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Understanding the used vehicle market and its implications for electric vehicles

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Executive Summary

New car sales is the primary metric for measuring electric vehicle (EV) adoption growth. 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 specific study area. By analyzing consumer expenditure survey data, we aim to understand the new versus used vehicle choice behavior and the consequent cost of vehicle ownership on a national scale. Applying discrete choice modeling, we find the factors influencing purchase behavior for used and new cars or larger vehicles, as well as the characteristics of vehicle buyers. Using these characteristics, the vehicle ownership cost is estimated to provide insights regarding EV affordability and the potential of the used EV market in the future. The results can help understand the characteristics of used vehicle owners and design policies to address equity concerns regarding the transition to EVs.

Keywords: used vehicle, vehicle ownership cost, discrete choice model, user behavior, electric vehicle (EV).

1 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 last year's sales [1]. Aggressive electrification targets set by the Advanced Clean Car II regulation aim 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]. Although high vehicle purchase price and total ownership costs have been extensively studied for new vehicles, there is a lack of extensive studies 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 EV sales will eventually enter the used car market [7], [9]. Hence, used vehicle buyers are expected to become a large potential segment of EV adopters and used EV sales have the potential to be significant in the market. An understanding and characterization of the used vehicle buyers could help inform policies to also target this market, not only to foster EV adoption beyond innovators but also to ensure the EV technology and its benefits are available to all population segments. According to Consumer Expenditure Survey (CES) data, the used vehicle market represents more than 40% of the total vehicle owners in the US [10]. Therefore, this dataset would be a useful source to explore the new and used vehicle owners.

Considering the limited number of studies examining the used EV market, [7] studied the implications of EV adoption, presenting cost-parity estimates for new and used EVs by income segment in the US. [11] explored potential barriers that low-income households face to access California's new and used EV markets. [5] examined the characteristics of used EV buyers in California, how used EVs are being utilized and the role of incentives in the purchase decision. [8] and [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. The studies above are either based on a specific study area (e.g., California) or include descriptive statistics analyses or qualitative discussion. Additionally, most studies mainly focus on electric passenger cars and do not account for the preference for larger vehicles such as light trucks separately. Understanding purchase decisions for both vehicle segments, though, 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 these two cost components, 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, 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.

This study extends previous research on the used vehicle market and ownership cost of EVs by focusing on both the new and the used vehicle market. It investigates the factors influencing the choice of new versus used passenger cars and light trucks or vans and the consequent cost of vehicle ownership using CES data on a national scale. The choice model provides a framework to understand the characteristics of buyers of used and new cars or light trucks/vans, and this knowledge is used to inform the cost of ownership analysis. Individuals who purchase used vehicles may eventually transition to used EVs when they become available in the second-hand market. As a result, exploring the characteristics of used vehicle buyers, in general, will be helpful to also understand the characteristics of used EV buyers, assuming these two groups share similarities. This way, the results can inform policies to target the used vehicle market and promote an equitable distribution of the benefits of EVs.

2 Data

2.1 New and Used Vehicle Buyers

The CES data from the Bureau of Labor Statistics of the US Department of Labor [10] builds the foundation of this research. The survey is conducted quarterly among US households through a rotating panel. Each component of the CES survey queries an independent sample of consumer units (CU) representative of the US population. It covers data on sociodemographic characteristics and expenditure items divided into over 50 categories. 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, vehicle ownership and disposal, and vehicle operating expenses, including licensing, registration, and inspection. Among the survey 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. In particular, data pre-processing constituted merging separate quarterly and annual files into a single dataset. Subsequently, duplicate records were removed, and variables were selected for the study. After data cleaning, 17,167 data points were used. The filters that were applied to the data were the following:

- 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.

Table 1 gives the distribution of the CES sample across key sociodemographic and vehicle ownership characteristics.

Table 1:Selected sample characteristics

Variable	Response Frequency (%)
Sample size	17,167
Households purchasing a: New car/Used car/New truck or van/ Used truck or van/Didn't purchase	3.9%/10.7%/6.9%/13.0%/65.6%
Household size: 1 member/2 members/3 members /4 members/5+ members	26.3%/36.7%/15.0%/12.7%/9.3%
Household income: =< 25,000/ (25,000 - 50,000]/ (50,000 - 70,000]/ (70,000 - 100,000]/ (100,000 - 500,000]/ >500,000	84.0%/23.1%/13.5%/ 15.6%/ 31.1%/ 0.5%
Housing tenure: Owned/ Rented	71.4%/27.1%
Households owning: 1 vehicle/2 vehicles/3 vehicles/4+ vehicles	46.2%/37.1%/11.8%/4.9%
Households owning: Cars only/Trucks or vans only/Both	30.0%/36.5%/33.5%
Households owning: Gasoline vehicles only/ Electric only/ Plug-in-hybrids only	92.2%/0.1%/1.1%
Proportion of urban vs rural	93.1%

Variable	Response Frequency (%)
Household education: Less than 9th grade/No college degree/College degree	0.8%/38.8%/60.3%
Households that have only 1 used truck in their fleet: Yes/No	16.2%/83.8%
Households that have only 1 battery EV in their fleet: Yes/No	0.1%/99.9%
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: Yes/No	4.0%/96.0%
Households that have new cars only in their fleet: Yes/No	12.1%/87.8%

2.2 Vehicle Ownership Cost

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. Vehicle specific data includes vehicle specifications like the make, fuel type, and model year, vehicle purchase year, net purchase price (after discount, trade-in, or rebate, including destination fee), downpayment, 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. This implies one cannot identify whether a specific vehicle in a CU was purchased or leased and the vehicle miles traveled using the vehicle. As a result, the most recent vehicle (by vehicle purchase year) is considered in this study to analyse the vehicle ownership cost. Only the net purchase cost metric is used in the ownership cost estimation. There is a lot of missing data for downpayment 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 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. Table 2 summarises some key components of the vehicle purchase cost for the most recent vehicle purchases, as tracked in the CES data.

Table 2: Average values of key cost metrics for the most recent household vehicle

	New Vehicle	Used Vehicle
Net purchase cost (Recent Vehicle)	$31,975	$18,426
Down payment amount	$3,512	$2,202
Amount of trade-in allowance	$7,834	$4,881
Vehicle financed (1 if financed, 0 otherwise)	70%	48%

3 Methods

3.1 Profile of New and Used Vehicle Buyers

Using the survey 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 of 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 frequency of the alternatives is shown in Table 1 (refer to Section 2. Data).

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. It was 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, which are shown in Table 3. 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.

3.2 Vehicle 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 [37]. 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 wass estimated. Equation 1 shows the calculation of the vehicle ownership cost.

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

where

NPP_V = Purchase price of a vehicle, assuming vehicles are always financed [37]

APR = Annual percentage rate of 5% (interest rate for loans considering an average credit score [38]; 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 [39])

N = Ownership period

4 Results and Discussion

4.1 Profile of New and Used Vehicle Buyers

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

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) are more likely to purchase a vehicle while households with non-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 to purchase a vehicle as new compared to larger families. Additionally, households with new cars only 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 with 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. [40]). 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 [41] 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 [42]. The effect of the household location was found to be stronger in the case of used trucks or vans, perhaps due to the lower market for new vehicles or lower availability of car dealerships in rural areas [43]. 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) [44].

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

	New Car	Used Car	New Truck or Van	Used Truck or Van	No Purchase
Variable	**Estimated parameter (p-value)**	**Estimated parameter (p-value)**	**Estimated parameter (p-value)**	**Estimated parameter (p-value)**	**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)	-	-
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
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	

4.2 Vehicle Ownership Cost Analysis

Consistent with the set of alternatives in the choice model estimated, the distribution of annual vehicle ownership cost is first shown by new and used cars and trucks or vans (Figure 1 and Figure 2). 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 case of used cars, the distribution is more 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).

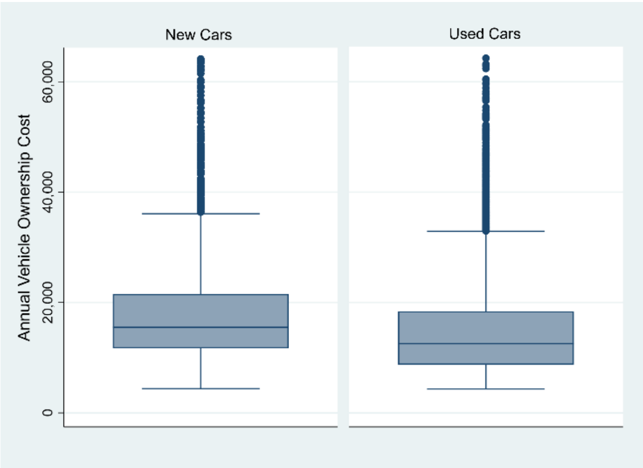

Figure 1: Distribution of annual vehicle ownership costs-cars

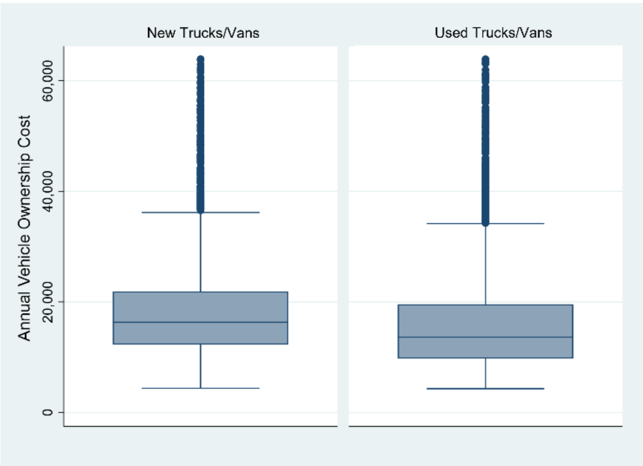

Figure 2: Distribution of annual vehicle ownership costs-trucks/vans

The vehicle ownership cost of new and used cars and trucks or vans is also estimated 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 4. Again, for each household type, new cars and trucks have a higher ownership cost than used cars and trucks, and the latter tend to have a higher cost. The annual vehicle ownership costs for households with income between around $70-100K were found to be higher, on average, compared to those for households with income of 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 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 4: Annual vehicle ownership cost by key household characteristics

	New Car ($)	**Used Car ($)**	**New Truck or Van ($)**	**Used Truck or Van ($)**
Family size between 2 and 4	18,713	15,326	18,649	16,043
Family size ≥5	20,200	16,198	20,752	17,786
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

5 Conclusions and Implications

The objective of this research was to explore the factors affecting the decision to purchase new or used cars and light trucks or vans and use this knowledge to estimate the cost of vehicle ownership based on CES data on a national scale. 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, specifically, examining the characteristics and vehicle costs of individuals who purchase used vehicles, in general, 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 be informed about the needs of potential used EV buyers.

The results revealed that households with more than 4 members, households who rent their house, households with a member between 40 and 50 years old and households with an annual income outside the range of around $25K to $70K show a strong inclination towards purchasing used cars. Used trucks or vans are more likely to be purchased by households located in rural areas, households with income more than $70K to less than or equal to $100K, households with individuals that are below 60 years old, and households with 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 or larger households. Assuming that they will transition to used EVs, incentives can target these demographic groups 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.

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 imply having access to used EVs that are comparable mainly in cost to the vehicles they typically purchase. The vehicle ownership cost analysis showed that the median annual vehicle ownership cost for used cars and trucks or vans is around $12,500 and $13,631, respectively. According to [45], the average price of used EVs has fallen by 4% in the past year and is on average $43,400. This implies that the ownership cost of used EVs will now be much higher than what used vehicle buyers are currently incurring. 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, the vehicle purchase and operating costs calculated are crucial in the purchase decision process [11] and constitute the main cost components that vary between conventional vehicles and EVs [7]. The cost results can provide a benchmark to compare used conventional vehicles and EVs and further explore the need for or appropriate amount of incentives towards the purchase or use of pre-owned EVs. Using the household characteristics affecting purchase behavior, this study provided additional insights regarding the annual costs within different socioeconomic groups that could be used to inform analyses exploring or modifying eligibility requirements for incentive programs.

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: cars and trucks or vans. Future studies can further disaggregate vehicle body types and estimate 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 and hybrid EV 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 the same 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. 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 be then compared to estimated costs of EVs and examine 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 of battery degradation on resale value, and the potential for third-party certification programs to impact pricing for used EVs.

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