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# An exploration of post-COVID household vehicle ownership in the USA using panel data: An application of the generalized ordered logit model

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## Abstract

Vehicle ownership is a key determinant of auto use, but while much COVID-19 research has focused on shifts from public transit to driving, changes in household vehicle ownership itself have received little attention. This study examines pre- and post-COVID changes in vehicle ownership propensity among US households using panel data from the Panel Study of Income Dynamics (PSID) for 2019 and 2021. A generalized ordered logit (GOL) framework is applied to model ownership changes between the two years, incorporating state dependency on 2019 ownership levels. Overall, vehicle ownership increased for 17% of households and decreased for 21%. Multivariate GOL results show that individual- and household-level demographic shifts, such as changes in marital status and increases in family size, had the largest marginal effects on ownership changes. However, even after controlling for these demographic factors, COVID-19-related variables, including financial difficulty and essential worker status, remained significant predictors of ownership change between the pre- and post-pandemic periods. Overall, the pandemic does not appear to have substantially altered vehicle ownership trends in the auto-oriented US context. Nonetheless, certain population segments, particularly households with essential workers, may face greater vehicle needs during or immediately after crises like COVID-19. These findings suggest that policies addressing transportation equity should account for demographic transitions alongside pandemic-specific stressors, as both jointly shape household vehicle ownership decisions in periods of disruption.

# 1 Introduction

Household vehicle ownership has been recognized as an essential determinant of trip generation and mode choice decisions since the mid-1960s. Early investigation of household vehicle ownership can be traced back to the seminal works of Lerman and Ben-Akiva (1975) and Train (1980). They used multinomial logit models to explore the dependency between household vehicle ownership decisions (i.e., the no of vehicles owned by households) and the primary worker's mode choice decision. Researchers have also examined vehicle ownership decisions and household vehicle utilization (Mannering & Winston, 1985). Early research on household vehicle ownership primarily relied on multinomial logit models. However, researchers have applied other statistical methods, such as ordinal logit (for example, Bhat and Pulugurta (1998)) and multivariate negative binomial (for example, Zhao and Kockelman (2002)). More recently, researchers have started experimenting with data-driven techniques such as neural networks to examine vehicle ownership decisions (for a comparison between ordinal logit and neural network for vehicle ownership modelling, please refer to Basu and Ferreira (2021)).

The COVID-19 pandemic has instigated extensive mobility and travel behaviour modifications, including increased teleworking and e-shopping (Belzunegui-Eraso & Erro-Garcés, 2020), increased risk sensitivity towards public transportation and ride-sharing services (Shamshiripour et al. 2020) among others. Consequently, the effect of the COVID-19 pandemic on day-to-day activity-travel behaviour changes (such as the trade-off between actual and virtual mobility (Fatmi et al. 2021) and modal shift (Das et al. 2021)) has been widely documented in the literature over the last couple of years. However, the impact of the pandemic on longer-term behavioural changes (such as changes in household/work location and vehicle ownership decisions) has not been adequately documented. The few studies that examined changes in vehicle ownership in the COVID-19 aftermath relied on anticipatory surveys.

According to a study by Eisenmann et al. (2021), a third of the zero-car households in Germany missed having a car during the pandemic. On the other hand, 1 in 5 households in Massachusetts, USA, were inclined to buy a car in 2020. Moreover, half of these households planned to buy the car within a year. Habib and Anik (2021) predicted a 74% increase in vehicle ownership in Nova Scotia, Canada, by 2030.

Recently, Thakuria (2024) conducted an exploration of vehicle ownership in the US using consumer expenditure data in the immediate aftermath of the COVID-19 pandemic. A recent study by Thakuria (2023) notes that the number of 0-vehicle-owning households in the US decreased in the immediate aftermath of COVID-19. However, this study analyses only the binary decision of owning a car versus being carless and does not consider changes in car ownership for households that already own a car. Another very recent study by Thakuria (2024) showed that the average number of household vehicles increased in the first 8 months after the start of COVID-19 in March 2020. According to the study, the stimulus funding increased the odds of vehicle ownership. However, it should be noted that the study uses data from January 2020 to March 2022; hence, the pre-COVID-19 vehicle ownership scenario might not be adequately captured in the analysis.

Table 1 below summarizes recent work on changes in vehicle ownership in Europe, the USA, and Asia. These studies have primarily focused on gender, household income, current vehicle ownership status, and household location. For example, females were found to be more likely than males to miss a vehicle in a 2020 German survey (Eisenmann et al. 2021). Similarly, households in suburbs have been consistently argued to prefer cars more than households in metropolises – this observation was also prominent in Canada and Germany. Household income showed a non-linear effect: households with high income were found to decrease the household vehicle count in the USA after the pandemic (Thakuria, 2023). On the other hand, the USA reported no discernible changes in vehicle ownership in the middle-income households. Interestingly, Klein and Smart (2019) predicted an increased propensity to car ownership among lower-income households in the

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USA following COVID-19. Vega-Gonzalo et al. (2023) reported that households with three or more cars are more likely to sell a car than buy a new one.

**Table 1. Summary of the recent work on vehicle ownership changes in Europe, the US, and Asia**

| No. | Title                    | Survey method                                                                                                                                  | Sample size    | Country             | Key findings                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-----|--------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|----------------|---------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1   | Basu and Ferreira (2021) | Web-based survey, April-October 2021                                                                                                           | 2200           | Boston, USA         | 20% of zero-car HHs agree with the intention of buying a car due to COVID-19. On average, 13% of such households anticipate purchasing a car within the next six months, while over 25% anticipate doing so within the next year. About 40% of zero-car households anticipate purchasing a car within the next one to two years.                                                                                                                                                                                        |
| 2   | Eisenmann et al. (2021)  | Travel survey, April 2020                                                                                                                      | 1000           | Germany             | Women are more likely than men to miss a car of their own, as are young adults and 35-44-year-olds compared to 25-34-year-olds, as the regression model suggests. People living in metropolitan areas and other urbanized regions were less likely to miss a car of their own. Same for families in the COVID-19 risk group and for groups who had to use public transport during and before the lockdown.                                                                                                              |
| 3   | Habib and Anik (2021)    | iTLE model using census data                                                                                                                   | Not applicable | Nova Scotia, Canada | 'no_action' (a household which has a vehicle and chooses not to make any transactions) behavior is more prominent in middle income (\$50,000-\$79,000 yearly) HH rather than low income (\$20,000-\$49,000 yearly)<br>High-income HHs will own more vehicles per HH by 2025 and 2030 than in the no-COVID scenario. Spatially, in 2025, a higher proportion of vehicle ownership increase is predicted in the suburban areas. The pandemic will cause a 0%-74% increase in vehicle ownership in suburban areas by 2030. |
| 4   | Thakuriah (2024)         | Consumer Expenditure Survey (CEX) (first quarter of 2020 - first quarter of 2022), multilevel Hurdle model with month and state random effects | From 42 states | USA                 | 13% of households increased their vehicle stock between their last survey quarter and their first. The propensity of gaining a car oscillated 1st for the 0-vehicle-owning HHs and rose slightly towards the end of the study period. The car-owning groups showed an earlier transition tendency to more cars, but showed a decline towards the end.                                                                                                                                                                   |

| No. | Title                      | Survey method                                                                                                                                   | Sample size           | Country      | Key findings                                                                                                                                                                                                                                                                                                                                                                  |
|-----|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|--------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 5   | Thakuriah (2023)           | (First quarter of 2018 to the first quarter of 2022) from the Consumer Expenditure Survey (CEX), binary logit                                   | 13,140                | USA          | Propensity for zero car ownership is lower after the pandemic for the full sample, low-income and minority households, and to a minor extent, for middle-income households. The number of vehicles for high-income HHs decreased by around 8% after the pandemic. No discernible change in young and middle-income HHs.                                                       |
| 6   | Javadinasr et al. (2022)   | Longitudinal two-wave panel survey data (Apr 20 - May 21), descriptive and econometric measures, including random effects ordered probit models | 2973                  | USA          | In post-pandemic times, 12 % of people expect to use private vehicles less than before, whereas 17 % expect to use them more. This indicates an expected decline in private vehicle commute trips but an overall increase in total use of private vehicles.                                                                                                                   |
| 7   | Das et al. (2021)          | online questionnaire survey (April-May 2020), logistic regression model                                                                         | 840                   | India        | In the overall post-pandemic scenario, shared modes (public transit, carpool) exhibit large mode switching behavior towards other unshared (private cars, motorized two-wheeler, and cab) and active travel modes (walking, bicycle). Over 80% of car commuters would still commute by car post pandemic, drawing 18% share from the normal public transport users            |
| 8   | Klein et al. (2023)        | Online survey, March and April 2022                                                                                                             | 999 valid among 1,324 | USA          | COVID-19 had the least impact on the decision to buy a car compared to the affordability and spatial access benefits. Pandemic may have accelerated planned car purchases, which may not be fully captured in the survey. Many lower-income households in the US will acquire a car as soon as they are financially able, and this factor is most prominent among this group. |
| 9   | Vega-Gonzalo et al. (2023) | Questionnaire survey during the second term of 2021                                                                                             | 10,125                | 21 EU cities | HHs with cars pre-pandemic were even more car-reliant during the pandemic and bought cars during this period. HHs with more than 3 cars were more likely to sell a car, but this odds ratio was lower compared to buying one. People who used shared mobility services more during the COVID-19 pandemic were more likely to buy a car.                                       |

| No. | Title                | Survey method                                                                                    | Sample size | Country             | Key findings                                                                                                                                                                                                                                                                        |
|-----|----------------------|--------------------------------------------------------------------------------------------------|-------------|---------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 10  | Zheng et al. (2023). | Online Survey (October 25 to November 8, 2021, and December 8, 2021, to December 18, 2021), SEM, | 425         | Greater Boston area | The decline of PT and TNC during this period can be attributed to an increase in car ownership and fear of the pandemic. Owning a car makes it more likely for people to choose to commute to work by driving rather than working from home or using other modes of transportation. |

## 2 Contribution of the study

The objective of the study is to explore changes in vehicle ownership in the USA between 2019 and 2021 using a revealed-preference panel survey. The study controls for various individual- and household-level demographic changes during the period, including changes in marital status, household size, income, and residential relocation. The study also explores the impact of COVID-19-related suffering and hardship on the vehicle ownership changes in the immediate aftermath of COVID-19. To this end, the study applies a generalized ordered model that captures the state dependency on 2019 vehicle ownership.

The study has examined the influence of multiple factors on changes in vehicle ownership, a topic that previous studies have not explored in sufficient detail. For example, the study explored the influence of the household head's gender and age on post-pandemic changes in vehicle ownership. Similarly, personal status changes, such as changes in relationship and job status, have also been explored in the study. Household-level changes, such as inclusion or deletion of household members, change in household income, household size, or household relocation, have also been explored in the paper. In summary, the paper sought to explore changes in household vehicle ownership in the post-pandemic context as a function of various individual- and household-level factors, thereby highlighting heterogeneity in post-pandemic vehicle ownership in the USA.

The following section introduces the data and provides a descriptive summary. A brief description of the statistical method applied in the study is provided next. The last section summarizes the results and discusses their significance.

## 3 Data

The data used in the research comes from the Panel Study of Income Dynamics (PSID) – one of the well-established longitudinal household surveys run by the University of Michigan. Among the many PSID supplements, the study used family-level information collected in 2019 and 2021.

PSID is often referred to as the longest-running panel study in the USA. The survey started in 1968 with 18,000 people in 5,000 families – the number of families has grown over the years to 9,100 in 2023, as younger families are added as they form their own families. The survey has consistently reported low attrition and high success rates. Nonetheless, immigrant families have been added to the sample to match the national population's composition (Social Research Center, 2023).

It can be noted that household composition can change across survey waves; however, the study used information from households in which the reference person remained the same in 2019 and 2021. A reference person is defined as an adult member who bears the majority of the family unit's financial responsibilities. The panel used in the study comprised 8056 households surveyed in 2019 and 2021. The survey collects detailed demographic information about one reference person (RP) of the family (often referred to as the “head”) and their spouse (SP).

**Table 2. Personal characteristics of the sampled households**

| Personal Characteristics                       | Count | Percentage |
|------------------------------------------------|-------|------------|
| Gender                                         |       |            |
| Male                                           | 5526  | 69%        |
| Female                                         | 2530  | 31%        |
| Age                                            |       |            |
| Between 18 and 25 years                        | 242   | 3%         |
| Between 25 and 35 years                        | 1815  | 23%        |
| Between 35 and 50 years                        | 2653  | 33%        |
| Between 50 and 65 years                        | 1841  | 23%        |
| Between 65 and 80 years                        | 1287  | 16%        |
| Greater than 80 years                          | 218   | 3%         |
| Marital Status                                 |       |            |
| Married                                        | 3733  | 46%        |
| Never married                                  | 2363  | 29%        |
| Widowed                                        | 406   | 5%         |
| Divorced, annulled                             | 1272  | 16%        |
| Separated                                      | 280   | 3%         |
| Ethnicity                                      |       |            |
| White                                          | 4378  | 54%        |
| Black, African-American                        | 3120  | 39%        |
| American Indian                                | 48    | 1%         |
| Asian                                          | 127   | 2%         |
| Native Hawaiian                                | 11    | 0%         |
| Other                                          | 317   | 4%         |
| Refused                                        | 55    | 1%         |
| COVID-19-related information                   |       |            |
| Whether you faced financial difficulty in 2020 |       |            |
| Yes                                            | 1775  | 22%        |
| No                                             | 6238  | 77%        |
| Whether as an essential worker in 2020         |       |            |
| Yes                                            | 4121  | 51%        |
| No                                             | 3880  | 48%        |
| Whether you work from home in 2020             |       |            |
| Yes                                            | 2239  | 28%        |
| No                                             | 5766  | 72%        |

**Table 3. Household characteristics of the sampled households**

| Household characteristics     | Count | Percentage |
|-------------------------------|-------|------------|
| Household size (# of members) |       |            |
| 1                             | 2295  | 28%        |
| 2                             | 2489  | 31%        |
| 3                             | 1258  | 16%        |
| 4                             | 1099  | 14%        |
| 5                             | 587   | 7%         |
| 6+                            | 328   | 4%         |
| Household child               |       |            |
| 0                             | 5022  | 62%        |
| 1                             | 1195  | 15%        |
| 2                             | 1083  | 13%        |
| 3+                            | 756   | 9%         |
| Household ownership           |       |            |
| Owns                          | 4436  | 55%        |
| Pays rent                     | 3191  | 40%        |
| Neither owns nor pays rent    | 429   | 5%         |
| Yearly Household income (USD) |       |            |

| Household characteristics            | Count | Percentage |
|--------------------------------------|-------|------------|
| Less than 30k<br>(category 1)        | 1896  | 24%        |
| Between 30 and 60k<br>(category 2)   | 2004  | 25%        |
| Between 60 and 100k<br>(category 3)  | 1710  | 21%        |
| Between 100 and 150k<br>(category 4) | 1109  | 14%        |
| Between 150 and 200k<br>(category 5) | 545   | 7%         |
| Between 200 and 250k<br>(category 6) | 271   | 3%         |
| Greater than 250k<br>(category 7)    | 335   | 4%         |
| Household location                   |       |            |
| Northeast                            | 963   | 12%        |
| Northcentral                         | 1956  | 24%        |
| South                                | 3699  | 46%        |
| West                                 | 1387  | 17%        |
| Alaska, Hawaii                       | 19    | 0%         |

### 3.1 Demographic characteristics in 2021

Table 2 and Table 2 summarize the individual- and household-level demographic data for 2021. Personal demographic characteristics are reported for the reference person. Around 70% of the reference persons were male, and the rest were female. 80% of the reference persons fall into the 25 to 65-year age category. Slightly less than 50% of the families contain married heads, while one-third (29%) of the family heads were never married. The heads of 54% of the families were White, and 39% were Black.

In terms of household characteristics, one-third (31%) of the households had two members. Slightly more than one-fourth of households (28%) had only one member. About two-thirds (62%) of households had no child (anyone below 18 years old). Around 40% of the families rented their houses. Almost an equal proportion of households (one-fourth each) belonged to the less than 30k, 30k-60k, and 60k-100k income categories. For around 20% of the households, the yearly household income was between 100k and 200k. 7% of the households have a yearly household income of more than 200k.

Geographically, most households (around 46%) hailed from the South. 24% of families lived in North Central, and around 12% and 17% resided in Northeast and West, respectively. The data generally cover the American population from all walks of life.

The 2021 survey data included additional information on households' COVID-19-related suffering. This information is also reported in Table 1. According to the survey, 22% of the families faced financial hardship during COVID-19. For half of the households, at least one family member worked as an essential worker. On the other hand, for less than one-third of the households, at least one member had the opportunity to work from home.

### 3.2 Changes in demography between 2019 and 2021

Table 4 presents the changes in the key demographic characteristics between 2019 and 2021. It can be noted that income changes are measured relative to the income categories identified in Table 2 above. In other words, an increase in income is evaluated if the household moves from a lower to the higher category – a change within the category is reported as no change in Table 4. Based on the above definition, half of the households reported no change in income between 2019 and 2021. Around 26% of households saw their income increase during the period, while 20% saw it drop. The family size was the same across the years for 80% of the households. Slightly more than 10%

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of family sizes increased between 2019 and 2021. The number of children increased in 7% of these households. 4% of the reference persons who were not working in 2019 started working in 2021. 11% of the referenced persons who were working in 2019 left work in 2021. Only 3% of households changed their location (across the 5 regions mentioned in Table 1: Northeast, North Central, South, West, and Alaska/Hawaii) during the survey period.

**Table 4. Changes in key demographic characteristics between 2019 and 2021**

| Variable                      | Count | Percentage |
|-------------------------------|-------|------------|
| Income                        |       |            |
| Increased                     | 2073  | 26%        |
| No change                     | 4282  | 53%        |
| Decreased                     | 1701  | 21%        |
| Household child               |       |            |
| Increased                     | 584   | 7%         |
| No change                     | 6815  | 85%        |
| Decreased                     | 657   | 8%         |
| Household location            |       |            |
| Changed state                 | 225   | 3%         |
| Household size (# of members) |       |            |
| Increased                     | 876   | 11%        |
| No change                     | 6423  | 80%        |
| Decreased                     | 757   | 9%         |
| Employment status             |       |            |
| Started working               | 360   | 4%         |
| working in both 2019 and 2021 | 6384  | 79%        |
| Left working                  | 867   | 11%        |
| Household ownership           |       |            |
| Started owning in 2021        | 518   | 6%         |

**Table 5. Change in vehicle ownership between 2019 and 2021**

| Change in vehicle ownership<br>Between 2019 and 2021 | Household Vehicle Count in 2019 |     |     |     |     |     |     |     |     |      |     |
|------------------------------------------------------|---------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|
|                                                      | 0                               | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9    | 10  |
| Decreased by 3 or more                               | 0%                              | 0%  | 0%  | 7%  | 11% | 18% | 42% | 50% | 25% | 0%   | 67% |
| Decreased by 2 or more                               | 0%                              | 0%  | 9%  | 6%  | 14% | 18% | 19% | 17% | 0%  | 0%   | 0%  |
| Decreased by 1 or more                               | 0%                              | 16% | 13% | 25% | 28% | 29% | 15% | 17% | 25% | 0%   | 0%  |
| Remained same                                        | 68%                             | 67% | 65% | 45% | 35% | 23% | 23% | 17% | 25% | 100% | 17% |
| Increased by 1 or more                               | 23%                             | 15% | 11% | 14% | 10% | 9%  | 0%  | 0%  | 0%  | 0%   | 17% |
| Increased by 2 or more                               | 6%                              | 2%  | 2%  | 2%  | 2%  | 1%  | 0%  | 0%  | 0%  | 0%   | 0%  |
| Increased by 3 or more                               | 2%                              | 0%  | 0%  | 1%  | 0%  | 2%  | 0%  | 0%  | 25% | 0%   | 0%  |

\* The percentages are calculated with the column sum as the denominator

### 3.3 Change in vehicle ownership between 2017, 2019, and 2021

In general, vehicle ownership increased for 17% of households and decreased for 21% between 2019 and 2021. The percentage decrease was statistically significantly higher than the percentage increase at a confidence interval greater than 99%. The percentages in Table 5 are calculated with the column sum as the denominator. Therefore, households with fewer vehicles were more likely to retain their fleet size. For example, 2/3<sup>rd</sup> of the 0-vehicle-owning households in 2019 retained their fleet size in 2021. Whereas only 1/3<sup>rd</sup> of the 4-vehicle-owning households in 2019 retained their fleet size in 2021. Additionally, it can be noted that, in 2019, almost equal proportions of 1-vehicle-owning households increased or decreased their fleet size. However, in 2 or more-vehicle-owning households, the likelihood of decreasing the vehicle fleet size was higher than that of increasing it.

In summary, it can be concluded that, in general, more households decreased their fleet size between 2019 and 2021 than increased it. The next section presents a multivariate statistical analysis

An exploration of post-COVID household vehicle ownership in the USA using panel data: An application of the generalized ordered logit model to identify the relative importance of different factors in the change in vehicle fleet size between 2019 and 2021.

## 4 Methods

The paper applies a generalized ordered logit (GOL) framework to examine post-COVID vehicle ownership behaviour. In the traditional ordered logit model – also known as the proportional odds model – the effects of exogenous variables are constrained to be identical across all outcome thresholds (McCullagh, 1980). This assumption implies that explanatory variables shift the probabilities of all ownership levels in parallel, which may be overly restrictive in the context of vehicle ownership decisions, where factors such as income, accessibility, and post-pandemic behavioural changes may exert differential influences across ownership transitions.

Two modelling approaches have been proposed to relax the proportional odds assumption. The partial proportional odds model allows selected coefficients to vary across outcome categories (Eluru & Yasmin, 2015). An alternative approach parameterizes the threshold terms as functions of exogenous variables, thereby permitting covariates to influence the transition points between ownership levels. The present study adopts this second approach, commonly referred to as the generalized ordered logit (GOL) model. By allowing threshold shifts to depend on observed characteristics, the GOL framework offers greater behavioural flexibility while retaining model parsimony, making it particularly suitable for capturing heterogeneous post-COVID vehicle ownership dynamics.

### 4.1 Generalized ordered logit framework

The household vehicle ownership changes between 2019 and 2021 (denoted by  $y$  below) are assumed to be generated by an underlying continuous latent propensity ( $y^*$ ). The latent propensity,  $y^*$ , is assumed to be a linear function of various exogenous variables, as in equation (1) below.

$$y^* = \alpha'Z + \varepsilon \quad (1)$$

Here,  $Z$  is the vector of covariates, including household and person-level demographics, and changes in these variables between 2019 and 2021 (e.g., household size, household ownership, household income, and the employment and marital status of the reference person). Additionally, the covariate  $Z$  includes the gender and age of the reference person in 2021, as well as the 2019 household fleet size.  $\alpha$  is the vector of the parameters to be estimated, and  $\varepsilon$  is the random error assumed to be logistically distributed.

The observable ordinal variable  $y$  is related to the unobservable latent propensity ( $y^*$ ) using threshold parameters,  $\tau$ . The function of the threshold parameters is to divide the latent propensity into  $J$  intervals, where  $J$  is the number of categories of the ordinal variable,  $y$ . In the current application, the ordinal variables,  $y$ , can assume seven categories as follows: decrease in vehicle fleet by 3 or more vehicles – category 1, decrease in vehicle fleet by 2 vehicles – category 2, decrease in vehicle fleet by 1 vehicle – category 3, constant vehicle fleet – category 4, increase in vehicle fleet by 3 or more vehicles – category 5, increase in vehicle fleet by 2 vehicles – category 6, increase in vehicle fleet by 1 vehicle – category 7. The relationship between  $y$  and  $y^*$  can be represented by equation (2) below.

$$y = j \text{ if } \tau_j < y^* < \tau_{j+1}, \quad \text{for } j = 1, 2, \dots, J \quad (2)$$

$J+1$  thresholds are needed to partition the latent propensity into  $J$  categories. The left and rightmost thresholds are fixed to negative and positive infinities, respectively, i.e.,  $\tau_1 = -\infty$  and  $\tau_8 = +\infty$ . The intermediate six thresholds are parameterized using equation (3) below.

$$\tau_j = \exp(\gamma_j'X) \text{ for } j = 2 \quad \text{and} \quad \tau_j = \tau_{j-1} + \exp(\gamma_j'X) \text{ for } j = 3, 4, 5, 6, \text{ and } 7 \quad (3)$$

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Where  $\gamma_j$  is a vector of the parameters to be estimated.  $X$  is the vector of exogenous variables. In the current application,  $X$  captures the COVID-19-related suffering. The exponential term ensures the ascending ordering of the thresholds, i.e., it ensures that  $-\infty < \tau_2 < \tau_3 < \tau_4 < \tau_5 < \tau_6 < \tau_7 < \infty$  (Eluru et al. 2007).

#### 4.2 Model estimation

Given equations (1) through (3), the probability of owning  $j$  vehicles can be denoted by equation (4) below

$$\pi_j = Pr(y = j|Z, X) = \Lambda(\tau_{j+1} - \alpha'Z) - \Lambda(\tau_j - \alpha'Z) \quad (4)$$

Where  $\pi_j$  denotes the probability of owning  $j$  vehicles  $\Lambda(.)$  and represents the standard logistic cumulative distribution function. Given the probability  $\pi_j$  the likelihood,  $L$  of the sample can be written using equation (5) below.

$$L = \prod_{n=1}^N \prod_{j=1}^J (\pi_{nj})^{\delta_{jn}} \quad (5)$$

In Equation (5),  $L$  denotes the likelihood of the sample,  $N$  denotes the sample size, and  $\delta$  is an indicator variable that assumes the value 1 if the  $j^{th}$  vehicle category is applicable for household,  $n$ , and 0 otherwise. The estimation of the parameters  $\alpha$  and  $\gamma$  are carried out by maximizing the likelihood equation (5) using the Apollo package in R Studio (Hess & Palma, 2019).

#### 4.3 Calculation of marginal effects

Marginal effects provide a quantitative valuation of the influence of exogenous variables on the choice outcome. Specifically, the marginal effects capture the change in the outcome variable due to an instantaneous change in the exogenous variables. In general, the marginal effects for ordered logit models can be calculated using equation (6) below.

$$ME = \hat{\alpha}' [\varphi(\hat{\tau}_{j+1} - \hat{\alpha}'Z) - \varphi(\hat{\tau}_j - \hat{\alpha}'Z)] \quad (6)$$

Where  $ME$  is used to denote the marginal effect.  $\hat{\tau}$  and  $\hat{\alpha}$  denote the estimate of the threshold,  $\tau$ , and the parameter vector,  $\alpha$  respectively.  $\varphi(.)$  is used to indicate the standard logistic density function. It can be noted that the ordered logit marginal effects depend not only on the parameter estimate but also on the density value of the chosen category. Hence, for every observation 7 marginal effects corresponding to the 7-vehicle ownership category can be calculated for each parameter.

## 5 Results

Table 6 presents the results of the generalized ordered logit model. The parameter estimates ( $\alpha, \gamma$ ), the odds ratio (calculated as  $\exp(\alpha)$  and  $\exp(\gamma)$ ), probability (calculated as  $(\exp(\alpha) - 1) \times 100$  and  $(\exp(\gamma) - 1) \times 100$ ) and the robust t-statistics are presented in the table.

**Table 6. Estimation result of the GOL model of household vehicle ownership change between 2019 and 2021**

| Independent variables                                                                    | Estimate | Odds ratio | Probability | Robust t-stat |
|------------------------------------------------------------------------------------------|----------|------------|-------------|---------------|
| Individual Demographic Variables: Corresponding to the reference person in the year 2021 |          |            |             |               |
| Gender indicator: Female                                                                 | -0.26    | 0.771      | -22.9       | -8.84         |
| Age indicator: Between 25 to 35 years old                                                | 0.326    | 1.385      | 38.5        | 6.14          |
| Age indicator: Between 35 to 50 years old                                                | 0.39     | 1.477      | 47.7        | 7.13          |
| Age indicator: Between 50 to 65 years old                                                | 0.344    | 1.411      | 41.1        | 6.2           |
| Age indicator: Between 65 to 80 years old                                                | -0.26    | 0.771      | -22.9       | -8.84         |
| Ethnicity indicator: Black                                                               | -0.198   | 0.82       | -18         | -6.87         |

| Independent variables                                       | Estimate | Odds ratio | Probability | Robust t-stat |
|-------------------------------------------------------------|----------|------------|-------------|---------------|
| Ethnicity indicator: Asian                                  | -0.24    | 0.787      | -21.3       | -2.61         |
| Change in individual demography between 2019 and 2021       |          |            |             |               |
| Widowed/divorced or separated after 2019                    | -0.535   | 0.586      | -41.4       | -4.86         |
| Started owning house after 2019                             | 0.1      | 1.105      | 10.5        | 1.85          |
| Left working after 2019                                     | -0.19    | 0.827      | -17.3       | -4.87         |
| Change in household demography between 2019 and 2021        |          |            |             |               |
| Household size                                              |          |            |             |               |
| Household size increased by 1 after 2019                    | 0.267    | 1.306      | 30.6        | 5.65          |
| Household size increased by 2 after 2019                    | 0.393    | 1.482      | 48.2        | 2.6           |
| Household size increased by 3 or more after 2019            | 0.505    | 1.656      | 65.6        | 2.69          |
| Household size decreased by 1 after 2019                    | -0.266   | 0.767      | -23.3       | -4.97         |
| Household size decreased by 2 after 2019                    | -0.502   | 0.605      | -39.5       | -4.55         |
| Household size decreased by 3 or more after 2019            | -0.935   | 0.393      | -60.7       | -4.27         |
| Household child count                                       |          |            |             |               |
| Household child count increased by 1 after 2019             | 0.2      | 1.222      | 22.2        | 1.11          |
| Household child count decreased by 1 after 2019             | 0.477    | 1.611      | 61.1        | 6.64          |
| Household child count decreased by 2 or more after 2019     | 0.384    | 1.468      | 46.8        | 1.7           |
| Household income                                            |          |            |             |               |
| Household income increased after 2019                       | 0.176    | 1.192      | 19.2        | 5.75          |
| Household relocation                                        |          |            |             |               |
| Household moved to metro area after 2019                    | -0.205   | 0.815      | -18.5       | -1.99         |
| Household moved to non-metro area after 2019                | 0.131    | 1.14       | 14          | 0.95          |
| 2019 household vehicle fleet size                           |          |            |             |               |
| Household fleet size in 2019: 0                             | 3.032    | 20.74      | 1974        | 12.57         |
| Household fleet size in 2019: 1                             | 2.27     | 9.675      | 867.5       | 9.52          |
| Household fleet size in 2019: 2                             | 1.802    | 6.063      | 506.3       | 7.6           |
| Household fleet size in 2019: 3                             | 1.496    | 4.463      | 346.3       | 6.22          |
| Household fleet size in 2019: 4                             | 1.022    | 2.779      | 177.9       | 4.15          |
| Household fleet size in 2019: 5                             | 0.723    | 2.06       | 106         | 2.67          |
| Threshold Parameters                                        |          |            |             |               |
| Constants                                                   |          |            |             |               |
| Threshold 1: Constant                                       | -0.209   | 0.811      | -18.9       | -0.88         |
| Threshold 2: Constant                                       | -0.316   | 0.729      | -27.1       | -5.58         |
| Threshold 3: Constant                                       | -0.143   | 0.866      | -13.4       | -3.46         |
| Threshold 4: Constant                                       | 0.778    | 2.177      | 117.7       | 45.92         |
| Threshold 5: Constant                                       | 0.005    | 1.005      | 0.5         | 0.16          |
| Threshold 6: Constant                                       | -0.471   | 0.624      | -37.6       | -5.61         |
| Financial difficulty faced in 2020 due to COVID-19          |          |            |             |               |
| Threshold 4: Financial difficulty in 2020 indicator (Yes)   | 0.146    | 1.158      | 15.8        | 3.7           |
| Threshold 5: Financial difficulty in 2020 indicator (Yes)   | -0.05    | 0.951      | -4.9        | -1.94         |
| Threshold 7: Financial difficulty in 2020 indicator (Yes)   | 0.449    | 1.567      | 56.7        | 2.61          |
| Served as essential worker in 2020 due to COVID-19          |          |            |             |               |
| Threshold 3: Essential worker in 2020 indicator (Yes)       | -0.099   | 0.906      | -9.4        | -1.59         |
| Threshold 4: Essential worker in 2020 indicator (Yes)       | -0.08    | 0.923      | -7.7        | -1.62         |
| Threshold 5: Essential worker in 2020 indicator (Yes)       | -0.161   | 0.851      | -14.9       | -7.35         |
| Worked from home in 2020 due to COVID-19                    |          |            |             |               |
| Threshold 2: Worked from home (WFH) indicator (WFH in 2020) | -0.105   | 0.901      | -9.9        | -2.07         |
| Threshold 4: Worked from home (WFH) indicator (WFH in 2020) | -0.095   | 0.909      | -9.1        | -1.59         |
| Threshold 6: Worked from home (WFH) indicator (WFH in 2020) | 0.068    | 1.071      | 7.1         | z1.13         |

### 5.1 Effect of individual demography

According to the results, households with female heads are more than 20% more likely to decrease the vehicle fleet size between 2019 and 2021. Although the 2021 German study found that women reported missing their cars more than men did in their 2020 survey, no prior study has reported a gender difference of this magnitude. Some statistically significant effect of age is also noted – households with a household head between 25 and 65 years are between 40 to 50% more likely to increase the fleet size after 2019 than households with a younger head. A reverse effect is observed among households with a head aged 65-80 years – these households are more than 20% more likely

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to decrease their household fleet size between 2019 and 2021. Existing studies did not examine the effect of the household head's age; according to Eisenmann et al. (2021), younger adults are more likely to miss a car than those aged 35 or older.

Regarding ethnicity, households with Black American heads are 18% more likely to decrease the household fleet size after 2019. Similarly, Asian American households are more than 20% more likely to decrease their vehicle fleet size. Historically, White American households enjoy better purchasing power than Black or Asian American households. Hence, it is likely that the COVID-19-related sufferings have impacted the Black and Asian Americans disproportionately compared to the White Americans, leading the prior groups to reduce their vehicle fleet size more. This observation echoes several recent studies on the topic – for example, Klein and Smart (2017) have shown using previous years' PSID data that families of immigrants and families of colour are more likely to go into a carless state than the US-born whites.

## 5.2 *Effect of change in individual demography*

It was interesting to note that the households with widowed/divorced or separated heads were 40% more likely to reduce their household fleet size after 2019. The partner who left the household might have taken the vehicle with them, reducing the household's fleet size. This observation has been corroborated by numerous previous studies – Oakil et al. (2018), using PSID data, have shown that dissolution of the relationship often negatively impacts car ownership. Similar observations have been noted among Dutch families by Klein and Smart (2019), who found that a breakup is associated with a decrease in car ownership.

Similarly, the vehicle fleet size was almost 20% more likely to decrease in the households where the head of household left work between 2019 and 2021. Leaving a job might have negatively affected the household's financial solvency, leading to a reduction in its fleet size. On the other hand, household heads who began owning their homes after 2019 were 10% more likely to increase their vehicle fleet. These results seem intuitive and support the authors' a priori hypothesis. Owning a household might indicate greater financial solvency, leading to an increase in the household's vehicle fleet.

## 5.3 *Effect of change in household demography*

Changes in household size, whether increases or decreases in household members, were found to have a clear, statistically significant impact on household fleet size. An increase in household size, by any magnitude, was found to positively influence the household fleet size – this is intuitive – since an increase in household size exerts additional demand on the household's existing vehicle fleet, which can prompt an increase in the existing fleet size. Similarly, any reduction in family size was found to negatively impact the vehicle fleet size. However, the magnitude of change was found to be highest where the family size changed by 3 or more people. For example, a change in family size by 1 member was found to be between 20% and 30% more likely to result in changes in their vehicle fleet size. However, a change in family size by 3 or more members was found to be 60-65% more likely to result in a change in vehicle fleet size. Through previous research, such as Prillwitz et al. (2006) has reported a positive relationship between increases in the number of family adults and car ownership; however, comparative exploration of increases versus decreases in the number of family adults and car ownership is rare in the existing literature.

Interesting effects were also noted for changes in household child number. The results indicate a drop in household child count, positively associated with an increase in household fleet size. A drop in household child count might induce pressure on the existing vehicle fleet, leading to a rise in household fleet size.

The results indicate that higher household income increases the probability of increasing vehicle fleet size by almost 20%. Previous research has shown that income is one of the strongest predictors of car ownership (Nolan, 2010). According to the model results, households are almost 20% more

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likely to reduce their fleet size if they move to a metro area. On the other hand, households become almost 15% more likely to increase their vehicle fleet size if they move to a non-metro area. This finding closely resembles the recent studies by Eisenmann et al. (2021) and Habib and Anik (2021) in the German and Canadian contexts, respectively. Both studies have predicted or inferred from survey results that post-pandemic car ownership will be higher in suburban areas than in metropolitan areas.

#### 5.4 *State dependency on 2019 vehicle ownership*

The model tries to capture the state dependency of 2019 vehicle ownership on the change in vehicle fleet size between 2019 and 2021. In general, the results indicate that households are more likely to increase their fleet size in 2021 as the fleet size in 2019 decreases. This somewhat validates the descriptive analysis presented in Table 4. According to Table 4, 23% of households owning 0 vehicles in 2019 increased their fleet size in 2021, whereas only 15% of households owning 1 vehicle did so. In the same vein, the percentage of households increasing their vehicle fleet in 2021 dropped to around 10% among households that owned 4 or 5 vehicles in 2019. Of course, households owning 0 vehicles in 2019 are bound to either maintain or increase their fleet size in 2021, which is one of the primary reasons for the considerably high proportion of 0-vehicle households increasing their fleet size in 2021. Nonetheless, this effect has been captured by the gradually decreasing (with the increase in baseline vehicle quantity) magnitude of the state dependency parameters.

#### 5.5 *Effect of COVID-19-related variables*

The influence of COVID-19-related variables was tested on different threshold parameters. Figure 1 shows the positions of the threshold parameters relative to the 7 categories of the dependent variable. The effect of the financial difficulty parameter was found to be positive on threshold 4. A positive effect on threshold 4 shifts the threshold to the right, thereby increasing the probability of reducing the vehicle fleet size by 1 or more vehicles.

The sign of the financial difficulty parameter at threshold 7 was also found to be positive. This indicates that households that reported financial difficulty in 2020 will be less likely to increase their vehicle fleet size by 3 or more.

It was found that the effect of financial difficulty on threshold 5 was negative, indicating a leftward shift in the threshold; however, the magnitude of this parameter was considerably smaller than that estimated for threshold 4. Nonetheless, the -ve sign of threshold 5 indicates that the region under “no change” in vehicle fleet size will be smaller for the households that faced financial difficulty in 2020.

The effect of essential worker parameters was negative and significant at thresholds 3, 4, and 5, indicating a leftward shift in these thresholds for households with at least one member who worked as an essential worker in 2020. Therefore, households with members who worked as essential workers in 2020 are less likely to reduce or maintain their vehicle fleet size in 2021. Or in other words, households will be more likely to increase their vehicle fleet size if a household member worked as an essential worker in 2020.

The above-mentioned result is not surprising – many households became apprehensive about using public transportation during COVID-19 (Shelat et al., 2022). Hence, during COVID-19, households that worked as essential workers were more likely to rely on their private vehicles, leading to an inclination to increase household fleet size in the immediate aftermath of COVID-19.

The parameters of the work-from-home indicators were found to be negative on thresholds 2 and 4. A negative parameter shifts the corresponding thresholds to the left. Therefore, the negative estimates for work-from-home parameters indicate that households with at least one member working from home during the pandemic will be less likely to reduce their vehicle fleet size in the immediate aftermath of COVID-19. The result might seem non-intuitive since the ability to work

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from home is supposed to reduce the commute burden. However, it should also be noted that work-from-home opportunities were primarily available to people pursuing blue-collar jobs; in other words, these families are more likely to be wealthier than families where no one had the opportunity to work from home. Hence, families with at least one member working from home during the COVID-19 pandemic were less likely to reduce their vehicle fleet size in the immediate aftermath of the pandemic.

However, interestingly, the impact of the home parameter was found to be positive at threshold 6, shifting the parameter to the right and thereby decreasing the probability of an increase in vehicle fleet size by 2 or more vehicles. Therefore, though households with some members working from home during the COVID-19 pandemic were less likely to reduce their fleet size in 2021, they were also less likely to increase their fleet size by 2 or more, which is quite an intuitive finding.

### 5.6 Analysis of the marginal effects: Average marginal effects

Table 7 presents the marginal effect of the generalized ordered logit model. It can be noted that, for indicator variables, the calculation of marginal effect boils down to the difference in the average probability for each outcome across two samples – one sample represents the case where the target indicator variable assumes a value of 1 for all observations, and the second sample represents the case where the indicator variable assumes a value of 0 for all observations. Therefore, the average marginal effect captures the impact of the target indicator variable on the entire sample, assuming that all other model variables (except the target indicator) are held constant.

The calculation of the marginal effect is especially important for ordinal logit/probit models, since the sign of the estimated parameters cannot precisely predict the direction of influence across the different categories of the ordinal outcome. However, the marginal effect can be easily calculated for different categories of the ordinal dependent variable, providing concrete evidence of the impact of the target variables on those categories. As can be noted from Table 6, the sign of the marginal effect changes across the category of the outcome variable, even though the sign of the estimated parameter is fixed.

For example, the parameter to the female indicator was estimated to be negative. From the marginal effects presented in Table 6 it can be seen that households headed by females were more likely to reduce their vehicle fleet but less likely to maintain or increase it. Without the calculation of the marginal effect, it was not possible to ascertain the sign of the change for the intermediate dependent variable categories, such as no change in household vehicle. In general, the calculated marginal effects ranged from 1 to 3%. For some variables, the magnitudes ranged from 4 to 5%.

Among the demographic variables, the households with widowed/separated or divorced heads were found to have a marginal effect in the range of -4% to +5%. A decrease in household size by 2 or more was also associated with high marginal effects, ranging from -7% to +10%. However, the largest magnitude of the marginal effects was observed for the state dependency variables – specifically, the marginal effect of the 2019 vehicle ownership values ranged from -23% to +40%.

**Table 7. Average marginal effects: Generalized ordered logit model**

| Target indicator variable                            | Estimate | Marginal effects                 |                          |                          |                           |                          |                          |                                  |
|------------------------------------------------------|----------|----------------------------------|--------------------------|--------------------------|---------------------------|--------------------------|--------------------------|----------------------------------|
|                                                      |          | Decrease in vehicle by 3 or more | Decrease in vehicle by 2 | Decrease in vehicle by 1 | No change in vehicle size | Increase in vehicle by 1 | Increase in vehicle by 2 | Increase in vehicle by 3 or more |
| Gender indicator: Female                             | -0.26    | 0.0213                           | 0.0131                   | 0.0174                   | -0.0047                   | -0.0213                  | -0.0109                  | -0.015                           |
| Age indicator:<br>Between 25 to 35 years old         | 0.125    | -0.0096                          | -0.0062                  | -0.0085                  | 0.0008                    | 0.0103                   | 0.0055                   | 0.0077                           |
| Age indicator:<br>Between 35 to 50 years old         | 0.326    | -0.0246                          | -0.0158                  | -0.0221                  | 0.0009                    | 0.0269                   | 0.0144                   | 0.0204                           |
| Age indicator:<br>Between 50 to 65 years old         | 0.39     | -0.0285                          | -0.0185                  | -0.0263                  | -0.0019                   | 0.0318                   | 0.0177                   | 0.0257                           |
| Age indicator:<br>Between 65 to 80 years old         | 0.344    | -0.0249                          | -0.0163                  | -0.0234                  | -0.0021                   | 0.028                    | 0.0157                   | 0.0229                           |
| Widowed/divorced or separated after 2019             | -0.535   | 0.0513                           | 0.0291                   | 0.0338                   | -0.0263                   | -0.0424                  | -0.0198                  | -0.0257                          |
| Started owning house after 2019                      | 0.1      | -0.0076                          | -0.0049                  | -0.0068                  | 0.0005                    | 0.0083                   | 0.0044                   | 0.0062                           |
| Left working after 2019                              | -0.19    | 0.0158                           | 0.0098                   | 0.0128                   | -0.0043                   | -0.0157                  | -0.0079                  | -0.0107                          |
| Ethnicity indicator:<br>Black                        | -0.198   | 0.0159                           | 0.01                     | 0.0134                   | -0.0029                   | -0.0163                  | -0.0084                  | -0.0116                          |
| Ethnicity indicator:<br>Asian                        | -0.24    | 0.0206                           | 0.0125                   | 0.0159                   | -0.0068                   | -0.0196                  | -0.0097                  | -0.013                           |
| Household size:<br>Increased by 1 after 2019         | 0.267    | -0.0192                          | -0.0127                  | -0.0184                  | -0.0014                   | 0.0221                   | 0.0121                   | 0.0174                           |
| Household size:<br>Increased by 2 after 2019         | 0.393    | -0.0266                          | -0.018                   | -0.0269                  | -0.0068                   | 0.0323                   | 0.0186                   | 0.0275                           |
| Household size:<br>Increased by 3 or more after 2019 | 0.505    | -0.0327                          | -0.0225                  | -0.0343                  | -0.013                    | 0.0409                   | 0.0245                   | 0.0371                           |
| Household size:<br>Decreased by 1 after 2019         | -0.266   | 0.0228                           | 0.0139                   | 0.0178                   | -0.0076                   | -0.0218                  | -0.0107                  | -0.0144                          |

| Target indicator variable                                      | Estimate | Marginal effects                       |                             |                             |                              |                             |                             |                                        |
|----------------------------------------------------------------|----------|----------------------------------------|-----------------------------|-----------------------------|------------------------------|-----------------------------|-----------------------------|----------------------------------------|
|                                                                |          | Decrease in<br>vehicle by 3<br>or more | Decrease in<br>vehicle by 2 | Decrease in<br>vehicle by 1 | No change in<br>vehicle size | Increase in<br>vehicle by 1 | Increase in<br>vehicle by 2 | Increase in<br>vehicle by 3<br>or more |
| Household size:<br>Decreased by 2 after 2019                   | -0.502   | 0.0476                                 | 0.0272                      | 0.0319                      | -0.0235                      | -0.04                       | -0.0188                     | -0.0245                                |
| Household size:<br>Decreased by 3 or more after<br>2019        | -0.935   | 0.1039                                 | 0.0518                      | 0.0512                      | -0.0687                      | -0.0694                     | -0.0305                     | -0.0384                                |
| Household child count:<br>Increased by 1 after 2019            | 0.2      | -0.0146                                | -0.0096                     | -0.0138                     | -0.0007                      | 0.0166                      | 0.0091                      | 0.013                                  |
| Household child count:<br>Decreased by 1 after 2019            | 0.477    | -0.0318                                | -0.0216                     | -0.0325                     | -0.0099                      | 0.0388                      | 0.0228                      | 0.0341                                 |
| Household child count:<br>Decreased by 2 or more after<br>2019 | 0.384    | -0.0261                                | -0.0176                     | -0.0262                     | -0.0065                      | 0.0314                      | 0.0182                      | 0.0269                                 |
| Household income:<br>Increased after 2019                      | 0.176    | -0.0134                                | -0.0086                     | -0.0121                     | 0.0008                       | 0.0146                      | 0.0078                      | 0.0109                                 |
| Household moved to metro area<br>after 2019                    | -0.205   | 0.0174                                 | 0.0106                      | 0.0137                      | -0.0054                      | -0.0168                     | -0.0083                     | -0.0112                                |
| Household moved to non-metro<br>area after 2019                | 0.131    | -0.0098                                | -0.0064                     | -0.009                      | 0.0002                       | 0.0108                      | 0.0058                      | 0.0082                                 |
| Household fleet size in 2019: 0                                | 3.032    | -0.1372                                | -0.0807                     | -0.1259                     | -0.2317                      | 0.0529                      | 0.1039                      | 0.4188                                 |
| Household fleet size in 2019: 1                                | 2.27     | -0.1765                                | -0.0785                     | -0.0901                     | -0.054                       | 0.0926                      | 0.0852                      | 0.2214                                 |
| Household fleet size in 2019: 2                                | 1.802    | -0.1424                                | -0.0653                     | -0.0757                     | -0.0409                      | 0.0849                      | 0.0739                      | 0.1656                                 |
| Household fleet size in 2019: 3                                | 1.496    | -0.0855                                | -0.0513                     | -0.0787                     | -0.0947                      | 0.0831                      | 0.0745                      | 0.1526                                 |
| Household fleet size in 2019: 4                                | 1.022    | -0.0581                                | -0.0388                     | -0.0625                     | -0.0572                      | 0.0722                      | 0.0528                      | 0.0917                                 |
| Household fleet size in 2019: 5                                | 0.723    | -0.0436                                | -0.0301                     | -0.0475                     | -0.0294                      | 0.0561                      | 0.0364                      | 0.0581                                 |

### 5.7 Analysis of the marginal effects: Average marginal effects

It can be noted that, for each dependent variable category, the marginal effects will be distributed across the sample due to heterogeneity in demographic characteristics (e.g., age, gender). The narrow distribution indicates that for most of the sample population, the marginal effect is rather close to the average marginal effect. The marginal effect was calculated for the twenty-eight parameters estimated in the model. However, Figure 1 presents the distribution for the selected 7 parameters, which had an interesting impact on the outcome variables.

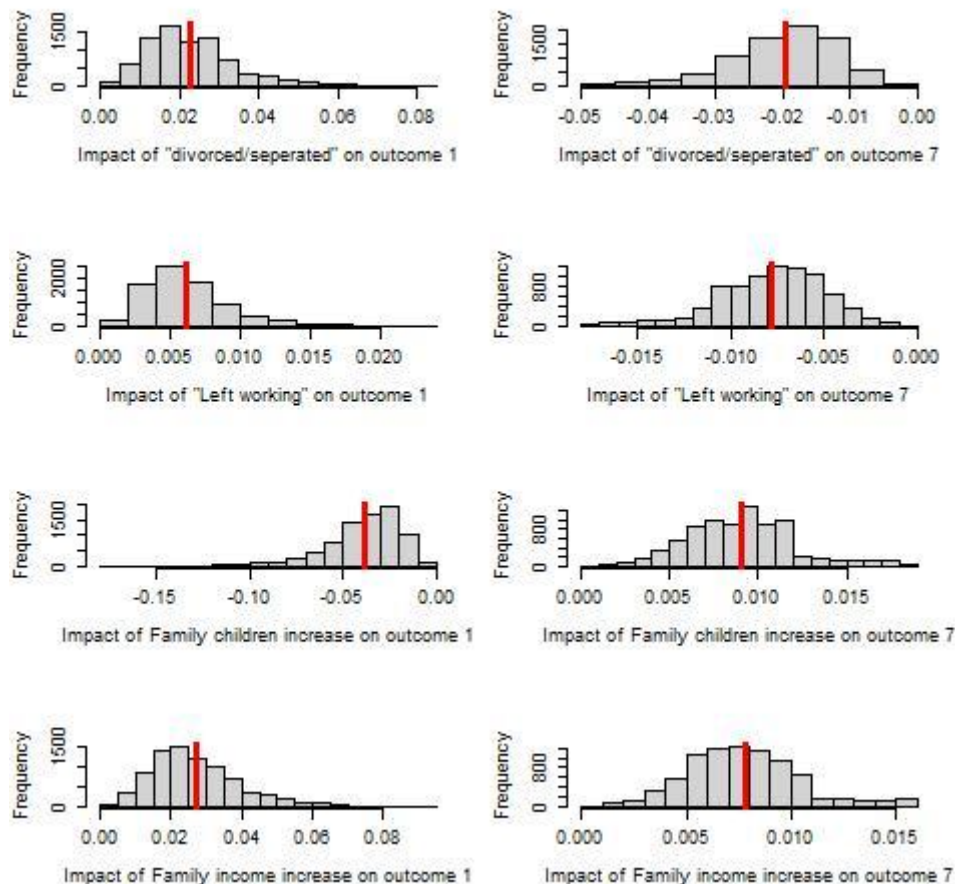


Figure 1. Distribution of the marginal effects of the selected demographic variables of the Ordered Logit model or vehicle change

Specifically, Figure 1 presents the distributions of the marginal effects for the demographic variables across the lowest and highest dependent variable categories. As expected, the range of the marginal effects across the sample in any specific dependent variable category was found to be quite narrow – around 0. The red lines in Figure 1 represent the average marginal effect presented in Table 6. As shown in the figure, the mean aligns well with the peak of the marginal effect distribution. Another assuring thing is the change in the sign of the marginal effect distribution from one outcome category to another. For example, the parameter for the leaving work indicator was negative; hence, the marginal effects are positive for the lowest dependent variable category in the full sample. Similarly, the marginal effect values for this parameter were found to be negative, as expected, in the highest outcome category for the full sample. In summary, the narrow range of the marginal effect distribution across the sample insinuates that the average marginal effects presented in Table 6 are representative of the sample population.

## 6 Conclusion

Our paper is one of the first studies to analyse the vehicle ownership change between 2019 and 2021 – essentially capturing some of the immediate impacts of COVID-19 pandemic on the vehicle ownership decision in the USA. The study uses an actual panel of 8,000 plus households – the responding households reveal their vehicle ownership counts in the respective years – hence, unlike some of the existing studies assessing the impact of COVID-19, this study did not have to rely on any prospective or retrospective information – which sometimes does not represent the revealed scenario appropriately (Thigpen, 2019).

The study identifies some assuring findings. In general, between 2019 and 2021, vehicle ownership increased for 17% of households and decreased for 21% of households – this is contrary to the change observed between 2017 and 2019. Between 2017 and 2019, vehicle ownership increased for a larger percentage of households – i.e., increased for 19% households and decreased for 17% households. Other than that, the overall trends held constant across the four years. For example, across both pairs of years (i.e., between 2017 and 2019 and 2019 and 2021), households that owned fewer vehicles in the previous years were more likely to maintain their fleet size. On the other hand, households with more vehicles were more likely to change their fleet size.

The multivariate ordered logit model estimated on the change in vehicle ownership between 2019 and 2021 found that households owning fewer vehicles in 2019 were more likely to increase their vehicle fleet than households owning more vehicles in 2019. This corroborates the observations from descriptive analyses conducted between 2017 and 2019 and between 2019 and 2021. Therefore, it can be concluded that, though the increase in vehicle ownership subsided slightly between 2019 and 2021 compared to 2017 and 2019, no paradigm shift has been observed at least in the immediate aftermath of the COVID-19 pandemic.

The control variables, such as change in individual status of the household head (such as change in work status or divorce) and the change in household demography (such as change in income and relocation) were found to have a significant impact on the vehicle ownership change between the pre- and post-pandemic period – this is an assuring finding since this is corroborated by previous research as well (Yamamoto, 2008). However, some COVID-19-related impacts were also found to be significant – for example, families facing financial difficulties during the pandemic were less likely to increase their vehicle fleet by a large number as expected. On the other hand, families of essential workers were found to be inclined to increase their vehicle fleet in the immediate aftermath of the COVID-19 outbreak.

In summary, it can be concluded that the pandemic did not seem to have any considerable impact on the vehicle ownership trend in the US, at least in the immediate aftermath, which is historically a highly auto-dependent country (Pucher & Lefèvre, 1996). However, some sections of society might be in higher need of cars, as evident from the multivariate analysis. Even after controlling for important demographic changes, households with essential workers showed a higher propensity to expand their vehicle fleets. Therefore, assistance for such families might need to be prioritized during and after the pandemic.

### *Data Access Statement*

The data that support the findings of this study are available from the Panel Study of Income Dynamics Repository through <https://simba.isr.umich.edu/default.aspx>

### *Contributor Statement*

Annesha Enam: Conceptualization, Methodology, Data Curation, Formal Analysis, Software, Visualization, Writing – Original draft, Writing – Review & Editing.

## Use of AI

During the preparation of this work, the author used Grammarly software for grammar and spell checking in order to reduce errors while proofreading. After using this tool/service, the author reviewed, edited, made the content their own, validated the outcome as needed, and took full responsibility for the publication's content.

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## Conflict Of Interest (COI)

There is no conflict of interest.

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