KAPSARC
مركز الملك عبدالله للدراسات والبحوث البترولية
King Abdullah Petroleum Studies and Research Center

Understanding Long-Term Consumer Demand For Fuel-Efficient Vehicles

Rubal Dua and Kenneth White

April 2017 / KS-2017--DP08

About KAPSARC

The King Abdullah Petroleum Studies and Research Center (KAPSARC) is a non-profit global institution dedicated to independent research into energy economics, policy, technology and the environment, across all types of energy. KAPSARC's mandate is to advance the understanding of energy challenges and opportunities facing the world today and tomorrow, through unbiased, independent, and high-caliber research for the benefit of society. KAPSARC is located in Riyadh, Saudi Arabia.

Legal Notice

Key Points

Consumer adoption of fuel-efficient vehicles is a crucial step in improving energy use and reducing emissions from the transportation sector. The range of options includes hybridization of powertrains all the way through to fully electric vehicles. To promote adoption, policymakers have employed supply side policies such as the Greenhouse Gas (GHG) Emissions/Corporate Average Fuel Economy (CAFE) standards and the Zero Emission Vehicle (ZEV) mandate, which require automakers to produce and sell fuel-efficient and alternative fuel vehicles. In addition, demand side measures in the form of financial and non financial incentives promoting ZEV adoption have also been employed. We measure the changes in consumers' purchase motivations and potential demand in the wake of such programs by analyzing the past 11 years of new vehicle buyer survey data in the United States as a case study. We find that:

> Hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs), collectively termed xEVs, had the potential to secure as much as ~11 percent of the U.S. automotive market in model year 2015, but the actual market share was only one-third of this.

> A narrowing of the consumer's valuation gap between buyers of non xEVs and xEVs for purchase motivations – including fuel economy, environmental friendliness, technical innovation and price – is increasing the potential consumer demand for xEVs. The term valuation gap refers to the difference between the average rating given by buyers of non xEVs and buyers of xEVs for a particular purchase motivation question in the survey. The closer the ratings, the smaller will be the valuation gap.

> Policy instruments such as sales weighted fuel economy target show strong correlation with the consumer valuation gap. In combination with demand side policies that make xEVs more accessible to mainstream consumers, they could be considered as viable tools if policymakers are seeking to nudge consumers toward xEVs.

Executive Summary

The federal Corporate Average Fuel Economy (CAFE) program in the U.S., similar to that in the Kingdom of Saudi Arabia, sets specific sales weighted fuel economy targets for automakers with the goal of improving energy use and reducing emissions. In addition, the state level Zero Emission Vehicle (ZEV) program in California and nine other U.S. states aims to accelerate the adoption of zero emission vehicles by setting mandated ZEV sales targets. For these supply side policies to achieve their intended goals, it would be useful to understand the demand for these fuel-efficient and zero emission vehicles from a consumer's perspective.

To do this, we used a new data mining approach, ex-post counterfactual inference, which we had previously developed to examine the survey data of new vehicle buyers. This approach aims to identify: current adopter types, their reasons for adoption, potential adopters, size of the potential market and factors that could induce potential buyers to adopt more fuel-efficient vehicles.

In this paper, we analyze the past 11 years of new vehicle buyer survey data, relating to more than 1 million respondents, to estimate potential market size and to understand the relationship between observable macro factors and consumer motivation to adopt fuel-efficient vehicles. In terms of vehicle technologies, we primarily focus on hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs), collectively termed xEVs, where x could be H, PH or B, respectively.

In a counterfactual scenario, assuming optimistic growth, we find that the xEV fuel types had the potential to secure about 11 percent of the U.S. new vehicle sales in model year 2015. In reality, the xEVs achieved only one-third of this. Realization of the full potential would depend on the public and private sector's ability to encourage fuel economy conscious conventional gasoline vehicle buyers to adopt even more fuel-efficient xEVs.

In addition to fuel economy, environmental friendliness and technical innovation, potential xEV consumers also desire features and factors such as exterior styling, safety, warranty coverage and better resale value that are more common to conventional vehicles. Achieving market share beyond the estimated potential share of 11 percent would require features that mainstream gasoline vehicle buyers value, such as reliability, handling and value for money, to be offered. Currently, both actual and potential xEV buyers are willing to trade these features for fuel economy, environmental friendliness and technical innovation. Future mainstream xEV buyers, however, may not be willing to make that trade-off. The addition of desirable features may increase the up-front cost of xEVs, which could negatively impact adoption as these potential buyers tend to have lower incomes.

The estimated potential market share for xEVs increases with narrowing of the valuation gap for purchase motivations of fuel economy, technical innovation, environmental friendliness and price. This is because the potential market share is estimated by identifying non xEV buyers who have purchase motivations and demographics very similar to those of xEV buyers. Thus, as the gap in valuation of these purchase motivations for non xEV and xEV consumers narrows, a higher potential market share for xEVs is estimated.

The narrowing of the valuation gap in turn is strongly correlated with the CAFE target and moderately correlated with the gasoline price, two important macro factors exogenous to our model. We note the valuation gap for these purchase motivations reduces over time, because the non xEV consumers' valuation is increasing while that of xEV buyers is decreasing. Non xEV consumers may derive higher utility from the innovative fuel-efficient technologies added to non xEVs to meet the CAFE target, thus leading to their rising valuation. On the other hand, demand side policies have made xEVs more affordable and accessible for a larger proportion of mainstream consumers, thus leading to their decreasing valuation.

Accordingly, a combination of these supply side and demand side policies represents a viable tool if policymakers wish to nudge non xEV buyers' purchase motivations closer to those of xEV buyers.

The moderate effect of the gasoline price on the valuation gap for purchase motivations may be due to mandated targets for automakers to produce and sell increasingly fuel-efficient vehicles irrespective of the gasoline price.

Introduction

Federal and state level policy programs in the U.S. encourage automakers to sell fuel-efficient and alternative fuel vehicles. Emissions reduction, air quality improvement and energy security drive such programs to achieve these intended goals.

The federal level GHG/CAFE program requires automakers to achieve a specific sales weighted average of GHG emissions per mile/fuel economy each year up to model year (MY) 2025. The state level ZEV mandate in California and nine other U.S. states promotes the adoption of ZEVs by requiring automakers to achieve a set target of ZEV sales each year. Both programs are examples of supply side policies with specific targets that increase annually. To promote ZEV adoption, states have also implemented demand side policies such as offering rebates up to about $2,500, as well as incentives such as high occupancy vehicle (HOV) lane permits. In the past, similar support incentives were also offered to promote HEV adoption. U.S. states, primarily California, are also investing in charging station infrastructure.

The success of such policy programs depends on consumer adoption. Until now, most research aimed at understanding consumer inclination to adopt fuel-efficient and alternative fuel vehicles relied on stated preference surveys. However, in stated preference experiments, consumers may misrepresent their choices. They tend to react differently to hypothetical choice experiments than they do when facing the same alternatives in a real market (Brownstone, Bunch and Train 2000). Only a few recent studies have used revealed preference surveys, i.e., data obtained from buyers of fuel-efficient and alternative fuel vehicles (Axsen, TyreeHageman and Lentz 2012; Axsen, Bailey and Castro 2015; Tal et al. 2013). Most such studies focused only on developing a better understanding of the variation in demographics and attitudinal values of current buyers of fuel-efficient and alternative fuel vehicles, but not on nationwide potential market share estimations.

We recently developed a new data mining approach, ex-post counterfactual inference, to estimate nationwide consumer demand for BEVs using revealed preference survey data from MY 2013 new car buyers (Dua, White and Lindland 2016). In this paper, we extend the approach to understand consumer demand for fuel-efficient and alternative fuel vehicles including HEVs, PHEVs and BEVs, using the past 11 years of revealed preference consumer survey data from MY 2005 to MY 2015. This paper provides an assessment for:

- Potential consumer demand for all xEV types in each year.
- Identifying helpful factors in achieving the estimated potential demand.
- Linkage between potential consumer demand, micro consumer level factors and exogenous macro factors.

Data

This study relies on data from a large-scale, nationally representative, revealed preference survey of new vehicle buyers, known as New Vehicle Experience Survey (NVES) conducted by Strategic Vision Incorporated. We analyzed 11 years of NVES data from MY 2005 to MY 2015. To understand the consumer's choice, we used two sets of attributes: (a) purchase motivations and (b) demographics. Surveying their purchase motivations, consumers rate, on a scale of one to five, the importance of a set of purchase considerations to their decision. For more details on the data, please see Appendix A.

Heterogeneity in the xEV Market

To account for heterogeneity among xEV buyers, we segmented current xEV buyers into distinct profiles using k-means clustering, as shown in Figure 1(a). Please see Appendix A.2.1 in the paper by Dua, White and Lindland (2016) for more details on consumer segmentation. The major differences, and similarities, between the different xEV segments as against their respective purchase motivations and demographics relative to a representative gasoline vehicle cluster are highlighted in Figure 2. See Figures A1-A3 in the Appendix for detailed results and Appendix B for a description of the method used.

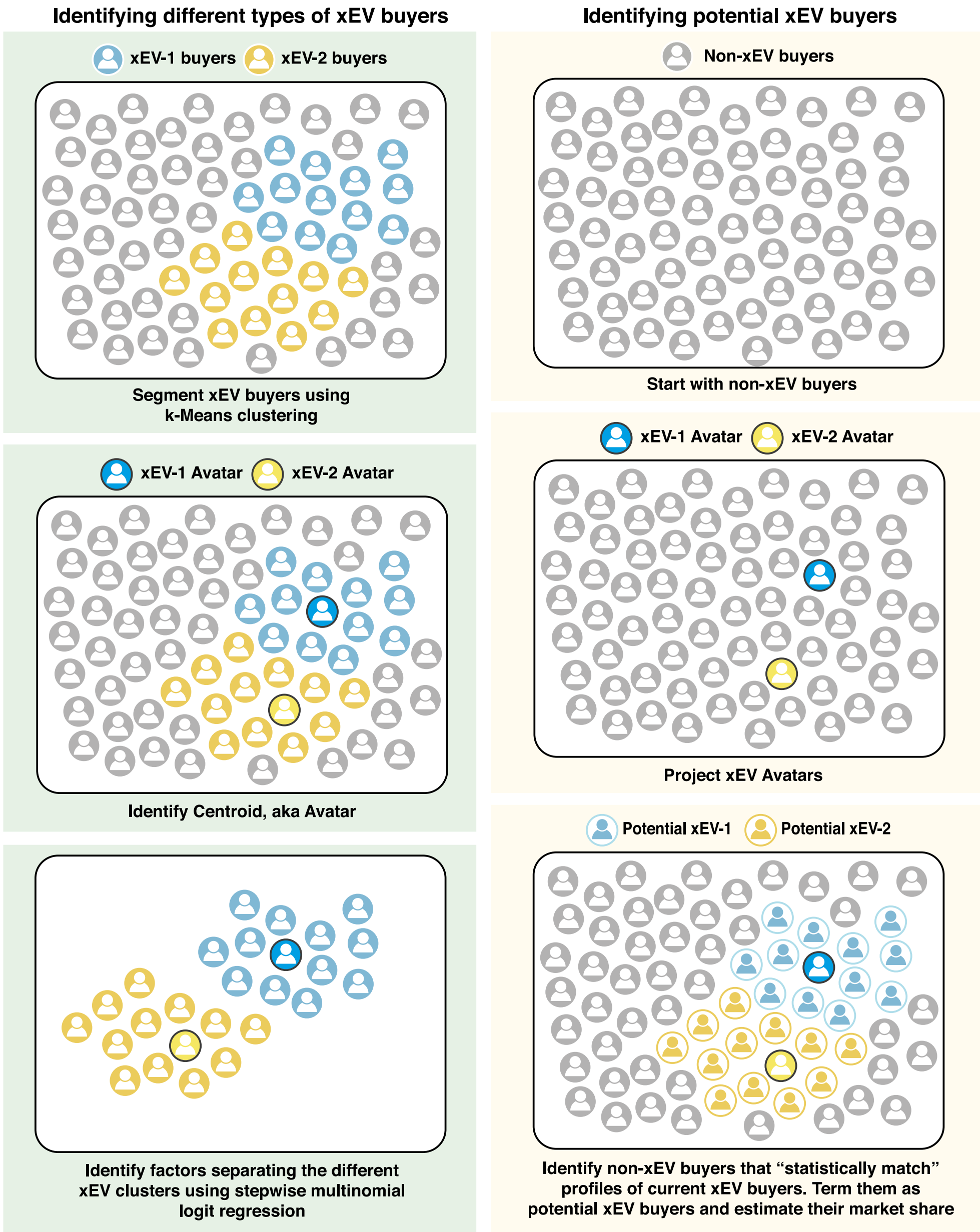

Figure 1. Identifying types and potential xEV buyers.

Note: This figure sets out the approach for identifying: (a) different types of xEV buyers and (b) potential xEV buyers. See Appendix A.2 in the paper by Dua, White and Lindland (2016) for more details on the methodology.

Source: KAPSARC analysis.

Figure 2. Similarities and differences among various xEV segments.

Note: This figure shows Venn diagrams highlighting the similarities and differences between distinct (a) HEV, (b) PHEV and (c) BEV clusters relative to a representative gasoline vehicle cluster.

Source: KAPSARC analysis.

As shown in Figure 2, fuel economy, environmental friendliness and technical innovation are the three most important purchase motivations for all the xEV clusters relative to the representative gasoline vehicle cluster. On the other hand, value for money, exterior styling, safety, reliability and handling are more important for the representative gasoline vehicle cluster. Among the two hybrid clusters, HEV-1 buyers have fewer expectations from their vehicle. Table 1 shows that both HEV clusters purchase similar types of vehicles, but as seen in Figure 2, they have different expectations from their vehicle, highlighting the heterogeneity among consumers. The BEV and PHEV buyer clusters also care about leasing terms, which to some extent lowers risk associated with uncertain resale value, battery decay and rapid technology improvements.

Table 1. Top 5 models purchased by xEV fuel type buyers.

HEV-1	HEV-2	PHEV-1	PHEV-2	BEV-1	BEV-2
Toyota Prius	Toyota Prius	Chevrolet Volt	Chevrolet Volt	Tesla Model S	Nissan Leaf
Toyota Prius c	Toyota Prius c	Ford Fusion Plug-in	Ford Fusion Plug-in	Nissan Leaf	Fiat 500e
Toyota Prius v	Toyota Camry Hybrid	Ford C-MAX Energi	Ford C-MAX Energi	Fiat 500e	Chevrolet Spark EV
Toyota Camry Hybrid	Toyota Prius v	Toyota Prius Plug-in	Toyota Prius Plug-in	Mercedes BEV	Tesla Model S
Ford Fusion Hybrid	Lexus CT200h		Honda Accord Plug-in Hybrid Sedan	Ford Focus Electric	BMW i3 Hatchback

Source: KAPSARC analysis.

Potential Buyers and Size of Market

Using the data mining approach with optimistic growth assumptions for all fuel types, we identified non xEV buyers who statistically resemble profiles of current xEV buyers. Please see Appendix A.2.2 in the paper by Dua, White and Lindland (2016) for more details on how the potential buyers are identified. The potential market share for all xEV types from MY 2005 to MY 2015 are shown in Figure 3.

The total market share for xEVs combined shows a potential to increase by an average factor of almost three over the past 11 model years. To understand the variation of the estimated potential market share, we look at the non xEV and xEV consumers' valuation of purchase motivations. This is because the potential market share is estimated by identifying non xEV buyers that have purchase motivations and demographics very similar to those of xEV buyers. From Figure 2, we know that fuel economy, environmental friendliness, technical innovation and price are four important purchase motivations that set apart xEV buyers. Thus, in any model year, as non xEV and xEV consumers come close in terms of their valuation of these purchase motivations, a higher potential market share for xEVs would be estimated, as is confirmed in Figure 3.

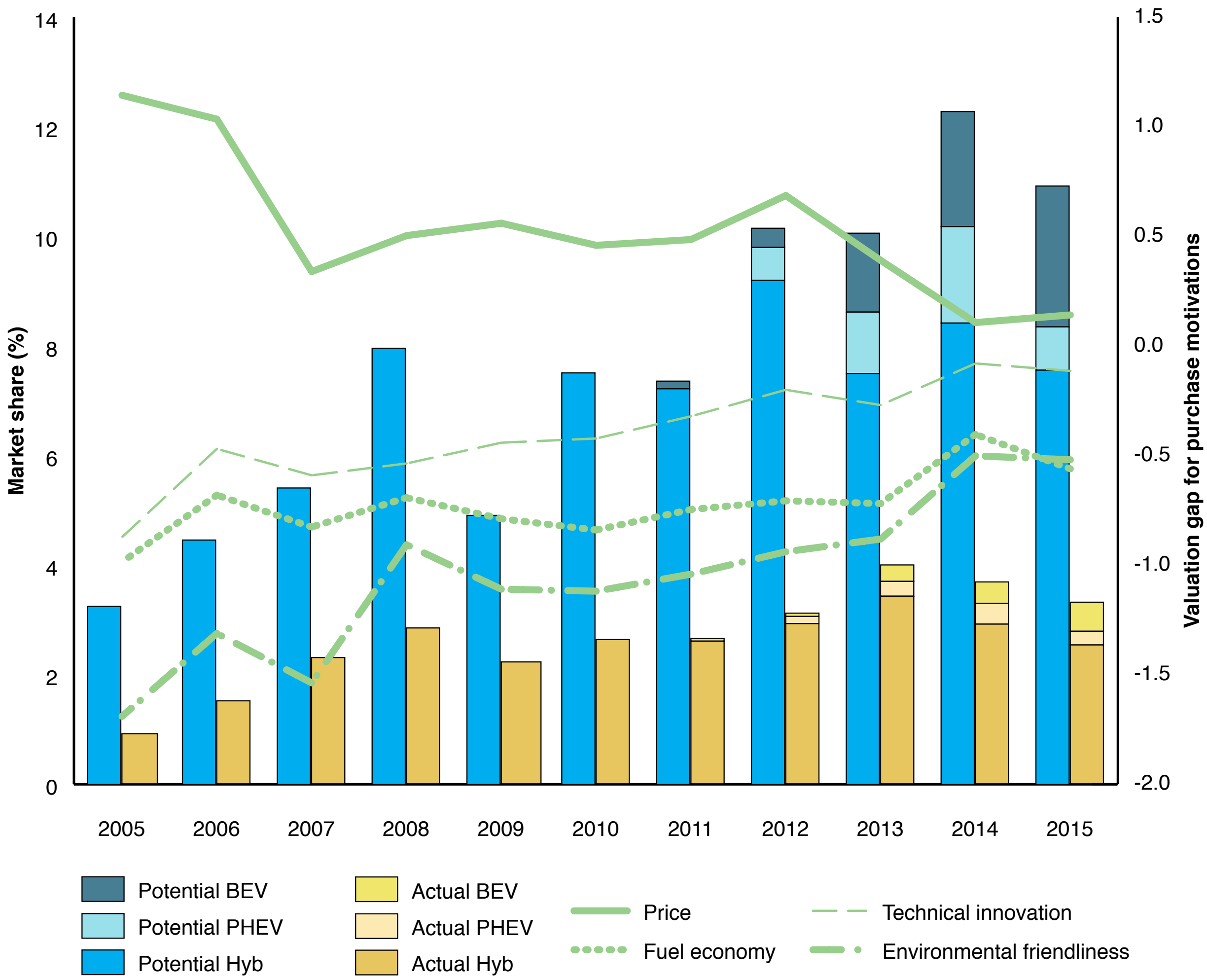

Figure 3. Variation of: (i) actual and potential market share for xEVs on primary axis and (ii) difference between non xEV and xEV consumers' valuation of purchase motivations on secondary axis.

Source: KAPSARC analysis.

The estimated potential market share for xEVs exhibits strong positive correlation with the valuation gap for fuel economy (correlation coefficient, r = 0.79), environmental friendliness (r = 0.91) and technical innovation (r = 0.89) and strong negative correlation with price (r = -0.75). See Appendix C for the mathematical definition of the valuation gap.

In Figure 4, we examine the variation in the valuation gap for fuel economy, environmental friendliness, technical innovation and price with exogenous macro factors such as the CAFE target and gasoline price. We find that the CAFE target exhibits a strong positive correlation with the valuation gap for environmental friendliness (r = 0.83), technical innovation (r = 0.89) and fuel economy (r = 0.69).

To meet the CAFE targets, automakers have been adding innovative fuel-efficient and environment friendly technologies to non xEVs. Non xEV consumers may experience increased utility from driving their newly purchased vehicle, compared with their previous vehicle, before taking the survey. This could have led to non xEV consumers' higher valuation of technical innovation, fuel economy and environmental friendliness as important purchase motivations over successive model years (as shown in Figure A4 in the Appendix). On the other hand, the xEV consumers' valuation of these purchase motivations is decreasing over time (also shown in Figure A4 in the Appendix). This could be because xEV technologies, especially HEVs, have been on the market for more than a decade and are increasingly becoming mainstream. In addition, demand side policies providing financial and non financial incentives have made HEVs more affordable and accessible for a higher fraction of mainstream consumers. Moreover, with the arrival of newer xEV technologies such as PHEVs and BEVs, the HEV consumers' valuation for the previously mentioned purchase reasons decreases, as they are not buying the most fuel-efficient and environmentally friendly vehicle available on the market. Among xEVs, the market share for HEVs is almost an order of magnitude higher and thus the overall trend for xEV consumers' valuation follows the trend for HEV consumers' valuation.

As a result of the GHG/CAFE standards, the price for non xEVs is increasing due to the addition of fuel efficiency improvement technologies. On the other hand, battery costs, a major contributor to xEVs costs, are decreasing with time through learning-by-doing, economies of scale and vertical chain integration. The price premium between non xEVs and xEVs is thus decreasing with time. Correspondingly, the valuation gap for price is decreasing, exhibiting a moderate negative correlation with the CAFE target (r = -0.64), resulting in higher estimated potential market share.

In summary, a combination of supply side and demand side policies serves as a useful tool if policymakers are seeking to nudge non xEV buyers' purchase motivations closer to those of xEV buyers.

The gasoline price also exhibits a moderate positive correlation with the valuation gap for fuel economy (r = 0.53), technical innovation (r = 0.60) and environmental friendliness (r = 0.59). As gasoline prices go up, fuel economy, environmental friendliness and, to some extent, even technical innovation, also become important to non xEV buyers. The moderate effect of the gasoline price on the valuation gap for purchase motivations could be because of supply side policies such as GHG/CAFE targets and the ZEV mandate. Such policies have the potential to reduce the impact of a low gasoline price on consumers' purchase motivations by requiring automakers to produce and sell increasingly fuel-efficient vehicles. In the absence of such policies, gasoline prices could have had a stronger impact on consumers' purchase motivations.

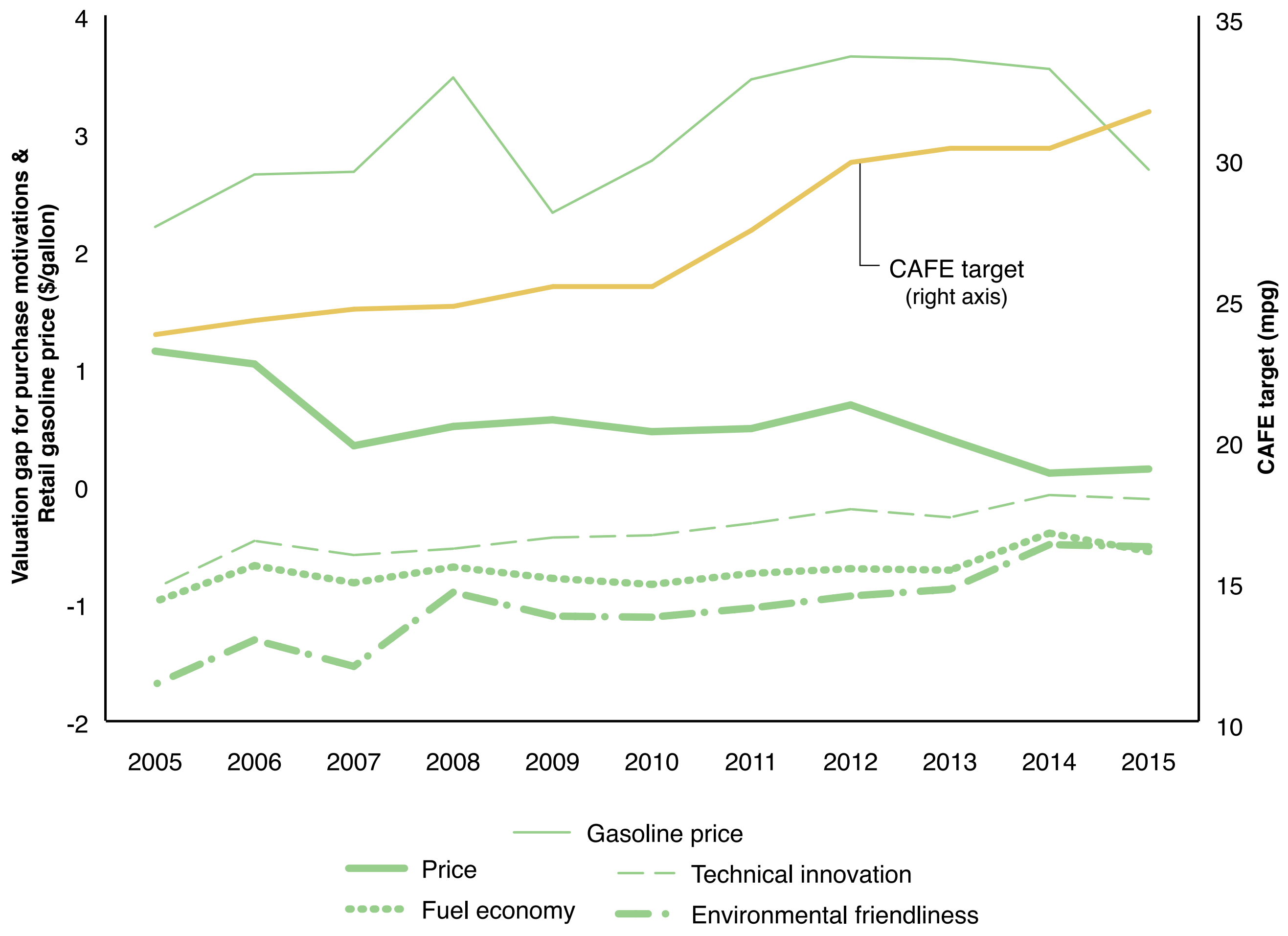

Figure 4. Variation of (i) valuation gap for fuel economy, technical innovation, environmental friendliness and price, (ii) retail gasoline price and (iii) CAFE target.

Note: The retail gasoline price is obtained from U.S. EIA (EIA 2016) and the CAFE target is obtained from NHTSA (NHTSA 2016).

Source: KAPSARC analysis.

Factors that can Induce Switching

To identify factors that could induce potential xEV buyers to adopt xEVs, we compare actual xEV buyers with potential xEV buyers. Comparing their profiles helps identify further steps that private and public sector entities could deploy to encourage potential xEV buyers to become actual xEV buyers. We focus our attention here on HEV-1, PHEV-1, PHEV-2, BEV-1 and BEV-2 buyers only, as those groups show the maximum scope for growth, as shown in Table A3 in the Appendix. In Table 2, we summarize the differences between potential and actual xEV buyers, and factors that private and public sectors might consider to facilitate adoption. For details on how the factors are identified, see Appendix D.

Consider potential BEV-2 buyers. Based on Figure 2, we know that BEV-2 buyers care about environmental friendliness, technical innovation, leasing terms, fuel economy and rebates. Non BEV buyers who also care about such factors, but care less about other factors, are likely to switch to BEV-2. As highlighted in Table 2, potential BEV-2 buyers also care more about these factors compared with Gasoline-1 buyers. In spite of caring more about these factors than average Gasoline-1 buyers, these potential BEV-2 buyers still end up buying a gasoline vehicle.

A way forward can now be seen. Such consumers either need encouragement to care even more about such purchase motivations, or they need the utility they derive from gasoline vehicles, which current BEVs do not provide. For example, as highlighted in Table 2, these potential BEV-2 buyers do care about exterior styling, warranty coverage and resale value, as do gasoline vehicle buyers, and more so than actual BEV-2 buyers. Providing these features or capabilities in BEVs could encourage potential BEV-2 buyers to adopt BEVs.

To achieve market share beyond the estimated potential, factors and features from which mainstream gasoline vehicle buyers derive high utility, such as value for money, reliability and handling, would also have to be offered. Currently, both actual and potential xEV buyers are willing to trade these factors and features for fuel economy, environmental friendliness and technical innovation. But future mainstream xEV buyers, beyond the identified potential xEV buyers, may not be willing to make that trade-off. In the long term, therefore, providing such features or capabilities in xEVs would be vital in bringing about this transition.

Table 2. Adoptive factors.

Note: This table shows factors that can induce potential xEV buyers to adopt xEVs. These findings were obtained by comparing potential xEV buyers with actual xEV and Gasoline-1 buyers. See Figures A5-A9 in the Appendix for detailed results.

	Factors and features where potential xEV buyers are closer to actual xEV buyers		**Factors and features where potential xEV buyers are closer to Gasoline-1 buyers**	
	Relative to Gasoline-1 buyers, both favor	**Relative to Gasoline-1 buyers, both are willing to trade off**	**Relative to actual xEV buyers, both favor**	**Relative to actual xEV buyers, both are willing to trade off**
HEV-1 (MY 2015)	• Fuel economy • Environmental friendliness • Past experience with brand • Navigation system • Technical innovation	• Value for money • Fun to drive • Exterior styling • Handling • Availability of AWD Demographics* • Younger • Lower income	• Warranty coverage • Dealer reputation • Cargo capacity • Safety	
PHEV-1 (MY 2015)	• Leasing terms • Environmental friendliness • Interest rate/credit terms • Car reviews • Discounts, rebates and incentives	• Reliability • Exterior styling • Price/value for money • Manufacturer's reputation • Fun to drive Demographics* • Younger • Lower income	• Safety • Performance • Handling • Ease of front-seat entry/interior roominess	• Advertising and promotion • Ease of customization • Advice of friends and relatives • Towing capability • Availability of AWD
PHEV-2 (MY 2015)	• Environmental friendliness • Technical innovation • Fuel economy • Discounts, rebates and incentives • Performance	• Price/value for money • Handling • Safety • Ease of customization • Towing capability Demographics* • Younger	• Cargo capacity • Interior roominess • Interest rate/credit terms • Dealer reputation • Manufacturer reputation	• Leasing terms • Future trade-in/resale value • Total other vehicles owned/leased Demographics* • Lower income
BEV-1 (MY 2015)	• Environmental friendliness • Technical innovation • Navigation system • Fun to drive • Car reviews	• Price/value for money • Handling • Reliability • Exterior styling • Interest rate/credit terms Demographics* • Younger	• Seating comfort/interior room	Demographics* • Lower income
BEV-2 (MY 2015)	• Leasing terms • Environmental friendliness • Technical innovation • Discounts, rebates and incentives • Fuel economy	• Price/value for money • Reliability • Handling • Dealer reputation • Interior options Demographics* • Younger • Lower income	• Exterior styling • Warranty coverage • Interest rate/credit terms • Future trade-in/resale value	• Car reviews

* Denotes demographic differences between potential and actual buyers.

Source: KAPSARC analysis.

Can all xEVs Sales Grow Simultaneously?

Our analysis in this paper allows for optimistic growth for all fuel types. An obvious question arises: Would the different xEV fuel types cannibalize each other, or could they all grow simultaneously? As can be seen in Figure 5, for MY 2015, the majority (~70 percent) of potential xEV buyers is composed of fuel economy conscious conventional gasoline vehicle buyers. All xEV fuel types, therefore, can grow simultaneously at the expense of gasoline vehicles. However, because of the federal GHG/CAFE emission standards, gasoline vehicles, too, are becoming increasingly fuel efficient. Moreover, due to current low gasoline prices, the driving force encouraging fuel economy conscious gasoline vehicle buyers to adopt even more fuel-efficient xEVs remains limited. As far as competition among xEV fuel types is concerned, since all the xEV fuel types are competing directly with fuel-efficient gasoline vehicles, as shown in Table 3, they indirectly compete with each other. A buyer switching from a fuel-efficient gasoline vehicle to a BEV is one who did not switch to a PHEV.

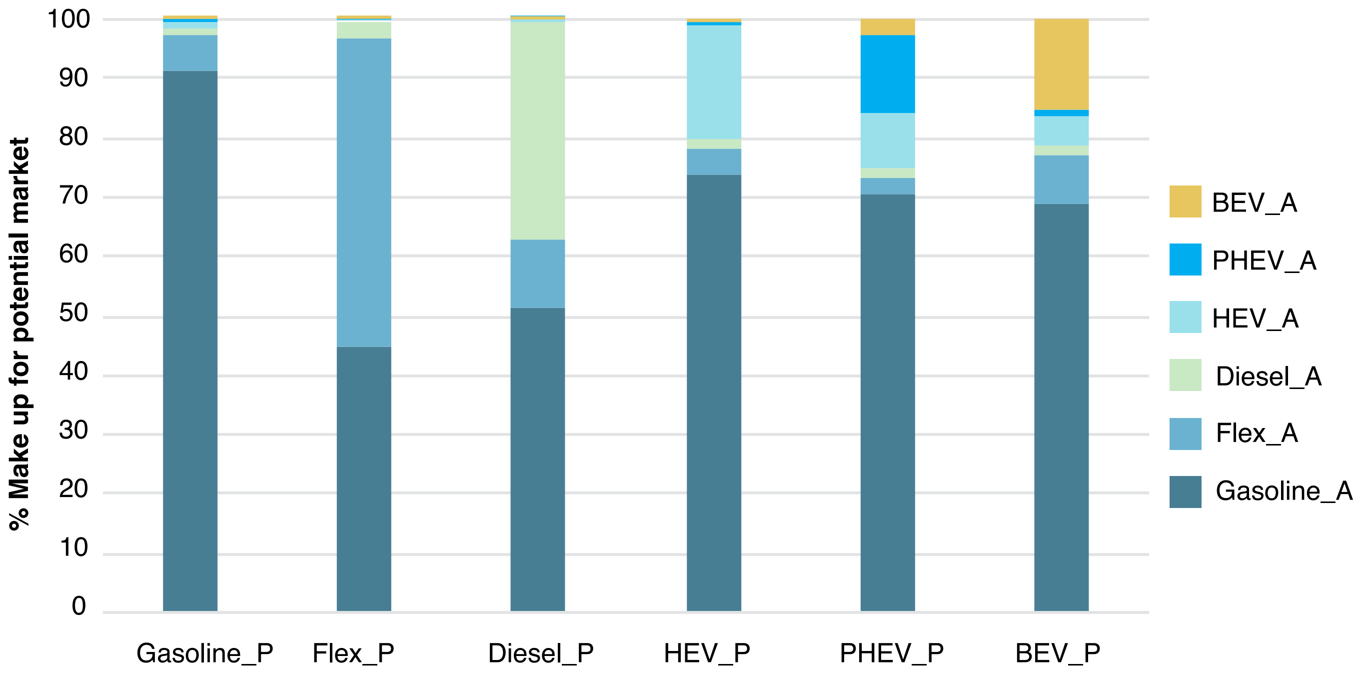

Figure 4. Percentage makeup for potential market for each fuel type.

Note: 'P' stands for potential, and 'A' stands for actual. To interpret the plot quickly, look, for example, at the column corresponding to PHEV-P, where 70 percent of this column is composed of Gasoline_A. This means 70 percent of potential PHEV buyers are composed of actual gasoline vehicle buyers.

Source: KAPSARC analysis.

Table 3. Top 10 models purchased by potential xEV fuel type buyers.

Potential HEV	Potential PHEV	Potential BEV
Toyota Camry	Kia Soul	Toyota Corolla
Toyota Corolla	Nissan Altima Sedan	Toyota Camry
Honda Civic Sedan	Volkswagen Jetta Sdn / GLI Sdn	Subaru Outback Wgn
Honda Accord Sedan	Honda Civic Sedan	Toyota RAV4
Nissan Altima Sedan	Toyota Prius	Kia Forte Sedan
Hyundai Elantra Sedan	Hyundai Sonata	Nissan Rogue
Honda Fit	Ford Fusion	Chevrolet Equinox
Hyundai Sonata	Honda Accord Sedan	Mazda CX-5
Honda CR-V	Chevrolet Camaro	Nissan Altima Sedan
Chevrolet Cruze	Ford Edge	Honda Accord Sedan

Source: KAPSARC analysis.

Conclusion

In summary, we have estimated potential market share for different xEV fuel types, using the past 11 years of consumer profile data. In a counterfactual scenario under optimistic growth conditions, we found the xEV fuel types had the potential to reach around 11 percent of the U.S. new vehicle sales in MY 2015. Instead, xEV fuel types captured only one-third of this market. Key to fulfilling the remaining potential is the public and private sector's ability to encourage fuel economy conscious conventional gasoline vehicle buyers to step up to even more fuel-efficient xEVs.

These potential consumers want features and factors such as exterior styling, safety, warranty coverage and better resale value. Such features are currently more commonly found in conventional gasoline vehicles than xEVs. Manufacturers could integrate the same features and factors into xEVs, which could drive up sales, but adding these desirable features may increase the up-front cost of xEVs – and that could have a negative impact on growth since potential buyers tend to have lower incomes.

The CAFE target exhibits a strong positive correlation with the valuation gap for purchase motivations of fuel economy, technical innovation and environmental friendliness. These are important purchase motivations for actual xEV buyers. Because of the CAFE targets, the non xEV vehicle offerings are becoming increasingly more fuel-efficient and environmentally friendly. The increased utility derived from the addition of these features could be leading to higher valuation of related purchase motivations by non xEV buyers. On the other hand, demand side policies have made xEVs more accessible to mainstream consumers. This may be leading to xEV consumers' lower valuation of these purchase motivations over time. Consequently, the combined effect of these supply side and demand side policies could be to bring the purchase motivations of non xEV buyers closer to those of xEV buyers.

Different xEV fuel types compete indirectly over similar segments of fuel economy conscious conventional gasoline vehicle buyers. Despite that, we find that the different xEV fuel types have the potential to grow up to three times their current market size. Because of GHG/CAFE targets, however, conventional gasoline vehicles are also becoming increasingly more fuel efficient. In the short term, consumers have more fuel-efficient options. Encouraging them to choose the most fuel-efficient xEVs at a time of low gasoline prices remains a challenge.

In the long term, as the CAFE targets become more stringent, conventional vehicle costs would keep rising following the addition of fuel-efficiency technologies. In addition, as battery costs are reduced, through learning-by-doing, supply chain integration and economies of scale, xEVs could become an economically feasible option for automakers to meet the mandated standards, and for consumers when choosing among different fuel-efficient vehicles. Thus, policy instruments such as the CAFE/GHG emission standards and ZEV mandate, combined with demand side support policies, represent viable tools if policymakers wish to nudge consumers toward xEVs.

References

Axsen, Jonn, Joseph Bailey and Marisol Andrea Castro. 2015. "Preference and lifestyle heterogeneity among potential plug-in electric vehicle buyers." Energy Economics no. 50:190-201. doi: http://dx.doi.org/10.1016/j.eneco.2015.05.003.

Axsen, Jonn, Jennifer TyreeHageman and Andy Lentz. 2012. "Lifestyle practices and pro-environmental technology." Ecological Economics no. 82:64-74. doi: http://dx.doi.org/10.1016/j.ecolecon.2012.07.013.

Brownstone, David, David S. Bunch, and Kenneth Train. 2000. "Joint mixed logit models of stated and revealed preferences for alternative-fuel vehicles." Transportation Research Part B: Methodological no. 34 (5):315-338. doi: http://dx.doi.org/10.1016/S0191-2615(99)00031-4.

Dua, R., K. White, and R. Lindland. Understanding Adoption of Energy-Efficient Technologies: A Case Study of Battery Electric Vehicle Adoption in the U.S. KAPSARC 2016. Available from https://www.kapsarc.org/wp-content/uploads/2016/06/KS-1638-DP032A-Understanding-Adoption-of-Energy-Efficient-Technologies.pdf.

EIA. U.S. Retail Gasoline Prices. U.S. EIA 2016. Available from http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMM_EPM0_PTE_NUS_DPG&f=M.

NHTSA. Fleet Fuel Economy Performance Report 2016. Available from https://one.nhtsa.gov/cafe_pic/CAFE_PIC_fleet_LIVE.html.

Tal, Gil, M Nicholas, Justin Woodjack and Daniel Scrivano. Who Is Buying Electric Cars in California? Exploring Household and Vehicle Fleet Characteristics of New Plug-In Vehicle Owners. ITS UC Davis 2013. Available from https://merritt.cdlib.org/d/ark:%252F13030%252Fm56692z3/1/producer%252F2013-UCD-ITS-RR-13-02.pdf.

Appendix A: Data

The dataset used in this study is from the New Vehicle Experience Survey (NVES) conducted by Strategic Vision Incorporated. The NVES is sent out to new vehicle buyers within three months of their purchase in a particular model year. The total number of respondents who completed at least part of the survey in each model year is presented in Table A1. For this study, a subset of the total respondents from each year is selected, based on the respondents who answered all the questions used in this analysis.

Our study primarily uses two sets of elements from the NVES data: (i) consumers' reasons for the purchase, (ii) their demographic characteristics.

A comprehensive list of variables used in this analysis combined across different model years is provided in Table A2. For each model year, variables with a pairwise correlation of less than 0.6 were automatically selected for the analysis. Among groups of variables that have a pairwise correlation of more than 0.6, only one representative variable is selected.

The demographic set of variables corresponds to questions related to respondents' age, income, children and total number of other vehicles in their household. The reported age is transformed into a continuous scale with a range from 1 to 5. The reported income is represented as a logarithmic scale and then transformed into a continuous scale with a range from 1 to 5.

The NVES data also provides weightings that correspond to the ratio of the number of buyers for each make and model in the national market to the number of respondents for the same make and model in the survey.

Table A1. Sample size for each model year.

Model year	Total number of respondents surveyed	Sample size used for analysis
2005	93,164	29,660
2006	99,694	27,961
2007	99,145	32,948
2008	119,115	39,741
2009	178,384	100,170
2010	302,931	159,777
2011	336,370	181,836
2012	339,162	191,568
2013	162,701	88,404
2014	317,493	94,557
2015	215,215	105,691

Source: KAPSARC analysis.

Table A2. List of variables used for the analysis for each model year.

Purchase reason				Demographics
Advertising & promotion	Handling	Past experience with brand	Convenience of controls	Total number of children
Advice of friends and relatives	Income	Reputation of manufacturer	Costs of operations and repair	Total other vehicles owned/leased
Audio/video system	Interest rate/credit terms	Technical innovation	Exterior color	Income
Cargo capacity	Interior roominess	Total children in household	Seating capacity	Age
Dealer reputation	Leasing terms	Total other vehicles owned/leased	Power pickup	
Discounts/rebates/incentives	Car reviews	Towing capacity	Prestige	
Ease of customization	Navigation system	Price/value for money	Price	
Ease of front-seat entry	Environmental friendliness	Warranty coverage	Size/weight of vehicle	
Performance	Exterior styling	Availability of AWD	Interior options	
Fuel economy	Reliability	Country of manufacture	Quietness	
Fun to drive	Safety	Availability of RWD	Design for theft protection	
Future trade-in/resale value	Seating comfort	A well-made vehicle	Quality of workmanship	
Vehicle image	Interior versatility			

Source: KAPSARC analysis.

Appendix B: Identifying Similarities and Differences Among Different buyer Types

The results presented in Figure 2 and Figure A1-A3 were obtained by comparing the utility scores for each xEV buyer group. The utility scores were estimated using a multinomial logit model fitted on the market share for different fuel types. The independent variables were composed of consumers' valuation of purchase motivations and their demographics. The utility score for a factor is calculated as follows:

$$U_{i,m}^{j} = Y_m^j * \left(\frac{\sum_{k=1}^{N_i} w_k X_k^m}{\sum_{k=1}^{N_i} w_k}\right)_i$$

where U_{im}^{j} denotes utility score of average i^{th} buyer of belonging to j^{th} group for m^{th} factor, Y_m^j denotes the coefficient for m^{th} factor in the multinomial logit model for the j^{th} group,

k denotes a respondent and varies from 1 to N_i, where N_i denotes the total number of respondents of i^{th} buyer type,

w_k represents weight associated with the k^{th} respondent and

X_k^m denotes the k^{th} respondent's rating/valuation for m^{th} factor.

To understand how the Venn diagrams are constructed, let's consider the case of the two HEV clusters in MY 2015. First, we compute the utility of an average HEV-1 buyer belonging to HEV-1 group (denoted by $U_{HEV_1,m}^{HEV_1}$), and the utility of an average HEV-2 buyer belonging to HEV-2 group (denoted by $U_{HEV_2,m}^{HEV_2}$). Since the Gasoline-1 cluster is considered as the reference case, the utility belonging to Gasoline-1 cluster is zero. The factors are classified into different parts of the Venn diagram as follows:

Factors listed at the intersection of HEV-1 and HEV-2	$U_{HEV_1,m}^{HEV_1} > 0 \;\&\; U_{HEV_2,m}^{HEV_2} > 0$	**Sorted as**	Maximum $\left(U_{HEV_1,m}^{HEV_1} + U_{HEV_2,m}^{HEV_2}\right)/2$
Factors listed under HEV-1	$U_{HEV_1,m}^{HEV_1} > 0 \;\&\; U_{HEV_2,m}^{HEV_2} < 0$	**Sorted as**	Maximum $\left(U_{HEV_1,m}^{HEV_1} - U_{HEV_2,m}^{HEV_2}\right)$
Factors listed under HEV-2	$U_{HEV_1,m}^{HEV_1} < 0 \;\&\; U_{HEV_2,m}^{HEV_2} > 0$	**Sorted as**	Maximum $\left(U_{HEV_2,m}^{HEV_2} - U_{HEV_1,m}^{HEV_1}\right)$
Factors listed under Gasoline-1	$U_{HEV_1,m}^{HEV_1} < 0 \;\&\; U_{HEV_2,m}^{HEV_2} < 0$	**Sorted as**	Maximum $\left(U_{HEV_1,m}^{HEV_1} + U_{HEV_2,m}^{HEV_2}\right)/2$

Appendix C: Valuation Gap

The valuation gap represents the difference between non xEV and xEV consumers' valuation for purchase motivations. It is calculated using the following formula:

$$Valuation\ gap = \left(\frac{\sum_{i=1}^{N_i} w_i X_i}{\sum_{i=1}^{N_i} w_i}\right)_{non-xEV} - \left(\frac{\sum_{j=1}^{N_j} w_j X_j}{\sum_{j=1}^{N_j} w_j}\right)_{xEV}$$

where, *i* denotes non xEV respondent,

j denotes xEV respondent,

N denotes the maximum number of respondents,

X denotes the consumer valuation for a purchase motivation and

w represents weight associated with the respondent.

Appendix D: Identifying Factors that can Induce Switching

To identify factors that could induce potential xEV buyers to adopt xEVs, we compare actual xEV buyers with potential xEV buyers. Let's consider the identifying factors that can induce potential HEV-1 buyers to adopt HEVs. We look to identify which factors could lead potential HEV-1 buyers to belong to the actual HEV-1 group. It is important to note that a majority of these potential HEV-1 buyers (90 percent) currently belong to the Gasoline-1 group. In principle, we want to understand what factors could lead these potential HEV-1 buyers to leave Gasoline-1 and move to the HEV-1 group. We fit a multinomial logit model on the market share for Gasoline-1, potential HEV-1 and HEV-1 groups, assuming Gasoline-1 as the reference group. The independent variables are consumers' valuation of purchase motivations and their demographics. Afterward, we calculate the utility scores for an average potential HEV-1 buyer of belonging to the actual HEV-1 group and the potential HEV-1 group. These utility scores are plotted in Figure A5 in the Appendix. The division of various factors in different columns in Table 2 is based on the following:

Factors and features on which potential xEV buyers are closer to actual xEV buyers	Relative to Gasoline-1 buyers, both favor	$U_{Pot\ HEV_1}^{Pot\ HEV_1} > 0 \ \&\ U_{Pot\ HEV_1}^{HEV_1} > 0$ $\&\ abs\left(U_{Pot\ HEV_1}^{Pot\ HEV_1} - U_{Pot\ HEV_1}^{HEV_1}\right) < abs\left(U_{Pot\ HEV_1}^{Pot\ HEV_1} - U_{Pot\ HEV_1}^{Gasoline_1}\right)$
	Relative to Gasoline-1 buyers, both are willing to trade off	$U_{Pot\ HEV_1}^{Pot\ HEV_1} < 0 \ \&\ U_{Pot\ HEV_1}^{HEV_1} < 0$ $\&\ abs\left(U_{Pot\ HEV_1}^{Pot\ HEV_1} - U_{Pot\ HEV_1}^{HEV_1}\right) < abs\left(U_{Pot\ HEV_1}^{Pot\ HEV_1} - U_{Pot\ HEV_1}^{Gasoline_1}\right)$
Factors and features on which potential xEV buyers are closer to Gasoline-1 buyers	Relative to actual xEV buyers, both favor	$U_{Pot\ HEV_1}^{HEV_1} < 0$ $\&\ abs\left(U_{Pot\ HEV_1}^{Pot\ HEV_1} - U_{Pot\ HEV_1}^{HEV_1}\right) > abs\left(U_{Pot\ HEV_1}^{Pot\ HEV_1} - U_{Pot\ HEV_1}^{Gasoline_1}\right)$
	Relative to actual xEV buyers, both are willing to trade off	$U_{Pot\ HEV_1}^{HEV_1} > 0$ $\&\ abs\left(U_{Pot\ HEV_1}^{Pot\ HEV_1} - U_{Pot\ HEV_1}^{HEV_1}\right) > abs\left(U_{Pot\ HEV_1}^{Pot\ HEV_1} - U_{Pot\ HEV_1}^{Gasoline_1}\right)$

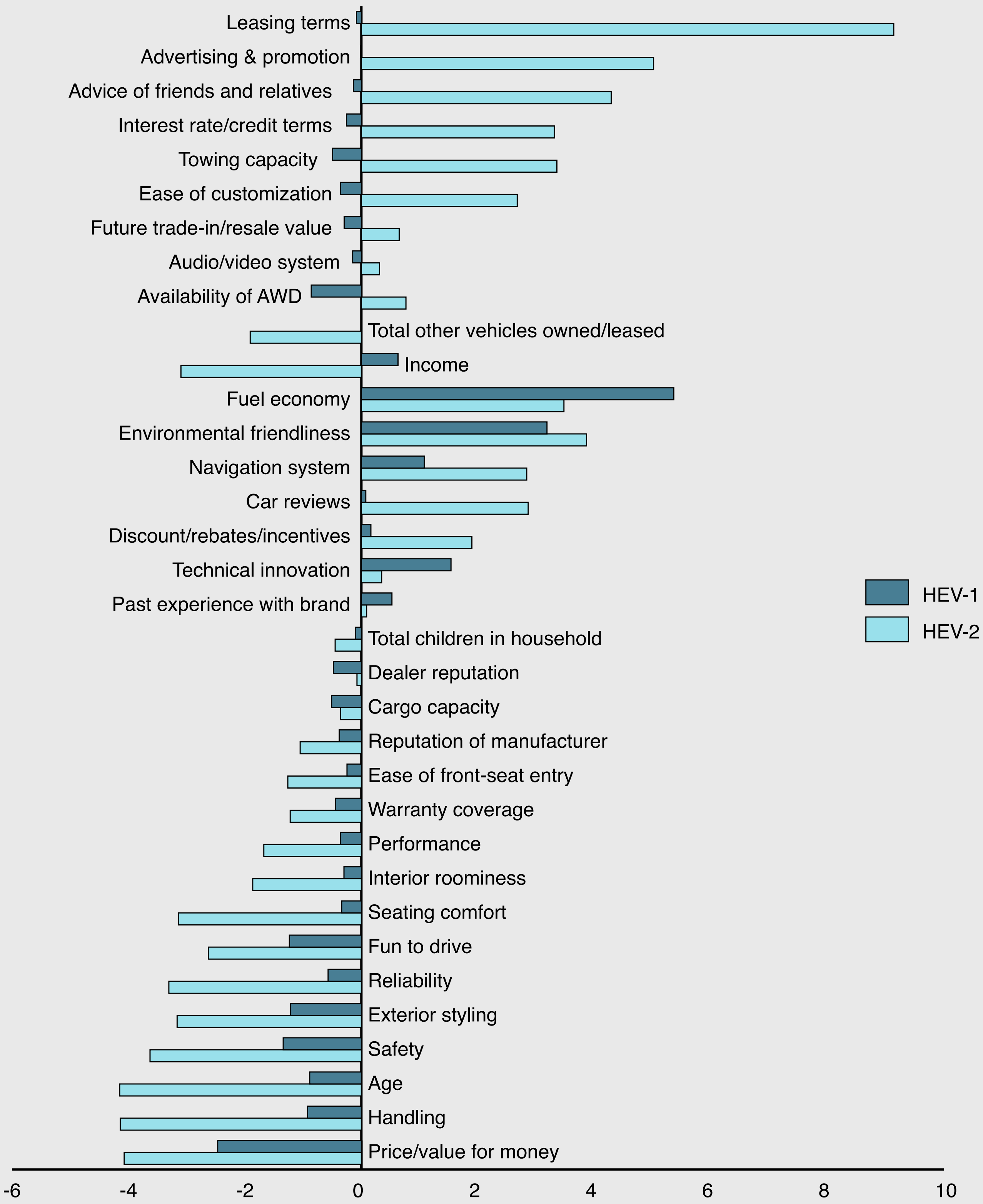

Figure A1. Utility score values for the HEV-1 and HEV-2 buyer groups, considering the Gasoline-1 cluster as the reference case.

Source: KAPSARC analysis.

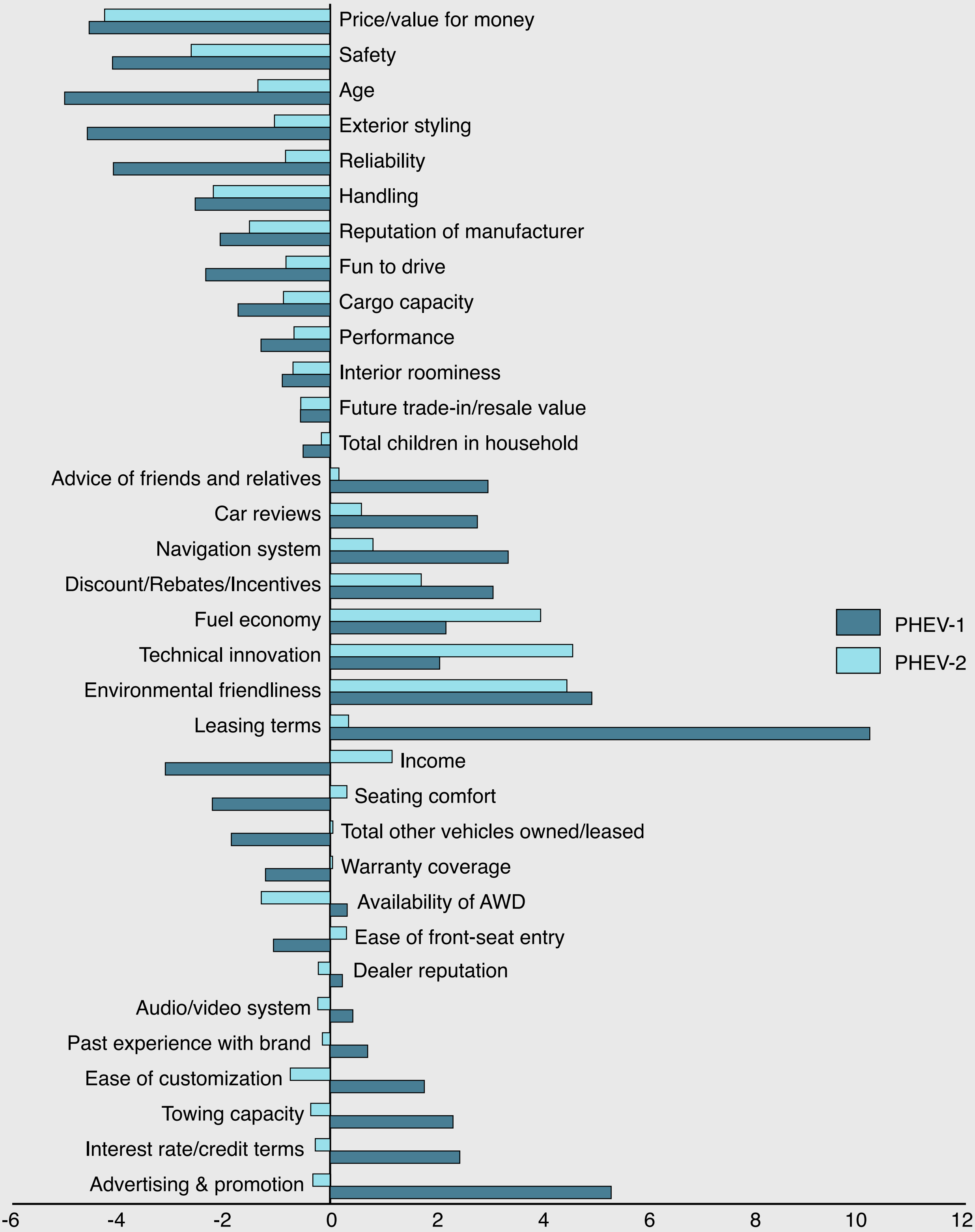

Figure A2. Utility score values for the PHEV-1 and PHEV-2 buyer groups, considering the Gasoline-1 cluster as the reference case.

Source: KAPSARC analysis.

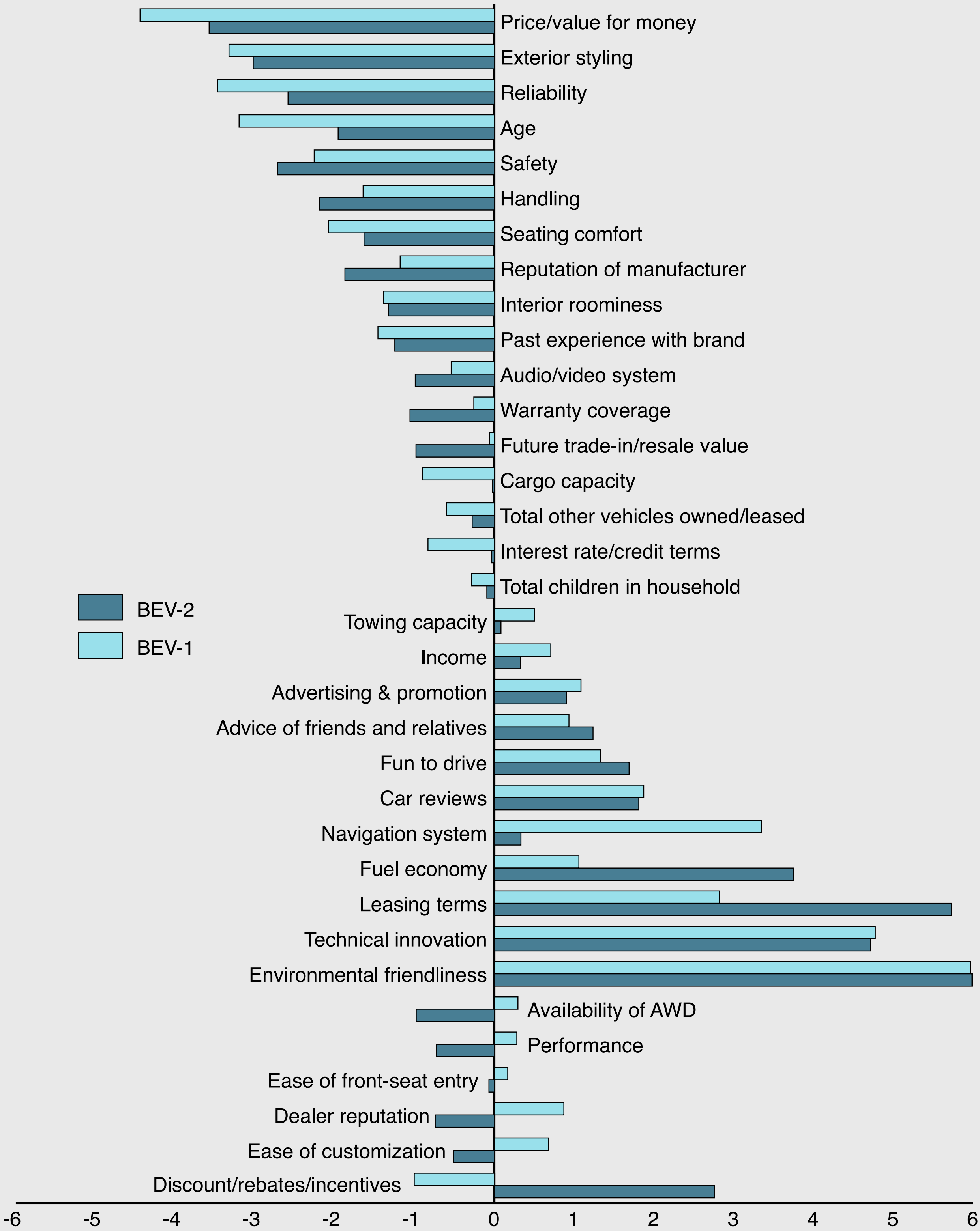

Figure A3. Utility score values for the BEV-1 and BEV-2 buyer groups, considering the Gasoline-1 cluster as the reference case.

Source: KAPSARC analysis.

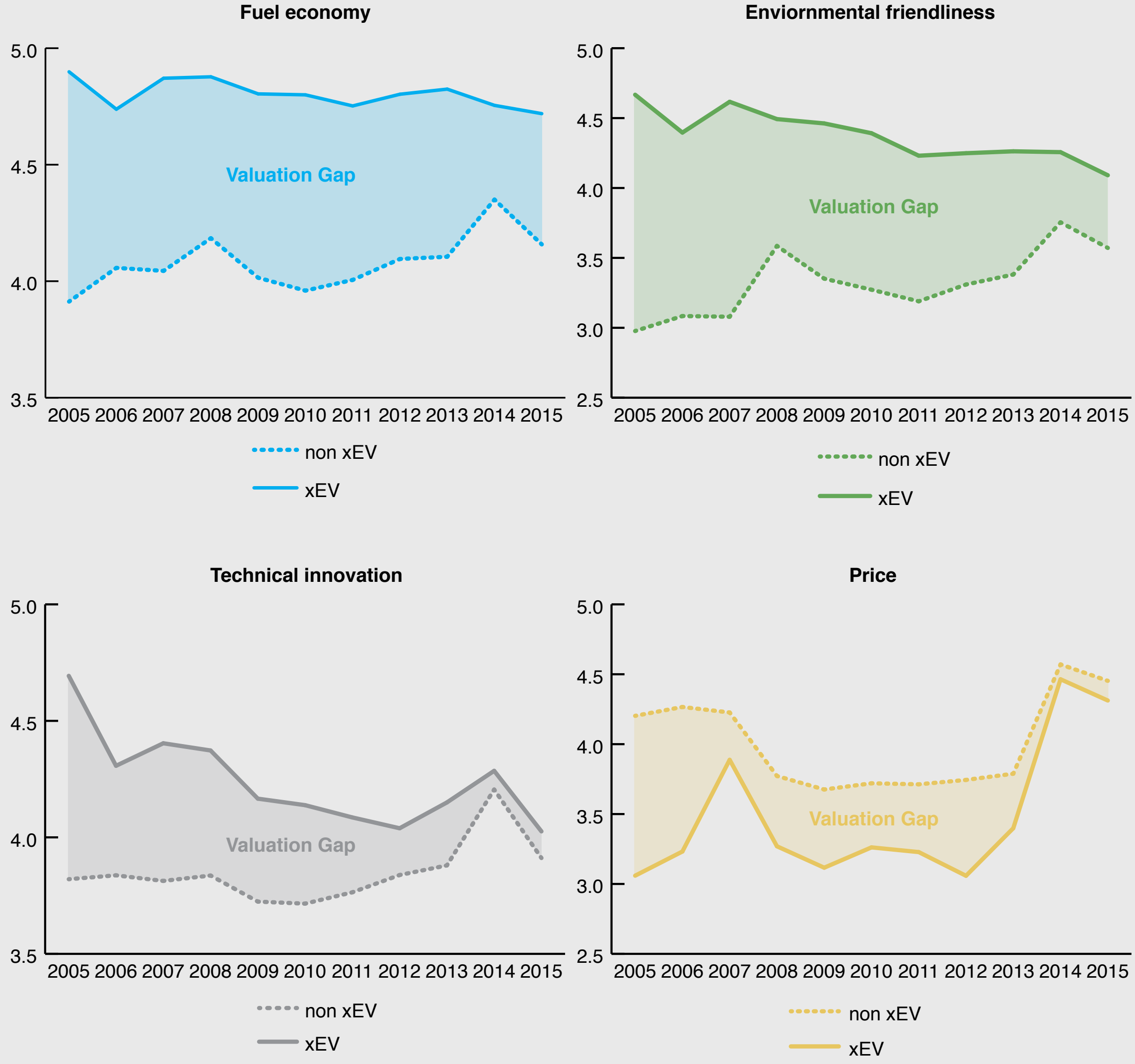

Figure A4. Variation of consumers' valuation of purchase motivations, y-axis represents consumer valuation, solid lines represent xEV consumers and dotted lines represent non xEV consumers.

Source: KAPSARC analysis.

Table A3. Scope for growth for different xEV clusters in MY 2015

Cluster	Actual market share (percent)	Potential market share (percent)	Growth factor (potential/actual)
HEV-1	1.62	6.54	4.04
HEV-2	0.92	1.02	1.11
PHEV-1	0.11	0.40	3.65
PHEV-2	0.14	0.39	2.79
BEV-1	0.28	1.50	5.36
BEV-2	0.25	1.07	4.29

Source: KAPSARC analysis.

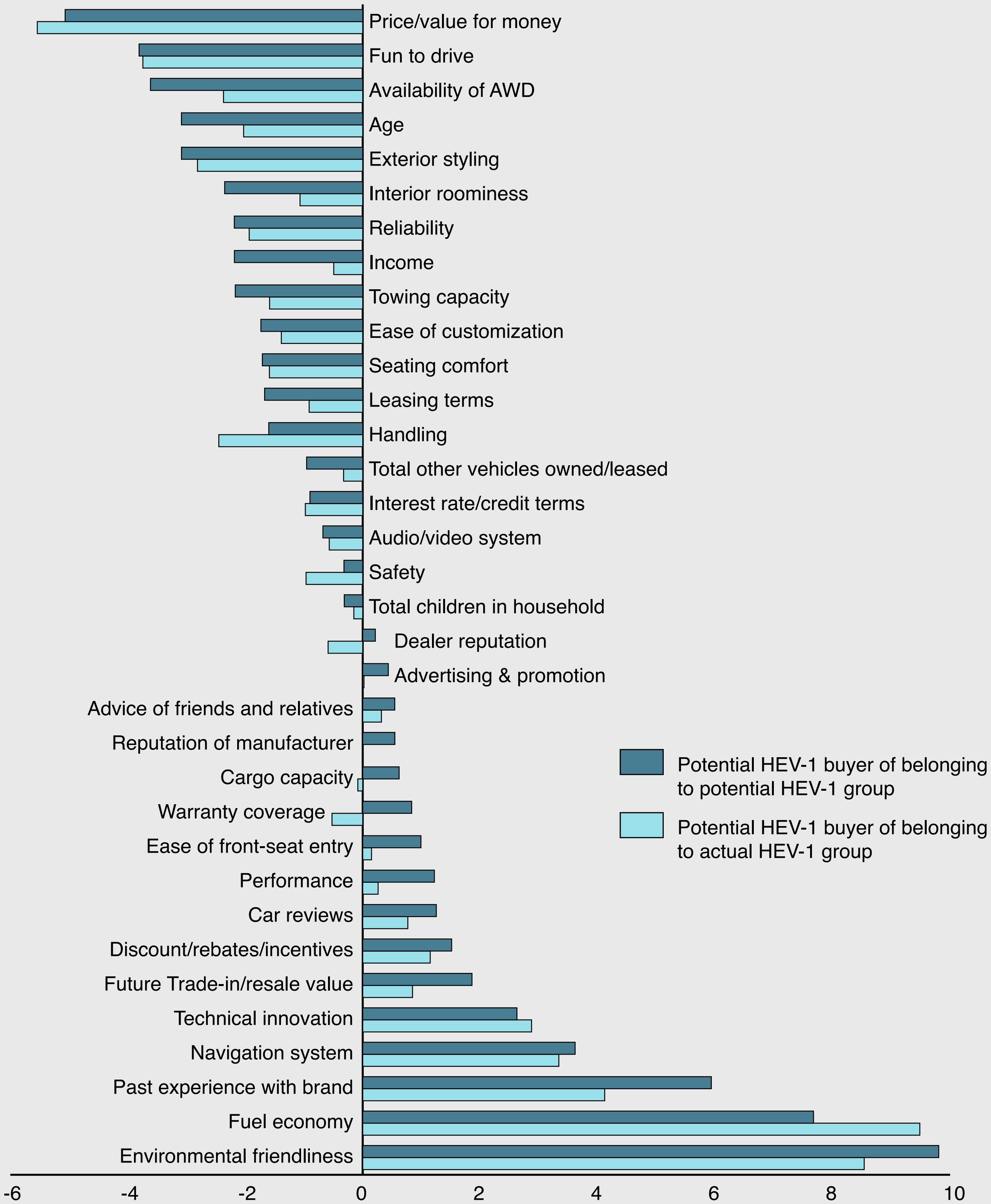

Figure A5. Utility score values for potential HEV-1 buyers of belonging to the actual HEV-1 group and potential HEV-1 group, considering the Gasoline-1 group as the reference case.

Source: KAPSARC analysis.

Appendix D: Identifying Factors that can Induce Switching

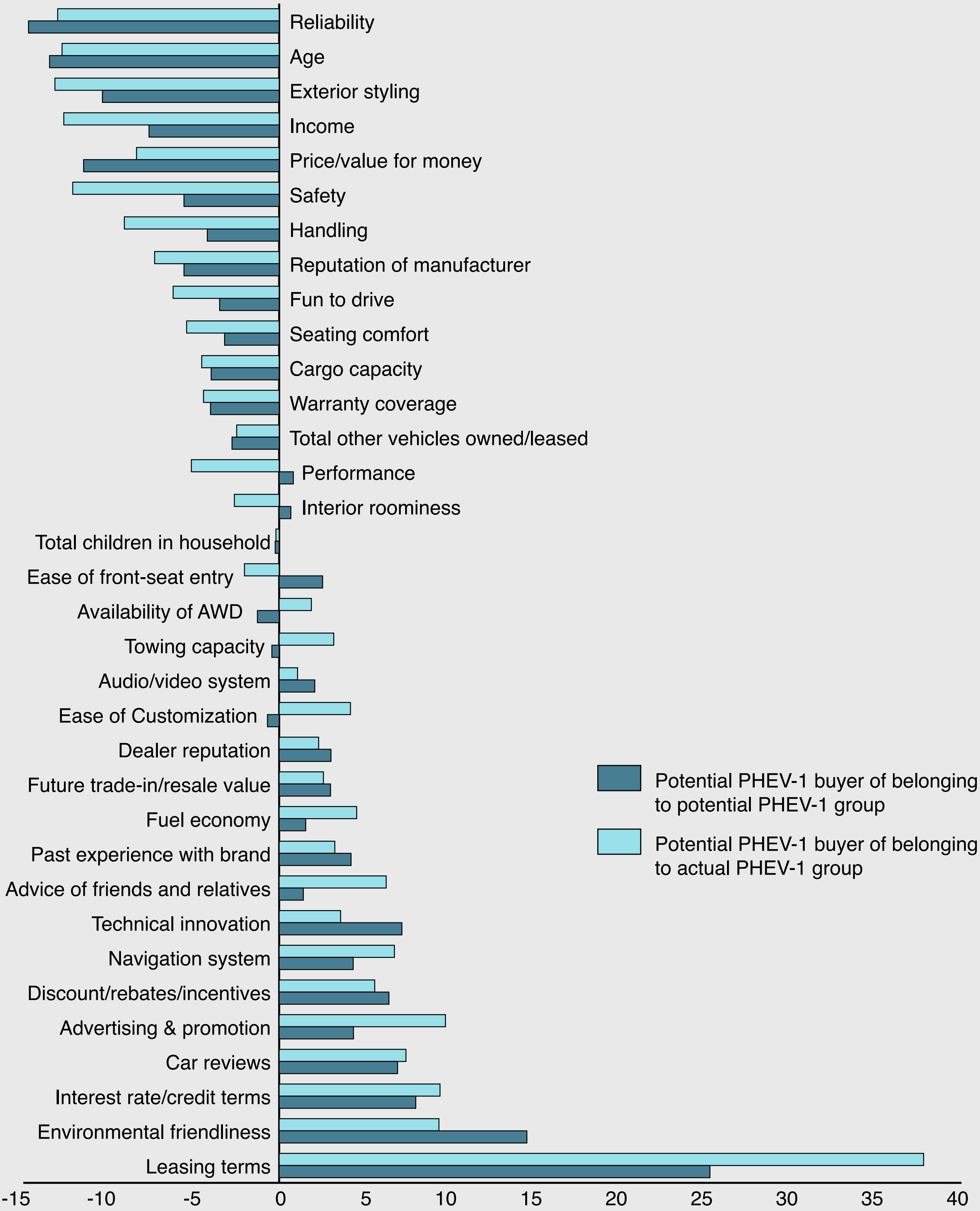

Figure A6. Utility score values for potential PHEV-1 buyers of belonging to the actual PHEV-1 group and potential PHEV-1 group, considering the Gasoline-1 group as the reference case.

Source: KAPSARC analysis.

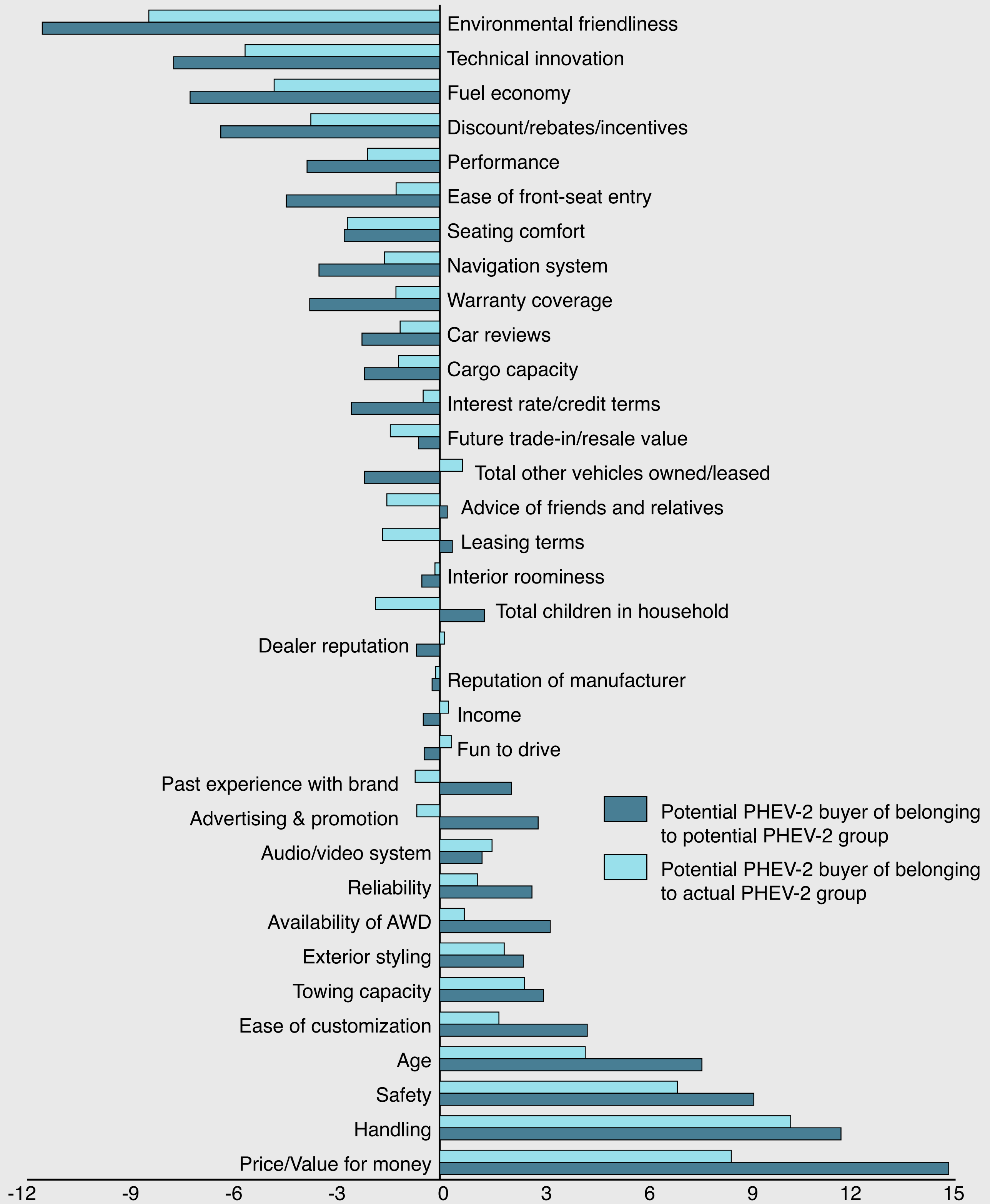

Figure A7. Utility score values for potential PHEV-2 buyers of belonging to the actual PHEV-2 group and potential PHEV-2 group, considering the Gasoline-1 group as the reference case.

Source: KAPSARC analysis.

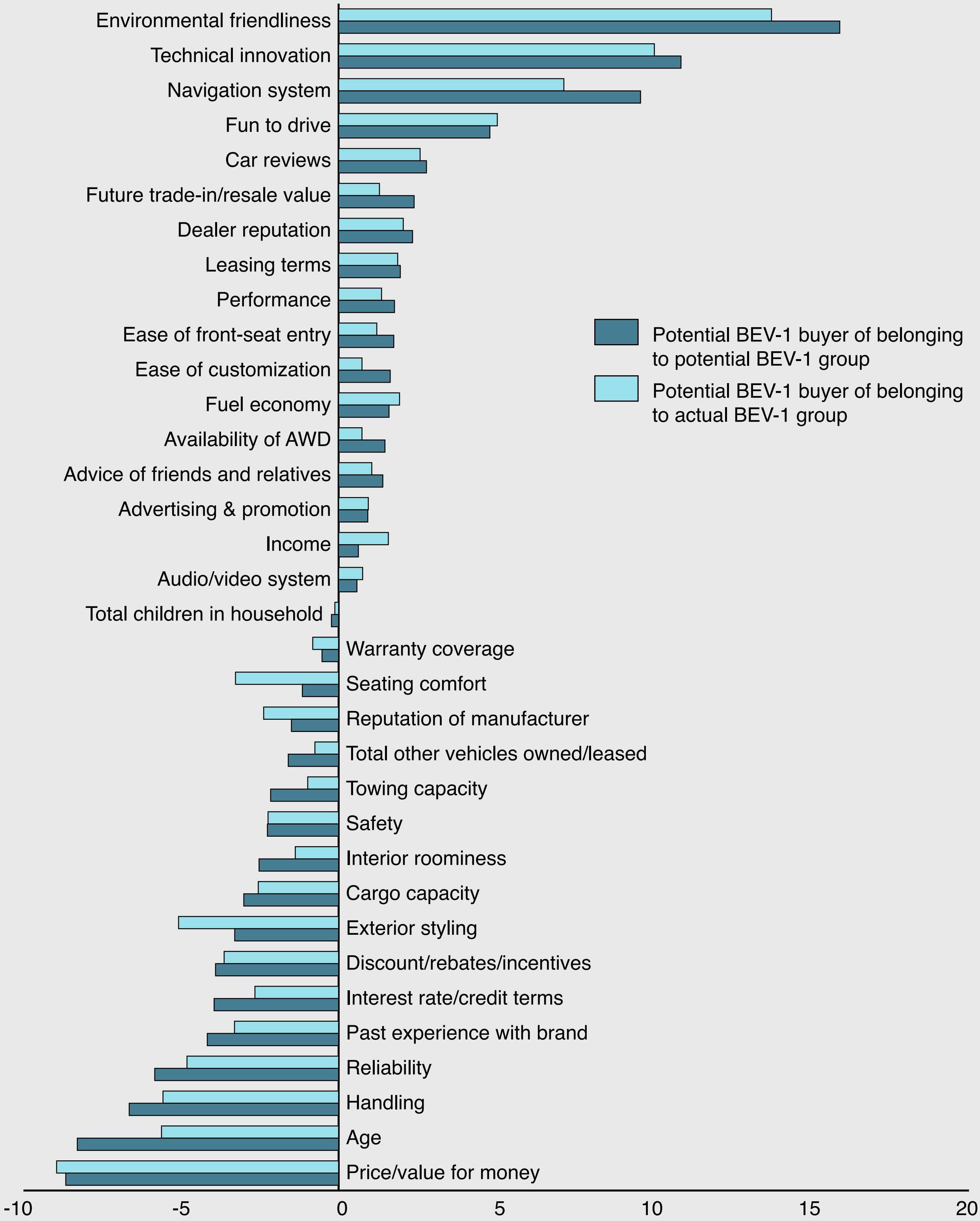

Figure A8. Utility score values for potential BEV-1 buyers of belonging to the actual BEV-1 group and potential BEV-1 group, considering the Gasoline-1 group as the reference case.

Source: KAPSARC analysis.

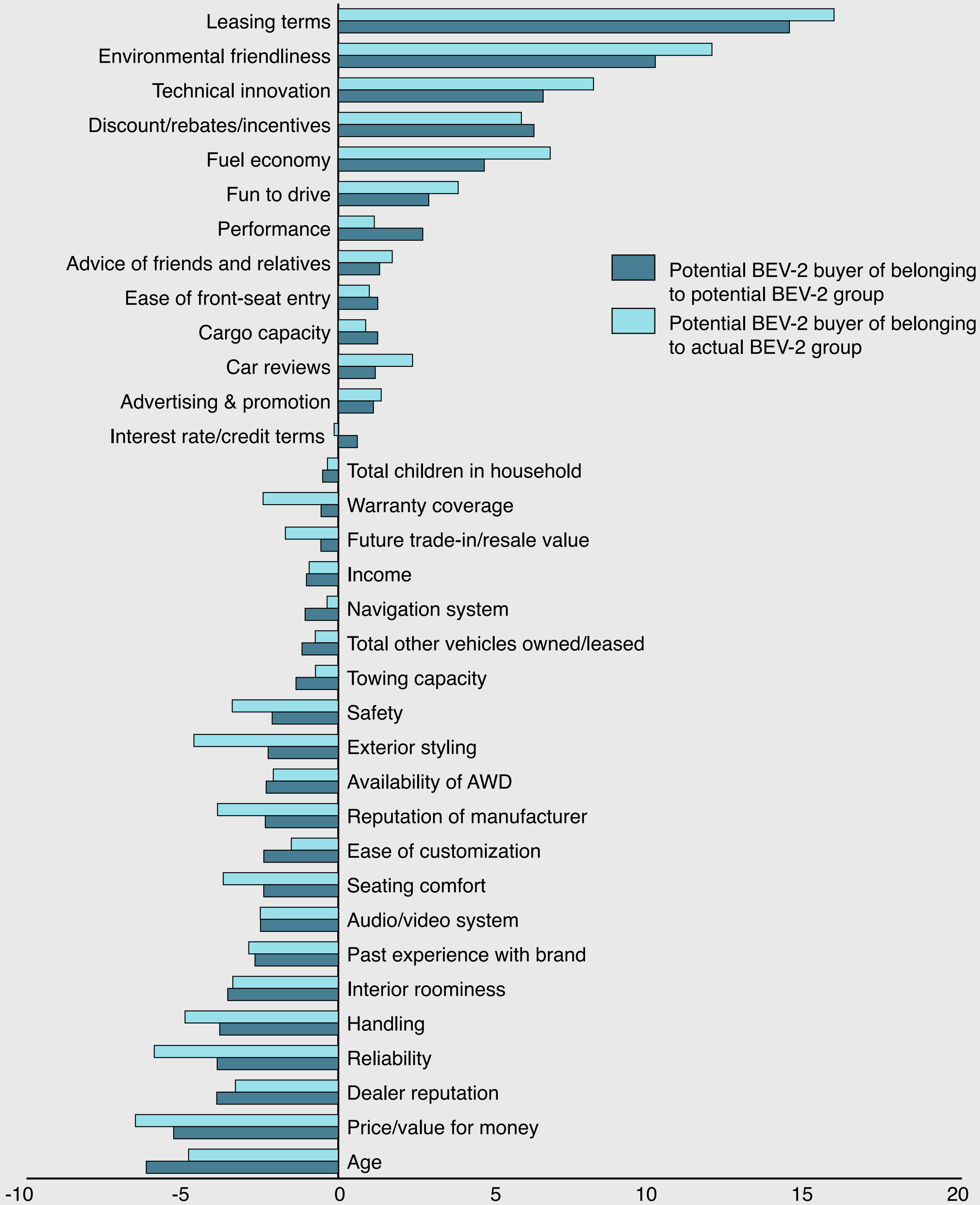

Figure A9. Utility score values for potential BEV-2 buyers of belonging to the actual BEV-2 group and potential BEV-2 group, considering the Gasoline-1 group as the reference case.

Source: KAPSARC analysis.

Notes

About the Authors

Rubal Dua

Rubal is a senior research associate at KAPSARC, leading vehicle regulatory policy and shared mobility research using the consumer perspective. He holds a PhD from KAUST, KSA and a MS degree from the University of Pennsylvania, U.S.

Kenneth White

Kenneth was formerly a senior research analyst at KAPSARC, analyzing transportation and Chinese energy policy. He has an MPP from Stanford University, U.S.

About the Project

Promoting adoption of energy-efficient vehicles has become a key policy imperative in both developed and developing countries. Understanding the impact of various factors that affect adoption rates, such as: (i) consumer related factors – demographics, behavioral, psychographics; (ii) regulatory factors – policies, incentives, rebates, perks; and (iii) geo-temporal factors – weather, infrastructure, network effects; forms the backbone of KAPSARC's efforts in the transportation field. Our team is currently developing models at different levels of resolution – micro level models using large-scale data comprising of new car buyers' profiles and macro level models using aggregated adoption data, to understand and project the effects of various factors at play for the adoption of energy-efficient vehicles.

KAPSARC

مركز الملك عبدالله للدراسات والبحوث البترولية

King Abdullah Petroleum Studies and Research Center

www.kapsarc.org