: n=8384. ***, **, * denote statistical significance at 1%, 5%, and 10%, respectively.

BWS Multi-Profile Case: Interaction Terms (cont.)

Variable	With autonomous	w/o autonomous
CO_2×male	-0.00606***	-0.00295***
CO_2×h-income	0.00000361***	0.00000402***
CO_2×carowner	-0.00973***	-0.00791***
Level2×60&older	0.260***	-
Level3×60&older	0.118**	-
Level3×AutoD-interest	0.162***	-
Level3×AutoD4&5	0.226***	-
FCV×h-income	0.000111	0.000131**
FCV×knowledge	0.529***	0.509***
FCV×ExpP6mil.&higher	0.726***	-0.107
EV×rental-apartment	-0.0713*	0.00484
EV×NGMuse	0.272***	0.466***
EV×CarP5mil.&higher	-0.455***	0.105
EV×knowledge	0.134*	-0.267***
EV×driveDistance	0.00000205**	-0.00000411***
HEV×InconvResidence	-0.188**	-0.128
HEV×knowledge	0.260**	0.0686
PHEV×knowledge	0.463***	0.329***
CDV×knowledge	0.371***	0.428***

Note: n=8384. ***, **, * denote statistical significance at 1%, 5%, and 10%, respectively.

Results and Discussion

- FCV was not statistically significant but incorporating interaction terms and LCM revealed the conditions to be selected
  - Knowledge, income, NGM owner, etc.
- CDV was negative, and other next-generation models were positive
- Driving range was significant only for mean parameter
- Reduction of CO_2 emissions was not significant
  - But it was statistically significant when a gasoline car was used as a dummy variable (ASC)
  - Interaction terms were useful to reveal the conditions. Female, higher household income, respondents who do not own a private car
- Autonomous driving was statistically significant at all levels
  - The coefficient value of Level 1 was the largest
  - Only Level 2 showed the differences in consumer preferences

Conclusions

- Advantage of BWS application to the comparison of vehicles with high awareness of the power source mechanism (gasoline, HEV, CDV) and vehicles with low awareness (PHEV, EV, FCV)
- A high preference for Level 1, implemented in many cars, and Level 2 had a variety of preferences. Option equipment price might be affected
- It is necessary to establish legal systems, and reduce costs to achieve Level 3 and Level 4 where accident responsibility switches from drivers to the system
- If consumer awareness changes, it may increase acceptance of autonomous driving technology and drive the spread of autonomous driving technology