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PROJECTION OF TWO-WHEELER VEHICLE FLEET IN INDIA USING ROAD DENSITY PER CAPITA FOR ACCURATE EMISSION ESTIMATION

Kumar Saurabh[1, 2]
[1]National Institute of Advanced Studies (NIAS), IISc. Campus, Bengaluru, 560012, India
[2]Manipal Academy of Higher Education (MAHE), India
Email: k.saurabh.iitg@gmail.com

Rudrodip Majumdar[1]
[1]National Institute of Advanced Studies (NIAS), IISc. Campus, Bengaluru, 560012, India
Email: rudrodip@nias.res.in

ABSTRACT
GDP per capita is commonly used as the main explanatory variable for estimating the on-road vehicle stock. This study explores the use of road density per capita of a country as the main explanatory variable. Results prompt road density as a better explanatory variable than GDP (in PPP terms) per capita for projecting two-wheeler fleet size in India. A higher coefficient of determination was found for the road density-only based model (in the range 0.978-0.988) as against GDP-only based model (in the range 0.880-0.945).

***Keywords*:** Vehicle stock projection, Gompertz function, GDP per capita, Road density per capita

ABBREVIATIONS

2W	Two-wheeler
GDP	Gross Domestic Product
GHG	Green House Gas
MoRTH	Ministry of Road Transport and Highways
PPP	Purchasing Power Parity
SIAM	Society of Indian Automobile Manufacturers

INTRODUCTION

At COP 26 held in Glasgow in 2021, India promised to reduce its emissions to net zero by 2070 [1]. Indian road transport accounts for 85% of total energy consumption and 75% of emissions emanating from all modes of transport, making it a highly polluting mode of transport [2, 3]. India is envisaging a transition in the sector by diversifying the fuel mix (energy sources) which will abate the rising Green House Gas (GHG) emissions as well as reduce the energy import bills. Hence, it is paramount to project the travel demands for different vehicle segments and the associated emissions with adequate accuracy, so that the necessary interventions can be planned and implemented gradually and synergistically.

The prediction of travel energy demand and associated emissions is a complex task as it is influenced by multiple factors. With increasing multi-modal transport integration for mobility, projecting these numbers become even more complicated. There is an established relationship between vehicle ownership and the Gross Domestic Product (GDP) per capita of a country [4]. Apart from GDP, growth in the vehicle fleet size is also linked to road density, urbanization, public transport standard, and public behaviour [5]. The road network density of a country increases as it progresses and urbanizes. However, because of the constraint of land availability, the road density per capita acts as a limiting factor to the growth of the vehicle fleet size [6].

Global studies indicate that the relationship between GDP per capita and vehicle ownership follows an S-curve, where vehicle ownership per 1000 people grows slowly with rising GDP/capita up to a threshold point initially, increases exponentially thereafter, and finally plateaus with a further rise in GDP per capita [7]. This plateauing value is known as the saturation ratio/level of vehicle ownership (denoted as γ) and it has been observed to be 0.8 for North America, 0.6 for Europe, and 0.55 for Japan [7]. It is believed to be in the range of 0.4-0.5 for developing countries like Indonesia, China, and India [8]. Since GDP per capita follows an S-curve (represented by either logistic or Gompertz function), the road density per capita must also follow similar curves as there is a high degree of correlation (0.98) between GDP per capita and road length per capita in India (see **Figure 1**).

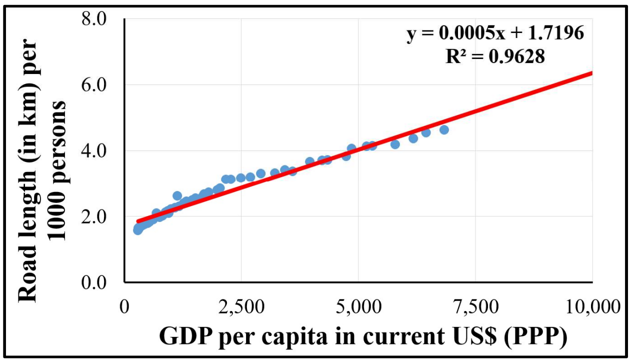

FIGURE 1: Road length per capita (in km) v/s GDP per capita in current US$ (PPP) in India

LITERATURE REVIEW AND GAP(S)

Several studies have estimated the vehicle fleet size in the Indian road transport sector since the ASIF scheme for bottom-up estimation of emissions had been designed. In 2004, Fulton and Eads applied the Gompertz function in the IEA/SMP model for vehicle stock estimation based on GDP per capita [9]. A study by Singh in 2006 used both Gompertz and logistic functions with GDP per capita as the main explanatory variable, while time was included in the model as another explanatory variable to capture the impact of omitted variables [10]. In 2007, Bouachera and Mazraati applied Gompertz, logistic and quasi-logistic functions to project the on-road vehicle fleet based on per capita income and per capita road density [11]. Recent studies have predominantly used the Gompertz function for the on-road vehicle stock estimation, considering GDP per capita as the only explanatory variable [8, 12-15]. As the recent studies for vehicle ownership projections have excluded per capita road density as an explanatory variable that Bouachera and Mazraati (in 2007) had deemed important in projecting the on-road vehicle fleet, this study makes a case for the use of road density per capita as the main explanatory variable for the on-road stock vehicle estimation.

DATA SOURCES

To project the two-wheeler (2W) vehicle fleet size in India, vehicle stock data for the 60-year period (1960-2019) has been used in this study. The number of registered 2W per 1000 persons for the period 1960-2019 has been taken from the 'Road Transport Year Book' published by the Ministry of Road Transport and Highways (MoRTH) every year [16]. The sales data for the 2W has been obtained from the annual reports released by the Society of Indian Automobile Manufacturers (SIAM) [17]. The population data for India from 1960 to 2021 and the population projections from 2022 to 2050 have been taken from the United Nation Population Division repository [18]. The GDP (in current US Dollars) data for India from 1960 to 2019 has been taken from the World Bank [19]. The data for Purchasing Power Parity (PPP) and the exchange rate (from US$ to Indian Rupee) from 1970 to 2019 were taken from the Organization for Economic Co-operation and Development (OECD) database [20, 21]. Data for road length in India was accessed from the MoRTH database which was available every 10 years for the pre-2000 period (1961-2001) and annually since 2001 [16].

DATA PREPARATION

The data for the PPP and the exchange rates for the period 1960-69 were back-projected using the available data from 1970 onwards. Thereafter, the data for India's GDP (in current US$), PPP, and exchange rate were used to calculate the GDP (in current US$) in terms of PPP. The 2W sales data for the period 1960-94 were back-projected using available 2W sales data from 1995 onwards. The missing annual road length data for the years 1960 to 2000 (data available only for decadal years) was calculated using the power law function. The survival rate of the 2W vehicles with age is taken from Arora et al. (2011) [8], and these values were used to calculate actual on-road 2W vehicles in India for a particular year as against the registered 2W vehicles.

METHODOLOGY

In this study, the S-curve relationship between the two-wheeler (2W) vehicles per 1000 people and GDP per capita is defined by the Gompertz function as below (see **Equation 1**).

$$V_t^* = \gamma e^{\alpha e^{\beta GDP_t}} \tag{1}$$

Where $\boldsymbol{V_t^*}$ signifies the equilibrium vehicle ownership level in year t. Its value stands for vehicle ownership that would be in the year t which has its actual per capita GDP (in terms of PPP) as GDP_t. The value of GDP_t denotes GDP (in US$) per capita in terms of PPP in year t. The symbol γ stands for the saturation level of 2W vehicle ownership per 1000 persons. The value of γ depends on various factors such as average household size and an increase in urbanization among others. The symbols α and β represent the shape parameters for drawing S-curve. The values of α and β are country-specific and they assume negative values.

The Gompertz function is used to create the time series model to obtain the actual vehicle ownership per 1000 people in a given year. This model is represented by **Equations 2** and **3**, as given below.

$$V_t = \theta V_t^* + (1-\theta)V_{t-1} \tag{2}$$

$$V_t = \gamma\theta e^{\alpha e^{\beta GDP_t}} + (1-\theta)V_{t-1} \tag{3}$$

Where V_t denotes the actual 2W vehicle ownership per 1000 people in year t, V_{t-1} represents the actual 2W vehicle ownership per 1000 people in the year $(t-1)$, and θ gives the speed of adjustment for vehicle ownership with respect to the GDP growth $(0 < \theta < 1)$. The parameter θ is impacted by the changes (rise or fall) in the national GDP per capita or earnings of the individuals.

The time series functions shown in **Equation 2** and the Gompertz function (**Equation 1**) are rewritten as **Equations 4** and **5,** respectively, to obtain linear regression functions that are used to obtain the values for the estimates α, β, and θ along with their statistical significances for various values of γ.

$$(V_t - V_{t-1}) = \theta(V_t^* - V_{t-1}) \quad (4)$$

$$ln\left(ln\left(\frac{\gamma}{V_t^*}\right)\right) = ln(-\alpha) + \beta GDP_t \quad (5)$$

The expression shown in **Equation 5** is suitably altered to incorporate road length per 1000 people as an explanatory variable instead of GDP per capita (see **Equation 6**). **Equation 7** incorporates both the road length per 1000 people and GDP per capita as the explanatory variables.

$$ln\left(ln\left(\frac{\gamma}{V_t^*}\right)\right) = ln(-\alpha) + \delta RL_t \quad (6)$$

$$ln\left(ln\left(\frac{\gamma}{V_t^*}\right)\right) = ln(-\alpha) + \beta GDP_t + \delta RL_t \quad (7)$$

Where RL_t denotes the road length per 1000 people in year t and δ defines the shape of the curve based on road density (road length per 1000 people).

Therefore, for this study, three models were defined and compared with each other. The first model (**Model A**) was based on GDP-only (defined by **Equations 4** and **5**); the second one (**Model B**) was dependent on road length-only (defined by **Equations 4** and **6**); while the integrated model (**Model C**) incorporated both GDP and road length based on **Equations 4** and **7**. The mathematical values of the parameter estimates (α, β, δ, and θ) were obtained from the ANOVA table along with their statistical significance for all the three models stated above for different γ values (200, 250, 300, 350, 400, 450, and 500). In addition, the R-squared values for all the models with different γ values were also recorded. The statistical significance of the additional explanatory variable in **Model C** as against **Model A** and **Model B** was also evaluated. Based on the parameter estimates obtained, the projections for the 2W vehicle fleet were done by assuming a constant GDP per capita (in PPP terms) growth rate of 6%, and a constant growth rate of 2% for road density per 1000 persons.

RESULTS

The growth in 2W vehicle ownership per 1000 people for various saturation levels (γ) has been given in **Figures 2** and **3**, drawn based on Gompertz functions represented in **Equations 6** and **7** respectively. The estimates (α, β, δ, and θ) were mathematically obtained from the ANOVA tables drawn for both **Models A** and **B** for the aforesaid different values of γ and these values were found to be statistically significant with p<0.01.

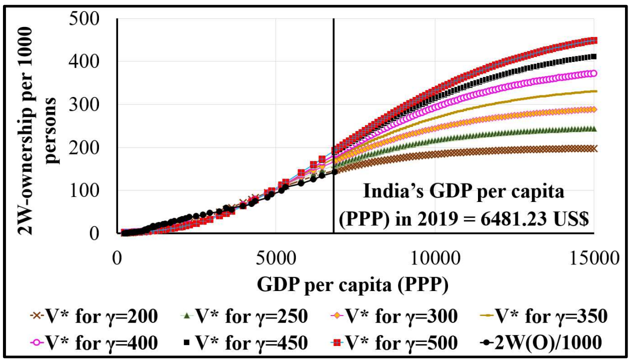

FIGURE 2: Equilibrium 2W vehicle ownership per 1000 people v/s GDP per capita (US$) in PPP terms in India

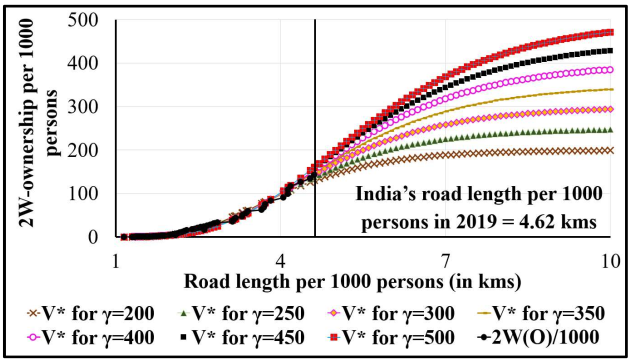

FIGURE 3: Equilibrium 2W vehicle ownership per 1000 people v/s road length per 1000 persons (in km)

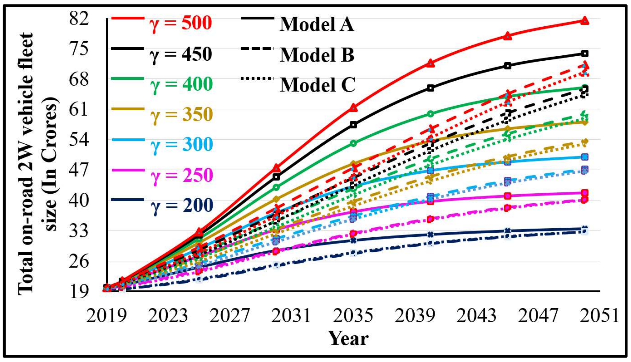

FIGURE 4: Projected 2W vehicle fleet for different saturation levels (γ) (for the three models) till 2050

Most parameter estimates (except β) for **Model C** were found to be statistically significant at 1% (p<0.01). The estimate β was found to be statistically significant at only 10% (p<0.1) for $\gamma = 200$ and insignificant for $\gamma = 250$. Subsequently, F-test was done to find the statistical significance of an additional explanatory variable. The addition of GDP per capita over the existing explanatory variable (road density per capita) was statistically significant at only 10% (p<0.1) for $\gamma = 200$ and it was insignificant for $\gamma = 250$. However, for all the values of γ, the addition of road density per capita over the existing explanatory variable (GDP per capita) is statistically significant at 1% ($p<0.01$). The R-squared values for **Models A**, **B**, and **C** varied between the ranges (0.880-0.945), (0.978-0.988), and (0.988-0.989), respectively, for different γ values (200, 250, 300, 350, 400, 450, and 500).

Figure 4 represents the projections for the 2W vehicle fleet for all the saturation levels (γ) of interest (for all three **Models A**, **B**, and **C**) till 2050. It can be seen that **Model A** gives over projections as compared to **Models B** and **C** for all the saturation level values (γ) of two-wheelers in India.

DISCUSSION

The results from the three models **(A**, **B**, and **C)** show that GDP per capita is an important explanatory variable for vehicle ownership per 1000 people. However, a better R-square value for **Models B** and **C**, as compared to **Model A**, prove that road density per capita is a better explanatory variable. The difference in the vehicle fleet projections can be understood from the example for $\gamma = 500$ in 2050, where **Model A** (GDP-only), **Model B** (road density-only), and **Model C** (both GDP and road density) projected 2W vehicle fleet to be 81.50 Cr., 71.25 Cr. and 69.50 Cr., respectively. It is also intuitive that a rise in GDP may not necessarily result in an increasing number of vehicles if there is no increase in the roads. The use of road density per 1000 people as the main explanatory variable for vehicle fleet estimation reduces the over projections in the vehicle fleet size emanating from the use of GDP per capita as the main explanatory variable.

CONCLUSION

The estimation of the vehicle fleet size is a complex task as it depends on a number of factors. However, increasing the number of factors may lead to undesirable redundancy in the model. Therefore, the road density per 1000 people as the sole explanatory variable is a preferable choice as opposed to GDP per capita for projecting vehicle fleet size.

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