S-Curve Models to Determine the Car Ownership in Turkey

Kemal Selçuk Öğüt

Transportation Department, Civil Engineering Faculty, Istanbul Technical University, 34469 Istanbul, Turkey
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Car ownership and use influence the city structure, public investment priorities including the roadway infrastructure, and the patterns of daily life. The study of car ownership, as a classic topic in the area of transportation, is assistive to the transportation officials in the road system planning, policies and design. In the developed countries, car ownership study has already been advanced to the household level and currently is being refined to the daily usage level through micro simulation. However, in the developing countries, due to the lack of the disaggregated data, the car ownership study is at the aggregated level. In this study, the car ownership in Turkey is modeled by using three extrapolatory models, which are the logistic, power growth and Gompertz curves. In addition, three scenarios are developed in order to make forecast until 2020.

Keywords: S-Curve model, Gompertz curve, power growth curve, logistic curve, car ownership

1. Introduction

While the developed countries are confronting serious auto-oriented problems, the motorization in most developing countries is still in its infancy; by and large, the automobile is a luxury. In comparison to the developed countries, the developing countries have a much lower Gross National Product per capita (GNPPC). However, the economic expansion and the improvement in quality of life in recent years have generated a high demand for private mobility, which is reflected in the national automobile registrations.

The implications for nations where growth takes place are being felt not only in terms of pressures on the national road networks, but also through higher import bills for both vehicles and fuel. This growth in vehicle ownership is also continuing hand-in-hand with rapid urbanisation, and the strains on many national transport infrastructures are particularly severe in cities. The rising of the vehicle fleets impose pressures on the available vehicle maintenance facilities, and also the administrative and planning structures are required to police and regulate the road system. Since there are similar growth trends in the commercial vehicle numbers and use, questions of road maintenance are compounded. More generally, there are questions of social equity and mobility associated with rising levels of personal car ownership, (CO), and availability.

2. Objective and Scope

The aim of this study is to determine a mathematical model, which is able to forecast the CO in Turkey. This model has to be simple because of the problem of gathering detailed economic and social data. In this study, three S-curve models such as, the logistic, power growth and Gompertz curves are developed.

3. Previous Studies

The CO models can be grouped into two basic categories. First category includes the regression models whereas the second is composed of the S-curve models.

[1-4] developed different regression models for the CO forecast in USA. Apart from these, lots multiple regression approaches for various countries as for Great Britain [5], for the developing countries [6], for Singapore [7], for the Asia countries [8] have carried out.

At the regression model, all variables that effect the CO have been included in the model structure providing the change of CO as dependent variable. However, the regression models have the following disadvantages:

1. All independent variables have commonly a time trend which cause to the inner correlation problem.

2. As the regression model does not include the saturation level, the long-term forecast
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of the CO is not reliable.

S-curve models have two branches namely an extrapolatory model that depends on aggregated data and cross sectional models, which are developed generally by using the disaggregated data. The basic extrapolatory model which is developed by Tanner [9,10], is the logistic curve:

\[ CO = \frac{S}{1 + a \exp(-bt)} \]  

where CO is the car ownership per capita at time t, S is the saturation level of CO, t is year and “a” and “b” are model coefficients. Tanner [11] modified his model by adding the causal variables of the income and the motoring costs as,

\[ CO = \frac{S}{1 + a \exp(-bt + c \ln(i) + d \ln(p))} \]  

where \( i \) is the per capita income, \( p \) is the composite index of the real motoring costs (purchase and running cost); \( a, b, c, \) and \( d \) are model coefficients. Tanner [12,13] introduced the power growth function whereby the rate of the CO growth slows rather quickly over time, thus giving a slower approach to the saturation level.

\[ CO = \frac{S}{1 + [a + bt + c \ln(i) + d \ln(p)]^{-n}} \]  

where \( n \) is the additional coefficient and if it approaches infinity then the Eq. 3 is approximated by Eq. 2.

Gompertz curve, another extrapolatory curve, is used for determining CO in Netherlands [14], and in the developing countries [15]. The form of Gompertz curve is:

\[ CO = S \exp[-a \exp(-bx)] \]  

where \( x \) is the major independent variable that affects CO. The graphic representation of the three extrapolatory model curves is presented in Fig.1.

The development of the cross sectional models has reached to their validity after many censuses and surveys in the form of data. These censuses and surveys provided the data set for CO modelling. Quarmby and Bates [16] developed first cross sectional model. This approach is followed by Burns et al. [17], Button et al. [18], Berkovec [19], Kitamura [20], Olszawski and Turner [21], Sansom et al. [22], Jong and Pommer [23]. These models are determined for the developed countries where the disaggregate data are present.

4. CO in Turkey

In the developed models, the CO consists of the number of the private cars. Trial cars, as taxis and the cars owned by the government are excluded from the total car population. CO values have been expressed as the number of private car per 1000 persons.

Before 1970, the CO was extremely low, less than 4, with a slight increase trend. In 1970, the opening of two new car factories, Tofaş-Fiat and Oyak-Renault, has changed the increase trend. The development of CO in Turkey is given in Fig. 2 between 1950-2002. Thus, the starting year of the CO model is chosen as 1970 and all models are developed with the data between 1970-2002.

At the S-curve models, the GNPPC is used as the user income variable. Because of the high inflation, it is expressed with the 1987-constant price in Turkish Lira, TL.

In order to express the cost variable in the model structure, the average vehicle cost and the gasoline price are thought. However, these two variables, have an increase trend between 1970-1999 [24]. When the cost variables, which are the average vehicle cost and/or the gasoline price, are involved into the model structure, the CO is determined as it is directly proportional with the cost. In other word, the cost variable coefficients are calculated as positive value, thus the increase of the cost caused to an increase at the CO. Due to this unrealistic result, the cost variable is omitted at the CO models.
The long-term CO forecast models incorporate the idea of the saturation level, either explicitly or implicitly. The saturation level is the level that would be reached in the distant future, when the income no longer acts as a restraint. The level reached in the distant future is then a function of socio-economic variables as well as of the hypothetical saturation level. The saturation level of the CO is estimated as 500 by taking into account the structure of Turkish family and the age distribution [24].

4.1. Logistic Curve

The logistic curve formula of the developed model is:

\[ CO = \frac{S}{1 + a \exp[-bt + c \ln(GNPPC)]} \quad (5) \]

The coefficients \(a\), \(b\) and \(c\) are calculated as \(1.9091 \times 10^9\), \(0.0837\) and \(0.9308\) respectively. The model estimate is presented in Fig. 3.

4.2. Power Growth Curve

The used power growth curve is expressed as,

\[ CO = \frac{S}{1 + [a + bt + c \ln(GNPPC)]^{-n}} \quad (6) \]

The model coefficients \(a\), \(T\), \(c\) and \(n\) are found as \(9.0274 \times 10^{-3}\), \(1939\), \(6.191 \times 10^{-8}\) and \(4.7\), consecutively. The model estimate is given in Fig. 3.

4.3. Gompertz Curve

Gompertz curve formula is determined as follows,

\[ CO = S \exp[-a \exp(-b \ln(GNPPC))] \quad (7) \]

The model coefficients \(a\), \(b\) and \(c\) are \(9.8903 \times 10^{21}\), \(2.4789 \times 10^{-2}\), and \(1.8486 \times 10^{-7}\), respectively, and the model estimation is given in Fig. 3.

4.4. The Comparison of the S-Curve Models

At each model, the time and the GNPPC are used as variables. The sum-square of error terms, SSET, which is defined as \(\Sigma(CO_{\text{realised}} - CO_{\text{model}})^2\) are calculated in order to compare the models. The SSET are calculated as 358, 145, 152 for the logistic, power growth and Gompertz curves respectively. The model outputs of the power and Gompertz curves are similar to each other. The logistic curve model has overestimated the CO since 1996.

4.5. Forecasts

As the S-curve models depend on the GNP, three scenarios are developed for the forecasts. The projection year is considered as 2020. Three developed scenarios have constant growth rate as follow:

I. Scenario: The GNP growth rate is 5.53%, which is the maximum average growth rate between the decade 1984-1993.

II. Scenario: The GNP growth rate is 4.00%, which is the average growth rate between 1970-2002.

III. Scenario: The GNP growth rate is 2.64%, which is the minimum average growth rate between the decade 1992-2001.

The population of Turkey is projected with a logarithmic model, with a similar approach of the
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State Institute of Statistics publication [25]. The population model, where time is used as independent variable, is developed with the data set of 1970-2000. The population model, which the coefficient of determination is calculated as 0.9965, is as follows:

$$Population = (2109.9017 \times \ln(year) - 15970.3348) \times 10^6$$  (8)

The GNPPC scenarios are given in Fig. 4. According to each scenario, the forecasts of the logistic, power growth and Gompertz curve models are presented separately in Fig.5-7.

5. Conclusions

The logistic curve model overestimated the CO between 1996-2002 and it gives the biggest CO level upon the forecast.

The forecasts of the power growth and Gompertz curves models are similar to each other. There is about 10% difference between two model outputs for the projection year 2020. At the projection year, the forecasts of the power growth curve model are, 218, 188 and 166 for the first, second, and third GNPPC scenarios, respectively. These values are 197, 170 and 151 for the Gompertz curve. The similarity of the models outputs and the SSET values for the power growth and Gompertz curve models increase the reliability of these model forecasts. According to the second scenario, which has a moderate GNPPC growth trend, the CO in 2020 is projected be-
tween 188 and 170. However, the model forecasts are based on the continuous increase of GNPPC, which means they are not sensitive to an economic crisis.

In the future, by gathering especially disaggregated data, the cross sectional models, which are more powerful and reliable, must and will be studied in Turkey. On the other hand, as the socio-economic and financial variables are unstable in Turkey, the models with disaggregated data must be studied more carefully than in the developed countries.

References

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