Applying Best–Worst Scaling to Assess Consumer Preferences for Alternative Fuel Vehicles in Japan

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Outline

- Japanese consumers' preferences for alternative fuel vehicles (AFVs)
- Best–Worst Scaling (BWS)
  - Choice modeling with <u>Best</u> & <u>Worst</u> choices
- Multi-profile case (case 3)
  - Hybrid (HEV)
  - Plug-in hybrid (PHEV)
  - Clean diesel (CDV)
  - Electric vehicle (EV)
  - Gasoline

Alternative Fuel Vehicles and GHGs Emissions

- Widespread adoption of AFV may contribute to the alleviation of climate change and air pollution (Liao et al. 2017)
  - The current global penetration of AFV is relatively low in spite of governments implementing strong promotion policies
- Global electric vehicle (EV) shift
- New energy vehicle (NEV) mandate policy in China, and zero emission vehicle (ZEV) program in the state of California
  - CASE (Connected, Autonomous, Shared, Electric)
- 18% of GHGs from automobile sector in Japan
  - Decrease by 11.9% from 2005 and 18.3% from the 2001 highest level
    - Improved fuel economy and logistics
  - HEV, PHEV, EV, and FCV
    - New model launch of the best selling EV (LEAF, Nissan; 62kWh)

The Yearly Sales of New Cars and Targets

Japan car market	2017	(thousand)	2030 target
Last generation model	63.6%	2,791	30 – 50%
Next generation model	36.4%	1,595	50 – 70%
Hybrid	31.6%	1,385	30 – 40%
Electric (BEV)	0.41%	18	20 – 30%
Plug-in hybrid	0.82%	36	
Fuel cell	0.02%	0.849	- 3%
Clean diesel	3.5%	155	5 – 10%

Nissan LEAF (BEV)

Toyota MIRAI (FCV)

AFV Policies in Japan

- Pricing policies: One-time reduction
  - Clean energy vehicles (CEV) subsidy
    - e.g., fuel cell vehicle (2 million yen), EV: LEAF & TESLA (400 thousand yen), plug-in hybrid (200 thousand yen)
  - Local governments subsidy for CEV
    - e.g., LEAF, 50 thousand yen by the city of Yokosuka
  - Eco-car tax reduction
    - e.g., LEAF, 150 thousand yen
- Infrastructure subsidy
  - Charging facilities and station of electricity and hydrogen

Choice Modeling and Valuation

- Best-worst scaling study of AFV is a new modeling approach to estimate 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

Data Collection

- Online questionnaire survey in Japan
- Survey in January 2019
- Samples: 3,100 monitors with a valid driver's license
  - Of the respondents, 81.5% had at least one vehicle in their household
- Male and female 50%
- Age groups: teens (10.0%), 20s (18.0%), 30s (18.0%), 40s (18.0%), 50s (18.0%), and 60s and older (18.0%).
- Types of engine
  - Gasoline (83.3%), AFVs (16.7%)
- Regions in which respondents live
  - Tokyo (10.9%), Kanagawa (8.4%), Osaka (7.3%), Aichi (6.4%), Hokkaido (5.6%)

Survey Design

- 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
  - Engine and/or motor type, reduction of CO_2 emissions, purchase price, operation cost (fuel/electricity) per 100 km drive, and maximum driving distance after filling up or at full charge.
  - Engine types were gasoline, HEV, CDV, PHEV, and EV
- The hypothetical scenario requires respondents to bear an additional financial burden to purchase AFVs compared with purchasing a conventional gasoline car
  - The purchase price range of AFVs was established at up to 1,100,000 yen

Attributes and Levels

Attribute	Level 1	Level 2	Level 3	Level 4
Engine/motor type (power train)	HV	CDV	PHEV	EV
CO_2 emissions: HEV (% reduction)	50	40	30	20
CO_2 emissions: CDV (% reduction)	10	5	0	-5
CO_2 emissions: PHEV (% reduction)	70	60	50	40
CO_2 emissions: EV (% reduction)	90	80	70	60
Price: HEV (thousand yen)	200	300	400	500
Price: CDV (thousand yen)	200	300	400	500
Price: PHEV (thousand yen)	500	700	900	1100
Price: EV (thousand yen)	500	700	900	1100
Operation cost: HEV (yen/100km)	500	600	700	800
Operation cost: CDV (yen/100km)	600	700	800	900
Operation cost: PHEV (yen/100km)	400	500	600	700
Operation cost: EV (yen/100km)	100	200	300	400
Driving range: HEV (km)	1100	1000	900	800
Driving range: CDV (km)	900	800	700	600
Driving range: PHEV (km)	1150	1050	950	850
Driving range: EV (km)	550	450	350	250

Multi-Profile Case BWS

"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."

Attribute	Car A	Car B	Car C	Car D	Car E
Engine/motor	Gasoline	HEV	CDV	PHEV	BEV
Fuel/electricity	Gasoline	Gasoline	Diesel oil	Gasoline & electricity	Electricity
CO_2 emissions (reduction)	0%	20%	10%	70%	80%
Purchase price (+ thousand yen)	Asking price	+500	+500	+700	+900
Operation cost (yen/100km)	1,200	500	900	500	400
Driving range	600 km	800 km	600 km	850 km	550 km

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

BWS Question

- "Please imagine yourself thinking about visiting a car dealer and purchasing a car. There are five types of engines for each car. The types are normal gasoline engine, HEV, CDV, PHEV, and EV. Levels of CO_2 emissions, purchase price, operation cost, and driving range are different"
- (1) When renewable energy is used to charge an EV and fuel economy of HEV is efficient, "reduction of CO_2 emissions" can be achieved in comparison with a conventional gasoline car
- (2) "Purchase price" is the actual purchase price (thousands of yen higher than the gasoline-powered equivalent) after subtracting the government/local government subsidy and eco-car tax reduction from the manufacturer selling price. Because purchase choice varies from person to person, it is a price setting that thousands of yen is higher if the power source is electric, compared with the gasoline-powered equivalent to the car you are going to purchase
- (3) "Operation cost" is a standard electricity cost for driving 100 km
- (4) "Driving range" is not the numerical value in the catalog, but is the average driving distance after full charge in a situation close to actual driving such as using the air conditioning

Model Specification of Multi-Profile BWS

- Combination of Best and Worst
  - $J\,(J\text{-}1) = 5 \times 4 = 20$
  - cf., $J = 5$ (traditional DCE)
- Probability to choose *i* as Best, and *i'* as Worst ($i \neq i'$)
- $$P_{BW}(ii'|X) = \frac{\exp \beta'(x_i \boxed{-x_{i'}})}{\sum_{\substack{j,j' \in X \\ j' \neq j}} \exp \beta'(x_j \boxed{-x_{j'}})}$$

RPL Estimation Results of Multi-Profile BWS

Variable	Mean parameter		S.D. parameter	
	Coefficient	t-value	Coefficient	t-value
ASC: HEV	0.927***	23.61	0.317***	6.11
ASC: CDV	0.0867***	2.74	0.00758	0.18
ASC: PHEV	0.483***	9.10	0.0767	1.03
ASC: EV	0.219***	3.10	0.550***	10.51
CO_2 emissions	0.00261***	4.52	0.00547***	5.35
Price	-0.0120***	-32.54	0.00439***	5.64
Operation cost	-0.00060***	-10.42	0.00255***	67.53
Driving range	0.00076***	14.34	0.0000829	0.95
Number of observations	27900			
Pseudo-R^2	0.0933			

Note: *** denotes significance at the 1% level.

Common Question Result

The first choice set was the same for all respondents.
The level of purchase price of each engine type was made equal, and the environmental performance of AFVs was maximized compared with a normal gasoline car

Attribute	Car A	Car B	Car C	Car D	Car E
Engine	Gasoline	Hybrid	Diesel	PHEV	EV
CO_2 emissions	100%	80%	105%	60%	10%
Purchase price (mil. yen)	Asking price	Same	Same	Same	Same
Operation cost (price/100km)	1200	800	900	600	100
Driving range	600 km	800 km	600 km	850 km	550 km

Most	**13.9%**	**24.5%**	**9.5%**	**21.0%**	**31.1%**
Least	41.7%	5.1%	20.6%	9.0%	23.5%

Drivers are more likely to prefer AFVs. EV was the highest and gasoline was the lowest. Japanese consumers are likely to choose newer technologies, e.g. HEV.

Discussion and Conclusions

- all of the AFVs were likely to be chosen as opposed to a normal gasoline vehicle in an environmentally-friendly hypothetical scenario setting
  - Specifically, HEV was highly preferred by Japanese consumers, possibly because Japanese consumers are familiar with hybrid engine cars
- The coefficients of purchase price, fuel/electricity cost, reduction of CO_2 emissions and maximum driving range were significant
- The diffusion of AFVs excluding HEVs are still limited in the current Japanese car market. The shift of EVs to the early-adopter stage may be the next milestone in Japan
- General consumers would change their attitudes toward AFVs if the environmental performance and price was more ideal and acceptable for them

Thanks for your attention!

Fuel Cell Vehicles (Official Cars of Kyushu University)

Toyota MIRAI (left) & Honda Clarity Fuel Cell (right)

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