Determinants of the Interest in Electric Vehicles

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Dec. 4th, 2015

For the collaborative research project, we will work on adoption of electric vehicles in the UK, focusing on identifying the potential buyers which hopefully helps the UK government to differentiate EV promoting strategies by target groups. This document presents detailed proposal for our project.

Background

As a part of the efforts to cope with the climate change, countries have been trying to reduce greenhouse gas (GHG) emissions. Considering the fact that the large portion of GHG emission is attributed to road traffic (European Comission 2015), reducing the emission from vehicles is an important issue for many industrialized countries.

Several types of low emission vehicles have been invented and released into the world as listed below (US Department of Energy 2014).

- Hybrid electric vehicles (HEVs), which use both a conventional inner combustion engine (e.g. gasoline engine) and an electric motor, are the early generation of the low emission vehicles. HEVs store electric powers in a battery from braking and the inner combustion engine, which are normally lost in conventional vehicles. Thus, HEVs have better fuel efficiency and less emission compared to the conventional vehicles.
- Plug-in hybrid electric vehicles (PHEVs) are the improved version of HEVs. PHEVs have a smaller inner combustion engine and more powerful batteries that can be charged by plugging into charging infrastructures, as well as the energy captured from braking and the inner combustion engine. Thus, PHEVs have further better fuel efficiency and less emission compared to HEVs.
- Battery Electric Vehicles (BEVs) are the most recent generation of the low emission vehicles, which powered only by an electric motor. The batteries that drive the motors are charged by plugging into charging infrastructures. Because EVs do not use inner combustion engines at all, they make no emission when they drive.

From the environmental point of view, PHEVs and BEVs are the ideal type of vehicles because they use electric powers from plugs, instead of fossil fuels. In this project, we will collectively reffer to them as electric vehicles (EVs). In reality, however, because of many reasons, the adoption rates of EVs are not as high as the desirable level. One of the biggest reasons is the costs. Although some articles report that EVs are cheaper than conventional vehicles in long-term thanks to no fuel costs (e.g. Herron 2015a), people tend to refrain from buying EVs because of the high purchase prices. Also, current technical standards such as battery capacities (maximum driving distance with one-time charging) are pointed out to be an obstacle to the widespread EV adoption (Lieven et al. 2011). Availability of charging stations matters as well (Herron 2015b).

Aiming to promote EVs and other types of low emission vehicles, governments have been taking various kinds of means such as financial incentives to owners, R&D grants, installation of charging infrastructures. In order to maximize the performance of those governments' efforts, and thus to accelerate low emission vehicle adoption, it is crucial to **identify the characteristics of the potential EV buyers**, and **reasons that makes those potential buyers to choose EVs over conventional vehicles**.

This study will focus on EVs, which is the most recent generation of low emission vehicles and thus not many researches have made so far compared to other types of sustainable vehicles.

Literature Review

Previous studies have examined various factors that are related to consumers' choice.

At the macro level, the relationship between demographic characteristics and EV adoption has been analyzed. For instance, Sierzchula et al. (2014) identify financial incentives, the prevalence of charging stations, and the presence of a local EV manufacturer as the relevant factors, using data on 30 countries. Interestingly, however, they do not find socio-economic variables to be good predicators of a country's EV adoption level. Another macro-level study divides Finland into grids with different socio-economic characteristics and finds that "the income and education level, the amount of families with children and the average size of the residences" (p. 459) are related to the region-level or neighborhood-level adoption rate of EVs (Saarenpää, Kolehmainen, and Niska 2013).

At the micro level, motivations and individual characteristics that affect individual choice are studied. Egbue and Long (2012) explores characteristics of potential EV buyers through a survey targeting current conventional vehicle owners, which asked their opinions, perceptions, and attitudes towards EVs, besides socio-economic attributes. Using 481 observations gained from the web-based survey, the authors performs chi-square analyses and find out that different groups of people have different stances towards EVs. For instance, likelihood to purchase an EV differs by gender, education level, age, and income of respondents. In addition, based on the survey questions regarding the respondents' concerns, the authors reveal that more than a quarter of them were unsure about the safety of EVs. Therefore, they concluds that people with better knowledge about EVs are more likely to purchase one.

There are not many studies that observed people who actually bought an EV, possibly resulting from the small adoption rate. However, a similar study for another type of low emission vehicle may be helpful to think about the motivations that push people to purchase one. Ozaki and Sevastyanova (2011) analyze consumers' motivations to purchase an HEV. Based on a survey data of HEV owners, the authors discovers that people bought an HEV motivated by environmental benefits, as well as personal economic benefits. As a policy implication, advertisements to the public are suggested along with financial incentives to the owners.

In addition, possible policy options to promote low emission vehicle adoption are also covered in several articles. For an example of PHEVs, Skerlos and Winebrake (2010) discuss an effective way to allocate government's financial resources. Currently, the U.S. federal government provides uniform tax credits to all PHEV owners aiming to expand share of PHEVs in the car market. Considering the social benefits of PHEVs including reduced GHG emission, air pollution abatement, increased energy security, the authors argue that the tax credits could have worked better if the government differentiated the incentives depending on consumers' purchasing power and geographical locations. As for the purchasing power, more credits to lower income individuals and fewer to higher income ones may have increased PHEV adoption, considering that current level of financial incentives may not be enough for low income people, while high income people would have bought one anyways with less or no financial incentives. As for the environmental benefit, PHEV owners in highly populated areas should have received larger credits because one unit reduction of pollution delivers larger benefits (i.e. affects more people). It would also be ideal to promote PHEVs in the areas where the electric powers are generated from alternative sources rather than thermal powers that use fossil fuels.

Since policies of financial incentives are the most common one, Gallagher and Muehlegger (2011) compare a number of policies to promote EV in different US states. Mainly focusing on the efficacy of sales tax waivers and income tax credits, they find that the former is "associated with ten-fold increase in hybrid sales" (p.1) and that tax incentives are generally more effective than non-tax incentives. Thus, both to identifying the characteristics of potential buyers and to design government interventions targeting those individuals are the essential strategies to promote low emission vehicles.

Regarding EV adoption, more detailed researches that focus on EVs are needed. In particular, not many studies have been done on the relationship between EV adoption and individual-level motivations/characteristics, partly due to a lack of survey data on people's attitudes towards EVs that covers both those who buy (or are willing to buy) and those who do not. In this study, we will examine the micro-level relationship using a recent dataset from the UK.

Data Gathering and Methodology

This analysis is based on survey data in the UK called "Opinions and Lifestyle Survey, Electric Vehicles Module, February 2014 and February 2015" (Office for National Statistics. Social Survey Division 2015). Note that registration is required to download the dataset from the UK Data Service website above. After logging in and agreeing with the terms of conditions, the datasets are available for download in STATA or other format. The registration process may take a few days. However, other documents (e.g. questionnaire, brief summary) are available at the link above without registration. This module comes with two datasets: survey results from 2014 and 2015. For our study, we use both survey years by combining both datasets together.

We are interested in the potentially different attitudes and priorities of different groups and in identifying potential buyers of EVs as well as obstacles preventing EV consumption. (To better understand the regional differences, if there are, we will look closer into regional policies or aggregate-level characteristics of Great Britain.) Therefore, we will be using the three core questions as dependent variables and demographic variables as independent variables. We will also be primarily using data from 2015, and might draw on data from 2014 in case of a need for contrast or support.

As our dependent variables are all categories variables, **multinomial logistic regression** will be adopted:

$$\ln \frac{Pr(Y_i = 1)}{Pr(Y_i = K)} = \beta_{0,1} + \beta_{1,1}x_{1,i} + \beta_{2,1}x_{2,i} + \cdots = \boldsymbol{\beta_1 \cdot x_i}$$

$$\ln \frac{Pr(Y_i = 2)}{Pr(Y_i = K)} = \boldsymbol{\beta_2 \cdot x_i}$$

$$\vdots$$

$$\ln \frac{Pr(Y_i = K-1)}{Pr(Y_i = K)} = \boldsymbol{\beta_{K-1} \cdot x_i}$$

Where $Pr(Y_i = 1)$ to $Pr(Y_i = K)$ are the probabilities that the ith person is classified into the first category to the Kth category, and $\boldsymbol{x_i}$ is a vector of the ith person's independent variables, i.e. the individual's characteristics in our study.

By converting the log odds into probabilities, we will obtain the probability of the ith person being classified into the Jth category (e.g. buying an EV) depending on his/her personal characteristics. For the Kth category (the category used as a reference), the predicted probability is calculated by the second formula.

$$Pr(Y_i = J) = \frac{e^{\boldsymbol{\beta_J \cdot x_i}}}{1 + \sum_{k=1}^{K-1} e^{\boldsymbol{\beta_k \cdot x_i}}}$$

$$Pr(Y_i = K) = \frac{1}{1 + \sum_{k=1}^{K-1} e^{\boldsymbol{\beta_k \cdot x_i}}}$$

Thus, we are expecting to see different predicted probabilities of showing certain attitudes or making certain decisions for different demographic groups, which will provide some useful information for the policy makers to create efficient means to promote EVs.

Descriptive Analysis

Variables

The list of variables are shown in the table below.

Table 1: List of Variables

Names	Types	Descriptions
EVinterest	dummy	Whether the respondent is interested in EVs or not
RAGE	continuous	Respondent's age
Male	dummy	Respondent's sex
inccat	categorical	Respondent's income in 4 categories (low, low-mid, high-mid, high)
degree	dummy	Whether the respondent is a college graduate or not
licence	dummy	Whether the respondent has a valid drivers licence or not
NumCar	continuous	Number of cars in the respondent's household
DVHsize	continuous	Respondent's household size
havechildren	dummy	Whether the Respondent has children or not
Scotland	dummy	Whether the Respondent lives in Scotland or not

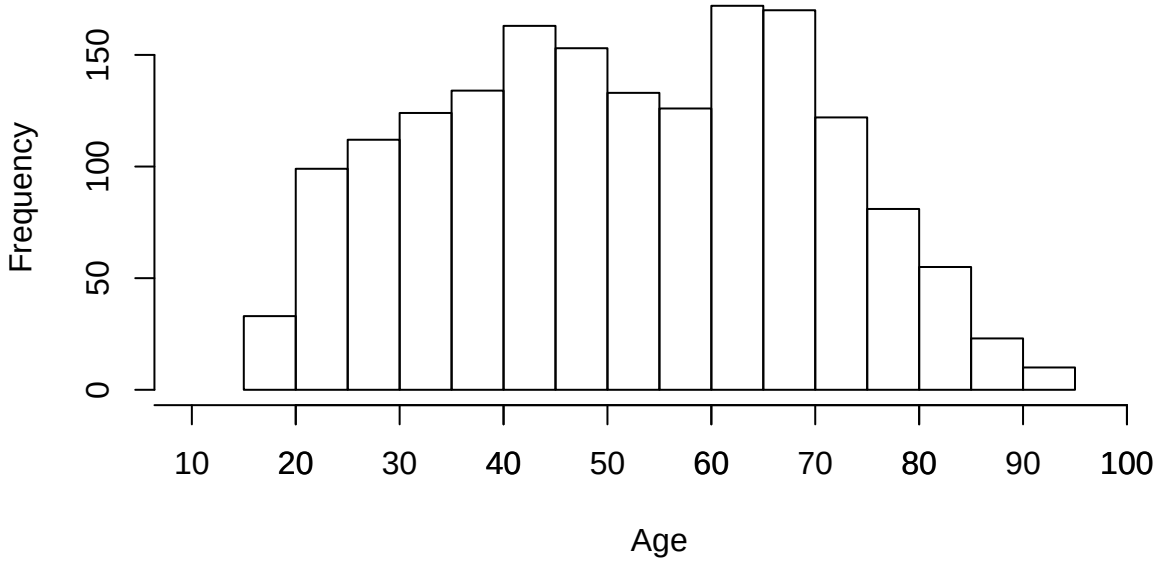
Summary statistics

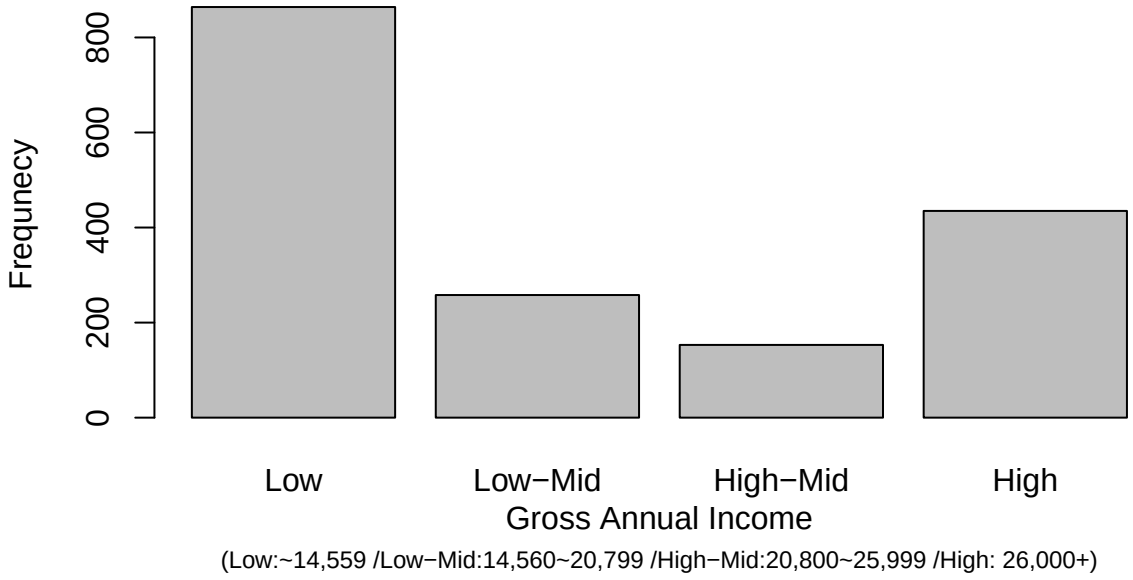
- **EVinterest**: 18.48 % of respondents are interested in EVs
- **RAGE**: Mean=52.03, Standard deviation=17.92. The distribution of age is shown in figure 1 below.
- **Male**: 46.84 % of respondents are male
- **inccat**: distribution is shown in table 2 and figure 2 below. The thresholds of each category are based on 25, 50, 75 percentile gross income from Survey of Personal Incomes 2012-13 in the UK(Office for National Statistics. HM Revenue and Customs (2015)).

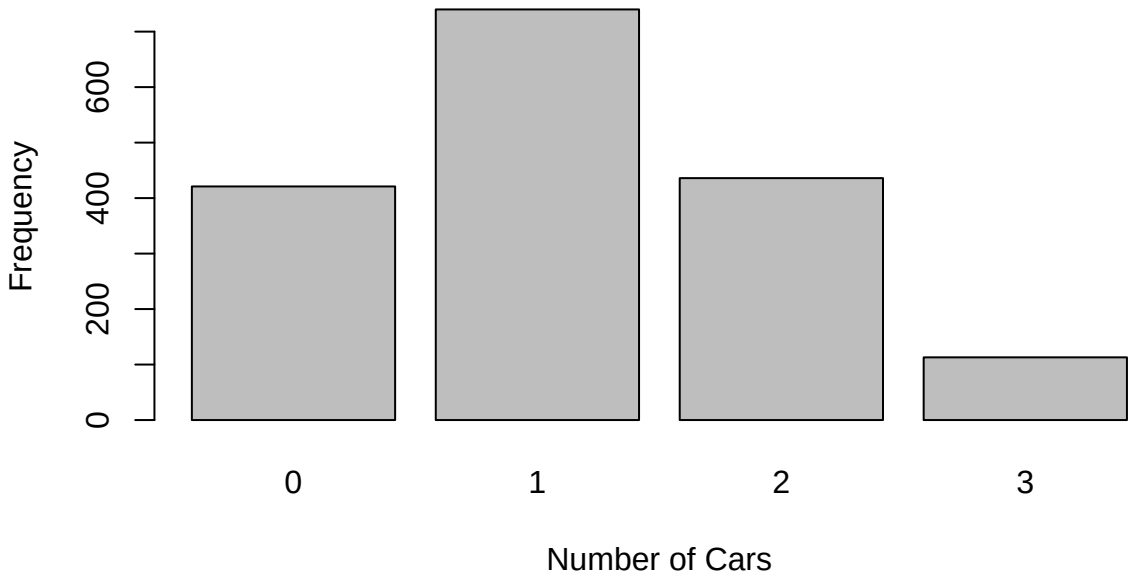
Table 2: Distribution of Income

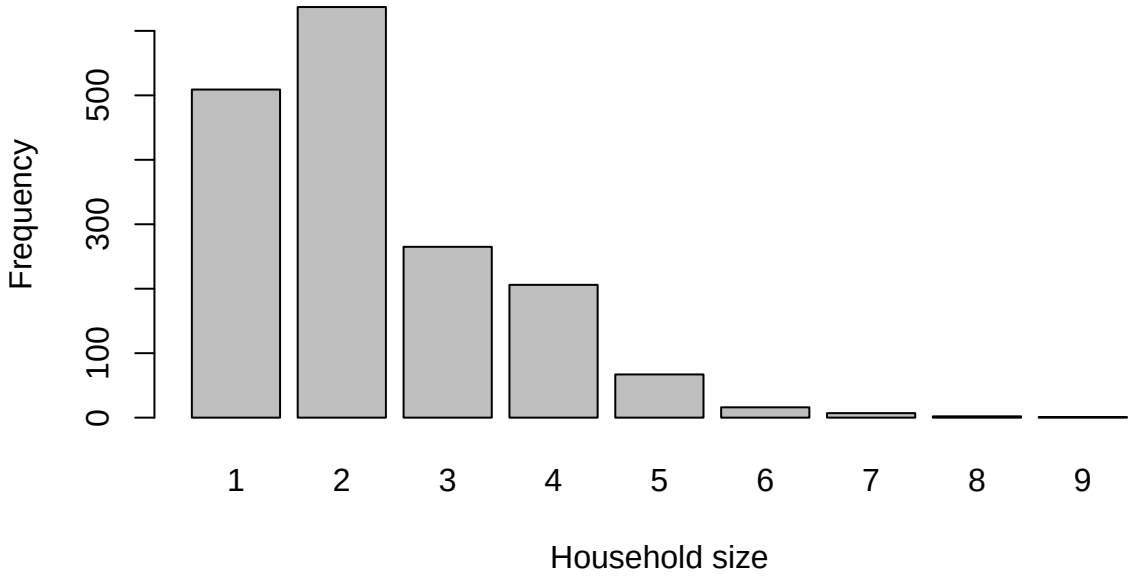
Income	Range	Percentage
Low	Below £14,559	50.53
Low-Mid	£14,560~£20,799	15.09
High-Mid	£20,800~£25,999	8.95
High	£26,000 and Above	25.44

- **degree**: 24.39 % of respondents have college degree
- **licence**: 76.55 % of respondents have valid drivers licence
- **NumCar**: Mean=1.14, Standard deviation=0.86. The distribution of the number of cars in respondent's household is shown in figure 3 below.
- **DVHsize**: Mean=2.28, Standard deviation=1.24. The distribution of household size is shown in figure 4 below.
- **havechildren**: 28.07 % of respondents have children
- **Scotland**: 8.71 % of respondents lives in Scotland


Frequency
0
50
100
150
10
20
30
40
50
60
70
80
90
100
Age


Frequnecy
0
200
400
600
800
Low
Low−Mid
High−Mid
High
Gross Annual Income
(Low:~14,559 /Low−Mid:14,560~20,799 /High−Mid:20,800~25,999 /High: 26,000+)


Frequency
0
200
400
600
0
1
2
3
Number of Cars


Frequency
0
100
300
500
1
2
3
4
5
6
7
8
9
Household size

Logistic Regression

Modelling

This section presents our efforts to answer the question, "Who are more/less likely to be interested in EVs". Since the dependent variable is a binary variable, i.e. respondents having an interest in EVs or not, we adopt logistic regression models here.

Nine independent variables are categorized into four groups. Socio-economic variables include age, sex, gross annual income level, and education level. The second group includes having driver's license or not, and the number of cars available to the household, which to some extent describe the respondents' potential to buy a new car. The third one is household-level variables, including household size and whether or not having depedent children. The last one is region. (The UK has 11 regions in total. However, our preliminary analysis suggests that, using London as the baseline, only Scotland is significantly different. Therefore, we only include "Scotland" in the regression.)

We only include socio-economic variables in our base model (regression 1) and add in a new group of independent variables each time. As the results in table 3 show, all models are significant at 99% level. Except for the two variables, size of household and having dependent children or not, all other variables are statistically signifcant as well. The fact that household-related variables are effective predictors at macro level, but not at micro level, may suggest a neighborhood effect, but it is beyond the scope of this paper.

Table 3: Step-wise Modelling

	Dependent variable:			
	EVinterest			
	(1)	(2)	(3)	(4)
Age	-0.01^{*}	-0.01^{*}	-0.01^{*}	-0.01^{*}
	(0.004)	(0.004)	(0.004)	(0.004)
Male	0.49^{***}	0.46^{***}	0.46^{***}	0.47^{***}
	(0.14)	(0.14)	(0.14)	(0.14)
Income: low-middle	0.07	-0.09	-0.09	-0.10
	(0.20)	(0.21)	(0.21)	(0.21)
Income: high-middle	0.27	0.05	0.05	0.03
	(0.23)	(0.24)	(0.24)	(0.24)
Income: high	0.57^{***}	0.31^{*}	0.30^{*}	0.29^{*}
	(0.17)	(0.17)	(0.17)	(0.17)
College degree	0.69^{***}	0.65^{***}	0.65^{***}	0.65^{***}
	(0.15)	(0.15)	(0.15)	(0.15)
Drivers licence		0.92^{***}	0.92^{***}	0.90^{***}
		(0.24)	(0.24)	(0.24)
Number of cars		0.18^{**}	0.19^{**}	0.19^{**}
		(0.08)	(0.09)	(0.09)
Size of household			-0.02	-0.03
			(0.08)	(0.08)
Having dependent children			0.04	0.02
			(0.21)	(0.21)
Scotland				-0.70^{**}
				(0.29)
(Intercept)	-1.79^{***}	-2.63^{***}	-2.59^{***}	-2.49^{***}
	(0.23)	(0.29)	(0.36)	(0.36)
Observations	1,710	1,710	1,710	1,710
R^2	0.08	0.11	0.11	0.12
χ^2	90.15^{***} (df = 6)	124.56^{***} (df = 8)	124.64^{***} (df = 10)	131.59^{***} (df = 11)
Note:				*p<0.1; **p<0.05; ***p<0.01

Based on this analysis, we leave out the two household-related variables and use the following formula.

$$\ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 Age + \beta_2 Male + \beta_3 Lowmid + \beta_4 Highmid + \beta_5 High + \beta_6 College$$
$$+\beta_7 license + \beta_8 NumCar + \beta_9 Scotland$$

Where p is the probability of being interested in EVs. The estimated model is shown in table 4.

Table 4: Interests in EVs

	Dependent variable:
	EVinterest
Age	-0.01^{*}
	(0.004)
Male	0.47^{***}
	(0.14)
Income: low-middle	-0.10
	(0.21)
Income: high-middle	0.03
	(0.24)
Income: high	0.29^{*}
	(0.17)
College degree	0.65^{***}
	(0.15)
Drivers licence	0.91^{***}
	(0.24)
Number of cars	0.18^{**}
	(0.09)
Scotland	-0.70^{**}
	(0.29)
(Intercept)	-2.56^{***}
	(0.29)
Observations	1,710
R^2	0.12
χ^2	131.47^{***} (df = 9)
Note:	*p<0.1; **p<0.05; ***p<0.01

The model is statistically significant at 99% level and five out of the seven variables are significant at 95% level. On average, males are more likely to be interested in EVs: the odds of being interested in EVs are 60% higher ($e^{0.47} = 1.60$) for male than female, holding other variables constant [z=3.36, p<0.001]. Having a college degree or driver's license also increases the likelihood of being interested: the odds of having interested in EVs are 92% higher ($e^{0.65} = 1.92$) for people with college degree compared to people without [z=4.38,

p<0.001], the odds are 148% higher ($e^{0.91} = 2.48$) for those who have drivers licence compared to those who don't [z=3.83, p<0.001]. The number of cars is positively relative to the likelihood, suggesting that people who already have the "basics" are more likely to consider EVs: each additional car in a housheild increases the odds of being interested in EVs by 20% ($e^{0.18} = 1.20$), holding other variables constant [z=2.12, p=0.034]. However, being in Scotland reduces this likelihood: people who live in Scotland have 50% lower ($e^{-0.7} = 0.50$) odds of being interested in EVs compared to people who live in other regions of the UK [z=-2.44, p<0.015].

The less significant variables are age and income level. Age is negatively relative to the likelihood of being interested, meaning that younger people are more likely to have an interest in EVs: each one year increase in the respondent's age is associated with 1% decrease ($e^{-0.01} = 0.99$) in the odds of having interests in EVs [z=-8.73, p<0.001]. Interestingly, income level seems not to matter much. Using the lowest quartile group as the baseline, only the highest quartile group is significantly different: high income people have 34% higher ($e^{0.29} = 1.34$) odds of being interested in EVs compared to low income people [z=1.70, p<0.089]. Nevertheless, results from regression 1 shows that income level (at least when comparing the highest quartile to the lowest quartile) is statistically significant at 99% level. The decrease in significance is due to the correlation between income level, and having driver's license and number of cars available.

Predicted Probabilities of Interest in EVs by Group

In addition to the odds ratio provided in the regression output, we want to be more specific with the size of effects of the seven independent variables. Therefore, the ranges of probability based on the variation of different variables are provided as following.

$$Pr(Interested) = \frac{1}{1 + e^{\boldsymbol{\beta_k} \cdot \boldsymbol{x_i}}}$$

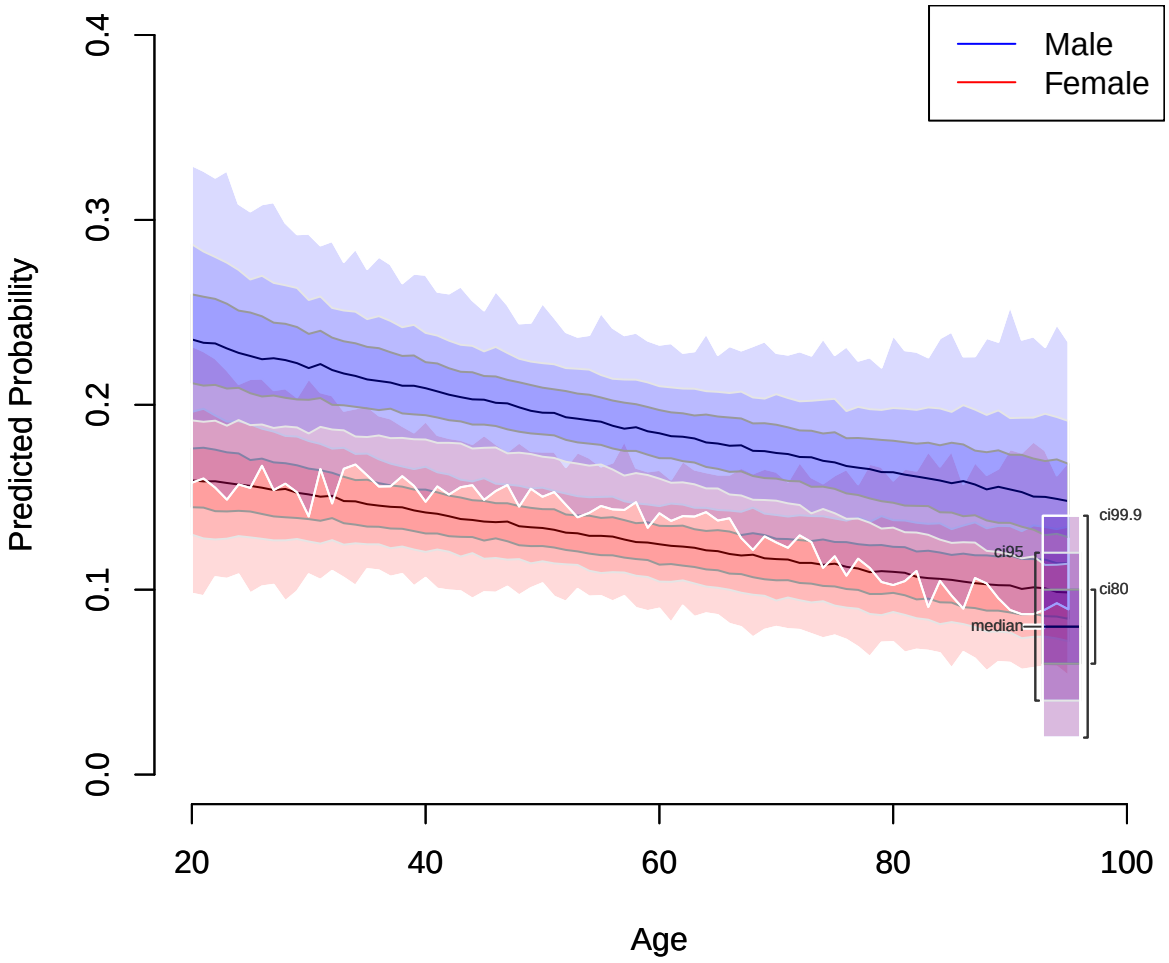

Male
Female
Predicted Probability
0.0
0.1
0.2
0.3
0.4
20
40
60
80
100
Age
ci99.9
ci95
ci80
median

Figure 5 shows the predicted probability of having an interest in EVs by age and sex. Regardless of age, males show a greater interest than females. Even though the variation among males is larger too, the difference in probability is on average about 5 percentage points. The linear relationship between age and this probability is clearly demostrated here as well. Younger people are more likely to be interested than older people.

Table 5-9 summarize predicted probabilities of having an interest in EVs of different groups and allow us to know the differences between groups.

- By Income Level & Sex: predicted for those people with mean age, valid licence, college degree, a car, and who doesn't live in Scotland.

Table 5: Probability by Income Level & Sex

Income Level	Male	Female
Lowest quartile	32.06	22.86
Second lowest quartile	30.02	21.22
Second highest quartile	32.72	23.4
Highest quartile	38.79	28.47

- By Education Level & Sex: predicted for those people with mean age, lower-middle income, valid licence, a car, and who doesn't live in Scotland.

Table 6: Probability by Education Level & Sex

Education Level	Male	Female
At least have a college degree	30.02	21.22
Do not have a college degree	18.35	12.37

- By License Status & Sex: predicted for those people with mean age, lower-middle income, college degree, a car, and who doesn't live in Scotland.

Table 7: Probabilities by Driver's License Status & Sex

License Status	Male	Female
At least have a college degree	30.02	21.22
Do not have a college degree	14.74	9.8

- By Number of Cars & Sex: predicted for those people with mean age, lower-middle income, college degree, valid licence, and who doesn't live in Scotland.

Table 8: Probabilities by Number of Cars & Sex

Number of Cars	Male	Female
0	26.36	18.35
1	30.02	21.22
2	33.95	24.40
3	38.12	27.89

- By Region & Sex: predicted for those people with mean age, lower-middle income, college degree, valid licence, and a car.

Table 9: Probabilities by Region & Sex

Region	Male	Female
In Scotland	17.56	11.8
In other regions	30.02	21.22

Obstacles to Buying EVs

Encouragements

Discussion and Limitations

In general, interest in EVs is rather limited. Among all respondents, only 18.48% are interested. This, on the other hand, suggests the need to better understand the factors related to the interest in EVs, and this is what motivated our research too.

Above analysis shows that the variations among different groups are quite large. For instance, people having a college degree, on average, have a probability of 30.7% to be interested in EVs, while people without a degree only have a probability of 14.5%. This kind of variation (especially the one related to education level) is actually a good sign, suggesting that interest in EVs could be potentially increased. Promotion of EVs should give more attention to the needs and comsumption patterns of low-interest groups.

However, this also leads to one of the limitations of this paper, not being able answer why different groups show different levels of interest. This question is very hard, not just because we do not have more detailed surveys, but also because different groups may be systematically different in many unobeserved ways. Even though, we will still attempt to make contributions on this question in our final paper.

Another limitation is due to the design of the survey, which did not exclude respondents who are not interested in buying cars in genereal. Therefore, varialbes, including having driver's license and number of cars available, need to be interpreted with great caution. The low interest shown in groups without driver's license or cars might not be caused by their lack of interest in EVs, but by their lack of interest in cars.

Lastly, R^2 of the model is only 0.12, meaning that these variables only explain 12% of the variations in the probability of having an interest in EVs. Partly, this is because of a lack of available information, as it is impossible to survey everything. Partly, attitudes are just not easy to explain, because they could be influenced by countless factors, sometimes as trivial as an image or some careless words. Nevertheless, we believe that there are patterns and these patterns are what we should better understand if EVs are to be further promoted.

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