RESEARCH REPORT

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Assessing the Cost of Ownership of Electric Vehicles Among California Households

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16. Abstract

The primary metric for measuring electric vehicle (EV) adoption growth is new car sales. However, to enable mass market penetration, EV adoption in the used car market will play a crucial role. The used vehicle market is relatively under-studied or has been studied mostly for specific regions. This project analyzed US national consumer expenditure survey data that tracks households' expenditure on vehicle acquisition and operation. The study aim is to understand new versus used vehicle choice behavior and the consequent cost of vehicle ownership, with the larger aim of determining how much households who generally buy used vehicles can gain or lose if they transition from a used internal combustion engine vehicle (ICEV) to a used EV. A choice model and cluster analysis showed that ownership of used vehicles is influenced by family size, income, housing tenure, and age. For lower-income renters, current vehicle ownership and purchase costs tend to constitute a high fraction of their household income, raising concerns related to equity and suggesting that these households in particular should be considered in policies to encourage the EV transition. Moreover, while at present the average price paid for a used ICEV is approximately $18,000, the price of a comparable used EV can range between $14,000 (e.g., lower electric range Nissan Leaf) to $50,000 (high-range Tesla), suggesting the need for incentives to encourage the used EV market.

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Table of Contents

About the UC Institute of Transportation Studies

The University of California Institute of Transportation Studies (UC ITS) is a network of faculty, research and administrative staff, and students dedicated to advancing the state of the art in transportation engineering, planning, and policy for the people of California. Established by the Legislature in 1947, ITS has branches at UC Berkeley, UC Davis, UC Irvine, and UCLA.

The California Resilient and Innovative Mobility Initiative

The California Resilient and Innovative Mobility Initiative (RIMI) serves as a living laboratory – bringing together university experts from across the four UC ITS campuses, policymakers, public agencies, industry stakeholders, and community leaders – to inform the state transportation system's immediate COVID-19 response and recovery needs, while establishing a long-term vision and pathway for directing innovative mobility to develop sustainable and resilient transportation in California. RIMI is organized around three core research pillars: Carbon Neutral Transportation, Emerging Transportation Technology, and Public Transit and Shared Mobility. Equity and high-road jobs serve as cross-cutting themes that are integrated across the three pillars.

Acknowledgments

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Table of Contents

List of Tables

List of Figures

List of Acronyms

CES	Consumer Expenditure Survey
CU	consumer unit
EV	electric vehicle
ICEV	internal combustion engine vehicle
TCO	total cost of ownership

Executive Summary

Executive Summary

The primary metric for measuring electric vehicle (EV) adoption growth is new car sales. However, to enable mass market penetration, EV adoption in the used car market will play a crucial role. The used vehicle market is relatively under-studied or studied for a localized market. By analyzing the consumer expenditure survey (CES) data that tracks households' expenditure on vehicle acquisition and operation on a national scale, we aim to understand the new versus used vehicle choice behavior and the consequent cost of vehicle ownership. The motivation here is to understand how much households who generally buy used vehicles can gain or lose if they transition from an internal combustion engine vehicle (ICEV) to an EV. Due to the limited data and research available on used EV buyers, examining the characteristics and vehicle costs of individuals who purchase used vehicles could help in understanding this group. The current study can serve as a starting point in that direction and may be of interest to stakeholders such as policymakers, who can benefit from information about the needs of potential used EV buyers.

We estimated a choice model to understand the factors that influence the choice of new versus used vehicles. The results of the discrete choice model revealed that households with the following characteristics had a strong inclination to purchasing used passenger cars: having more than 4 members, renting their house, having a member between 40 and 50 years old, or having an annual income outside the range of around $25K to $70K. Used trucks or vans are more likely to be purchased by households with these characteristics: location in rural areas, having an annual income more than $70K to less than or equal to $100K, having individuals that are younger than 60 years old, and having one used truck in their fleet (and no other vehicle).

These findings may have implications for future electrification. For example, the used car market includes renters and households with more than 4 members. Assuming that these demographic groups will transition to used EVs, incentives can be designed to make EVs more accessible to them. Policy adjustments may be needed, including additional financial incentives for larger families or infrastructure investments in communities with renters. Similarly, the used truck or van market includes households living in rural areas. Since there is currently limited availability of electric truck models that could eventually enter the secondary market, this finding may indicate that EV adoption by truck owners in rural areas will be slower. Additionally, this may further highlight the need for geographic coverage of charging infrastructure and programs targeting truck owners in rural areas.

Building upon the broader understanding of used vehicle buyers obtained from the discrete choice model, we conducted a market segmentation analysis of used vehicle buyers. Three clusters were identified. Cluster 2, labeled as *low-income single-vehicle home-renters*, primarily includes households who rent their residences, have the smallest family size and the lowest average income ($52,868), and mainly own a single used vehicle (99.8%). Cluster 3, *affluent dual-vehicle homeowners*, comprised households who own their homes, with a higher average income ($107,096) and a mixed fleet of one new vehicle (77.9%) and one used vehicle (69.3%). Cluster 1, *moderate-income multi-vehicle homeowners*, consisted of households that owned their homes, had a moderate average income ($83,204), and owned an average of two used vehicles per household (71.6%). This segmentation approach enables a more precise understanding of the diverse range of individuals within the used vehicle market, facilitating the development of tailored strategies and initiatives to cater to the distinct needs and preferences of each segment that may eventually transition to EVs.

For electrification to be advantageous for households, it is essential to have EV options that meet their requirements. For low-income households especially, this may mean having access to used EVs with costs that are comparable to those of the vehicles they typically purchase. On average, the price paid for a 1- to 3-year-old used vehicle by the low-income segment that bears the highest cost burden with respect to their household income is $17,280, while the price of a used EV in the market can vary between $14,681 (2017 Nissan Leaf) and $50,806 (2017 Tesla Model S). This highlights that while some lower range EVs may be comparable to ICEVs in terms of purchase cost, the high range EVs are still more expensive than what households tend to pay for used ICEVs. However, the vehicle ownership cost analysis that accounts for both purchase and operating costs showed that the median annual ownership cost for used cars and trucks or vans in the CES sample is around $12,500 and $13,631, respectively, whereas the annual total ownership cost of a used 2017 Nissan Leaf is approximately $7,300 and for a 2017 Tesla Model S is $12,780.[1] Additionally, the median annual vehicle ownership cost across the three clusters (*moderate-income multi-vehicle homeowners*, *low-income single-vehicle home-renters*, and *affluent dual-vehicle homeowners*) ranges from $12,332 to $14,442. The median annual vehicle ownership costs for the three clusters is given in **Table ES 1.**

Table ES 1. Median annual vehicle ownership costs across clusters of vehicle buyers

Cluster	Median annual vehicle ownership cost
Moderate-income multi-vehicle homeowners	$12,332
Low-income single-vehicle home-renters	$14,442
Affluent dual-vehicle homeowners	$13,390

The difference in purchase price between average used vehicles and used EVs raises concerns about equity and access to EVs, since households that have at least one used vehicle constitute around 68%[2] of the total vehicle owners in the US. Policy intervention may be necessary to overcome the potential obstacle that the cost of owning used EVs could pose to their adoption.

Although this study did not estimate the total cost of ownership (accounting for resale or scrappage value), the vehicle purchase and operating costs calculated are crucial in the purchase decision process and constitute the

[1] Total cost of ownership for the 2017 Nissan Leaf and Tesla Model S is calculated using the Edmunds Cost of Car Ownership tool https://www.edmunds.com/tco.html. Note, that the total cost of ownership estimates for the Nissan Leaf and Tesla Model S includes the depreciation cost along with the purchase and operating costs.

[2] This percentage is estimated based on (i) the number of households owning at least one used vehicle (which is the sample used in the cluster analysis) and (ii) the population of vehicle owners in the US based on CES data that is considered representative of the US population.

main vehicle ownership cost components that vary between ICEVs and EVs. The cost results can provide a benchmark to compare used ICEVs and EVs and further explore the optimal incentive types and monetary values of incentives for the purchase or operation of used EVs. Second, the annual costs reported for different market segments could be used to inform analyses exploring or modifying eligibility requirements for incentive programs.

Contents

Introduction

Global electric vehicle (EV) sales have sharply increased in recent years, responding to both EV promotion policies worldwide and growing acceptance and familiarity with the technology. In the United States (US), new EV sales, including battery and plug-in hybrid EVs, represented 6.1% of the total car sales in 2022, almost doubling 2021 sales [1]. In the US, California has the most aggressive electrification targets set by the Advanced Clean Car II regulation aiming to drive new EV sales to 100% by 2035 [2]. While the EV market continues to grow and market mechanisms are being designed to help achieve such electrification targets, there remain major barriers to adoption, such as high vehicle purchase price, range anxiety, and lack of charging infrastructure [3], [4]. The used vehicle market for EVs is also in nascent stages; 71% of the total vehicle sales nation-wide were of used vehicles in 2019, with the average price of used vehicles being half of that of new vehicles (includes passenger cars and trucks, as well as purchases and leases).[3] The lack of a good understanding of the role of used vehicle market on vehicle technology diffusion may also be a barrier for the electrification goals set nation-wide and in California. Although vehicle purchase price and total ownership costs have been extensively studied for new vehicles, there is a lack of extensive research on used EVs [5]–[7]. Research on used vehicles and buyers of used vehicles is essential since they are usually low or middle-income households [5], [7], and most EV models on the market are still luxury vehicles [7], [8].

Cumulative EV sales in the US reached around 1.6 million units in August 2020, and a significant portion of these will eventually enter the used car market [7], [9]. Hence, used EV sales have the potential to be significant share of the market for EVs and used vehicle buyers are expected to become a large potential segment of EV adopters. An understanding and characterization of the used vehicle buyers could help inform policies to target this market, not only to foster EV adoption beyond early adopters but also to ensure the EV technology and its benefits are available to all population segments. In this study, we use the Consumer Expenditure Survey (CES), a database that tracks quarterly household expenditure for an exhaustive list of items, including vehicle purchase and usage, to understand the characteristics and the cost of vehicle ownership of buyers of used vehicles [10].

From a vehicle choice perspective, there are a limited number of studies examining the used EV market. Bauer et al.[7] studied the implications of EV adoption, presenting cost-parity estimates for new and used EVs by income segment in the US. Muehlegger and Rapson [11] explored potential barriers that low-income households face to access California's new and used EV markets. Turrentine et al. [5] examined the characteristics of used EV buyers in California, how used EVs are being used and the role of incentives in the purchase decision. The studies by Hardman et al. [8] and Lee [12] presented a brief overview of EV policies in the US and their implications on equity, highlighting that EV buyers are still heavily concentrated around high-income households. These multiple studies are either based on a specific geographical area (e.g., California) or are restricted to descriptive statistics analyses or qualitative discussion. Additionally, most studies mainly focus

[3] https://www.bts.gov/content/new-and-used-passenger-car-sales-and-leases-thousands-vehicles

on electric passenger cars and do not account for the preference for larger vehicles such as light trucks. Understanding purchase decisions for both vehicle segments can have significant implications for informing transportation policy decisions.

Vehicle purchase and operating costs are critical factors in the vehicle purchase process, particularly for low-income vehicle buyers [11]. Thus, examining the vehicle ownership cost, which consists of purchase and operating costs, is a key metric that can offer policymakers an estimate of the potential market for used EVs and the cost savings used EVs can offer to potential EV buyers. Research on the cost of vehicle ownership, primarily total cost of ownership (TCO) analysis, has been growing over the past few years. Researchers have traditionally used TCO estimates to identify the tipping point in economic competitiveness for new EVs—i.e., when the TCO of an EV will be less than or equal to that of a comparable internal combustion engine vehicle (ICEV), and therefore, vehicle buyers may voluntarily adopt EVs based on economic rationality. These TCO studies often focus solely on the impact of changes in technology costs and average household characteristics, primarily average miles traveled in the TCO calculations [13]–[16]. At the household-level however, the TCO can be complicated and involve other factors, such as household-specific behavior, access to vehicle charging at home, regional difference in energy price, and variation in local taxes and fees [17]–[20]. In general, for a comprehensive understanding of the cost of transitioning to an EV-dominated fleet to meet the aggressive EV penetration targets, it is necessary to focus on both changes in EV technology costs and household factors that may influence the TCO of a new or used EV. In this study, we focus on 5-year vehicle ownership costs that includes vehicle purchase price and annual vehicle operating costs instead of TCO that also includes a resale value. This is primarily done because this vehicle ownership cost estimate can capture the cost heterogeneity across households, and it is hard to reliably estimate the resale value of vehicles across makes, models, and vintages at the household-level.

This study expands upon previous research by examining both the new and used vehicle markets on a national scale. It investigates the factors influencing consumers' choices of new and used passenger cars and light trucks or vans and applies this knowledge to identify distinct market segments within the used vehicle buyer population. Additionally, the study collects and analyzes data on the prices of used EVs and compares them to the purchase price of used vehicles reported by households in the CES data. By doing so, it aims to uncover any potential affordability gap between used EV prices and the typical vehicle purchase patterns observed within different segments of used vehicle buyers. This research not only sheds light on the characteristics of used vehicle buyers but also offers insights into potential pathways for transitioning these buyers to the used EV market. Ultimately, the findings can contribute to the development of targeted policies that facilitate a fair and widespread adoption of EVs within the used vehicle market.

Data for Analysis

Data on Vehicle and Household Characteristics

The Consumer Expenditure Survey (CES) data from the Bureau of Labor Statistics of the US Department of Labor [10] forms the foundation of this research. The survey is conducted quarterly among US households using a rotating panel whereby households/consumer units (CUs) recruited for the survey are expected to report their quarterly expenditure for different categories including transportation-related expenses. Up to four quarters of vehicle expenditure data are available per CU, with an average of 2.6 quarters of data per CU due to non-response and attrition. Overall, the CES collects data on sociodemographic characteristics and expenditure items divided into over 50 categories under two different sets of data files, the diary and the interview files. This study used the interview files, which record quarterly expenditures on major and recurring items in the following categories: CU characteristics, income and summary level expenditures on vehicle purchase/lease, method of vehicle acquisition (gift/dealer/only, etc.) and disposal, and vehicle operating expenses, including licensing, registration, and inspection. Among its questions, the survey asks whether each vehicle of the household was new or used when it was first acquired, as well as whether the vehicle is a car or truck/van (no further vehicle classification is provided). For this analysis, the data set consists of unique CU-level records over four years (2018–2021).

To facilitate this study's purpose and modeling effort, pre-processing the data was required. Data pre-processing constituted merging separate quarterly and annual files into a single dataset. Subsequently, households with no vehicles and duplicate records were removed. Moreover, given the focus of the research here and to avoid the problem of attrition in rotating panel data, we considered the first interview record for each CU in the sample. After data processing, the final sample used for analysis consisted of 17,127 responses. The sample was further split into three groups: “New Buyers only,” “Used Buyers only,” and “Mixed Buyers”. “New Buyers only” and “Used Buyers only” constitute vehicle owners having exclusively new or used vehicles, respectively. “Mixed Buyers” include vehicle owners that own a mix of new and used vehicles in their household fleet.

Figure 1 shows the distribution of the three groups of households across different regions of the US. The West region includes the state of California with 1,787 CUs in the sample.

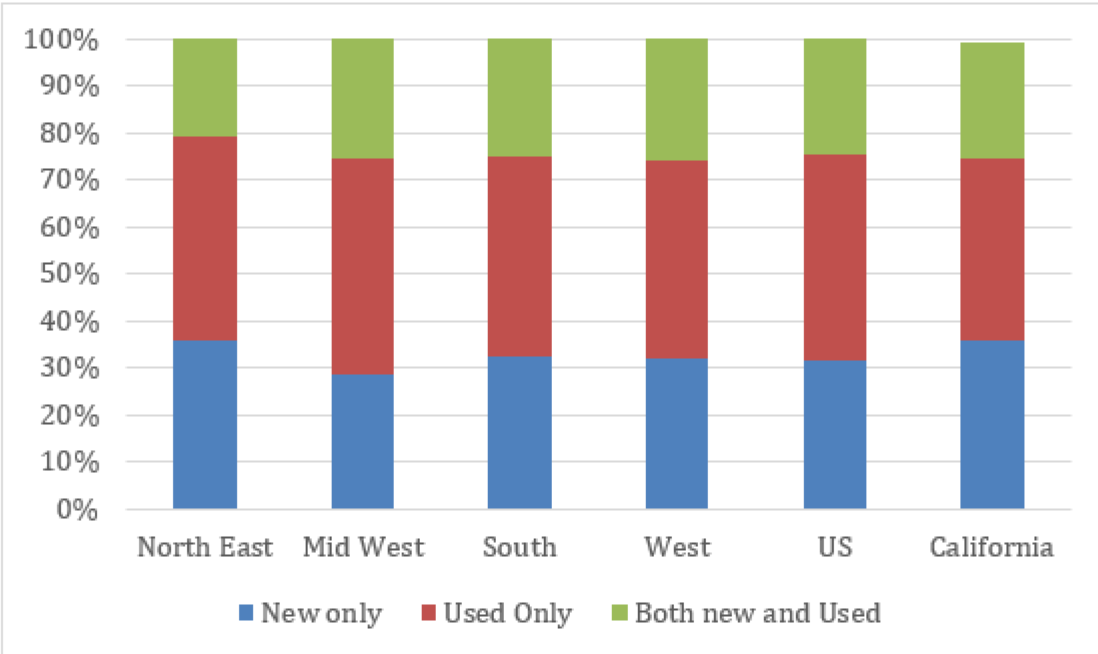

Figure 1. Distribution of the three groups of vehicle owners across US regions.

Table 1 gives the distribution of the CES sample across key sociodemographic and vehicle ownership characteristics for the three groups defined earlier.

Table 1. Descriptive statistics of key sociodemographic characteristics.

	New Buyers only		Used Buyers only		Mixed buyers	
Sample size (n = 17,127)	5,423		8,366		3,338	
% of total sample	31.7%		48.8%		19.5%	
Household size (number of persons)						
1	1,866	34.4%	2,360	43.5%	258	4.8%
2	2,134	39.4%	2,715	50.1%	1,445	26.6%
3	659	12.2%	1,235	22.8%	675	12.4%
4	513	9.5%	1,129	20.8%	540	10.0%
≥5+	251	4.6%	927	17.1%	420	7.7%
Annual Household Income						
Average	$99,897		$74,109		$122,983	
Distribution						
≤$25,000	845	15.6%	1,699	20.3%	204	6.1%
($25,000–$50,000]	1,203	22.2%	2,230	26.7%	532	15.9%
($50,000–$70,000]	687	12.7%	1,221	14.6%	402	12.0%
($70,000–$100,000]	807	14.9%	1,296	15.5%	583	17.5%

	New Buyers only		Used Buyers only		Mixed buyers	
($100,000–$500,000]	1,847	34.1%	1,903	22.7%	1,589	47.6%
>$500,000	34	0.6%	17	0.2%	29	0.9%
Housing tenure						
Own	4,293	79.2%	5,019	60.0%	2,920	87.5%
Rent	1,072	19.8%	3,180	38.0%	388	11.6%
No. of vehicles per household						
1	3,279	60.5%	4,631	55.4%	--	-
2	1,791	33.0%	2,659	31.8%	1,901	57.0%
3	304	5.6%	772	9.2%	955	28.6%
≥4	49	0.9%	301	3.6%	482	14.4%
Households that own a car vs truck/van						
Car	1,879	34.6%	2,816	33.7%	440	13.2%
Van/truck	2,248	41.5%	3,159	37.8%	850	25.5%
Both	1,296	23.9%	2,391	28.6%	2,048	61.4%
Households that own EV vs ICEV						
EV only*	15	0.3%	2	0.0%	–	0.0%
ICEV only	4,989	92.0%	7,874	94.1%	2,919	87.4%
Plug-in hybrids only	110	2.0%	71	0.8%	2	0.1%
ICEV & EV*	143	2.6%	122	1.5%	172	5.2%
Proportion of urban households	94.9%		91.9%		93.1%	
Household education						
Less than 9th grade	27	0.5%	105	1.3%	11	0.3%
No college degree	1,719	31.7%	3,925	46.9%	1,001	30.0%
College degree	3,677	67.8%	4,336	51.8%	2,326	69.7%

**Plug-in hybrid vehicles are not included*

To understand the purchase behavior of new and used vehicle buyers, the filters that were applied to the data were the following, resulting in 17,127 responses:

- Households owning at least one automobile, truck, or van were considered.
- The maximum number of vehicles considered for each CU was truncated at 8 since the majority of households owned up to 8 vehicles.
- Only the records for the first interview of each CU were kept. This decision was first made based on the research objective, which did not involve examining changes in purchase decisions over time. Second, all respondents were interviewed at least once, meaning that, during their first interview, they answered or thought of the survey questions similarly, with no prior experience or exposure to them.

Additionally, past research has shown that respondents usually become worse reporters in later waves of a panel survey (e.g., [21], [22]).

- For the analysis described below, certain variables were created that identified the latest vehicle purchased by each CU, which was acquired within one year up to the date of the interview. The vehicle purchases by a CU were arranged by year and month of purchase to enable identification of the most recent purchase.

The CES interview data was also utilized and preprocessed to accurately identify distinct segments of used vehicle buyers. In line with the filters above, only the first interviews of each CU were retained, and a maximum of 8 vehicles per CU were considered. The market segmentation analysis focused specifically on respondents who owned at least one used vehicle (without imposing the constraint of having purchased a vehicle within one year from the interview). The final sample for the market segmentation analysis consisted of 11,731 responses.

The CES data tracks the quarterly expenditure on cost components like net outlay for new and used vehicles purchased by the household, toll and parking expenses, lease costs, maintenance, insurance, and fuel costs by fuel type (gasoline, diesel, electric) for the total household fleet. This implies one cannot identify the cost components for a specific vehicle in a CU and the vehicle miles traveled using the vehicle. Vehicle specific data however includes vehicle specifications such as the make, fuel type, model year, vehicle purchase year, net purchase price (after discount, trade-in, or rebate, including destination fee), down payment, net trade-in value, whether the vehicle was bought new or used, whether it was financed, the purpose of the vehicle, and the loan status for the vehicle. Given the focus of the research, since the purchase/vehicle acquisition cost details are primarily available for the most recent purchase, the most recent vehicle (by vehicle purchase year) is considered in this study to analyze the vehicle ownership cost of new and used vehicles There is still a lot of missing data for down payment and trade-in allowances. Moreover, there can be recollection bias in the data reported. As a result, even though it may not accurately capture the actual purchase cost of the vehicle, the net purchase price reported by the CU is used for this analysis as it gives an estimate of the price consumers are willing to pay for new and used vehicles and an upper bound of the vehicle acquisition cost. For the operating cost component of the ownership cost, we divide the total fuel cost by the number of vehicles to get the cost for individual vehicles. This is a crude estimate of the fuel cost of a vehicle but gives an average cost estimate for a CU. **Table 2** summarizes some key characteristics of the most recent vehicle acquisitions, as tracked in the CES data.

Table 2. Key metrics for the most recent household vehicle.

	New Vehicle	Used Vehicle
Net purchase cost (Recent Vehicle)	\$30,934	\$18,210
Down payment amount	\$3,514	\$2,202
Amount of trade-in allowance	\$7,834	\$4,881
Vehicle financed (1 if financed, 0 otherwise)	70%	48%
Vehicle purchased from private individual	–	34%
Vehicle received as a gift	–	0.04%

Methods

Profile of New and Used Vehicle Buyers

Discrete Choice Model

Using the CES data, a discrete choice model was estimated to capture recent purchase behavior and identify the factors affecting the likelihood that a household purchases a vehicle within one year up to the interview. The time frame was selected to be relatively small (a year) so that the sociodemographic characteristics reported in the interview would be more accurate and could better reflect the decision for the latest purchase. The alternative choices related to vehicle purchase (the dependent variable) are the following: a) a household purchases a new car ("new car"), b) a household purchases a used car ("used car"), c) a household purchases a new truck or van ("new truck or van"), d) a household purchases a used truck or van ("used truck or van"), and e) a household does not purchase any vehicle ("no purchase") within that period. The frequencies of the alternatives are: a) 3.9%, b) 10.7%, c) 6.9%, d) 13.0%, and e) 65.6%. The last option (no purchase) constitutes the base alternative for the choice model.

A random parameter multinomial or mixed logit model was derived by assuming that the estimated parameters vary across observations according to some predicted distribution [23], [24]. This approach was chosen, as a fixed-parameter assumption might be incorrect due to unobserved factors affecting an individual's sensitivity to any explanatory variable [24]. As a result, inconsistent outcome probabilities and estimates of parameters may occur. Additionally, mixed logit models can overcome the independence of irrelevant alternatives problem in standard multinomial logit models since the ratio of any two outcome probabilities is no longer independent of any other outcomes' probabilities [24]. To identify the final model for the current study, various variables were created by observing the data, reviewing the literature on vehicle or transaction choice models (e.g.,[25]–[34]) and testing the variables in the model. We ensured that there was an adequate number of observations (at least 10 to 15) for partitioned variables in every situation. Each of the variables in the survey was examined for their significance as fixed and random parameters and tested using the generic and the alternative specific structure. The random parameters' standard deviation should be statistically significant to be considered in the model. Different distributions were tested for the random parameters, and the assumption of normal distribution yielded the best statistical fit. The approach of 200 Halton draws was used [35] to draw values of parameters and estimate possible mixing distributions, as it has been shown to be more efficient [24], [36]. The final model included variables found to be statistically significant using a one-tailed hypothesis test with a confidence interval of 90% and critical t-value of 1.282. Correlation matrices for independent variables were also reviewed, and there was no correlation issue (the established threshold is 0.5). The evaluation of the statistical fit of the model was based on the goodness-of-fit measures; McFadden ρ^2 values of 0.2 to 0.4 represent an excellent fit for such models [23]. The model was estimated using NLOGIT 4 and by standard maximum likelihood procedures.

Cluster Analysis

A cluster analysis was used to identify homogenous groups of used vehicle buyers, specifically, on the basis of the characteristics found in the data [37]. The first step of any cluster analysis is to determine the characteristics that will be used to segment the sample (clustering variables) [37]. The clustering variables should offer a clear distinction between the segments, without exhibiting high correlation among themselves [37], [38]. In this study, the discrete choice model developed (refer to previous section "Discrete Choice Model") provided initial insights about the factors that affect the most recent purchase behavior of vehicle buyers. These factors were used to inform the decision on the clustering variables. Additional variables were created based on educated assumptions for their significance in the clustering solution. These variables included the average household fleet age and annual vehicle ownership cost for each household. The latter was calculated following the procedure described in the next section "Vehicle Acquisition and Ownership Cost Analysis." We ensured that the associations across each pair of variables participating in the cluster analysis were weak to moderate, if not negligible. Given the nature of the CES data, the types of clustering variables are mostly observable, although the variables regarding the vehicle holdings might be considered as a proxy for households' unobservable preferences. Data scaling was performed since the clustering variables have different scales or units and may not contribute equally to this clustering technique. In particular, continuous data were normalized in the range of 0 to 1 using the min-max scaling technique.

The next step involved the selection of the appropriate clustering technique. The data for this study contains a mix of categorical and continuous variables and thus, a two-step cluster analysis would be appropriate. This clustering technique offers several benefits, including the ability to analyze large datasets ($n > 500$), handle diverse types of data (ordinal/continuous and nominal discrete/categorical attributes), analyze outliers, and automatically determine the optimal number of clusters based on statistical measures of fit [39]–[41]. Due to these benefits, the two-step cluster analysis has gained increasing popularity in market research (e.g.[40], [42]–[44]).

The two-step cluster analysis is a hybrid method, integrating the principles of hierarchical and partitioning clustering methods. It initially employs a distance measure to differentiate groups and then a probabilistic approach, similar to latent class analysis, to determine the most suitable subgroup model [40], [41], [45]. The two-step cluster analysis uses the log-likelihood as a distance measure to determine how the similarity across clusters is computed. Since it forms clusters hierarchically, a range of solutions is produced which is eventually narrowed down to the optimal number of clusters using the Schwarz's Bayesian information criterion (BIC) (the optimal number of clusters has the lowest BIC value). After forming the cluster solution, the significance of individual variables within the clusters is assessed using χ^2-tests for categorical variables and student t-tests for continuous variables [46].

The silhouette coefficient of cohesion and separation was used to compare and validate cluster solutions. This measure shows the overall quality of the clustering solution by estimating the similarity of an observation to its cluster (cohesion) compared to other clusters (separation) [47]. The silhouette coefficient ranges from 1 to -1. It is considered advantageous if the silhouette measure of cohesion and separation exceeds 0.2, indicating a reasonable separation distance between clusters [38]. Apart from considering the silhouette coefficient, the relevance of clustering variables and the validation of a cluster solution are assessed by reviewing the input (predictor) importance [2]. The importance of variables is expressed on a scale from 0 to 1. Variables with a low rating (0.02 or below) should be carefully examined or removed from the final solution. Lastly, the clustering solution may also be validated through randomly dividing the sample into two subsets and comparing the results with the final cluster solution. Validation is confirmed if both the final solution and the split solutions are similar in terms of the number of clusters, and the characteristics of the clusters. In this study, the two-step cluster analysis was conducted using the IBM SPSS Statistics software, version 26 [12].

Vehicle Acquisition and Ownership Cost Analysis

Considering the newest vehicle purchased by a CU, the cost of vehicle ownership was calculated. The two components of ownership cost are vehicle acquisition and operation costs. The vehicle acquisition cost was estimated using the net purchase price reported by the CU (price after discount, trade-in, or rebate, including destination fee). The operation cost constituted the fuel cost, the cost of maintenance, insurance, license, vehicle registration and inspection, toll fees, and parking fees. The operation cost data in the CES survey is collected for the total household fleet and as a quarterly estimate. To estimate the operating cost of the latest vehicle exclusively, the overall operating cost for the entire fleet was divided by the total number of vehicles in the CU. This method provides a rough estimate since driving patterns and fuel consumption rates vary across the vehicles in a household, and some vehicles may be subject to toll discounts. Despite the limitations of this approach, it was employed to estimate the operating cost of recently acquired cars or trucks, as more accurate data was not readily available. To obtain an annual estimate, the estimated operating cost was multiplied by four. This was subsequently converted to a net present value, based on the assumption of a five-year ownership period [48]. It was further assumed that the various operating cost components remain constant throughout this duration. By summing up the two cost components, the net present value of the cost of vehicle ownership over five years was estimated. Equation 1 shows the calculation of the vehicle ownership cost.

$$\textbf{Vehicle Ownership Cost} = \frac{NPP_V \cdot APR}{1-(1+APR)^{-N}} + \sum_{n=1}^{N} \frac{OC_V}{(1+i)^n}, \quad \textbf{(1)}$$

where:

NPP_V = purchase price of a vehicle, assuming vehicles are always financed [48]

APR = annual percentage rate of 5% (interest rate for loans considering an average credit score [49]; the vehicle acquisition cost is a one-time cost. This is used to convert it to an annual estimate.

OC_V = quarterly operating cost expenditure converted to an annual estimate

i = real interest rate of 1.25% (interest rate of US treasury bonds with a residual maturity of five years as of February 2020 [50])

N = ownership period (5 years)

Results and Discussion

Profile of New and Used Vehicle Buyers

Discrete Choice Model

Table 3 presents the model estimation results of the mixed logit model. Variables related to household socio-demographic or other characteristics and variables related to household current vehicle holdings result in statistically significant parameters. The lack of a constant in the no-purchase function establishes it as a zero baseline. Considering the alternative specific constants, all else being equal, not purchasing a vehicle is more likely to be selected than the other choices. Similarly, all else being equal, the order of probabilities for different purchases is: used truck/van > used car > new truck/van or new car.

The results show that age and race affect the likelihood of (not) purchasing a vehicle (no purchase function). Households with individuals in their late twenties (between 26 and 30 years) compared to those with other aged individuals are more likely to purchase a vehicle, and households with non-white individuals compared to those with white individuals are less likely to purchase a vehicle. Next, households with a family size of 2 to 4 members are more likely to purchase new cars. This may be associated with the fact that medium-sized households can be better served by a smaller vehicle (i.e., a car) and may have more financial capability than larger households to purchase a new vehicle. Additionally, households with only new cars in their fleet are more likely to purchase new cars, indicating that experience or familiarity with a particular body type or vintage combination may influence the perception of quality or sense of trust in it, which can influence future purchases. This could be related to past research findings regarding the relationship between satisfaction with previous vehicles and future vehicle repurchase (e.g., [51]). Moreover, households with EVs are more inclined to purchase cars as new, potentially due to the advantages of new EVs (versus used EVs), including longer battery life, financial incentives, and strong resale value.

In contrast with the results for new car buyers, households with more than 4 members are more likely to purchase cars as used. Larger families may have greater financial pressure [52] and prefer used cars that are considered less expensive. Furthermore, households who rent their house or households with a member between 40 and 50 years seem to prefer used cars. These characteristics could indicate individuals who prioritize cost savings. The parameter of the variable representing households with annual income more than $25K to less than or equal to $70K is normally distributed with a mean of −0.370 and a standard deviation of 1.058. In almost 64% of the observations, this variable has a negative sign, reducing the probability of purchasing a used car (see the distributional effect of random parameters in **Table 3**).

The results show a strong disinclination toward purchasing new trucks or vans among households residing in urban areas. The same applies to purchasing used trucks or vans, suggesting that trucks may be more appealing for households living in rural areas [53]. The effect of the household location was found to be stronger in the case of used trucks or vans, perhaps due to the smaller market for new vehicles or fewer car dealerships in rural areas [54]. Households with a mix of cars and trucks, with more trucks than cars, are less likely to purchase new trucks. In addition to this finding, the model showed that households with one used truck in their fleet (and no other vehicle) are more likely to purchase a truck as used. The likelihood of purchasing a new truck is higher for households whose income is between $100K to $500K or with 2 or more income earners. On the other hand, households with income between $70K to less than or equal to $100K are more inclined to purchase used trucks. Thus, middle to high-income households are more likely to purchase trucks than cars, and even among households in the middle to high-income brackets, used vehicles (trucks) are not uncommon [25]. Around 86% of households with individuals that are 60 years old or older seem to be less likely to purchase a used truck or van, presumably due to the reliability and safety that comes with a new vehicle warranty or more options for customizing the vehicle to meet their needs (e.g., accessibility, visibility) [55].

Table 3. Mixed logit model estimation results — Purchase decision for new and used cars or trucks/vans.

Variable	New Car	Used Car	New Truck or Van	Used Truck or Van	No Purchase
	Estimated parameter (p-value)				
Constant	-3.107 (<0.001)	-2.144 (<0.001)	-2.199 (<0.001)	-0.835 (<0.001)	-
Household sociodemographic characteristics and location					
Number of members in the household is between 2 and 4 (1 if yes, 0 otherwise).	0.320 (<0.001)	-	-	-	-
Number of members in the household is 5 or above (1 if yes, 0 otherwise).	-	0.500 (<0.001)	-	-	-
Housing tenure is rented (1 if yes, 0 otherwise).	-	0.724 (<0.001)	-	-	-
Household is in an urban area (1 if yes, 0 otherwise) (based on the US Census definition).	-	-	-0.385 (<0.001)	-0.678 (<0.001)	-
Total amount of family income in the last 12 months is more than $100K to less than or equal to $500K (1 if yes, 0 otherwise).	-	-	0.780 (<0.001)	-	-
Total amount of family income in the last 12 months is more than $70K to less than or equal to $100K (1 if yes, 0 otherwise).	-	-	-	0.208 (<0.001)	-
Total amount of family income in the last 12 months is more than $25K to less than or equal to $70K (1 if yes, 0 otherwise) *(random parameter)*.	-	-0.370 (0.291)	-	-	-
(Standard error of parameter distribution)	-	*1.058 (0.045)*	-	-	-
Number of income earners in the household is 2 or above (1 if yes, 0 otherwise).	-	-	0.163 (0.018)	-	-

Variable	New Car	Used Car	New Truck or Van	Used Truck or Van	No Purchase
	Estimated parameter (p-value)				
Individual characteristics					
Age of the reference person is between 40 and 50 years old (1 if yes, 0 otherwise).	-	0.252 (<0.001)	-	-	-
Age of the reference person is between 26 and 30 years old (1 if yes, 0 otherwise).	-	-	-	-	-0.297 (<0.001)
Age of the reference person is 60 years old or above (1 if yes, 0 otherwise) *(random parameter).*	-	-	-	-1.905 (0.074)	-
(Standard error of parameter distribution)	-	-	-	*1.779 (0.090)*	-
Race of reference person is non-white (1 if yes, 0 otherwise).	-	-	-	-	0.200 (<0.001)
Current vehicle holdings (before latest purchase)					
Households that have new cars only in their fleet (1 if yes, 0 otherwise).	0.172 (0.134)	-	-	-	-
Households that have at least 1 truck/van and at least 1 car (mixed fleet) and have more trucks or vans than cars in their fleet (1 if yes, 0 otherwise).	-	-	-0.619 (<0.001)	-	-
Households that have only 1 used truck in their fleet (1 if yes, 0 otherwise).	-	-	-	0.467 (<0.001)	-
Households that have at least 1 battery EV (car/truck/van) in their fleet (1 if yes, 0 otherwise).	2.513 (<0.001)	-	-	-	-
Distributional effect of random parameters		**Below zero (%)**		**Above zero (%)**	
Total amount of family income (after taxes) in the last 12 months is more than $25K to less than or equal to $70K (1 if yes, 0 otherwise).		63.68		36.32	
Age of the reference person is 60 years old or above (1 if yes, 0 otherwise).		85.79		14.21	

Variable	New Car	Used Car	New Truck or Van	Used Truck or Van	No Purchase
	Estimated parameter (p-value)				
Goodness-of-fit measures					
Number of parameters	23				
Log-likelihood function	-18,226.23				
Restricted log-likelihood	-27,629.22				
Adjusted McFadden pseudo ρ^2	0.340				
Total number of observations	17,167				

Cluster Analysis

The two-step cluster analysis generated three clusters within the dataset. The final cluster solution yielded a silhouette coefficient of 0.3, indicating a fair separation distance between the clusters. It was also noted that the final and split solutions were similar with only minor changes identified. The solution was based on six clustering variables, which are described in **Table 4**. The three clusters were heterogeneous in terms of household size, housing tenure, number of used and new vehicles in the household fleet, annual household income, and average household fleet age. The average household fleet age was the least important (predictor importance of 0.3), while the rest of the variables proved to have the highest predictive importance in differentiating the clusters. **Figure 2** shows the clustering variables with their overall importance value.

Table 4. Final clustering variables.

Variable name	Description
Household size	Number of members in the household
Housing tenure	1: owned w/ mortgage, 2: owned w/o mortgage, 3: owned mortgage not reported, 4: rented, 5: occupied w/o payment of cash rent, 6: student housing
Used vehicles	Number of vehicles purchased as used in the household
New vehicles	Number of vehicles purchased as new in the household
Household income	Annual household income in dollars
Fleet age	Average age of vehicles in the household in years

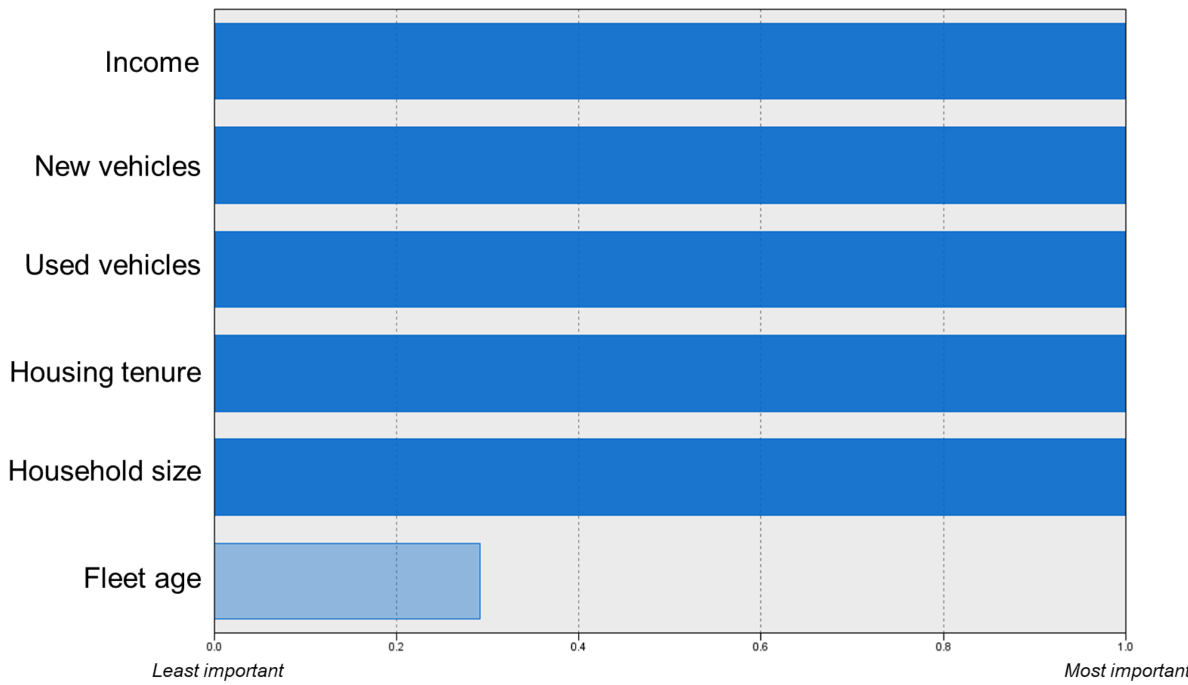

Figure 2. Overall predictive importance of six clustering variables.

Figure 3 shows that clusters 1, 2, and 3 constituted around 32%, 42%, and 26% of the total sample, respectively. There were 37 cases (0.3%) that were not assigned to any of the clusters because of missing or incomplete data for the clustering variables. The size of the final clusters is relatively balanced, indicating that no cluster was significantly under-represented. **Figure 3** also illustrates the (i) overall importance of the variables, as indicated by the cell background color which aligns with the findings presented in **Figure 2** and the (ii) the significance of variables within each cluster. The variables are arranged in order of significance for each cluster, with the most important ones appearing first or in the initial rows, and the least important ones appearing last. The number of new vehicles is the most significant factor in clusters 1 and 3. Although the number of used vehicles is the most crucial variable characterizing cluster 2, it is the least important factor in cluster 3. Furthermore, household income holds the third highest importance in clusters 2 and 3 but the second least important factor in cluster 1.

Overall predictor importance

1.0 0.8 0.6 0.4 0.2 0.0

Cluster	1	2	3
Size	31.9% (3731)	42.2% (4936)	25.9% (3027)
Clustering variables	New vehicles 0 (99.8%)	Used vehicles 1 (99.8%)	New vehicles 1 (77.9%)
	Used vehicles 2 (71.6%)	New vehicles 0 (94.2%)	Housing tenure 1 (60.1%)
	Household size 2 (38.1%)	Income ($52,868)	Income ($107,096)
	Housing tenure 1 (49.0%)	Housing tenure 4 (51.4%)	Household size 2 (43.6%)
	Income ($83, 204)	Household size 1 (41.4%)	Fleet age (6.3 years)
	Fleet age (5.0 years)	Fleet age (4.5 years)	Used vehicles 1 (69.3%)

Figure 3. Cluster distribution, cluster description, and within-cluster predictor importance.

The mean values are also reported for continuous variables in **Figure 3**. For categorical variables, the percentage and the most frequent category is presented. Based on the mean values or most frequent categories of the clustering variables, *Cluster 2* (42.2% of the sample) is characterized by individuals or households who rent their homes (51.4%) and have a smaller family size, often consisting of a single member (41.4%). They have the lowest income level among the clusters ($52,868 on average), potentially indicating financial constraints. Vehicle ownership in this cluster is mainly limited to a single used vehicle (99.8%), reflecting a focus on essential transportation needs. Additionally, the fleet age is the lowest (4.5 years), possibly suggesting a preference for more recently manufactured and reliable options. Cluster 2 represents households who may prioritize affordability but also reliability in their transportation choices. Used vehicle buyers included in this cluster can be labeled as *"Low-income single-vehicle home-renters"*.

Cluster 3 (25.9%) comprises households with higher income ($107,096 on average) who own their homes (60.1%), typically with a family size of two (43.6%). This cluster represents the highest socioeconomic status group in the analysis. Their vehicle fleet is mixed, mainly consisting of one new vehicle (77.9%) and one used vehicle (69.3%) per household. The fleet age in this cluster is the highest (6.3 years), indicating a tendency to retain vehicles for longer periods. Cluster 3 may represent a market segment that emphasizes both luxury and practicality, demonstrating a preference for maintaining a diverse fleet that combines the prestige of new vehicles with the reliability of used ones. Based on these characteristics, this cluster can be labeled as "*Affluent dual-vehicle homeowners*".

Cluster 1 (31.9%) consists of households who own their homes (49%), with a family size of two (38.1%). Their income level ($83,204 on average) is moderate compared to the other two clusters, suggesting a middle-class demographic segment. In terms of vehicle ownership, Cluster 1 shows a preference for used vehicles, with two such vehicles per household (71.6%). The fleet age falls within an intermediate range (5 years), indicating a balance between vehicle longevity and maintenance. This cluster may value homeownership, practicality, and the cost-effective utilization of vehicles. The label assigned to this cluster is "*Moderate-income multi-vehicle homeowners*".

Vehicle Ownership Cost Analysis

Consistent with the set of alternatives in the choice model estimated, the distribution of vehicle ownership cost is first shown by new and used cars and trucks or vans (**Figure 4**). As expected, the median vehicle ownership cost is higher for new cars and trucks compared to used vehicles. This is potentially due to the higher net purchase price of new vehicles. In the case of used cars, the distribution is right skewed, implying that while, on average, the used car price is around $12,500, there is a long right tail on the distribution that represents households with very high vehicle ownership costs. For trucks or vans, while the median price of a new truck or van is $16,300, it is $13,631 for a used one, and the distribution is symmetrical (no skewness compared to passenger cars).

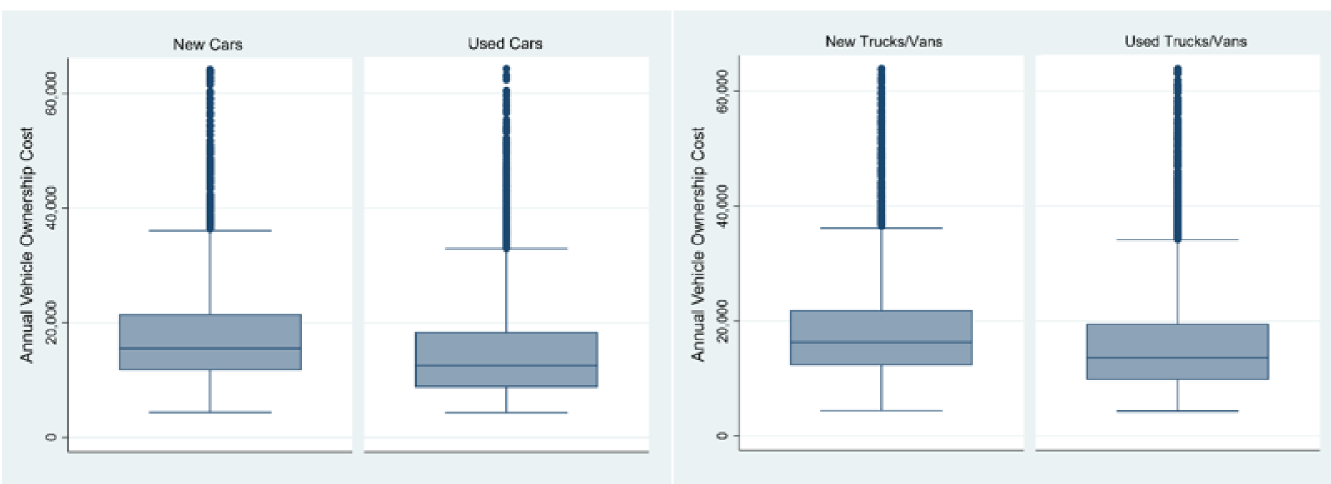

Figure 4. Distribution of 5-year vehicle ownership costs—cars, trucks/vans.

(The box limits indicate the range of the central 50% of the data [interquartile range]; the central lines in the boxes indicate medians; the whiskers [solid lines projecting vertically from the boxes] extend to the furthest data point from the box that is within 1.5 times the height of the box [i.e., 1.5 × the interquartile range]; dots beyond the whiskers are considered outliers.)

We also estimated the vehicle ownership cost of new and used cars and trucks or vans by selected household characteristics that had a statistically significant impact on the vehicle purchase behavior of a CU (refer to **Table 3**). The results are shown in **Table 5**. Again, for each household type, ownership costs are higher for new cars and trucks than for used cars and trucks, and higher for used trucks than for used cars. The annual vehicle ownership costs for households with incomes around $70–100K were higher, on average, than those for households with incomes around $100–500K. Households with 5 or more members tend to incur higher costs than households with 2 to 4 members. This is because larger households (with 5 or more members) may need to buy larger vehicles to accommodate their transportation needs or may be driving longer distances. While interpreting the ownership cost results, one must remember the CES data's caveat related to operating cost estimation. Used vehicles may have a higher proportion of the operating cost in a household fleet with a mix of new and used vehicles. This variation is not captured in the current estimation process.

Table 5. Annual vehicle ownership cost by key household characteristics.

	New Car ($)	Used Car ($)	New Truck or Van ($)	Used Truck or Van ($)
Household size 2 to 4	18,713	15,326	18,649	16,043
Household size ≥5	20,200	16,198	20,752	17,786
Home-renters	19,408	15,725	20,869	17,511
Urban	18,191	15,126	18,755	16,278
Rural	16,249	12,270	16,387	14,375
Income $70–100K	20,211	16,654	20,548	17,586
Income $100–500K	18,198	15,672	18,309	16,363

Vehicle Ownership Costs of the Clusters of Used Vehicle Buyers

After identifying and labeling the clusters and estimating the vehicle ownership cost of new and used cars and trucks/vans, we examined the relationship between the obtained clusters and cost-related variables as well as additional sociodemographic variables. **Figure 5** illustrates the annual vehicle ownership cost distribution for each cluster. Low-income single-vehicle home-renters (Cluster 2) have the highest median cost at $14,442, followed by affluent dual-vehicle homeowners (Cluster 3) at $13,390 and moderate-income multi-vehicle homeowners (Cluster 1) at $12,332. Although the median costs of vehicle ownership are relatively close across the three clusters, a deeper examination may reveal certain differences in their financial burden. **Figure 6** shows the average ratio of annual vehicle ownership cost to annual household income. Low-income single-vehicle home-renters have the highest average ratio of annual vehicle ownership cost to annual household income at 61.7%, indicating a significant portion of their income is dedicated to vehicle expenses. In comparison, affluent dual-vehicle homeowners have the lowest ratio at 23.2%, while moderate-income multi-vehicle homeowners fall between the other two clusters at 28.7%.

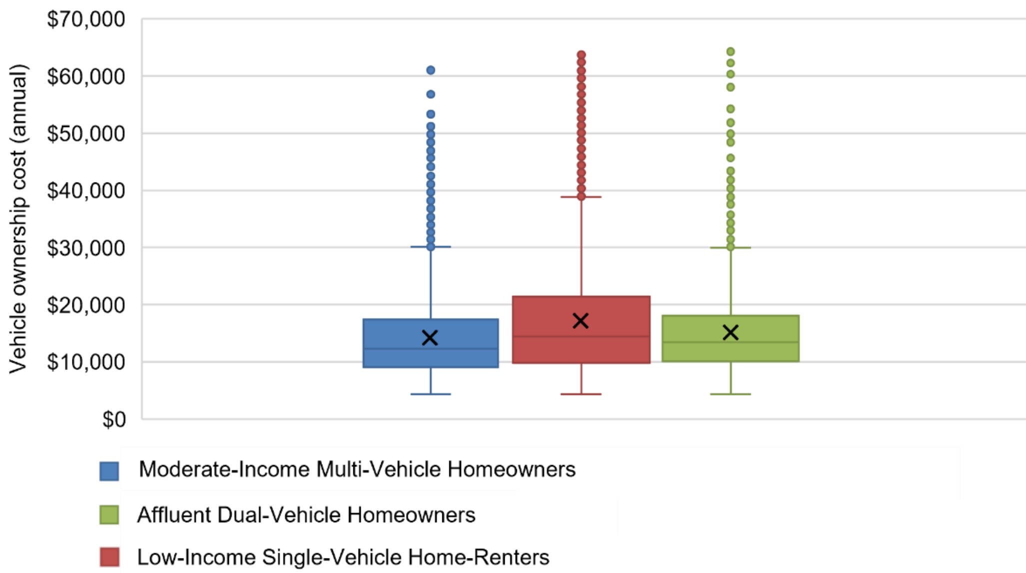

Figure 5. Annual vehicle ownership cost across clusters.

(The box limits indicate the range of the central 50% of the data [interquartile range]; the central lines in the boxes indicate medians; “x” markers represent the average or mean values; the whiskers [solid lines projecting vertically from the boxes] extend to the furthest data point from the box that is within 1.5 times the height of the box [i.e., 1.5 × the interquartile range]; dots beyond the whiskers are considered outliers.)

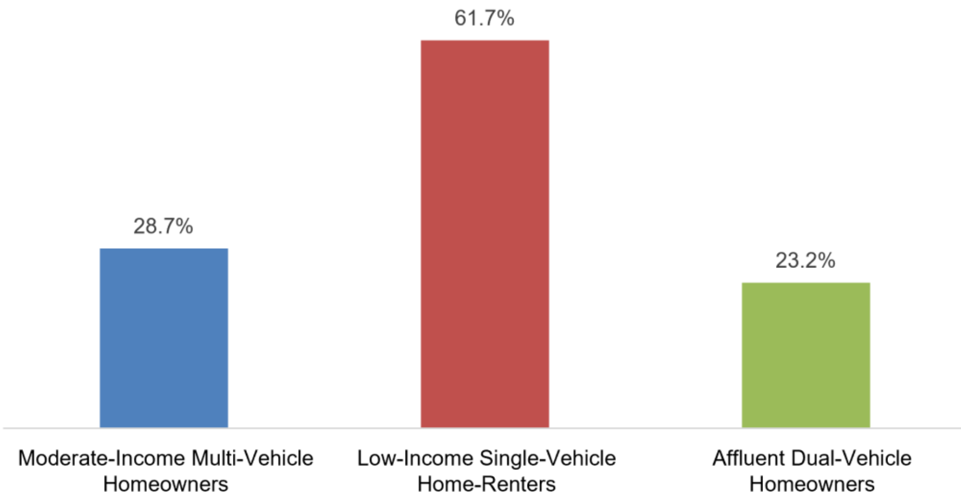

Figure 6. Average ratio of annual vehicle ownership cost to annual household income.

Vehicle acquisition costs generally constitute the biggest fraction of the total vehicle ownership costs. According to the CES data analyzed here, while the average price paid for a new vehicle is $30,934, the average price paid for the latest used vehicle purchase is $18,210. The variation in the price paid for new and used vehicles across income groups is shown in **Figure 7**, reflecting the affordability of households in the low-, middle-, and high-income groups as defined in the CES data.

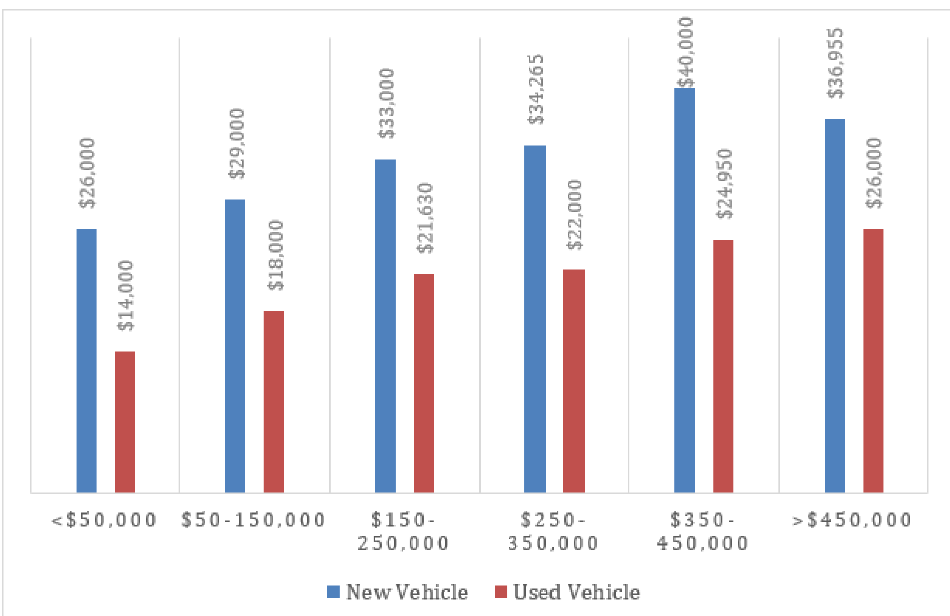

Figure 7. Average price paid for new and used vehicle (latest purchase) in the CES data (2018-2021) across income groups.

The price for a new and used vehicle varies considerably by body type, mileage driven, as well as vintage. As suggested by **Figure 7**, the amount of money that households spend on acquiring new or used vehicles is related to their income. This implies that the clusters identified above may be spending different amounts on vehicle acquisition. We analyze the average vehicle purchase expenditure of the three clusters for two vintage categories: 1- to 3-year-old and 4- to10-years old. As **Figure 8** suggests, though the average price paid across the clusters do not differ considerably for the vintages analyzed here, on average, Cluster 2 – the low-income single-vehicle home-renters tend to pay a lower price for used vehicles.

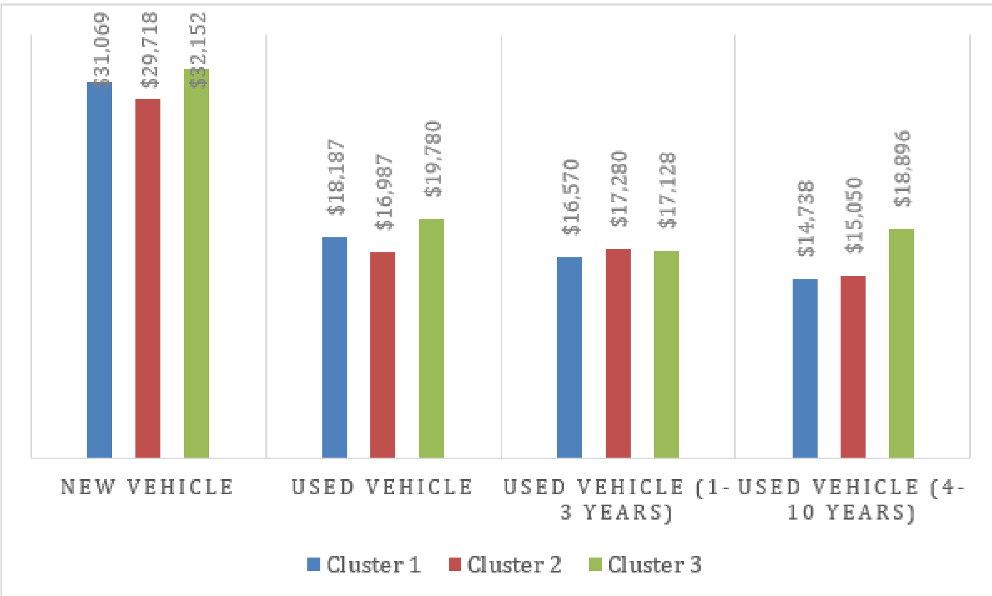

Figure 8. Average vehicle acquisition cost/purchase price of used vehicles across clusters.

Next, we examine in detail the characteristics of the three clusters of used vehicle buyers identified above. Among low-income single-vehicle home-renters, 51.0% own cars exclusively, which may reflect limited affordability for larger vehicles such as trucks or vans (**Figure 9**). As could have been expected, affluent dual-vehicle homeowners exhibit a higher ownership percentage of both cars and trucks/vans (60.4%). Moderate-income multi-vehicle homeowners appear to have a more balanced vehicle type distribution, possibly suggesting a diverse range of transportation needs.

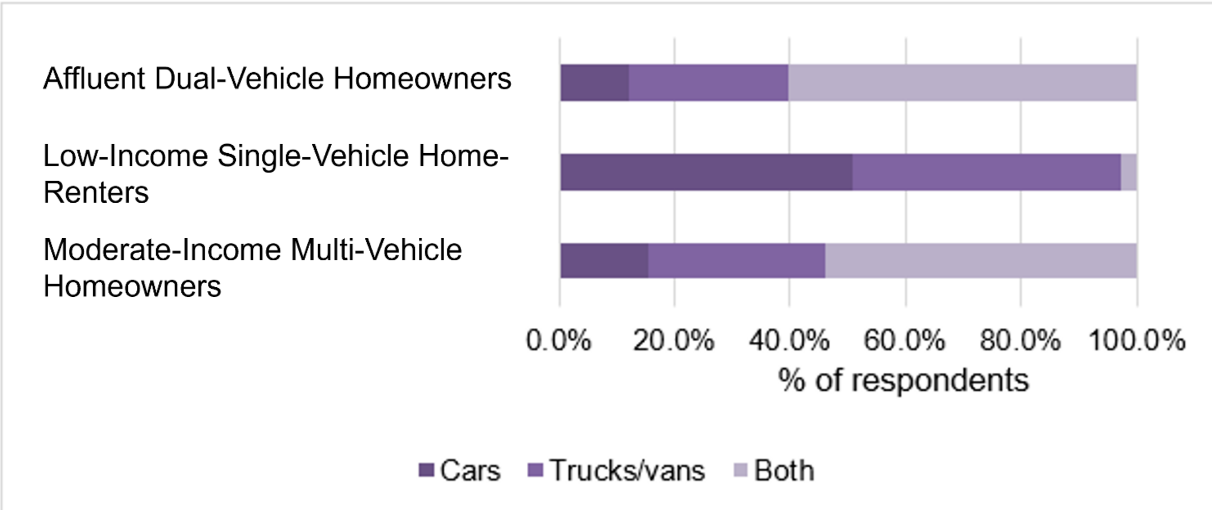

Figure 9. Distribution of vehicle types (cars and trucks/vans) across clusters.

Figure 10 demonstrates the distribution of different home types across clusters. For moderate-income multi-vehicle homeowners, the majority (79.5%) reside in single-family detached homes. Low-income single-vehicle home-renters show a lower percentage (54.2%) of single-family detached homes, potentially due to financial limitations. Affluent dual-vehicle homeowners are associated with a significantly higher rate (91.1%) of single-family detached homes, as expected based on their higher income levels. In terms of apartment or flat units, low-income single-vehicle renters have the highest proportion (22.5%), reflecting the higher prevalence of rental properties in this cluster.

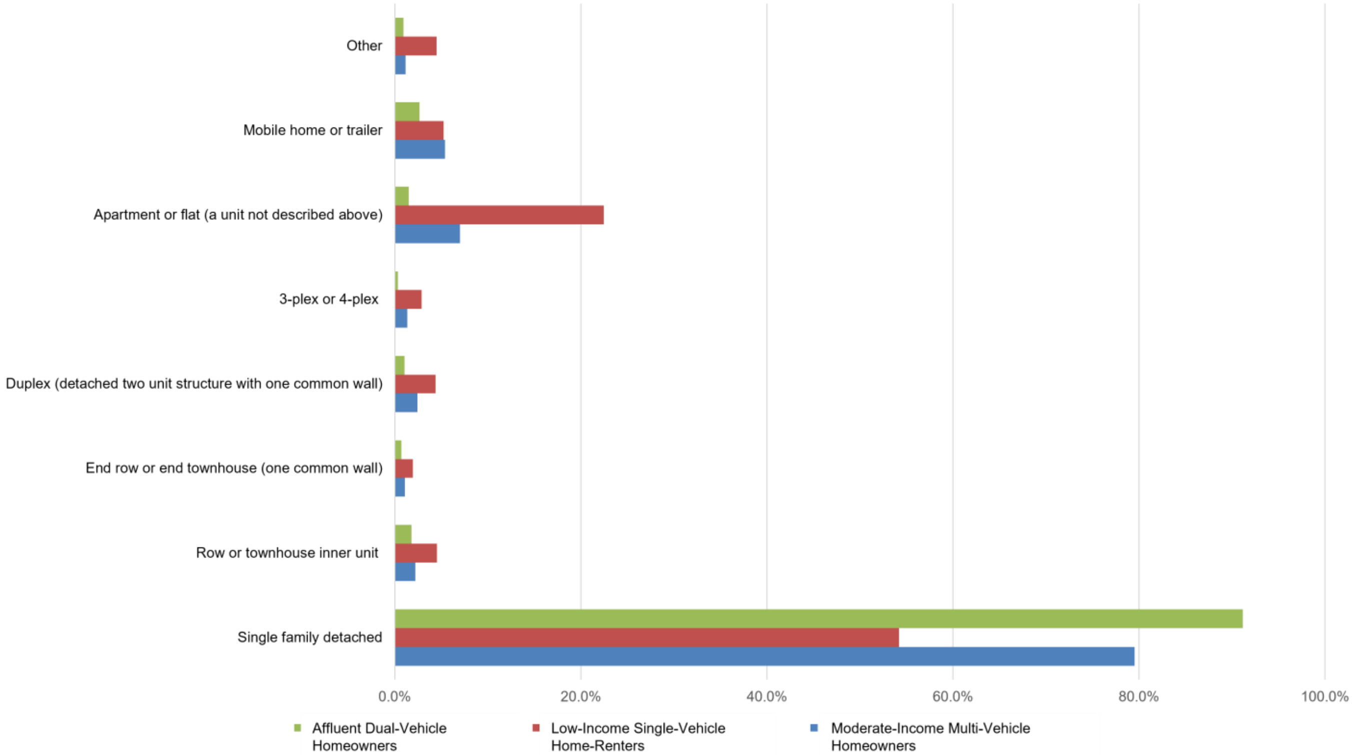

Figure 10. Home types across clusters.

According to **Figure 11**, low-income single-vehicle homerenters have a higher percentage of individuals without a college degree (51.3%). Affluent dual-vehicle homeowners display the highest percentage of individuals with a college degree (70.8%), which could imply the strong link between educational achievement and higher income levels. In the moderate-income multi-vehicle homeowners cluster, the majority (58.3%) also holds a college degree.

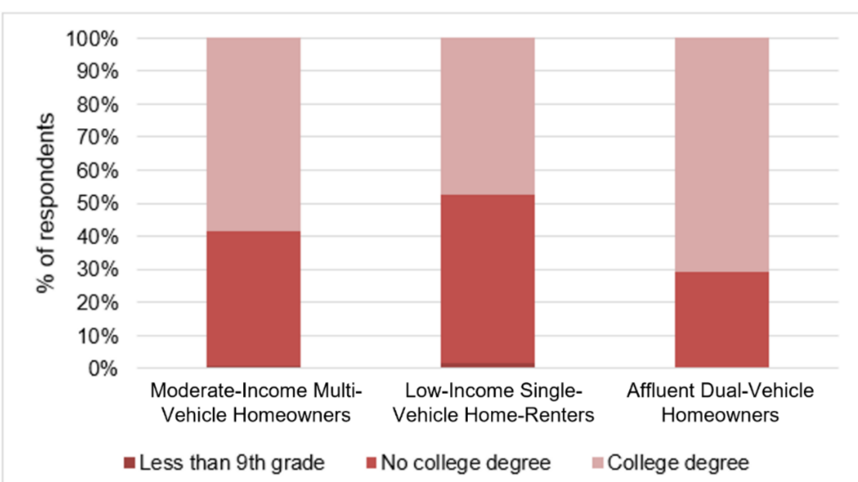

Figure 11. Educational level across clusters.

The vast majority of vehicle owners in all clusters have yet to embrace EVs (**Figure 12**). Affluent dual-vehicle homeowners have the highest percentage of battery EV owners at 0.9%, followed by moderate-income multi-vehicle homeowners at 0.3%, and low-income single-vehicle home renters having the lowest percentage at 0.1%.

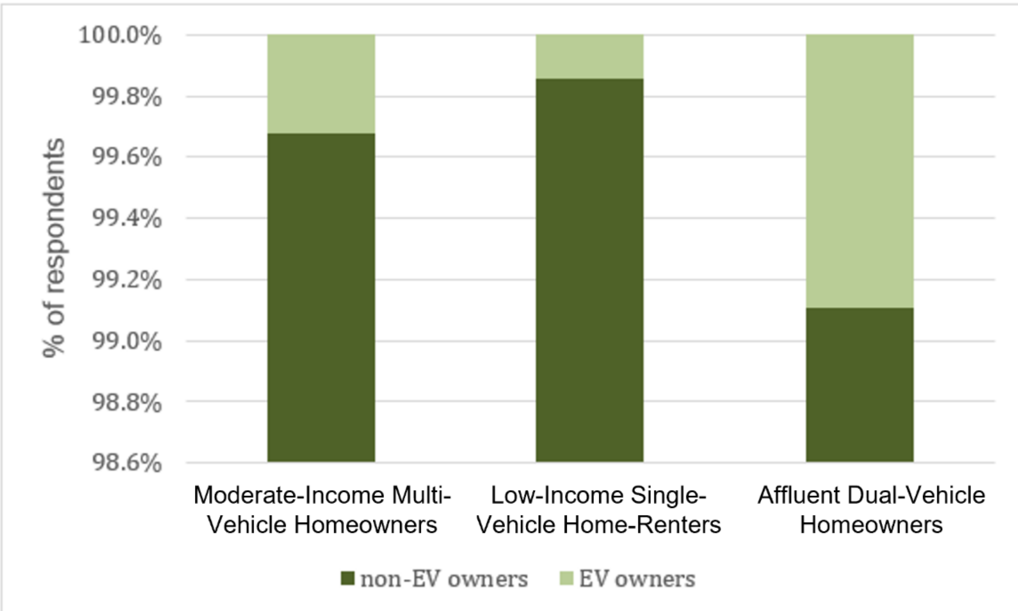

Figure 12. EV ownership across clusters.

Conclusions

Summary and Implications

The objective of this research was to explore the characteristics of the used vehicle buyers and estimate the cost of vehicle ownership based on CES data and other sources on a national scale. The motivation here is to understand how much households who generally buy used vehicles can gain or lose if they transition from a used ICEV to a used EV. The cost of EV ownership is not analyzed here, but this study sets the stage for it. This study explored both the new and used vehicle market since the former's success is key to creating a large secondary market [5]. Due to the limited data and research available on used EV buyers, examining the characteristics and vehicle costs of individuals who purchase used vehicles could be particularly beneficial in understanding this group. The current study can serve as a starting point in that direction and can be of great interest to stakeholders such as policymakers, who can benefit from information about the needs of potential used EV buyers.

The results of the discrete choice model revealed that households with any of the following characteristics had a strong inclination to purchasing used cars: having more than 4 members, renting their house, having a member between 40 and 50 years old, or having an annual income outside the range of around $25K to $70K. Used trucks or vans are more likely to be purchased by households with one of these characteristics: location in rural areas, having an income more than $70K to less than or equal to $100K, having individuals that are younger than 60 years old, and having one used truck in their fleet (and no other vehicle).

These findings may have implications for future electrification. For example, the used car market includes renters and households with four or more people. Assuming that these demographic groups will transition to used EVs, incentives can be designed to make EVs more accessible to them. Policy adjustments may be needed, including additional financial incentives for larger families or infrastructure investments in communities with renters. Similarly, the used truck or van market includes households living in rural areas. Since there is currently limited availability of electric truck models that could eventually enter the secondary market, this finding may indicate that EV adoption by truck owners in rural areas will be slower. Additionally, this may further highlight the need for geographic coverage of charging infrastructure and programs targeting truck owners in rural areas.

Building upon the broader understanding of used vehicle buyers obtained from the discrete choice model, we conducted a market segmentation analysis of used vehicle buyers. Three clusters were identified. Cluster 2, labeled as *low-income single-vehicle home-renters*, primarily includes households who rent their residences, have the smallest family size and the lowest average income ($52,868), and mainly own a single used vehicle (99.8%). Cluster 3, *affluent dual-vehicle homeowners*, comprised households who own their homes, with a higher average income ($107,096) and a mixed fleet of one new vehicle (77.9%) and one used vehicle (69.3%). Cluster 1, moderate-income multi-vehicle homeowners, consisted of *households that* owned their homes, had a moderate average income ($83,204), and an average of two used vehicles per household (71.6%). This segmentation approach enables a more precise understanding of the diverse range of individuals within the used vehicle market, facilitating the development of tailored strategies and initiatives to cater to the distinct needs and preferences of each segment that may eventually transition to EVs.

The statistics reported regarding the vehicle ownership cost across clusters as well as the ratio of annual vehicle ownership cost to annual household income provide further insights. For electrification to be advantageous for households, it is essential to have EV options that meet their requirements. For low-income households especially, this may mean having access to used EVs with costs that are comparable to those of the vehicles they typically purchase. On average, the price paid for a 1–3-year-old used vehicle by the low-income segment that bears the highest cost burden with respect to their household income is $17,280, while the price of a used EV in the market can vary between $14,681 (2017 Nissan Leaf) and $50,806 (2017 Tesla Model S). This highlights that while some lower range EVs may be comparable to ICEVs in terms of purchase cost, the high range EVs are still more expensive than what households tend to pay for used ICEVs. According to Shepardson [56], the average price of used EVs has fallen by 4% in the past year and is on average $43,400. This statistic also suggests that households whose members may want to transition to a used EV instead of used ICEV may have to incur on average a 40%-higher purchase cost. **Table 6** gives the average highest and lowest listed prices of the six most popular used EVs across US states that have adopted a zero-emission vehicle mandate.

Table 6. Highest and lowest listed price of popular used EVs (Source: US News).

	Avg. Lowest Price	Avg. Highest Price
2019 Tesla Model 3	$31,205	$44,177
2017 Tesla Model S	$39,397	$50,806
2017 Nissan Leaf	$12,575	$14,681
2017 Chevrolet Bolt	$20,012	$23,514
2019 Kia Niro EV	$26,113	$28,643
2017 BMW i3	$17,608	$21,069

The vehicle ownership cost analysis that accounts for both purchase and operating costs showed that the median annual ownership cost for used cars and trucks or vans in the CES sample is around $12,500 and $13,631, respectively, whereas the annual total ownership cost of a used 2017 Nissan Leaf is approximately $7,300 and for a 2017 Tesla Model S it is $12,780.[4] Additionally, the median annual vehicle ownership cost ranges from $12,332 to $14,442 across all three clusters: *moderate-income multi-vehicle homeowners*, *low-income single-vehicle home-renters*, and *affluent dual-vehicle homeowners* (**Figure 5**). The difference in purchase

[4] Total cost of ownership for the 2017 Nissan Leaf and Tesla Model S is calculated using the Edmunds Cost of Car Ownership tool https://www.edmunds.com/tco.html. Note, that the total cost of ownership estimates for the Nissan Leaf and Tesla Model S includes the depreciation cost along with the purchase and operating costs.

price between used ICEVs and used EVs raise concerns about equity and access to EVs, since households that have at least one used vehicle constitute around 68%[5] of the total vehicle owners in the US.

Although this study did not estimate the total cost of ownership, the vehicle purchase and operating costs calculated are crucial in the purchase decision process [11] and constitute the main cost components that vary between ICEVs and EVs [7]. The cost results can provide a benchmark to compare used ICEVs and EVs and further explore the optimal types and monetary values of incentives for the purchase or operation of pre-owned EVs. Second, the annual costs reported for different market segments could be used to inform analyses exploring or modifying eligibility requirements for incentive programs.

Limitations and Future Work

This research entails certain limitations that can constitute avenues for future work. Due to data limitations, the study was based on two main vehicle classifications to examine vehicle purchase behavior: cars, and trucks or vans. Future studies can further disaggregate vehicle body types and assess the characteristics of new and used vehicle buyers and their vehicle costs. Additionally, the sample includes relatively few EV owners. Thus, an analysis based on only EV owners would not be meaningful. Future research can work on collecting data specifically from used EV owners (or separately battery EV and plug-in hybrid owners) in the US and repeat the analysis. The CES data is appropriate for cost analyses but does not contain variables related to vehicle usage or travel behavior that would be important. Thus, future research can work on supplementing CES data with such additional information. Furthermore, the discrete choice model used is built based on a snapshot of vehicle purchases and does not consider the case of vehicle owners that may have purchased more than one vehicle in a short period. Although it is expected that few vehicle owners would fall into this category, a more detailed vehicle transactions model can be developed to account for this issue and explore changes in purchase decisions over time.

The cluster analysis of this study identified market segments based on generally observable variables, which is a common approach in market research studies. Nevertheless, incorporating both observable and unobservable (inferred) variables—such as psychographics, perceptions, and attitudes [37]—can provide a deeper understanding of consumer behavior and enhance long-term marketing strategies.

In this study, the vehicle ownership cost analysis focused on the vehicle acquisition and operation costs. Future research can estimate the total cost of ownership by market segment, including more precise estimates of operation costs and resale values. These costs can then be compared to estimated costs of EVs to determine potential cost savings for different market segments. Additional potential areas of exploration could include the development of standardized methods for assessing the health and value of used EV batteries, the impact

[5] This percentage is estimated based on (i) the number of households owning at least one used vehicle (which is the sample used in the cluster analysis) and (ii) the population of vehicle owners in the US based on CES data which is considered representative of the US population.

of battery degradation on resale value, and the potential for third-party certification programs to impact pricing for used EVs. Lastly, while the results offer a glimpse into the cost of vehicle ownership across clusters, it is important to conduct further analysis to comprehensively understand the underlying reasons for these differences and for vehicle purchase decisions in general. Factors such as financing terms, insurance rates, model availability, driving patterns, personal preferences, and needs can be explored to help devise strategies addressing disparities within the market.

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