Different Types of Electric Vehicles: What do consumers want?

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Background

The increasing interest of policy makers in electric mobility is reflected in recent attempts of the US and European governments to set ambitious goals for the penetration of electric vehicles (EVs) in national car fleets. However, consumer adoption of EVs has long been hampered by high acquisition costs, considerable uncertainty over developments in battery technologies, and drivers' reluctance to accept changes in their current refuelling behaviour. Aiming to partially address these concerns, car manufacturers have recently developed intermediate solutions based on the parallel use of internal combustion engines (ICE) and electric propulsion systems, i.e. plug-in hybrids and extended-range electric cars (PHEVs). At the same time, new refuelling concepts aiming to bring the EV charging time down to the levels of the refuelling time of ICE-propelled cars, such as fast-charging and battery-swapping, have been developed and are currently tested worldwide. In light of these developments, we revisit the way in which consumer stated preferences for electric and other alternative fuel vehicles have been elicited in transportation literature (see e.g. [1]-[3]).

Data and Methodology

We employ a discrete choice experiment to investigate the preferences of Dutch private car owners for battery electric vehicles (BEVs) and PHEVs. Our findings draw on the outcome of more than 1500 responses to an online survey carried out between November 2012 and January 2013. During the survey, respondents were invited to engage in eight hypothetical choice exercises. In each of them, they made a choice among four alternative propulsion systems: a system propelled by an internal combustion engine (ICE) and driver's preferred fuel type, a PHEV, and two types of electric cars; a fixed-battery EV (FBEV) allowing for fast-charging, and a swappable-battery one (SBEV) providing the option of battery-swapping at specialised stations. Both types allowed for home or workplace charging of several-hour duration. The alternatives differed in terms of: (i) three monetary attributes (purchase price, fuel costs per 100 kilometres and car resale value), (ii) a policy intervention attribute (temporary exemption from road tax), (iii) driving range, and (iv) three refuelling activity attributes (station refuelling time, home/workplace charging time, and extra detour time required to reach the nearest refuelling station). Table 1 presents the attributes and attribute levels used in the choice experiment.

Table 1: Attributes and attribute levels used in the choice experiment

Attributes	Attribute levels			
Propulsion system and fuel type	ICE or Hybrid	Plug-in hybrid	Electric with fixed battery	Electric with swappable battery
Purchase Price (€)	Customised on respondent's reported price range for next car purchase	0.8 * ICE 1.4 * ICE 2.0 * ICE	0.8 * ICE 1.4 * ICE 2.0 * ICE	0.8 * ICE 1.1 * ICE 1.4 * ICE
Fuel costs (€/100km)	Base value - 2.5 Base value Base value + 2.5	3.5 5.5 7.5	3 4.5 6	9 11 13
Residual value after 5 years (% of purchase price)	40% 50% 60%	30% 45% 60%	30% 45% 60%	30% 45% 60%
Range (kilometres)	600 750 900	500 700 900	100 300 500	100 300 500
Refuel time at the station (minutes)	5	5	15 30 45	5
Charging time at home or work (hours)	N.A.	1.5 3 5	4 8 10	4 8 10
Extra detour time (minutes)	N.A.	N.A.	0 10 20	0 15 30
Exemption from annual road tax (years)	No exemption	No exemption Exemption for 2 years Exemption for 4 years	No exemption Exemption for 2 years Exemption for 4 years	No exemption Exemption for 2 years Exemption for 4 years

Results

Choice data are analysed by the use of Biogeme 1.9 [4]. The results of a basic MNL specification are provided in the first four columns of Table 2. All coefficients have the expected signs. ICE technologies rank first in drivers' preferences, followed by their closest alternative in terms of performance and refuelling behaviour, PHEVs. The disutility derived from FBEVs is more than twofold the one derived by PHEVs, while the one derived from SBEVs is threefold. The latter finding probably reflects drivers' reluctance to trust a battery-exchange scheme where they have only limited potential to control the state and quality of the battery with which their depleted battery is swapped. Furthermore, consumers are willing to pay, on average, around €140 to have the resale value of their car increased by one percentage point, and €645 to have a total amount of €1,000 deduced from their road tax expenses in the course of the next 4 years. Each increase of fuel costs by €1 per 100 km is valued at €1,290. Drivers value increases in driving range and reductions of fast-charging and detour time rather highly, whereas reductions of home charging time are not equally appreciated. Willingness to pay (WTP) for range is estimated at €13/km at the mean of 513 kilometres. The opportunity costs of detouring, fast-charging and charging at home are substantially different from each other, as the range of other activities that drivers can perform while engaging in each of these refuelling-related actions varies widely. In line with our expectations, drivers' value of detour time is higher than (about twofold) the value of fast-charging time, while their value of home-charging time is considerably lower.

Columns 5-8 of Table 2 illustrate an alternative MNL specification, where the effects of BEV driving range, refuel times and detour time have been dummy-coded. We find that preferences for driving range and refuelling-related attributes are largely alternative-specific, as well as that consumers' utility is non-linear in range, refuel times and detour time. In all cases, drivers' WTP for driving range decreases in the considered range levels. Consumers do not seem to value increases in the range of ICE cars in the examined interval (600-900 kms), as well as increases in driving range over 700 kilometres in general. Interestingly, valuation of range is also different between the two BEV technologies, despite the fact that the same attribute levels are used. Increases in the SBEV driving range are valued 37-55% higher than increases in the FBEV one, while WTP for SBEV range diminishes at a slower pace than WTP for FBEV range.

With the exception of reductions from 3 hours to 90 minutes in the PHEV charging time, decreases of home-charging time in the examined intervals do not have a significant effect on consumers' utility. In regard to FBEV *fast-charging time*, a reduction from 45 to 30 minutes is valued around €146/minute[1], while consumers' WTP for a decrease from 30 to 15 minutes is statistically insignificant. A similar pattern is found for consumer valuation of extra detour time to reach the nearest *battery-swapping station*. A decrease from 30 to 15 minutes of extra detour time is valued at €218/minute, whereas a reduction from 15 minutes to no extra detour time does not have a significant value. The opposite pattern is observed for the extra detour time required to reach the nearest *fast-charging station*; consumers are indifferent between detouring for 10 or 20 minutes, while they value reductions from 10 minutes to no extra detour time at €210/minute.

The last three columns of Table 2 illustrate the results of a mixed logit model for panel data specified in the WTP space, formulated in accordance with the suggestions of [3]. We assume that WTP for FBEV, SBEV and PHEV is distributed normally and that the price coefficient follows a log-normal distribution. Fixed parameters are employed for the rest of the attributes. The standard deviations of random parameters reveal substantial heterogeneity in the WTP for the three technologies and the price coefficient. Interestingly, the mean of the WTP for the plug-in hybrid is indistinguishable from zero, providing further support for the similarity of ICE and PHEV technologies. All estimates of fixed parameters are lower than the WTP estimates provided in the basic MNL.

Estimates from model specifications with interaction effects between attributes and respondents' socioeconomic characteristics reveal that consumers are more likely to opt for an EV when their choice concerns the second or third car of the household rather than when it concerns the primary car. Respondents primarily driving in a hybrid-electric vehicle (HEV) are significantly more likely to purchase a PHEV next. Women and drivers who have already had some experience with BEVs are more inclined to opt for EV technologies than men or respondents that have never driven electric. By contrast, drivers who often make trips abroad have a stronger disutility for FBEVs. Last, EVs are more popular among consumers reporting

[1] On average, survey respondents reported that around 2/3 of their charging actions would take place at home. Assuming car ownership duration of 5 years, 16,400 kilometres travelled annually (sample average) and that the BEV is recharged every 100 kilometres, the valuation of each minute of fast-charging or detour time corresponds to the valuation of ca. 4.5 hours of fast-charging or detouring in the course of driver's BEV ownership.

that their next car purchase will concern a small car or a van. In line with intuition, drivers travelling longer annual distances experience a higher disutility from short driving ranges. Additional insights stemming from the application of Latent Class Logit models are expected in the immediate future.

Table 2: Results of discrete choice models

Variable	Basic MNL				MNL with dummy-coded attributes				Mixed MNL for panel data in WTP space		
	Coefficient		Willingness to pay		Coefficient		Willingness to pay		Parameter		
	Estimate	Std. error	Estimate	Std. error	Estimate	Std. error	Estimate	Std. error	Description	Estimate	Std. error
Electric: fixed battery [FBEV]	*-0.9505****	(0.1018)	*-€ 12,280****	(1378)	*-2.372****	(0.103)	*-€ 30,759****	(1594)	Mean WTP	*-€ 7,275****	(1,421)
Electric: swappable battery [SBEV]	*-1.2647****	(0.0801)	*-€ 16,339****	(1157)	*-2.855****	(0.122)	*-€ 37,020****	(1922)	Mean WTP	*-€ 11,187****	(993)
Plug-in hybrid [PHEV]	*-0.4189****	(0.0457)	*-€ 5,412****	(633)	*-0.669****	(0.067)	*-€ 8,672****	(930)	Mean WTP	*€ 2,593*	(2,198)
Purchase price (€ 1000)	*-0.0774****	(0.0023)	-	-	*-0.077****	(0.002)	-	-	Mean of ln(-coeff)	*-1.91****	(0.05)
Resale value (%)	*0.0109****	(0.0010)	*€ 141****	(14)	*0.011****	(0.001)	*€ 140****	(14)	WTP for 1%	*€ 109****	(20)
Fuel costs (€/100km)	*-0.0999****	(0.0048)	*-€ 1,291****	(71)	*-0.099****	(0.005)	*-€ 1,282****	(71)	WTP for €1/100km	*-€ 897****	(117)
Road tax savings (€ 1000)	*0.0499****	(0.0095)	*€ 644****	(124)	*0.049****	(0.009)	*€ 641****	(124)	WTP for €1000 savings	*€ 586****	(121)
logarithm of Driving range (kms)	*0.5182****	(0.0317)	*€ 13****	(1.0)	-	-	-	-	WTP per km at 513 km	*€ 10****	(1.3)
Refuel time at the station (mins)	*-0.0065****	(0.0025)	*-€ 84****	(32)	-	-	-	-	WTP for 1 min.	*-€ 83****	(23)
Extra detour time (mins)	*-0.0129****	(0.0023)	*-€ 167****	(31)	-	-	-	-	WTP for 1 min.	*-€ 103****	(27)
Home-charging time (mins)	*-0.0004****	(0.0001)	*-€ 4.6****	(1.6)	-	-	-	-	WTP for 1 min.	*-€ 3.57****	(1.37)
Driving range: ICE 600 → 750 kms	-	-	-	-	*0.039*	(0.048)	*€ 507*	(616)	-	-	-
Driving range: ICE 600 → 900 kms	-	-	-	-	*0.041*	(0.048)	*€ 526*	(622)	-	-	-
Driving range: PHEV 500 → 700 kms	-	-	-	-	*0.157****	(0.052)	*€ 2,036****	(673)	-	-	-
Driving range: PHEV 500 → 900 kms	-	-	-	-	*0.236****	(0.052)	*€ 3,060****	(677)	-	-	-
Driving range: FBEV 100 → 300 kms	-	-	-	-	*0.542****	(0.083)	*€ 7,030****	(1089)	-	-	-
Driving range: FBEV 100 → 500 kms	-	-	-	-	*0.798****	(0.079)	*€ 10,342****	(1061)	-	-	-
Driving range: SBEV 100 → 300 kms	-	-	-	-	*0.745****	(0.118)	*€ 9,661****	(1565)	-	-	-
Driving range: SBEV 100 → 500 kms	-	-	-	-	*1.238****	(0.114)	*€ 16,046****	(1533)	-	-	-
Detour time: FBEV 10 → 20 mins	-	-	-	-	*-0.119*	(0.077)	*-€ 1,542*	(994)	-	-	-
Detour time: FBEV 10 → 0 mins	-	-	-	-	*0.161***	(0.073)	*€ 2,094***	(944)	-	-	-
Detour time: SBEV 15 → 30 mins	-	-	-	-	*-0.252***	(0.098)	*-€ 3,263***	(1279)	-	-	-
Detour time: SBEV 15 → 0 mins	-	-	-	-	*0.131*	(0.091)	*€ 1,697*	(1178)	-	-	-
Fast-charging time: FBEV 30 → 45 mins	-	-	-	-	*-0.169***	(0.075)	*-€ 2,187***	(979)	-	-	-
Fast-charging time: FBEV 30 → 15 mins	-	-	-	-	*0.029*	(0.073)	*€ 381*	(949)	-	-	-
Home-charging time: PHEV 3 → 5 hours	-	-	-	-	*0.011*	(0.050)	*€ 143*	(654)	-	-	-
Home-charging time: PHEV 3 → 1.5 hours	-	-	-	-	*0.111***	(0.050)	*€ 1,441***	(651)	-	-	-
Home-charging time: BEVs 8 → 10 hours	-	-	-	-	*-0.013*	(0.059)	*-€ 171*	(760)	-	-	-
Home-charging time: BEVs 8 → 4 hours	-	-	-	-	*0.082*	(0.057)	*€ 1,067*	(742)	-	-	-
Standard deviation of WTP for FBEV	-	-	-	-	-	-	-	-	Standard deviation	*€ 12,239****	(741)
Standard deviation of WTP for SBEV	-	-	-	-	-	-	-	-	Standard deviation	*€ 14,677****	(1,977)
Standard deviation of WTP for PHEV	-	-	-	-	-	-	-	-	Standard deviation	*€ 13,433****	(811)
Standard deviation of ln(-coeff) of Price	-	-	-	-	-	-	-	-	Standard deviation	*0.68****	(0.06)
Observations	12,112				12,112				12,112 (1,514 respondents)		
R^2	0.257				0.258				0.382		
R^2-*adjusted*	0.256				0.256				0.381		
Log-likelihood	-12,483				-12,464				-10,377		

Note: Robust standard errors in parentheses. ***,** and * indicate that the parameter is statistically significant at the 1%, 5% or 10% significance level respectively.

Conclusions

The large-scale adoption of EVs has been lately considered a potentially promising means of confronting mounting concerns about environmental degradation, oil dependence and increasing petroleum prices. We find that battery electric vehicles are still far from attractive for the majority of consumers, who seek for EV alternatives whose attributes resemble the ones of ICE-propelled cars. To this end, the recently introduced PHEVs have considerable potential to mitigate drivers' concerns over short driving ranges and long charging times. On the contrary, at their early introduction stage, swappable-battery EVs are not on average considered as improvements to their fixed-battery counterparts. However, their short refuelling time makes drivers more willing to suffer higher extra detour times to reach battery-swapping stations. Our analysis further reveals strong non-linearities in the effects of changes in driving range, refuel time and coverage of refuelling infrastructure on drivers' utility, as well as considerable heterogeneity in consumer preferences.

References

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