sciendo

CzOTO 2022, volume 4, issue 1, pp. 164-169

PREDICTION OF VEHICLE OWNERSHIP GROWTH USING GOMPERTZ MODEL, CASE STUDY OF HUNGARY

doi: 10.2478/czoto-2022-0017
Date of submission of the article to the Editor: 14/12/2021
Date of acceptance of the article by the Editor: 22/06/2022

Adam Torok – *orcid id: 0000-0001-6727-1540*
Budapest University of Technology and Economics, **Hungary**

Abstract: Autonomous Vehicles (AVs) are expected to introduce numerous benefits for future mobility. These potential benefits and many others vary substantially by the market share of AVs. Therefore, this research empirically estimates, using the Gompertz function, the projected growth rates of passenger vehicles in Hungary using historical patterns of human-driven vehicle ownership data based on projected per capita GDP. This study's contribution to the literature is through a mathematical approach that predicts passenger cars market penetration rate, in which the assumptions and the used parameters of the model can be easily modified based on different case studies, or they can be updated due to the advancement in technology and progress in knowledge of the studied market.
Keywords: forecast, market penetration, passenger cars

1. INTRODUCTION

Autonomous vehicles (AVs), also known as driverless or robotic vehicles, are defined as vehicles that operate by themselves without active control from a driver (Fagnant and Kockelman, 2015). AVs can drive using the information collected by their sensors, and they are not necessarily connected with the infrastructure or other vehicles (Talebpour and Mahmassani, 2016), (SAE, 2022). AVs are classified into five levels of automation, starting with Level 0 (i.e., regular human-driven car) up to Level 5 (i.e., full automation). This research considers Level 5 AVs, which operate under all conditions without requiring the driver to take over driving.

AVs are expected to introduce numerous benefits for individuals and overall future mobility. They, for instance, are expected to raise safety levels for road users (i.e., drivers, pedestrians, and passengers) and reduce road accidents as the negative influence of human driving will be decreased to the lowest possible (Fagnant and Kockelman, 2015), (Nadafianshahamabadi, Tayarani, Rowangould, 2021). Besides safety, the integration of AVs is also likely to offer benefits to road congestion because they have low reaction time and their complete comprehension of road elements compared to human-driven vehicles (Talebpour and Mahmassani, 2016). However,

these potential benefits and many others vary substantially by the market share of AVs [5]. The main issue is that this new technology is not matured yet, which makes the predictions of AVs penetration rate challenging.
This research empirically estimates the projected growth rates of passenger vehicles in Hungary based on historical patterns of human-driven vehicle ownership data to learn the pattern that can be easily transformed to investigate the AVs market penetration. We used the Gompertz growth model and developed it using the proportion coefficient method to estimate the relationship between ownership and per capita gross domestic product (GDP) over time.

2. METHODOLOGY AND DATA

2.1. Methodology

Vehicle ownership prediction methods can be categorized into two common models: the equilibrium model and the well-known and used method, the demand model (Li, Wang, Zhang, 2014). The latter method can also be divided into a set model used for long-term predictions and a non-set model often utilized in practice for short-term predictions. In this research, the Gompertz curve, classified as a saturation level limit method that is part of the set model, was employed to estimate car ownership growth in Hungary as it is, compared to the logistic model, more flexible and relatively easy to estimate. Named after the British statistician and mathematician Benjamin Gompertz in 1825, the Gompertz model was firstly employed in the biological field, and it showed a noticeable performance in estimating growth and mortality and, therefore, the lifespan (Talebian and Mishra, 2018). After nearly a century, the model became more popularly utilized in product life cycle analysis when R. Prescott, an American researcher, used it to estimate the market demand. As used in several previous studies, the general mathematical form of the Gompertz function is as follows:

$$A_t = \lambda e^{-\alpha e^{-\beta G_t}} \quad \beta, k > 0 \tag{1}$$

where
A_t and G_t are vehicle ownership (veh/1000 people) and GDP per capita in year t, respectively, λ is the upper limit of A_t (i.e., the saturation level), α and β are parameters that define the curvature of the function.

Then, equation (2) is produced by taking the logarithmic operation on both sides of equation (1):

$$\ln A_t = \ln \lambda - \alpha e^{-\beta G_t} \tag{2}$$

Equation (3) is obtained next by log-linearizing equation (2):

$$\ln\left(\ln \frac{A_t}{\lambda}\right) = \ln(-\alpha) - \beta G_t \tag{3}$$

Based on equation (3), ln(-α) and β can be calculated using the ordinary least square method (OLS) for time series data. The elasticity of car ownership, on the other hand, concerning GDP can be determined as follows:

$$E = \alpha\beta G_t e^{-\beta G_t} \tag{4}$$

Figure 1 illustrates the positive trend between motorization level and per capita GDP in an S-shaped curve, which is divided into four stages (Wang et al., 2012); 1) slow increment of ownership rates with increasing per capita GDP, 2) fast increment of vehicle ownership while increasing per capita income, 3) slower growth comparing with stage 2, and 4) saturation state, where vehicle ownership does not increase with increasing per capita GDP.

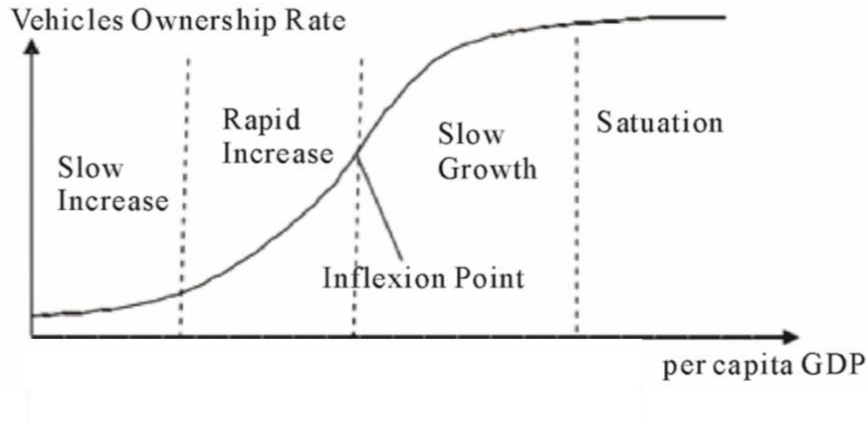

Fig. 1. Relationship between economic development and mobility level (Wang et al., 2012)

On the other hand, the elasticity is always positive for all levels of GDP per capita, reaches its maximum value at GDP = 1/β (also known as the inflection point), and declines gradually while approaching the saturation level. The inflection point is critical as it defines the transition limit between the rapid increase and slow growth stages. Accordingly, the Gompertz curve is split into two mathematical behaviours around the inflection point as follows:

$$A_t = \begin{cases} \text{quadratic}, & \text{if } G_t < inflection\ point \\ \text{logarithmic}, & \text{if } G_t > inflection\ point \end{cases} \tag{5}$$

The inflection point also represents the per capita GDP level that achieves the maximum elasticity, see Fig. 1. By taking the second derivative of equation (1) and setting it equal to 0, the inflection point will take place at GDP = $\frac{\ln \alpha}{\beta}$.

As the automated technology is not yet matured and is still under development, historical data on AVs ownership is not available to predict their future projections. However, as abovementioned, the growth of motorization, modelled by the Gompertz function, follows the S-shaped curve, which is proved by several studies, see for example (Li, Wang, Zhang, 2014), (Dargay, Gately, Sommer, 2007). Therefore, the ownership development of different types of vehicles, such as conventional, hybrid, electric, and even autonomous, can be described by Gompertz's S curve. Based on that, this research employed the recent years' data of human-driven vehicles in Hungary in order to obtain their curve fitting using the Gompertz function, then calculated the proportion of AVs from the predicted human-driven automobiles using the proportion coefficient method based on the behaviour of the Gompertz curve shown in equation (5).

2.2. Data

According to Felis Rola et al., (Felis Rota, Moral Carcedo, Pérez García, 2016), the level of civilian car ownership in Hungary will reach 570.2 vehicles per 1000, representing λ in equation (1). Then, according to the Hungarian Central Statistical Office (Hungarian Central Statistic Office, 2022), Eurostat (Eurostat, 2022), and the World Economic Outlook (World Economic Outlook, 2022), the data for human-driven car ownership rates and per capita GDP in Hungary are collected and demonstrated in Figure 2.

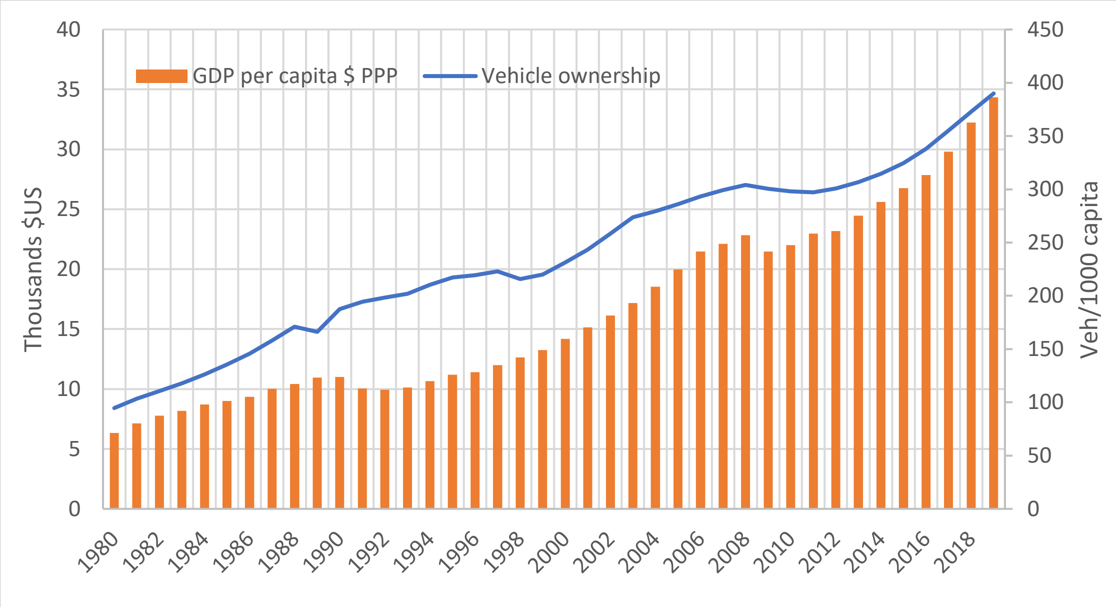

Fig. 2. Human-driven vehicle ownership rates and per capita GDP in Hungary between 1980 and 2019

3. RESULTS

Using the OLS method, α and β parameters were estimated using equation (3) based on the available statistical data collected. Thus, the growth model of civilian vehicle ownership in Hungary based on per capita GDP can be described as in equation (6), which is also demonstrated in Figure 3.

$$A_t = 570.2e^{-1.979e^{-4.987\times10^{-5}G_t}} \quad (6)$$

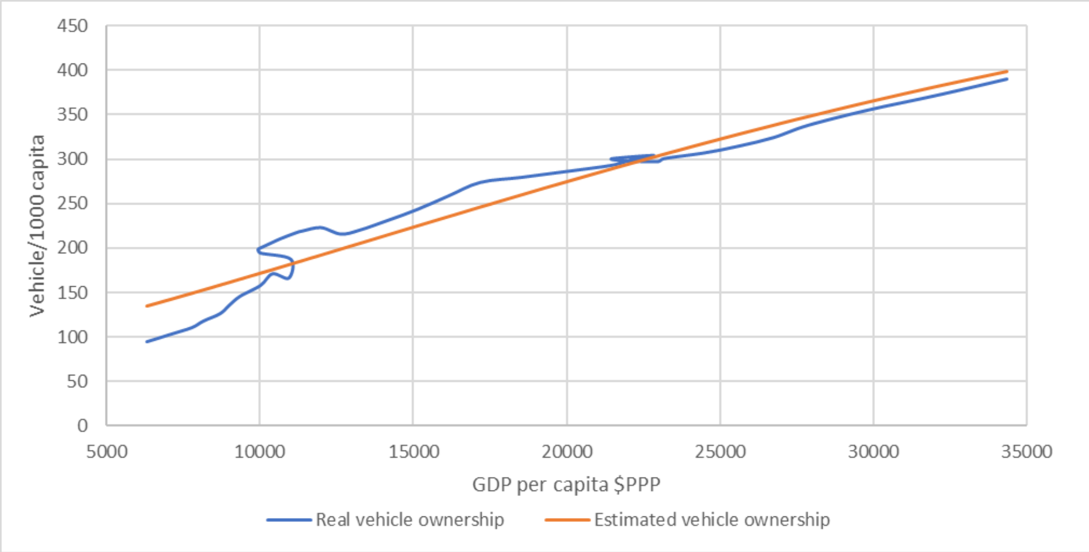

Fig. 3. Real and estimated vehicle ownership rates in Hungary between 1980 and 2019 based on per capita income

The inflection point for the Hungarian vehicle ownership rates will occur at $13,687 per capita GDP $PPP by deploying the obtained α and β parameters. This means that the inflection point for AVs ownership in Hungary is also expected to appear after an increment of approximately $14,000 on the per capita income because they are expected to follow the same growth patterns as civilian cars.

4. CONCLUSION

This research estimated Hungary's car ownership growth model by employing the recent years' data on human-driven vehicles in Hungary to obtain their curve fitting using the Gompertz function.

REFERENCES

Dargay, J., Gately, D., Sommer, M., 2007. *Vehicle ownership and income growth, worldwide*: *1960-2030*. The energy journal, 28(4). DOI: 10.5547/ISSN0195-6574-EJ-Vol28-No4-7.

Eurostat, 2022. URL: https://ec.europa.eu/eurostat (accessed Apr. 12, 2022).

Fagnant, D. J., Kockelman, K., 2015. *Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations*. Transportation Research Part A: Policy and Practice, 77, 167-181. DOI: 10.1016/j.tra.2015.04.003.

Felis Rota, M., Moral Carcedo, J., Pérez García, J, 2016. *Dual approach for modelling demand saturation levels in the automobile market.* The Gompertz curve: macro versus micro data. Investigación económica, 75(296), 43-72. DOI: 10.1016/j.inveco.2016.07.003.

Hungarian Central Statistical Office, 2022. URL: https://www.ksh.hu/?lang=en (accessed Apr. 12, 2022).

Li, X., Wang, E., Zhang, C., 2014. *Prediction of electric vehicle ownership based on Gompertz model.* In 2014 IEEE International Conference on Information and Automation (ICIA) (pp. 87-91). IEEE. DOI: 10.1109/ICInfA.2014.6932631.

Nadafianshahamabadi, R., Tayarani, M., Rowangould, G., 2021. *A closer look at urban development under the emergence of autonomous vehicles: Traffic, land use and air quality impacts.* Journal of transport geography, 94, 103113., DOI: 10.1016/j.jtrangeo.2021.103113.

SAE Levels of Driving AutomationTM Refined for Clarity and International Audience', 2022. https://www.sae.org/site/blog/sae-j3016-update (accessed Apr. 12, 2022).

Talebian, A., Mishra, S., 2018. *Predicting the adoption of connected autonomous vehicles: A new approach based on the theory of diffusion of innovations*. Transportation Research Part C: Emerging Technologies, 95, 363-380., DOI: 10.1016/j.trc.2018.06.005.

Talebpour, A., Mahmassani, H.S., 2016. *Influence of connected and autonomous vehicles on traffic flow stability and throughput.* Transportation Research Part C: Emerging Technologies, 71, 143-163. DOI: 10.1016/j.trc.2016.07.007.

Wang, J., Sun, X., He, Y., Hou, S., 2012. *Modeling motorization development in China. Journal of Transportation Technologies*, 2(03), 267. DOI: 10.4236/jtts.2012.23029.

World Economic Outlook, 2022. Databases - IMF, URL: https://www.imf.org/en/Publications/SPROLLs/world-economic-outlook-databases (accessed Apr. 12, 2022).