MODELING HOUSEHOLD CAR OWNERSHIP IN BELGIUM

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ABSTRACT
Private vehicles have dominated personal transportation for the past 50 years. They provide positive externalities such as accessibility and independence. However, their widespread use in urban areas has resulted in negative externalities such as traffic congestion, air pollution, human health problems and damage to the ecosystem. Therefore, understanding the underlying factors affecting car ownership has become an important research theme. This study focuses on assessing the main socio-economic factors that affect household car ownership in Belgium. To this end, we developed a household car ownership model based on the 2016 Belgian household travel survey. Overall, our results confirm the literature review's findings, highlighting the importance of socio-demographic and economic characteristics of households in explaining household car ownership. The results from the multinomial logit model show that: (i) income is positively associated with car ownership, (ii) living in Flanders and Wallonia increases the probability of having two or more cars compared to living in Brussels, (iii) having a driving license increases car ownership, (iv) a larger number of adults and children in a household is related to a higher likelihood of owning two or more cars per household, (v) higher level of education increases the probability of having more than one car per household and (vi) older people (65+) are less likely to have multiple cars. The results of this study can be used as a tool for researchers, policymakers and urban planners to define more effective sustainable mobility policies.
Keywords: household, multinomial logistic regression model, socio-economics characteristics, vehicle ownership.

1 INTRODUCTION

Despite a widespread recognition and understanding of the importance of sustainable mobility, private vehicle ownership and usage continue to rise [1]. Although cars provide convenience, the negative impact of increasing the number of cars on transportation infrastructure, ecosystem and human health has been emphasized in the literature [2]. Assessing car ownership is an important factor in studying individuals' and households' travel behavior and mode choice [3],[4].

Although car dependency is common in Belgian cities, it is surprising that there is no study on assessing factors that influence household car ownership in this. Moreover, most previous studies on household vehicle ownership around the world mainly focus on metropolitan areas. In a country, like Belgium with dense neighborhoods of big cities, e.g. Brussels, and mostly peri-urban and semi-rural areas in Flanders and Wallonia with significant diversities in terms of development, implementation and execution of mobility policies, the level of car ownership needs more investigation.

To contribute to the existing literature on household car ownership, this study looked at whether and to what extent socio-economic factors affect the number of cars owned by households in Belgium. The research aims at (i) determining the main socio-economic factors influencing household car ownership in Belgium and (ii) constructing a model that predicts the number of vehicles per household. To this end, we estimate a multinomial logit (MNL) model using data from the most recently available national household travel survey.

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2 PREVIOUS RESEARCH

Developed societies continue to rely heavily on private vehicles [5] to meet their mobility needs. Pollution, traffic congestion and long travel times are only a few of the challenges that cities face when it comes to mobility. A reduction in the number of private vehicles on the road could help to ease these issues [6]. Taking Belgium as an example, where 98.04 percent of the population lived in urbanized areas in 2019 [7], private cars remain the most common mode of transportation, both in terms of the number of trips and the distance traveled [8]. Managing and regulating vehicle demand to reduce the mobility-related adverse effects requires developing analytical models to help decision-makers in their strategic transport and urban planning [9]. Hence, both public agencies and private organizations are interested in modeling car ownership [10] to use it as a tool for strategic policymaking toward sustainable mobility. In the research literature, different models explain households' car ownership, and most of these models use socio-demographic, economic, spatial and land-use factors to describe the different levels of car ownership among households [11]. However, the factors that impact household vehicle ownership vary by region [12]. We restricted our literature review to studies that look at the different factors that affect the household (not individual) car ownership decision at a disaggregated level in which the household is the decision-maker. Below, the most important factors influencing household car ownership based on the literature review are discussed.

2.1 Socio-economics factors

The effects of socio-economic characteristics have been investigated in different studies. In several studies, it is confirmed that higher income has a positive effect on car ownership levels [13],[14] because of the increasing buying power of the household. According to Shen et al. [15], higher income and higher job positions with a flexible work schedule relate significantly to greater probabilities of owning and driving cars. Using Irish longitudinal data from 1995 to 2001, Nolan [16] found that the strongest determinants in household car ownership are income and previous car ownership. Household size and composition (i.e., presence of children in the household) and lifecycle events are also determining factors in household car ownership.

As illustrated in some other research studies, the number of family members [12], number of adults, number of employees in the household [2] and license holders [17] increase the probability of owning multiple cars in the household [18]. In addition, Maltha et al. [19] showed that the strong impact of household income on household car ownership decreased dramatically between 1987 and 2014 in the Netherlands, while the influence of household size increased substantially.

Studies on the relation between job status showed a positive relationship between having members with a full-time job and higher levels of car ownership [13]. The status of the household head as a pensioner (negatively) and the number of cars owned the year before (positively) are identified as variables that influence the level of car ownership [11]. In terms of gender, gender differences in household task allocation influence car ownership [20]. Owning a car is less important for young single and young couples [21]. The education level is another factor that influences car ownership. Higher education raises environmental awareness and changes people's attitudes toward private modes of transport [22]. However, Clark et al. [23] found a higher probability for highly educated households to own a car. To sum up, household income and composition, and the availability of driving licenses in the household are the important socio-economic factors that affect car ownership.

2.2 Spatial and land-use factors

The spatial or land-use characteristics such as urbanization [24], urban form, e.g., dense urban area or sprawling [25], proximity to public transport, the capacity of the road network [26], local efficiency access to local shopping, sidewalks, slow vehicle speeds, accessibility to job centers [27], ownership of electric bikes [28], access to motorcycles [29] and the neighborhood crime-related safety [30] play an important role in car ownership.

Car ownership is higher in suburban areas with a lower population density because of less access to public transit and other destinations. Studies by Shen et al. [15] and Pan et al. [31] confirmed that access to services, e.g. access to public transportation and recreational facilities, affected the desire of a household to own a car. The direct relationship between less private car ownership and accessible public transit has been studied in some studies [32],[33]. Woldemanuel et al. [34] confirmed that proximity to the subway or urban rail stations, proximity to shops, and accessible public transportation were all factors associated with lower household car ownership. Ding and Cao [35] found that individuals' car ownership is influenced by built environment characteristics, especially bus stop density at the job location. However, residence environments have a more significant impact than work locations. Li et al. [36] and Baldwin Hess and Ong [37] found that increased population and residential density had a negative impact on car ownership. In contrast, the results of a study in Manila showed that higher population density leads to a higher level of car ownership as a result of the inadequacy of public transit services in crowded areas [38]. According to Schimek [39] and Baldwin Hess and Ong [37], traditional communities with welcoming walking and biking environments continued to reduce car ownership.
To sum up, living in a dense area and near public transit facilities negatively affects household car ownership.

3 RESEARCH DESIGN

3.1 Data description and descriptive statistics

The household car ownership model is developed using data from the most recent national household travel survey (MONITOR), which was conducted using online questionnaires between 2016 and 2017. The database comes from two questionnaires that have been submitted to the same respondents. The intake dataset consists of general questions about the socio-economic characteristics of the household, the transport modes used, the mean of transport to go to work in general, etc., and the diary, where each respondent has to fill every trip of a specific day. Respondents may be heads of households. The household is defined as persons who live under the same roof and share the same monthly net income. Note that based on data availability, our unit of observation is technically the individual who responded to the survey. However, car ownership is a household-level decision. The choice of variables for investigating potential effects on car ownership was based on previous theoretical and empirical works found in the literature review and data availability. The variable categories followed the categorization framework in the MONITOR project. The number of cars is also defined as ready-to-use vehicles for private use, including company cars that are allowed to be used outside the work context.

Data from a national sample of 10,632 respondents (8,632 adults and 2,000 children) were used. For each household, we had the number of cars and socio-economic characteristics to build the model. We removed cases with missing values from the dataset. The number of cars owned by households was categorized into 0, 1 and 2 or more. We grouped the households with two and two or more cars, considering the sample size of people with more than two cars per household was small. Table 1 provides a descriptive analysis of the socio-economic profile for the sample of households, as well as the categorization of the dependent variable, i.e., the number of cars per household. The descriptive analysis showed that most of the study respondents had one car (4,354 households), followed by 3,310 households with two or more cars and 967 households with no car. Authors have also checked for multicollinearity of all the independent variables by calculating the variance inflation factor (VIF). All the VIFs are smaller than 10, indicating a low degree of multicollinearity. In the proposed model, we also assumed a homogeneous population and investigated the direct effects of socio-economics attributes on the level of car ownership.

3.2 Modeling framework

The methods used to model household car ownership vary from simple linear regression to complex econometric models based on the context of the study, which typically determines the framework of the models [40]. The focus of this study is on disaggregated models based on the household level. Disaggregated models consider the number of available cars in the household (i.e., 0, 1, 2, 3 or more) as ordinal or nominal discrete variables, leading to either ordered or unordered choice models [13]. Models with ordered response variables assume that choices of how many cars a household have are based on a 'unidimensional latent index' that indicates the likelihood that a household owns a car [13]. On the other hand, random utility maximization is the basis for unordered response models. Under this principle, different car ownership level is deemed to have a different utility value for a household and households choose the one which maximizes their utility [41].

The ordered logistic regression model (ORL) is the representative model to evaluate household car ownership using an ordered response mechanism. The ordered model is restricted to a single coefficient per explanatory variable in the household car ownership model and uses different thresholds to distinguish the number of cars. A significant assumption in the estimation of ordered response models is that of parallel slopes. Based on this assumption, the estimated coefficient of an explanatory variable is equal for all outcomes (i.e., i = 1, 2, 3 or more cars). The ordered response mechanism is ineffective if the parallel slopes assumption is invalid and coefficients associated with a particular variable differ across levels of car ownership. If this is the case, a model should be estimated using an unordered response model [41]. On the other hand, the multinomial logit model which is represented mostly by the MNL model is more flexible because it allows for alternative-specific effects of explanatory variables for each level of car ownership [13]. As a result of this difference, the MNL model offers a better alternative to ordered models since findings are also supported by a solid theoretical framework and not a single continuous propensity measure [41]. Though the discrete choice models are commonly used in household car ownership modeling, the literature reports other adopted methods used as well. Some studies have applied count models to predict household vehicle ownership since the observed household vehicle ownership levels are non-negative integers [42]. Poisson model is among the most common forms of count models used to model vehicle ownership. The Poisson model is based on the equal-dispersion assumption which assumes the mean is equal to the variance. However, this assumption is very restrictive because it does not hold in many cases. Therefore, the application of count data regression models for modeling car ownership is not quite common [42].

Table 1: Descriptive statistics of model variables.

Type of variable		Variable name	Total sample (%)	Notation in the model
Dependent variables		Zero car	11.20	Zero
		One car	50.44	One
		Two or more cars	38.35	Two or more
Independent variables	Job	Worker	5.22	JOB1
		Clerk	25.33	JOB2
		Civil servant	10.06	JOB3
		Teaching staff, middle management, senior management/director, (lawyers, doctors, etc.)	11.59	JOB4
		Shopkeeper/retailer, self-employed (farmer and entrepreneur) without employees, Manager	2.37	JOB5
		Housekeepers, unemployed	6.49	JOB6
		Retired	30.96	JOB7
		Jobseeker, student, other	7.86	JOB8
	Education level	Lower education	51.66	DPL1
		Higher education	48.33	DPL2
	Sex	Male	54.80	SEX1
		Female	45.19	SEX2
	Household situation	Single without children	25.03	HHS1
		Single with children	8.53	HHS2
		Married/partners without children	28.58	HHS3
		Married/partners with children	37.84	HHS4
	Region	Brussels	6.19	REG1
		Wallonia	18.00	REG2
		Flanders	75.79	REG3
	Age	18–34	16.63	AGE1
		35–49	24.55	AGE2
		50–64	35.37	AGE3
		65+	23.43	AGE4

Table 1: (*Continued*)

Type of variable		Variable name	Total sample (%)	Notation in the model
	Income (per month)	0–1,999 Euro	18.49	INC1
		2,000–3,999 Euro	37.78	INC2
		4,000-More than 10,000 Euro	13.04	INC3
		I prefer to not answer this question	19.47	INC4
	Number of children	Mean SD Min Max	0.32 0.75 0 10	NCH
	Number of adults	Mean SD Min Max	2.09 0.91 1 20	NADUL
	Availability of driving license	Have driving license	91.36	DRV1
		Have a temporary driving license	0.90	DRV2
		Have no driving license	7.00	DRV3

Bhat and Pulugurta [41] and Potoglou and Kanaroglou [13] argued that an MNL model would be more appropriate for modeling car ownership over an ordered logit (ORL) model. Hence, we ultimately chose MNL as the base model for this study. Cirillo and Liu [9] used the MNL model to forecast vehicle ownership in Maryland; this study follows a similar approach to estimate car ownership for Belgium. MNL model is an important tool to analyze categorical data; a good fit for this research, as the data is categorical and the dependent variable has more than two categories. MNL assumes that each decision-maker will choose the alternative within the choice set to maximize the utility. For a car ownership model, let U_{nj} be the utility of individual n choosing alternative *j* (in 0, 1, 2), where *j* = 0 for owning no vehicles, 1 for owning one vehicle, and 2 for owning two or more cars in the household. A linear form of the utility function is assumed with a deterministic component and a random component (eqn (1)):

$$U_{nj} = V_{nj} + \varepsilon_{nj}\text{, and } V_{nj} = \alpha_j + \beta_{nj} x_n \quad (1)$$

Where x_n is the vector of explanatory variables of individual n, αj and βnj are the parameters vectors to be estimated, and ε_{nj} is the random variable in the utility which is not observable [18].

The probabilities that household n chooses alternative i is given by

$$P_{ni} = Pr\,(U_{ni} > U_{nj}, \forall j \neq i) \quad (2)$$

The MNL assumes that the random variable ε_{nj} is independently and identically distributed and follows a Gumbel distribution, such that

$$P_{ni} = \frac{\exp(V_{ni})}{\sum_j exp(Vnj)} \tag{3}$$

The discrete choice model is estimated by the maximum likelihood approach and the software R-4.1.2 is used for the estimation purpose.

The category of zero cars is chosen as the reference category, and the probability of each category is compared to the probability of this reference category. After running the MNL model, the next step is to calculate the p-values of the regression coefficients using Wald tests. The coefficients are considered to be significant with a two-tailed value of p <.05, and variables with significant p-values are considered significant factors in the model. We used the results of the odds ratios for these significant variables to interpret the model's results. Table 5 shows the variables that have a statistically significant effect on the degree of car ownership for households at the 95% confidence level and clarity purposes are the only variables included in the Table.

4 RESULTS

4.1 Model performance

A likelihood ratio test was carried out to assess whether there is a relationship between the number of vehicles per household and the predictor variables. The Chi^2-value (3340.1) and corresponding p-value (<.001) indicate that predictor variables have a significant effect on car ownership and show our model as a whole fits significantly better than an empty or null model (i.e. a model with no predictors). To indicate the strength of the model, pseudo-R^2 values can be calculated. Table 2 provides an overview of different pseudo-R^2 values. The values indicate a good fit for the model.

Table 3 compares the predicted number of households with zero, one, and two or more vehicles to the observed numbers. The overall classification accuracy rate of the model was 0.70,

Table 2: Pseudo-R^2 values.

Cox and Snell	Nagelkerke	McFadden
0.35	0.41	0.22

Table 3: Confusion Matrix.

Classification			
Observed	Predicted		
	Zero	One	Two or more
Zero	0.25	0.10	0.01
One	0.12	0.79	0.23
Two or more	0.04	0.24	0.68

indicating that this multinomial regression model is reliable. It can be seen that the prediction results of one vehicle and two or more vehicles are more accurate, especially the prediction accuracy of one vehicle, but the prediction probability of zero cars is low. A possible reason is that the sample of households with zero cars is rather small compared to the other categories.

4.2 Model estimations and discussion

Table 4 shows the results of the likelihood ratio tests, which examine the overall association between the number of vehicles owned by households and each independent variable. These likelihood statistics can be seen as overall statistics to predict which predictors significantly assist in predicting car ownership. Thus, the variables that have a statistically significant effect (at the 95% confidence level) on the level of household car ownership for households are job, education level, household situation, age, income level, possession of a driving license, gender, the number of children in the household, the number of adults in the household, and the living region.

To interpret the contribution and direction of the effect of each predictor, table 5 provides insight into the size and sign of each of the significant factors at a 95% confidence interval. Overall, most of the estimated coefficients are intuitively consistent and statistically significant. Regarding household income, it can be deduced that by increasing the income of the household, the probability of having two or more cars rather than no car is more likely. The income coefficients for two or more cars are positive for all of the significant categories, indicating that the higher the income, the higher the probability for families to own two or more cars. The results are in line with our expectations and confirm other research findings which indicated that household income is a strong determinant of car ownership and households with higher income, irrespective of country and region, always have a stronger preference to own a higher number of private cars [10], [14], [25], [41],[42],[43].

It should be mentioned that, for the model presented here, we assume (for convenience) that each one-unit increase in income level has the same effect on the utility of vehicle ownership for all households.

Table 4: Likelihood Ratio Tests.

Likelihood Ratio Tests				
	-2 log-likelihood of the reduced model	Chi-square	df	Sig.
Job	−5,695.7	125.45	−14	0.00
Household composition	−5,655.1	44.26	−6	0.00
Sex	−5,637.4	8.74	−2	0.01
Education	−5,639.6	13.10	−2	0.00
Income	−5,776.9	287.69	−6	0.00
Number of children	−5,642.9	19.813	−2	0.00
Number of adults	5,933.4	600.69	−2	0.00
Age	−5,650.8	35.66	−6	0.00
Region of living	−5,741	215.98	−4	0.00
Driving license	−5,877.4	488.75	−4	0.00

Table 5: Parameter Estimates of Contributing Factors.

Number of cars	Variables	Coefficients (B)	Std. error	Sig.
One	JOB7	0.521	0.220	0.018
	HHS3	0.330	0.117	0.004
	REGFlandre	1.145	0.131	0
	REGWallonie	0.796	0.149	0.000
	DRV3	−1.926	0.114	0
	INC2	0.782	0.111	0.000
	NADUL	0.298	0.071	0.000
Two or more	JOB5	1.082	0.417	0.009
	DPL2	0.354	0.107	0.000
	SEX2	0.266	0.099	0.007
	AGE2	−0.337	0.162	0.037
	AGE4	−0.468	0.223	0.036
	HHS3	0.705	0.135	0.000
	HHS4	0.547	0.142	0.000
	REGFlandre	2.595	0.187	0
	REGWallonie	2.362	0.204	0.00
	DRV2	−1.026	0.467	0.028
	DRV3	−3.657	0.206	0.000
	INC2	1.607	0.135	0.000
	INC3	1.958	0.200	0.000
	INC4	1.313	0.144	0.000
	NADUL	1.218	0.077	0.000
	NCH	0.309	0.088	0.000

Concerning the occupation, the probability of having two or more cars rather than no car per household was higher for shopkeepers/retailers, self-employed, and managers compared to workers (reference category). Kermanshah and Ghazi [46] reported the tendency to own a second family car was higher when the heads of the households were either employers or retailers. Moreover, most Belgian employers offer mobility budget packages which include commuting for free or at a reduced rate with public transport or access to (electric) bicycles, which may have an impact on the level of household car ownership of employees. Retired people are more likely to own a car than do not own a car compared to the reference category. The finding is probably indicating that households with retired members afford to own private cars [25]. They presumably have the time flexibility to take frequent leisure trips and participate in activities and are more likely to be dependent on cars for their mobility needs due to their age [42].

With respect to the household situation, the analysis shows the probability of having one car and two or more cars rather than zero cars in married/partners people with/without children was higher compared to single people who do not have children. It can be argued that singles without children live usually in urban areas, which have less access to private parking and better accessibility to public transport facilities. The findings of other studies also confirm our results that single people are much less likely to own a car compared to couples [44], [45].

Regarding age, the probability of having two or more cars in the household decreases for respondents who are 65 years old and older compared to the youngest age group (18–34 years old). It seems that people older than 65 are less likely to buy a second car since they do not have specific mobility needs like commuting to work or dropping children to school. In terms of education level, the coefficient related to having two or more cars is positive and significant for higher education. This means that households with higher education are more likely to have two or more cars rather than no car compared to households with a lower education level. The results confirmed some studies which found that higher education increases the level of household car ownership [10]. In contrast with our results, another study found that higher education raises environmental awareness and sustainable mobility behaviors [22]. This opposite result could be linked to the fact that in some countries people with higher education backgrounds usually live and work in the area with better access to public transit, which is not the case in Belgium.

Table 5 reveals that a higher number of children and adults in the household increases the probability of having two or more cars. The number of adults was also significant and had a positive coefficient for the one car category. The number of children in some studies was associated with a reduced probability of owning multiple cars because an increasing number of children under 18 years old may affect the financial resources available for owning multiple cars [14]. Apparently, when the child is getting older, the mobility requirements of the households increase, which means they need multiple cars in the households [14],[18],[46]. Potoglou and Kanaroglou [13] also showed households with more employed adults (both full-time and part-time) were associated with higher levels of car ownership. Concerning the possession of a driving license, the results show that those having a temporary driving license are less likely to have two or more cars and people without a driving license are very likely to have no car in the household. This is in line with the literature [17]. The presence of employed adults and license holders increased the probability of owning multiple cars according to other studies too [13],[18]. Based on the results, households with female respondents were more likely to own two or more cars than families with male participants. Concerning the region of living, the coefficients for having one as well as two or more cars are positive for both Flanders and Wallonia. This means that living in Wallonia and Flanders increases car ownership considerably, compared to Brussels. The results confirmed our findings in the literature review about less car dependency in dense areas with more accessible public transport, which is the case of Brussels, compared to disperse areas, like Flanders and Wallonia. Statistics confirmed our results: only 53% of Brussels families own a car, compared to over 85% of Flemish and Walloon families [47].

5 CONCLUSION

This study developed a statistical model to understand the factors that affect household car ownership in Belgium. We used the multinomial logistic regression model to achieve this task. Descriptive statistics showed that the tendency of households to own more than one car in Belgium increases with the household's monthly income, living in the regions of Flanders and Wallonia compared to Brussels-capital, and the availability of driving licenses in the household. Overall the results of this study confirmed previously published findings highlighting the importance of socio-demographic and economic characteristics of households in explaining household car ownership. The main findings of the study are that: (i) monthly income is positively associated with car ownership, (ii) living in Flanders and Wallonia increases the probability of having two and more cars compared to living in Brussels, (iii) having a driving license increases car ownership, (iv) a larger number of adults and children in a household is related to a higher likelihood of owning two and more cars per household, (v) higher level of education increases the probability of having more than one car per household in Belgium and (vi) older people (65+) are less likely to have two and more cars. Presenting a case study with one of the highest population densities in Europe and a high level of car ownership rooted in car-centric culture with recent transition policies toward sustainable mobility, the study's findings can be used as a reference for future research in Belgium and similar locations and can be taken into account by urban planners and mobility policymakers when developing transportation policies to solve the country's urban traffic challenges.

The model fit, as indicated by McFadden R^2-value of 0.22, shows outstanding goodness of fit [13]. There is potential for a further study with includes more variables to explain better the car dependency in the country because buying a vehicle results from a complex process to adapt to life events (marriage, childbirth, retirement, etc.) and is not limited to socio-economic factors. Besides, technological advancement in the mobility sector can lead to more investigation into the impact of car-sharing and carpooling on the levels of household car ownership and dependency. Further research should consider additional aspects of vehicle ownership besides vehicle quantity. Furthermore, attributes like land-use information and accessibility of parking and public transport facilities could be retrieved to complement the MONITOR data.

AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: S.H. Bahreini, S. Reiter and M. Cools; data collection: S.H. Bahreini and M. Cools; analysis and interpretation of results: S.H. Bahreini; manuscript preparation: S.H. Bahreini, S. Reiter and M. Cools. All authors reviewed the results and approved the final version of the manuscript.

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