Implication of Fuel Price Deregulation on Fuel Demand and CO2 Emission: A Case Study of Car Ownership and Utilisation in India

Bandyopadhyay, Kaushik Ranjan

Asian Institute of Transport Development

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Kaushik Ranjan Bandyopadhyay
Senior Fellow
Asian Institute of Transport Development
Email: kaushik.banerjee@gmail.com

Abstract

India's road transport is characterised by a historical asymmetry in the auto-fuel prices due to lack of parity between international and domestic fuel prices and artificial deflation of domestic diesel price relative to that of petrol through differences in levies. This continued to provide a constant fillip to ownership and utilisation of personalised vehicles leading to higher energy consumption with negative spill-over on the environment. In this backdrop, the paper builds up a time series econometric model of car ownership and utilisation in India and examines the possible implication of price-deregulation and removal of price asymmetry between petrol and diesel for future energy saving and curtailment of CO_2 emissions for an on-road car.

JEL Classification Codes: Q48, R41, C01, C22

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1. Introduction

Transport plays a crucial role in development and constitutes a significant share of world energy consumption. Transportation primarily relies on petroleum which supplies nearly 95 per cent of the total energy used by the world transport and also accounts for nearly 60 per cent of all oil consumption. Hence, the transport sector has also been largely responsible for the pollution and greenhouse gas (GHG) emissions which pervade all across the globe (Kahn et al., 2007).

The IEA estimate shows that as of 2005 the total final consumption of petroleum products for World stood at 3,420 million tons of oil equivalent, of which 2,067 million tons or 60.4 per cent was consumed by the transport sector. Furthermore, within the transport sector, road transport consumed the largest share of 76.0 per cent (1,571 million tons of oil equivalent) followed by shipping 8.3 per cent, international aviation 6.8 per cent, domestic aviation 5.1 per cent, domestic navigation 1.7 per cent, rail 1.7 per cent, pipeline 0.2 per cent and others 0.1 per cent (IEA, 2007a).

Carbon dioxide (CO_2) comprises the lion's share of GHG emissions from the transport sector[1]. Furthermore, among the various sectors that account for the increasing concentration of CO_2 in the atmosphere the contribution of transport is significant. As of 2005, the total emission of CO_2 from the transport sector amounts to nearly 23 per cent of the world's energy related CO_2 emissions (IEA, 2007b). Fig.1 further disaggregates the transport CO2 emissions across the modes for 2005. The fig. clearly shows that road transport has the largest contribution to emissions from fuel combustion in the transport sector and the on-road vehicles that are primarily responsible for such emissions are cars

[1] Other GHGs include methane (CH4), nitrous oxide (N2O), HFCs, PFCs, and SF6.

and light duty vehicles (LDVs) that is four wheeled vehicles (including sports utility vehicles, small passenger vans with up to 8 seats), and trucks.

Insert Fig.1 here

The emerging Asian countries[2], led by India and China, have been projected to account for much of the future growth in oil consumption and GHG emissions due to their strong economic and population growth. According to recent projections made by Asian Development Bank (ADB), they are expected to account for 45per cent of the total world increase in oil use through 2025 (ADB, 2006).

The present paper considers a country case study of India. Moreover, in view of the fact that road transport especially cars and light duty vehicles constitute a substantial chunk of the oil consumption the focus in this paper would be on road transport in India with a particular focus on car ownership. The paper essentially builds upon a model of car ownership in India and examines the possible implication of price-deregulation and removal of price asymmetry between petrol and diesel for future energy saving and curtailment of CO_2 emissions.

[2] Includes Bangladesh, Bhutan, Cambodia, People's Republic of China (PRC), India, Indonesia, Lao PDR, Malaysia, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Vietnam.

2. Trend in Road-based Motorised Passenger Mobility in India

Within the transport sector in India, road transport has emerged as the dominant segment with a share of 4.5 per cent in India's GDP as of 2005-06[3]. An important feature in road transport mobility in India is the phenomenal growth registered by the motor vehicle population over the years. As per the latest Road Transport Yearbook for India, the country had nearly 75 million registered motor vehicles at the end of 2005. Table 1 below shows the growth in registered motor vehicle population from 1951 onwards till 2005 along with modal split and modal shares. Between 1951 and 2005 the vehicle population grew at a compound annual growth rate (CAGR) of nearly 11 per cent. Personalized modes (primarily comprised of two wheelers and cars) account for more than four-fifth of the motor vehicles in the country (according to the latest figure for 2004) as compared to their share of little over three-fifth in 1951. On the contrary, the share of buses (comprising primarily of public buses) in total registered vehicles has declined from 11.1per cent in 1951 to 1.1 per cent as in 2004.

Insert Table 1 here

The marginalization of Public Bus Transport (PBT) reflects major sociological and economic changes which could be attributed to increase in disposable income of households, changes in lifestyles and urbanization, among other factors. Furthermore, the prevalence of government regulation and control exacerbated the poor operational and financial performance of publicly owned transport undertakings, which are the main

[3] Reserve Bank of India (RBI), Handbook of Statistics for the Indian Economy, available at: www.rbi.org.in.

provider of bus transport services in the country, resulting in increasing reliance on personalized private modes of passenger transport. The demand for speed, service quality, convenience, flexibility and availability favoured adoption of private motorised modes as the main modes of transport resulting in rising number of cars and two-wheelers and leading to more congestion and further slowing down of the movement of public bus transport. With the economy gradually moving to a higher growth trajectory coupled with further rise in per capita income, larger need for mobility and increasing desire for safety, convenience and comfort the personalized modes of transport are only expected to grow in future.

Table 2 provides a summarised overview of the total road based passenger traffic and that by private and public motorised modes from 1971 onwards till 2004.

Insert Table 2 here

As seen from the table, over the period 1970–71 to 2003–04 absolute road-based motorized mobility (measured in terms of passenger-kilometers) registered an increase from 210 billion passenger km to 3070 billion passenger km in India which represents an overwhelming growth of around 1362 per cent at a compound annual growth rate of nearly 8.5 per cent per year. The table also shows that there has been a rapid growth in reliance on private motorized modes (cars, two wheelers and three wheelers) especially in the post-economic liberalization era (after 1991). Within the private modes the overall mobility share of cars increased from 19.43 per cent in 1990-91 to 27.47 per cent in 2003-04.

The demand for mobility depends on a panoply of socioeconomic, behavioural and policy related factors which includes, among others, age distribution and household composition, employment, educational level, state of supply of public transport services, infrastructure availability, government policy towards automobiles and transport, prices of different transport services, fuel and vehicle prices and income of the people. The rapid increase in private motorized mobility in India could, however, be primarily attributed to rapid urbanisation[4], increase in per capita income[5], increase in commercial and industrial activities, lack of parity between domestic and international fuel prices and asymmetry between domestic retail selling price of petrol (gasoline) and diesel (high speed diesel), the two primary fuel used for motorised mobility in India. These were coupled with a sea change in the automobile sector in India over the span of last two decades. Due to liberalization of the Indian economy, a number of new firms entered the automobile sector and started producing a large variety of cars in different segments (small, medium and large) and two-wheelers. The availability of plethora of vehicles coupled with conducive facilities for easy financing of purchase at competitive interest rates led to an increase in sale of private vehicles (cars and two wheelers) substantially during 1990s and afterwards.

The impetus to this unabated demand and growth for private motorised mobility was further provided by the failure of the Indian government to integrate land-use planning with transport planning in urban areas which led to de-densification and

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[4] The growing population in urban areas (especially the work force) has resulted in a huge increase in travel demand.

[5] The National Account Statistics brought out by the Central Statistical Organization (CSO), New Delhi reveals that the per capita income in India has increased at the rate of 4.1per cent per annum from 1994-95 to 2004-05 whereas the GDP has increased at the rate of 5.8per cent per annum during the same period (available at: www. mospi.nic.in).

development of satellite towns and peri-urban townships with a consequent increase in trip lengths. The longer trips to access jobs and services in turn fuelled a rapid decline in the use of environmentally benign modes of transport like walking and cycling (Sundar and Dhingra, 2008) and increasing use of private motorised modes.

Current transport planning and markets in India are also distorted in ways that tend to increase usage of personalised motor vehicles. For example, motorists are rarely charged the full costs of congestion, road space, parking, and air pollution. Public policies usually tend to favour the personalised modes, as already explained above, and the bulk of public expenditure in most cities has been on expanding infrastructure (like highways, roads, flyovers, parking facilities and so on) to cater to the needs of these personalised modes.

However, among all the aforementioned factors that exacerbated the growth of private motorised mobility in India what really turned out to be crucial is the insulation of domestic petrol and diesel prices from volatile international crude oil and petroleum product prices variation due to political and social compulsions, as claimed by the government. This was coupled with maintenance of a constant asymmetry between the price of petrol and diesel.

Considering historically, the pricing mechanism in India usually had a built-in cross subsidy burden on petrol which was used to keep the price of diesel artificially depressed. This was later substituted by imposing a much higher excise duty on petrol. The implicit assumption behind maintaining asymmetry in the retail selling prices of petrol and diesel by the Government has been that petrol is the fuel of the relatively better off[6]. The insulation of domestic vehicle fuel prices from international crude and product price variation coupled with continued price asymmetry between the primary fuels has had the unintended consequences of higher purchase and utilisation of vehicles besides generating an added incentive for motorists to opt for diesel rather than for gasoline cars in India especially in the post-liberalisation era leading to flooding of Indian roads with relatively larger number of diesel-run vehicles in the 1990s.

Rapid increase in private road-based passenger mobility has serious implications not only in terms of increasing consumption of fuel, as explained above, but also on the GHG emissions from the combustion of these fuels. It has already been mentioned in the introductory section that the private vehicles have been a major consumer of petroleum products. Thus, designing and implementation of effective strategies to reduce road transport sector's impact on energy demand and GHG emissions depends to a large extent on reducing fuel consumption by private vehicles. This could be taken care largely by maintaining parity between international crude and petroleum product prices with domestic petroleum product prices especially petrol and diesel and doing away with the asymmetry created by the uneven distribution of levies on these two fuels. However, no model based exercise has yet been undertaken in Indian context to assess the implication of fuel price rise on transport demand and intensity of utilisation of vehicles in India.

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[6] The report of the Working Group on Petroleum and Natural Gas for the Eleventh Plan (GoI, 2006), however, countered the implicit assumption behind this asymmetry and underscored that 71 percent of non-transport vehicles in India are two wheelers, which run on petrol. The report further underscores that these two wheelers essentially provide mobility to the aspiring class, the climbers and the middle class and not to the relatively affluent sections. Thus, the report asserts that the basic rationale for introducing the price differential does not seem to hold sufficient ground.

In order to assess properly the implication of income growth and fuel price rise on the energy use and implication for GHG emissions (particularly CO_2[7]) for private vehicles one needs to build up an appropriate model for vehicle ownership. The subsequent section lays the foundation of the same by setting up econometric models for car ownership and traffic volume per car[8]. The estimated model is then utilised to project for energy demand and CO_2 emissions from cars under alternate scenarios.

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[7] Apart from CO2, substantial amount of local pollutants like carbon monoxide (CO), unburnt hydrocarbons (HC), nitrogen oxides (NOx), sulfur dioxide (SO2), lead (Pb), and suspended particulate matters (SPM) are also emitted by the passenger transport sector. However, the focus in this exercise is on CO_2, which is the GHG that is emitted in largest quantity by the transport sector.

[8] It is quite difficult to come out with model based estimation of road based private two wheelers. The variables that could potentially affect per capita two wheeler ownership are per capita income and relative price of two wheelers as compared to cars. However since no systematic time series data is available on price of cars pertaining to different segments especially the lower segments (which could compete with two wheelers to some extent). Hence it may not be possible to appropriately model ownership of two wheelers. Similarly the modeling of new registration and vehicle km travelled for public transport and three wheelers would depend largely on the institutions and policies that are in place pertaining to these modes at different points in time which are challenging to bring under the ambit of a quantifiable model because of the complexities involved.

3. The Model and Its Rationale

Fuel demand for an on-road vehicle depends largely on the existing stock of fuel burning vehicles, the utilisation of these stocks and their fuel burning efficiency (Pindyck, 1979, Chapter 2). In view of that, a model of fuel demand (fuel consumption) for car is specified here by treating fuel demand as a derived demand dependent on stock of vehicles, traffic volume per car and the fuel efficiency of the stock of cars. It is further assumed that stock of cars is endogenous and depends partly on the price of fuel and on the per capita income. Thus, the fuel demand of a car has been assumed as depending indirectly on the price of fuel and per capita income rather than directly.

The following identity is considered for fuel consumption by all on-road cars

Fuel Consumption = [Stock of Cars (STK) × Traffic Volume per Car (TVPV)] / Fuel Efficiency (EFF)……….(1)

Thus, for an on-road car, the fuel consumption is given as:

Fuel Consumption = Traffic Volume per Car (TVPC) / Fuel Efficiency (EFF)………..(2)

The total CO_2 emissions from an on-road car could be given as:

CO_2 Emissions (E) = Fuel Consumption × CO_2 Emission Factor for Fuel (CEF)……..(3)

Traffic volume per car is the average number of miles or km driven per car each year and fuel efficiency basically implies the fuel (petrol or diesel)-burning efficiency of the stock of cars (expressed in km per litre). CO_2 Emission Factor for Fuel [expressed in kg per tera joule (TJ)] usually takes into account all the carbon in the fuel and assumes 100 per cent oxidisation of the carbon contained in the fuel.

The stock of cars could be expressed by the following accounting identity:

$$STK_t = (1- r) \times STK_{t-1} + NR_t \text{………}(4)$$

where STK is the stock of cars, r is the rate of depreciation of the stock of cars, and NR is the new registrations that is total additions to the stock of cars.

The depreciation rate differs across different segments of vehicles and across different modes of road transport. However, in India since no record is available on the rate of depreciation of on-road vehicles a normative annual rate of depreciation of 3 per cent has been considered here for modelling purpose to account for 'damages, accident, scraps as well as double counting in registration'. The normative rate has been adopted from the study on traffic flows brought out by the Ministry of Surface Transport (MoST, 1999, p 47).

The per capita new registration of cars has been assumed to be a function of relative fuel prices and real per capita income.

$$PCNR = f\,(Y, P_p / P_d) \text{…………} (5)$$

PCNR represents per capita new registration. However for computing PCNR the new registration of car (NR) has been divided by urban population instead of total population. The basic reason for this computation lies in the fact that the ownership of car, as has been observed in India, is totally skewed towards the urban metropolis and the ownership of cars (cars per thousand) among rural population is insignificant. Thus considering total population in the denominator provides an underestimation and fails to correctly reflect the true nature of car ownership in India[9].

P_p and P_d represents real retail selling prices of petrol and diesel respectively; Y represents real per capita income. All these variables have been used in their logarithmic form for estimation purpose. In the light of the asymmetry that is prevailing between the petrol and diesel price, it would also be worthwhile to consider the relative fuel prices to reflect upon the impact of auto-fuel price asymmetry on car ownership.

However it ought to be duly recognised that in reality the propensity to own a car and hence new car registration depends on a plethora of factors which include prices of cars for different segments and for different fuel-run fleets, availability of easy financing at cheaper interest rates, government policy towards private motorised mobility, among others. Moreover, the pattern of new registration for different segments of vehicles namely small, medium, and big and for vehicles using different types of fuels is also different. But in order to bring all these factors under the ambit of consideration of the present exercise one may require consistent record and reliable time series database on price of cars for different segments, rate of interest charged on loans for different segments and separate information on petrol-run and diesel run vehicle fleets. Unfortunately, neither the Department of Road Transport and Highways of Government of India nor the Society of Indian Automobile Manufacturers (SIAM) has comprehensive and reliable time-series on all these variables. This led to a more constrained formulation for new registration of cars, as above.

[9] In order to check for the brevity of this model assumption a separate exercise had also been carried out (results not reported here) by dividing the new registration of cars by total population. However the coefficients obtained from estimation, as par the expectation, have been observed to be statistically insignificant.

Traffic volume per car (TVPC) is also assumed here as a function of the relative real price of fuel and per capita income as below-

$$TVPC = \theta\ (Y, P_p / P_d) \ldots\ldots\ldots\ldots\ (6)$$

Given the fact that the existing car fleet comprises both diesel and petrol-run variants, TVPC should ideally be considered separately for both the variants. But again owing to non-availability of consistent time series data for each category, as already mentioned above, it is not possible to consider TVPC separately for petrol-run and diesel-run variants.

The average fuel burning efficiency is usually considered to respond to price of fuel but after a considerable lag and depends largely on the modification made, if any, on the conventional technology of the vehicles in use or pace of innovation and installation of new technology. The responsiveness also depends on the stringency of the government regulations that are in place like the presence of mandatory fuel efficiency standard, or otherwise. In the current exercise, however, normative fuel efficiency has been assumed for cars and the time span for responsiveness has been assumed as 5 years for the purpose of simulation.

4. Data Sources

The time period that has been considered for the study is 1971 to 2004. It is really difficult to find out a single source from where one can obtain continuous historical time series data pertaining to the aforesaid sample period for road-based passenger traffic volume in India. The data on road based passenger traffic (in billion passenger km travelled) has been compiled from several sources These include, among others, data provided in the Road Transport Yearbook for various years published by the Ministry of Road Transport and Highways, Government of India; Planning Commission (1998); Ministry of Surface Transport (1999); Planning Commission (2007). Besides for shares of cars and other private motorized modes in the total road traffic, additional studies or reports that have been consulted are Planning Commission (1980); Indian Road Congress (1984); Ministry of Surface Transport (1986); AITD (2002); and Singh (2006). The indicative shares of some missing years have been obtained by consulting with former officials associated with the Department of Road Transport and Highways, Government of India, New Delhi.

Average occupancy of a car (which includes jeeps and taxis) has been assumed to be 3.18. This is in line with the occupancy ratio that has been used as norm for developing countries in Dalkmann and Brannigan (2007) and Sperling and Salon (2002). As for average fuel efficiency of cars a normative fuel efficiency of 13km per litre has been assumed in consultation with the officials associated with the transport department. Data on GDP, Per capita GDP and population has been obtained from Handbook of Statistics for the Indian Economy published by Reserve Bank of India (RBI) and available at the website www.rbi.org.in.

Data and Information on retail petrol and diesel selling prices have been obtained from Centre for Monitoring Indian Economy (2002)**,** The Energy Data Directory and Yearbook (various issues) published by the The Energy and Resources institute (TERI), New Delhi and information on fuel prices provided by Petroleum Planning and Analysis Cell (PPAC), Government of India, which is available at the website: www.ppac.org.in.

Data and information on CO_2 emission factors for fuel has been obtained from Chapter 3 (on Mobile Combustion) of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories available at: www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm .

5. Method of Computation of the Variables Used

There is no ready-made data that is available in India for TVPV that is vehicle km travelled for any mode of road transport and has been computed as:

$$TVPC = \text{Passenger kilometre travelled (PKm) / [Stock of Cars (STK)} \times \text{Occupancy Ratio]} \ldots\ldots (7)$$

There is also no readymade data that is available on the stock of vehicles. Stock of vehicles, as already mentioned in section 3, has been computed for all the modes for each year after considering new registration and a normative rate of depreciation which is 3 per cent. For computational purpose the total registered motor vehicle population pertaining to the year 1951, the first year for which the data on motor vehicle population is available in India, is considered as initial stock and then making use of equation (4) for computing stocks for the subsequent years.

The real price of fuel (P_p and P_d) has been arrived at by dividing the nominal retail selling prices (in Rs/litre) by the GDP deflator index. The GDP deflator index for India has been computed as:

$$\text{GDP Deflator} = [\text{GDP (at factor cost) at current prices / GDP (at factor cost) at constant (1993) prices}] \times 100 \ldots\ldots (8)$$

For real per capita income 'Y', real per capita GDP is considered here. The real per capita GDP is the per capita GDP at factor cost and at constant (1993) prices.

For estimation of long run elasticities of TVPC and PCNR with respect to income and fuel prices the paper relied on the techniques of Cointegration and for the short-run dynamics the paper estimated Vector Error Correction Model (VECM) corresponding to each of these variables. Both these techniques have been explained briefly in the next section. The estimated model of TVPC and PCNR has been used for simulation of fuel consumption and CO_2 emissions for future years.

For simulation of fuel consumption and CO_2 emissions three indicative scenarios are considered in this paper. They are: 1) Business as Usual Scenario, where it is assumed that the passenger km travelled by car and the new registration of cars will increase at the trend rate of growth for the last preceding decade that is from 1993-94 to 2003-04 ; 2) High Price Scenario- where it is assumed that the real price of petrol and diesel will grow in a manner so as remove the asymmetry between them by 2012 and then continue after 2012 at the trend rate of growth global crude price[10] 3) High Price High Efficiency scenario where in addition to the assumption underlying the high price scenario an assumption of 10 per cent increase in fuel burning-efficiency of vehicles at the interval of every five years is invoked[11].

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[10] In the HP scenario, the per capita GDP is assumed to grow at the trend rate for the preceding decade (that is for the period 1994-2004) which is 4.21 per cent and the real prices of diesel and petrol are assumed to go up at a rate which is higher than the existing trend rate of growth for the same period for the real price of fuels. Accordingly the growth rate of real price of diesel has been assumed at 7.5 per cent whereas that for real price of petrol has been assumed as 1.5 per cent. In fact if these growth rates persist the difference in real price of the two fuels has been observed as nullified by 2012. After 2012, the growth rate of both the real fuel prices is assumed as the trend growth rate of global average real crude oil price, which for the period 1994 to 2004 has been observed as around 7 per cent .The same growth rate is also applied here for illustrative purpose to examine the implication on energy consumption and CO_2 emissions.

[11] According to the model assumption fuel efficiency has been considered as an exogenous variable. In reality fuel efficiency may vary as the price of the fuel increases albeit with a considerable time lag. Moreover, as no systematic records are available on car fuel efficiency, hence it is really difficult to model fuel efficiency for cars in Indian context. Furthermore, time lag for increased fuel efficiency is particularly debatable in the Indian context given the transport policy and land-use and infrastructural facilities that are in place and given the fact that there are no mandatory fuel-efficiency standards in India yet. So, this assumption is again for indicative purpose and may not necessarily be the case for future. However, Indian Government is in the process of implementing mandatory fuel efficiency standards for cars which holds considerable potential towards improvement of fuel efficiency of cars by the automobile manufacturers. Hence, albeit indicative, it would be worthwhile seeing the picture under

6. Brief Description of the Econometric Methodology[12]

The estimation that has been carried out in the paper is based on Johansen's procedure of Cointegration and VECM (Vector Error Correction Model), which are techniques normally used in multivariate time-series analysis. The multivariate time series approach, does not presume an underlying structural or theoretical framework. In this approach, a set of variables that seems to potentially reflect an agent's decision is considered as jointly endogenous and are thus conferred symmetrical treatment. The current realizations and / or future expectations of these selected variables are thus contingent upon the currently available information set[13].

This multivariate time series approach is often referred to as *Vector Autoregression* (*VAR*) Approach. In this approach every endogenous variable in the system is modelled as a function of the lagged values of all the endogenous variables in the system.

A *VAR* could be represented in the mathematical form as:

$$Y_t = \alpha + A_1 Y_{t-1} + A_2 Y_{t-2} + \dots\dots\dots + A_p Y_{t-p} + \varepsilon_t \quad \dots\dots\dots\dots\dots\dots(9)$$

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the third alternate scenario of an exogenous increase in car fuel efficiency on energy consumption and CO2 emissions.

12 This section draws largely on Coondoo and Mukherjee (2006); Enders (2004), Chapter 6; and Kirchgässner and Wolters, 2007, Chapter 6.

13 This methodology is quite contrary to Structural Equation Approach (SEA) which begins by pre-judging an endogenous-exogenous divide of the variables.

where $A_1, A_2 \ldots\ldots A_p$ are KxK matrices of parameters; α is a $Kx1$ vector of intercepts and ε_t is a K-vector of *temporally uncorrelated* variables with $E(\varepsilon_t) = \phi$, $E(\varepsilon_t \varepsilon_t') = \Sigma$ for all t and $E(\varepsilon_t \varepsilon_s') = \phi$ for $t \neq s$.

As Y_t is integrated of order 1, equation (9) can alternatively expressed as

$$\Delta Y_t = \alpha + A_1 \Delta Y_{t-1} + \ldots\ldots + A_p \Delta Y_{t-p+1} + BY_{t-p} + \varepsilon_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Thus equation (10) is basically a *VAR (p-1)* in difference with BY_{t-p} as an additional term, B being a KxK matrix of parameters[14].

Now, since $Y_t \sim I(1)$, the l.h.s. of (10) is I(0). Similarly with the exception of except BY_{t-p} all the terms of the r.h.s. are I(0).

As $Y_t \sim I(1)$, the consistency thus requires $BY_{t-p} \sim$ I(0).

This implies that each row of B should be a cointegrating vector of Y_t (the notion of cointegration has been explained before, albeit in two-variable case).

As Y_t can have at most $r \leq K-1$ linearly independent cointegrating vectors implies *rank (B) = r*.

Using the rank factorization result of linear algebra one gets, $B = CD$, where *C:Kxr* and *D:rxK* with *rank(C)=rank(D)=r*. Thus, (10) can be re-written as

[14] The extra term appears because a vector of *I(1)* variables cannot have a finite-order *VAR* representation in difference.

$$\Delta Y_t = \alpha + A_1 \Delta Y_{t-1} + ... + A_p \Delta Y_{t-p+1} + CDY_{t-p} + \varepsilon_t \quad \text{.................} (11)$$

where the *r* rows of *D* contain the *r cointegrating vectors* of Y_t and each of the *K* rows of *C* contains the corresponding set of *adjustment parameters.*

Each of the r elements of DY_{t-p} is a stationary random variable which measures the extent by which the realized values of the *K* variables deviate from the *long run equilibrium condition* that the corresponding cointegrating vector represents and hence these are called the *error correction terms* and the system of equations (8) is called the *Vector Error Correction Model* (*VECM*). [15]

Johansen's procedure of cointegration test is based on the estimation of the *VECM* (as shown in equation (11) using the maximum likelihood method. It also needs to be noted that since the *r* cointegrating vectors as contained in *D* are non-unique[16], these have to be normalized. Typically, using the normalization, one would obtain the cointegrating vectors as the rows of a matrix $D^* = [D_1 D_2]$, where $D_1 : rxr$ with *1* in the diagonals and $D_2 : rxK$.

In some software packages the set of *r* cointegrating vectors are presented in the form $[I\ D_3]$ where $D_3 = D_1^{-1} D_2$.

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[15] The system of equations (11) is usually referred to as the *Granger Representation* of a set of cointegrated *I(1)* variables .

[16] This is because for any *F:rxr* non-singular, *FD* is also a set of *r* linearly independent cointegrating vectors of Y_t .

Suppose one partitions the variables into two groups as $Y_t^* = \{Y_{1t}, Y_{2t}, ..., Y_{rt}\}$ and $X_t^* = \{Y_{(r+1)t}, Y_{(r+2)t}, ..., Y_{Kt}\}$. Then the set of cointegrating relationships can be expressed as

$$Y_t^* = -D_3 X_t^* + \nu_t \quad \text{.................................(12)}$$

where v_t is a *r*-vector of stationary random disturbance terms. It needs to be noted that (12) resembles the system of reduced form equations of a structural simultaneous equations model. Indeed, following this approach, one may try to arrive at a set of structural equations implied by the given sample data set. Such an exercise essentially involves the task of identifying the subset of (*K-r*) exogenous variables of the given set of variables.

In order to carry out the Johansen's maximum likelihood approach for testing cointegration it needs to be first ensured that the series with which one is working is non-stationary and integrated of order one. This could be ensured by carrying out *Dickey Fuller* (*DF*) or *Augmented Dickey Fuller* (*ADF*) test as the case may be.

The next problem, which one faces, is that of specification of lags. The lag order has been chosen by using *Akaike Information Criterion* (*AIC*), with the least value of *AIC* being used to select the optimum lags. The lag order in the current exercise has mostly been found to be 3.

The LR test Statistic, often referred to as Trace Statistic, that is used for testing cointegration is given below

$$Q_r = -T\sum_{i=r+1}^{k}\log(1-\lambda_i)\text{..}(13)$$

For r = 0… k-1. where λ_i is the ith largest eigen value (for more details on these see Enders, 2004 Chapter 6, sections 7 and 8 ; Kirchgässner and Wolters, 2007, Chapter 6 section 6.3).

The trace test has the null hypothesis

H_0: there are at most r positive eigenvalues

against the alternative hypothesis

H_1: there are more than r positive eigenvalues.

The test starts with r = 0 and is performed until the first time the null hypothesis cannot be rejected. The cointegration rank is given by the corresponding value of r. If the value of the trace test statistic exceeds the critical value, then the null hypothesis is rejected, otherwise accepted.

6. Cointegration and Short-run Dynamics

First, the unit root tests have been carried out on all the variables in their logarithmic form to check for their stationarity. The results of the unit root test are given in Tables 3 and 4. From the results of the unit root tests it could be observed that all the variables are non-stationary and integrated of order 1 that is I (1). Next the cointegration tests by Johansen procedure have been carried out on log of traffic volume per car (denoted as LTVPC) and on log of per capita new registration of cars (denoted as LPCNR). The results of the trace test are reported in Tables 5 and 6.

6.1 Results of Cointegration

Tables 7 and 8 show the statistically significant cointegrating vectors for LTVPC and LPCNR obtained through Johansen procedure[17].

Insert Tables 7 and 8 here

By convenient transposition, LTVPC and LPCNR (as shown above) can come on the left hand side as dependent variable and the variables representing relative real price and per capita GDP along with associated coefficients can come on the right hand side. As all the variables are logarithmically transformed the coefficients associated with relative real price and per capita income in the tables 7 and 8 represents the long-run elasticity of traffic volume per car and that of new registration with respect to these variables.

On the basis of statistically significant cointegrating vectors as obtained above the long-run elasticities has been provided in table 9.

Insert Table 9 here

Both the traffic volume per car and the per capita new registration are highly elastic to changes in real per capita income (real per capita GDP). However, the traffic volume is close to elastic and negatively responsive to the relative real price of petrol and the per capita new registration is inelastic but positively responsive to relative real price of petrol in the long run. This, in a way implies that as the real petrol price rises relative

[17] The optimum order of VAR in the cointegration analysis has been determined by using Akaike Information Criterion (AIC) and the optimum order has been observed as 4.

to that of diesel, the intensity of vehicle utilisation decreases in the long run whereas the movement tend to occur in the reverse direction as diesel price tend to become dearer relative to petrol (as real diesel price is in the denominator). The negative responsiveness for relative real price of petrol is not unusual in view of the fact that the car fleet for the sample period is primarily comprised of petrol variants[18]. Considering historically, however, even though the price of diesel increased it was never allowed to exceed petrol price at any point of time owing to politico-economic considerations. Thus albeit there had been a rise in the price of diesel the intensity of utilisation of personal cars does not seem to have been affected that significantly. However, all these explanations are underpinned by assumption of unaltered behavioural pattern of car-users and combustion efficiency of vehicles with lapse of time. So, the long-run elasticities that are obtained here are at best indicative.

On the other hand, the per capita new registration of cars is inelastic but positively responsive to the real price of petrol relative to that of diesel, which in a way indicates that relative fuel price may not affect per capita new registration even in the long-run. However the positive value of the elasticity indicates a very mild tendency of shifting from petrol to diesel run variants in the long-run as the price of petrol increases.

6.2 Short-run Dynamics

The individual equations of an estimated VECM describe the short run temporal movement of a set of cointegrated variables. Table 10 below shows the estimated VECM

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[18] Discussions with the Transport Ministry officials revealed that the car fleets in India comprised largely of petrol-run variants for the sample period that has been considered here that is 1971 to 2004. It is only towards the nineties that is over the last decade that the diesel-run variants have gradually started replacing the petrol-run ones. Hence the extent of new registration could be affected by the relative dearness of petrol as a fuel.

(lag intervals 1 to 3) for the set of variables (LTVPCCAR, LPERCAPGDP, and LRELATIVEREALP) after excluding all other explanatory variables with insignificant coefficients in the equations corresponding to each of the aforesaid variables. It needs to be reiterated here that all the variables are in logarithms. However, the results do throw some light on the intertemporal growth dynamics of the variables considered.

Insert table 10 here

As evident from table 10, the test of goodness of fit (that is adjusted R^2) is low for all the equations that have been taken into consideration, but is particularly low for the equation relating to PERCAPGDP. It also needs to be noted that for this variable, all the estimated coefficients except trend are insignificant hinting somewhat towards its more autonomous nature in the short run. For the equation corresponding to TVPCCAR, the coefficients associated with explanatory variables D(LTVPCCAR(-1)) and D(LPERCAPGDP(-1)) are significant. The positive coefficient corresponding to the autoregressive term D(LTVPCCAR(-1)) indicates that the growth in vehicle utilisation in the current period depends on the same for the preceding period. However the coefficient associated with D(LPERCAPGDP(-1)) is negative and significant which seems to indicate that the growth of real per capita income in the immediate short-run does not tend to be associated with a concomitant increase in growth of car utilisation. The adjustment coefficient E(-1) is significant and negative. Since the estimated cointegrating vector is normalized by setting the coefficient of LTVPCCAR equal to unity, a positive value of E(-1) signifies excess of realized LTVPCCAR over its long run equilibrium level in some preceding period. The negative value of the adjustment coefficient could then be interpreted as signifying the tendency of the system to converge towards the long run permanent or stable level (determined by the cointegrating equation) from any deviations in the preceding period.

Table 11 shows the estimated VECM (lag intervals 1 to 3) for the set of variables (LPCNR, LPERCAPGDP, LRELATIVEREALP), after excluding the explanatory variables with insignificant coefficients in the equations corresponding to each of the aforesaid variables in the VECM.

Insert table 11 here

Except for the equation corresponding to PCNR in the estimated VECM, the value of test of goodness of fit (adjusted R^2) for all other equations are extremely low. The adjustment coefficient E(-1) associated with the cointegrating equation, obtained by normalising and considering the coefficient corresponding to LPCNR as 1, is insignificant but negative which implies a tendency of convergence of the value of LPCNR to long-run equilibrium level obtained from the cointegrating relationship. However, with the exception of the intercept term, none of the explanatory variables are significant. The above findings hint towards a more autonomous nature of TVPCCAR in the short run.

7. Estimation and Analysis

For the long-run projection of traffic volume per car and new registration the normalised cointegrating equation, obtained through convenient transposition in tables 7 and 8, have been utilised.

Fig. 2 compares the actual traffic volume per car during the sample period (1971 to 2004) with the estimated traffic volume per car during the same period by using long run elasticities obtained from the cointegrating vector in table 7.

As seen from fig. 2, except for the initial years from 1971 till 1974, the actual and projected series remain more or less close to each other.[19]

Insert fig.2 here

Fig. 3 compares the actual new registration with the estimated new registration using cointegrating vector in table 8. The projected absolute figures for per capita new registration are multiplied with the urban population to arrive at the figures for new registration pertaining to the sample period 1971 to 2004. As seen from fig. 3 the actual and estimated new registration of cars is almost mingled with one another for the entire sample period 1971to 2004.[20] .

Insert fig.3 here

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[19] The value of RMSE (Root Mean Squared Error) obtained on the logarithm of the series has been observed to be around 0.05.

[20] The value of RMSE that has been obtained on the logarithm of the series is around 0.02

8. Implications for Fuel Demand and Emissions

The fuel consumption for an on-road car, as shown in equation (2), could be obtained by dividing traffic volume per car (TVPC) or vehicle km travelled (VKT) by average fuel efficiency (EFF) of a car. Thus, the fuel consumption by car for future years from 2005 to 2030 could be obtained by simulating TVPC for the future years. This is because for EFF a normative rate of 13 km per litre has been assumed for cars, as indicated before.

TVPC is computed in the Business As Usual (BAU) scenario (for the period 2005 to 2030) by using equation (7) and by making use of passenger km travelled and stock of cars in the BAU scenario[21]. In the and High Price (HP) scenario TVPC is simulated by making use of the long run elasticities with respect to relative real fuel prices and real per capita income obtained from cointegrating vectors in tables 7 and 8.

In addition to the BAU and HP scenarios an additional scenario has also been constructed while estimating the energy demand. The scenario is designated as 'High Price High Efficiency' (HPHE) scenario where in addition to the assumption of HP scenario an exogenous increase in fuel efficiency per vehicle at the rate of 10 per cent every five years is assumed[22]. The simulated fuel consumption and emissions under this

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[21] Passenger km travelled the BAU scenario is the trend growth of passenger km travelled by car where the trend growth rate is that for the preceding decade (1994 to 2004) and has been observed as around 14.90. The stock of cars in the BAU scenario has been computed by considering the trend growth rate of new registration for the preceding decade, the normative scrappage rate of 3 per cent, the computed stock of cars for the terminal calendar year (that is 2004) and making use of equation (4).

[22] The time lag for increased fuel efficiency is particularly debatable in the Indian context given the transport policy and land-use and infrastructural facilities that are in place and keeping in mind that there

scenario would facilitate in comparison of fuel savings and savings on emissions that could be made in HP scenario without any improvement or innovation in combustion efficient technology with that in HPHE scenario. Here again it needs to be reiterated that the results are at best indicative. As TVPC is expressed in km and the vehicle fuel efficiency is in km per litre. So, the unit of automobile fuel consumption that would be obtained is in litre. Using the heat equivalent or calorific value of fuel (petrol/diesel) as 1 litre = 0.0000357 Tera Joule (TJ) per litre, fig. 5 provide future energy (fuel) demand for an on-road car expressed in TJ. As seen from the figure, substantial savings in terms of automobile fuel demanded could be made if the real price of petrol and diesel converges and eventually follows the trajectory of global real crude prices as indicated in the 'High Price' scenario. In other words, if the asymmetry between diesel and petrol price is done away with and the growth in real price of petrol and diesel in India is aligned with growth in real global crude prices, then there could be significant benefits in terms of saving of automobile fuels in future. This could possibly be attributed to enhanced conservation encouraged by higher real prices of both petrol and diesel as is evident from the reduced energy demand under the high price scenario across all modes. Furthermore, if the high fuel prices are coupled with improved combustion efficiency then the energy saving would be substantial as is evident from the fuel demand under 'High Price High Efficiency' scenario for all modes of road transport. Although the results of simulation that are obtained here are indicative in nature but the inference that could be drawn from these observations is of paramount importance from the perspective of development particularly in the context of India's oil security with lion's share of refinery crude throughput in India being procured via imports.

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are no mandatory fuel-efficiency standards in India yet. So, this assumption is again for indicative purpose and may not necessarily be the case for future.

The saving on automobile fuel consumption for an on-road vehicle is concomitantly associated with savings in terms of CO2 emissions as indicated below-

CO_2 *Emissions = Fuel Consumption* × CO_2 *Emission Factor for Fuel (CEF)*............(14)

The CEF in the lower and upper range corresponding to petrol and diesel for an on-road vehicle is given in Table 12. Corresponding to the consumption of automobile fuel (petrol or diesel) expressed in TJ, the lowest CEF that is 67500 (pertaining to petrol/motor gasoline) and the highest CEF that is 74800 (pertaining to gas/diesel oil) have been considered here to get an idea of the range across which CO_2 emission might vary for an on-road car. Figures 5 and 6 indicate the CO_2 emissions in kg. for lower and upper range respectively for an on-road car.

As seen from figures 5 and 6, commensurate with the energy savings across all modes under HP and HPHE scenario in fig.4, CO_2 emissions for an on-road vehicle and across all modes also get reduced progressively over the years through 2010 to 2030 under both the scenarios with the saving in emissions being much higher in the latter case.

9. Challenges in Reducing Energy Consumption and Emissions from On-road Vehicles in India and Ways forward

The asymmetry that historically exists in India in the auto-fuel prices on account of artificial deflation of diesel relative to petrol coupled with a conducive policy and distorted market structure favouring private vehicle ownership; absence of adequate sound and attractive public transportation; lack of integration of land-use planning and infrastructure, generated perverse incentives for personalised mobility. The impact of improvement in vehicle technology and fuel quality have also been largely offset by the sops on fuel prices and prices of vehicles that continued to provide a constant fillip to higher rate of ownership and utilisation of personalised vehicles leading to higher energy consumption and exacerbation of negative spill-over on the environment- both locally and globally. The problem got compounded with increasing consumer preferences for larger cars, fitted with energy consuming power steering, air-conditioning essentially leading to higher energy consumption and more emissions per km travelled.

Although one can't vouch with certainty that international crude and refined petroleum product prices would inevitably rise further or even stay at current levels, there is no second thought about the ever-increasing volatility in oil prices and the associated instability in the world oil market. The increasing volatility creates uncertainties making it unfit for fresh investments to pour in and also leads to inevitable delay in major investments in fuel efficient car technology thus aggravating the problem for a major oil consumer like India. It is plausible to argue that high auto-fuel prices act like a signal to both consumers and automobile manufacturers that they need to take appropriate and adequate actions to reduce fuel consumption. Absence of this signal fails to provide the much-needed policy impetus in undertaking initiatives to reduce fuel consumption. So, unless the government acts now and progressively prune the subsidy on automobile fuel the opportunity might just get lost forever.

Furthermore, appropriate fuel-efficiency and vehicle emissions standards for new and in-use vehicles and a well-designed and operated Inspection and Maintenance (I/M) program, which are important elements of an overall strategy to reduce vehicle emissions and air pollution, are completely lacking in India. India is yet to set any roadmap for introducing mandatory fuel efficiency standards although the Government has approved the implementation of the same. With regard to emissions standards, while India's 2-wheeler standards are stricter than those in Europe, it lags way behind Europe in respect of 4-wheelers. Furthermore, the national roadmap for fuel quality and vehicle emission standards is selective and focuses only on the larger cities and neglects the rapidly motorizing medium and small towns (due largely to the non-availability of fuels of the appropriate quality). Emission standards in India were introduced with Bharat Stage I (equivalent to Euro1) in 2000 covering whole of India. Bharat stage II (equivalent to Euro II) standards came into force in the whole of India in 2005. Euro III standards were introduced in 2005 in 11 cities; these will be extended nationwide in 2010. Euro IV standards are scheduled for introduction in 2010 in 11 major and more polluted cities but no date has yet been set for introducing Euro IV equivalent standards in the rest of India. With regard to inspection and maintenance system (comprising inspection, maintenance, and certification of vehicles) the large population of personalised passenger vehicles in Indian metropolises is not yet covered by any mandatory requirement of periodic fitness certification. What exists in practice is a simple Pollution under Control (PUC) check which came into existence in 1991 for all on road vehicles.

In view of the aforesaid challenges it is imperative that the objective of reducing fuel consumption and mitigating CO_2 emissions in passenger road transport should be addressed in a multipronged manner rather than just focusing on a single policy. There is panoply of measures that could be undertaken but all of them could be clubbed under three broad categories:

- **Reducing emissions per kilometre driven**. This could be achieved in a number of ways which includes, among others, fuel switch to cleaner fuels with low carbon density (like CNG, LPG); introducing or expanding battery operated hybrid vehicles; introducing low carbon and combustion efficient vehicle technologies, introducing best practices (for example improved maintenance, introducing fuel efficiency standards and stringent fuel quality and emission standards for personalised modes)**,** changing behaviour (by creating incentives for purchase of more energy efficient vehicles) and continued infrastructure improvements to reduce congestion.
- **Reducing emissions per passenger unit:** This includes generating incentives of modal switch from private vehicles to public transport by restraining vehicle ownerships (using measures like increased fuel taxes, congestion charges, parking charges, toll taxes and road pricing for private vehicles); encouraging car-pooling and non-motorised transport like cycling and walking for shorter distances; increasing share of public transport and introducing high capacity comfortable and attractive buses along with bus rapid transit; expansion of mass rapid transit system (like metro rail) across all the cities in India.

- **Reducing the distances driven or the number of trips taken:** This includes, among others, changing people's behaviour, substituting/reducing the need to travel through various virtual mobility alternatives using information and communication technology; better traffic management and route designs; integrated land use and transport planning.

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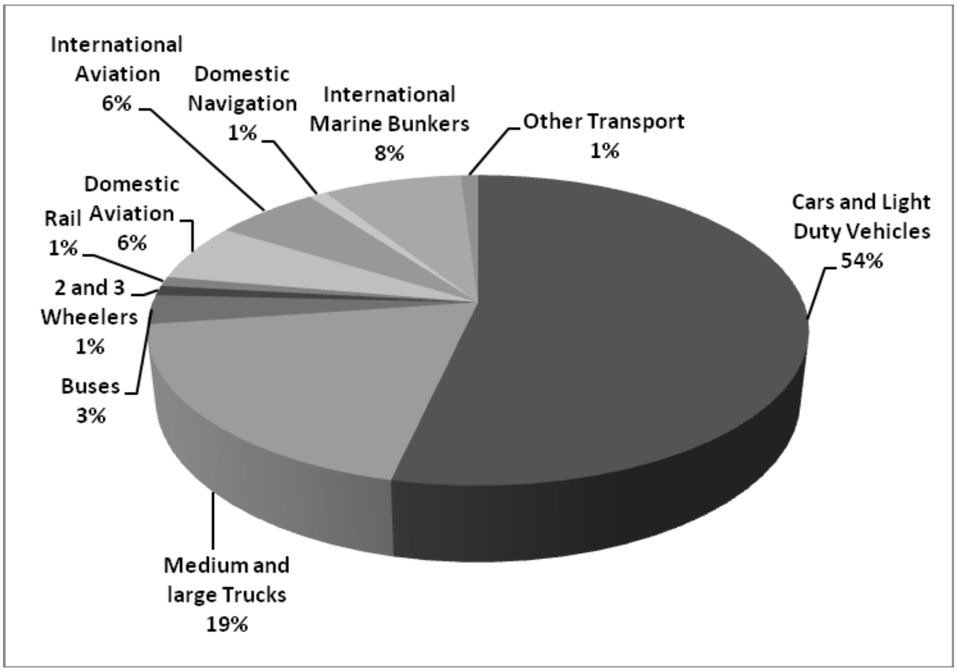
Fig. 1: Modal Shares of Transport CO2 Emissions (2005)



Source: IEA, 2007b

Fig 2: Actual and Estimated Traffic Volume per Car (in million vehicle km) from 1971-2004

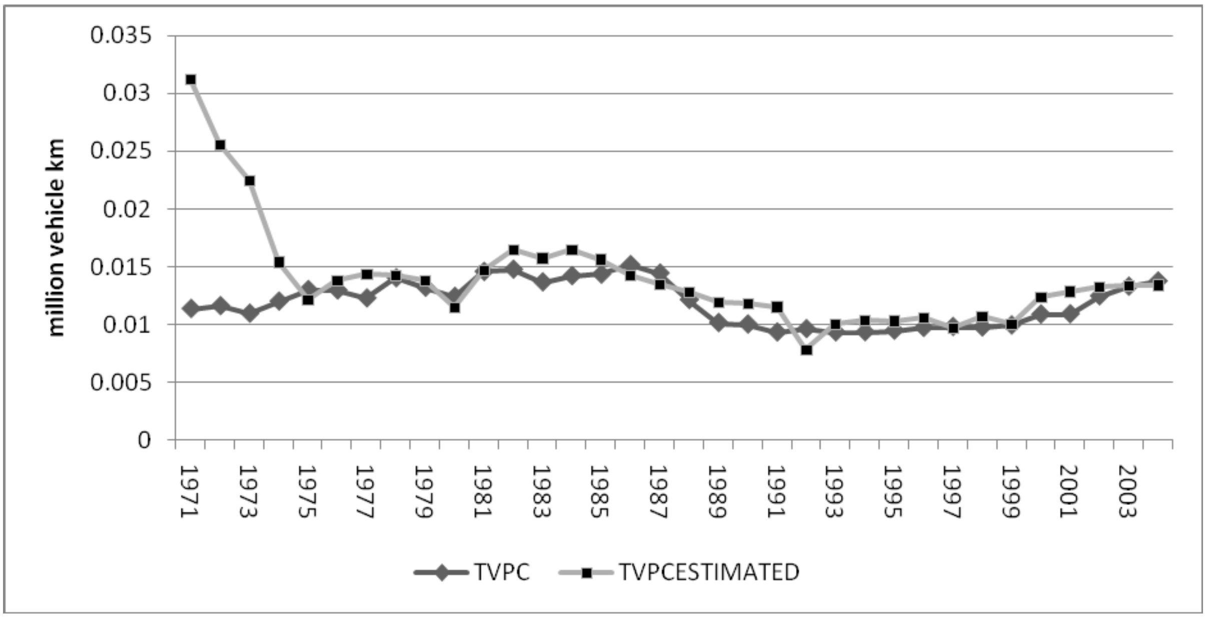


Fig 3: Actual and Estimated New Registration of Cars from 1971-2004

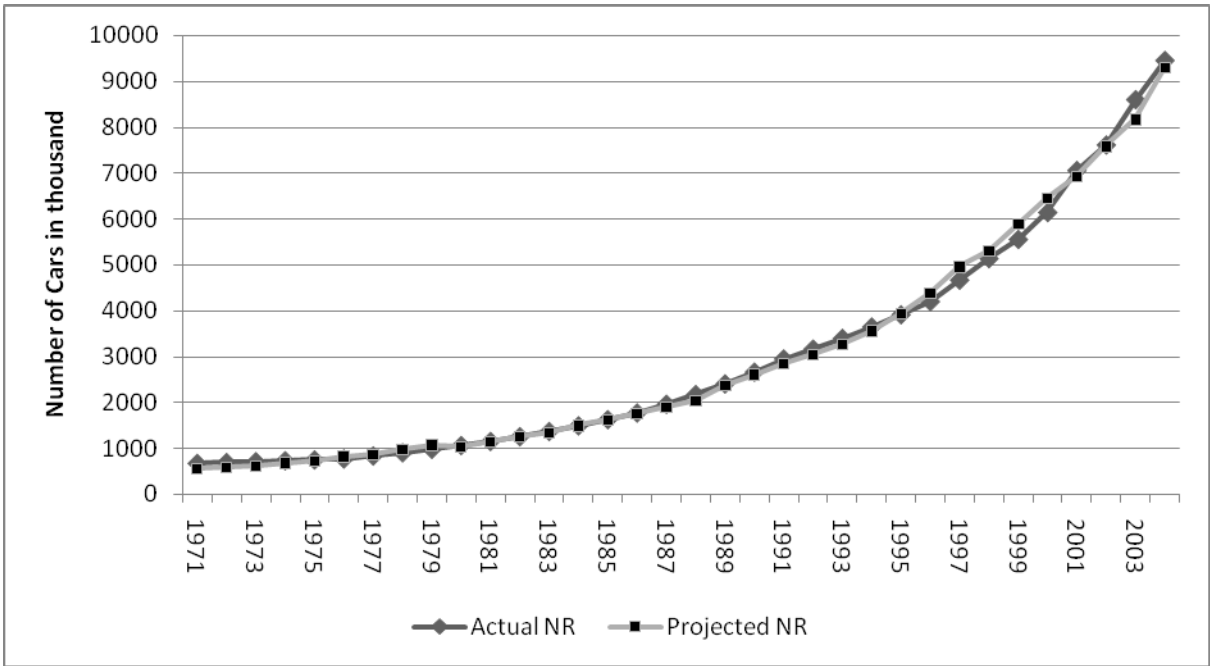


Fig. 4: Future Fuel Demand for a On-road Car under Various Scenarios

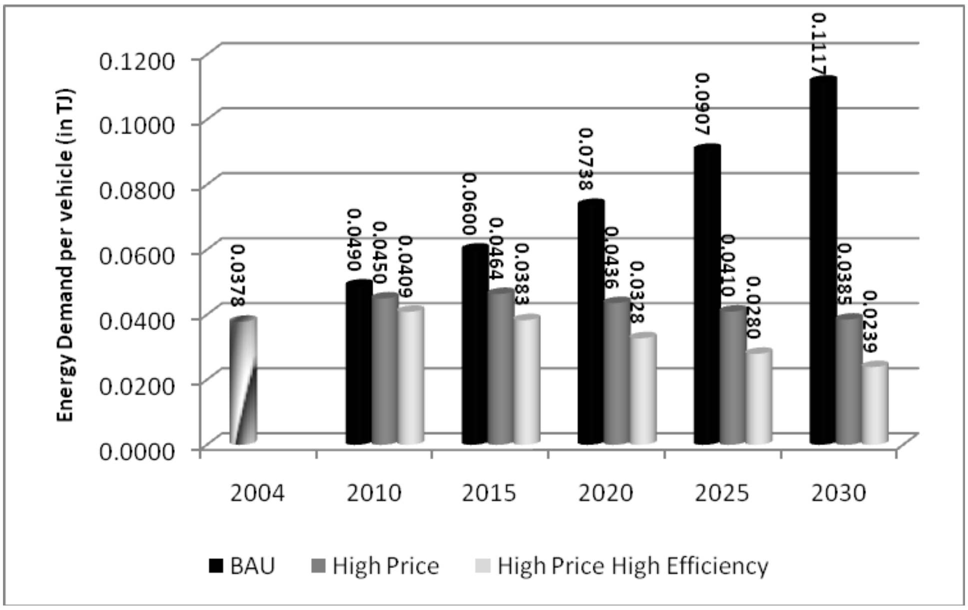


Fig. 5: CO_2 emission from an on-road car (in kg) in the lower range

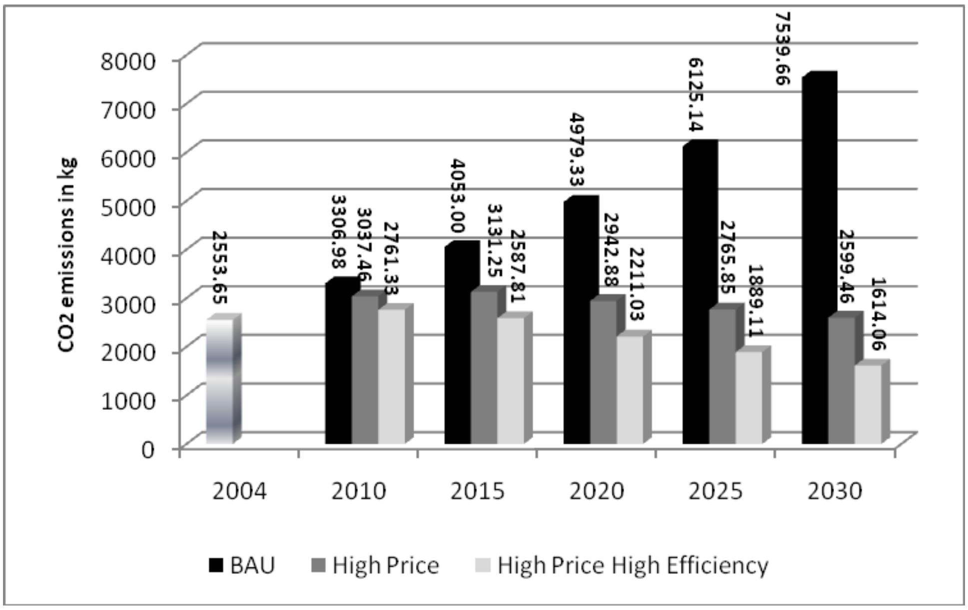


Fig. 6: CO_2 emission from an on-road car (in kg) in the upper range

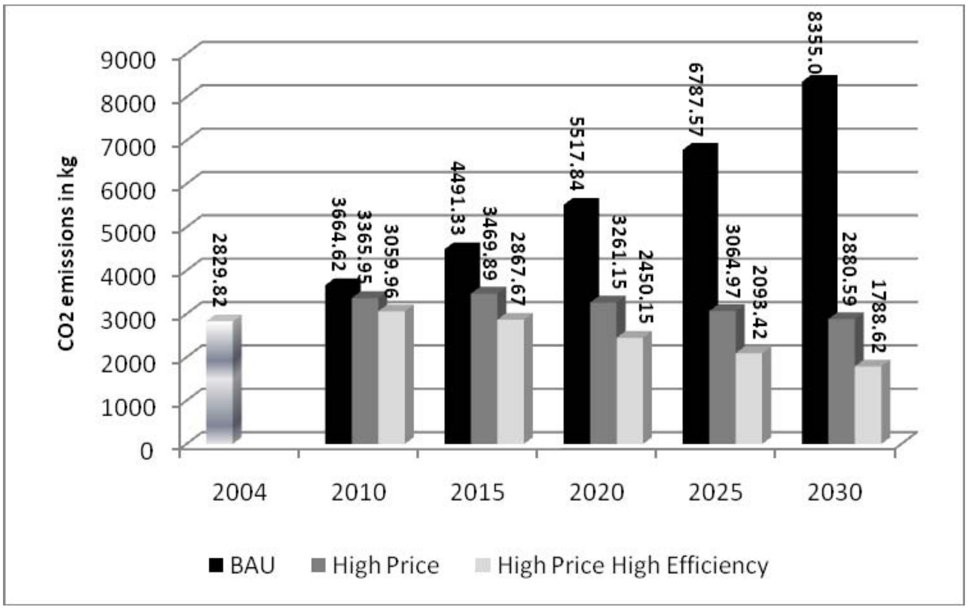


Table 1: Total Number and Share of Registered Motor Vehicles in India - 1951-2004
(in thousands)

Year (As on 31st March)	All Vehicles	Two Wheelers	Cars, Jeeps and Taxis	Buses	Goods Vehicles	Others*
1	2	3	4	5	6	7
1951	306	27 (8.82)	159 (51.96)	34 (11.11)	82 (26.80)	4 (1.31)
1956	426	41 (9.62)	203 (47.65)	47 (11.03)	119 (27.93)	16 (3.76)
1961	665	88 (13.23)	310 (46.62)	57 (8.57)	168 (25.26)	42 (6.32)
1966	1099	226 (20.56)	456 (41.49)	73 (6.64)	259 (23.57)	85 (7.73)
1971	1865	576 (30.88)	682 (36.57)	94 (5.04)	343 (18.39)	170 (9.12)
1976	2700	1057 (39.15)	779 (28.85)	115 (4.26)	351 (13.00)	398 (14.74)
1981	5391	2618 (48.56)	1160 (21.52)	162 (3.01)	554 (10.28)	897 (16.64)
1986	10577	6245 (59.04)	1780 (16.83)	227 (2.15)	863 (8.16)	1462 (13.82)
1991	21374	14200 (66.44)	2954 (13.82)	331 (1.55)	1356 (6.34)	2533 (11.85)
1996	33786	23252 (68.82)	4204 (12.44)	449 (1.33)	2031 (6.01)	3850 (11.40)
1997	37332	25729 (68.92)	4672 (12.51)	484 (1.30)	2343 (6.28)	4104 (10.99)
1998	41368	28642 (69.24)	5138 (12.42)	538 @ (1.30)	2536 (6.13)	4514 (10.91)
1999	44875	31328 (69.81)	5556 (12.38)	540 @ (1.20)	2554 (5.69)	4897 (10.91)
2000	48857	34118 (69.83)	6143 (12.57)	562@ (1.15)	2715 (5.56)	5319 (10.89)
2001	54991	38556 (70.11)	7058 (12.83)	634@ (1.15)	2948 (5.36)	5795 (10.54)
2002	58924	41581 (70.57)	7613 (12.92)	635@ (1.08)	2974 (5.05)	6121 (10.39)
2003	67007	47519 (70.92)	8599 (12.83)	721@ (1.08)	3492 (5.21)	6676 (9.96)
2004	72718	51922 (71.40)	9451 (13.00)	768@ (1.06)	3749 (5.16)	6828 (9.39)
2005	81501	58799 (72.14)	10320 (12.66)	892@ (1.09)	4031 (4.94)	7457 (9.15)

** : Others include tractors, trailers, three wheelers (passenger vehicles) and other miscellaneous vehicles which are not separately classified.*

@ : Includes omni buses (P) : Provisional (R) : Revised
Figures in the paranthesis indicates percentage share calculated by the author.

Source: Department of Road Transport, Government of India (morth.nic.in)

Table 2: Summary Data on Passenger Traffic for Buses, Cars, Private Motorised Modes and Total Road Transport

(billion passenger km)

Year	Public Transport (Buses)	Cars	Total Private Motorised Modes@	Total Passenger Road Transport
1970-71	179.39	23.95	30.61	210
	(85.42)	(11.40)	(14.58)	
1975-76	267.94	27.25	40.06	308
	(86.99)	(8.85)	(13.01)	
1980-81	468.3	43.03	73.7	542
	(86.40)	(7.94)	(13.60)	
1985-86	709.34	66.79	140.66	850
	(83.45)	(7.86)	(16.55)	
1990-91	692.11	68.36	166.89	859
	(80.57)	(7.96)	(19.43)	
1995-96	1062.21	97.76	259.79	1322
	(80.35)	(7.39)	(19.65)	
2000-01	1554.38	188.69	499.68	2054
	(75.67)	(9.19)	(24.33)	
2001-02	1801.38	231.13	611.62	2413
	(74.65)	(9.58)	(25.35)	
2002-03	2071.96	280.99	743.04	2815
	(73.60)	(9.98)	(26.40)	
2003-04	2226.62	319.16	843.38	3070
	(72.53)	(10.40)	(27.47)	

*Figures in the parenthesis indicate percentage share in road traffic

@ Total private motorised modes includes two wheelers, cars and three wheelers

Sources: Based on a number of sources as mentioned in details in the section on data sources and methodology.

Table 3

Results of Unit Root Tests on the levels of the Series

Series	Value of Test Statistic (ADF/DF)
LRELATIVEREALP	-1.015390**
LTVPC	-1.044766**
LPERCAPGDP	-2.267656**
LPCNR	-2.652142**
LMODESHRPUB	-0.962626**

L indicates logarithms and ** indicates significance at 1 per cent level

Table 4

Results of Unit Root Tests on the first differences of the Series

Series	Value of Test Statistic (DF)
D(LRELATIVEREALP)	-3.871747**
D(LTVPC)	-4.769851**
D(LPERCAPGDP)	-3.508219**
D(LPCNR)	-3.392293*
D(LMODESHRPUB)	-3.911771*

D indicates first difference, * indicates significance at 5 per cent level and ** indicates significance at 1 per cent level

Table 5

Results of Trace Test for the set of variables- (LTVPC, LPERCAPGDP, LRELATIVEREALP)

Hypothesized No. of Cointegrating Equations	Eigenvalue	Likelihood Ratio
None	0.786274	54.98908**
At most 1	0.235513	8.697219
At most 2	0.021130	0.640704

*(**) denotes rejection of the hypothesis at 5 per cent (1 per cent) significance level
L.R. test indicates 1 cointegrating equation at 5 per cent significance level

Table 6

Results of Trace Test for the set of variables- (LPCNR, LPERCAPGDP, LRELATIVEREALP)

Hypothesized No. of Cointegrating Equations	Eigenvalue	Likelihood Ratio
None	0.587187	41.41124**
At most 1	0.244980	14.86845
At most 2	0.193139	6.438127**

** denotes rejection of the hypothesis at 1 per cent significance level
L.R. test indicates 1 cointegrating equation at 5 per cent significance level

Table 7: Estimated Cointegrating Vector for (LTVPC, LPERCAPGDP, LRELATIVEREALP)

LTVPC	LPERCAPGDP	LRELATIVEREALP	Trend	Constant
1.000000	-1.225577	0.812201	0.026387	6.138567
	(0.30618)	(0.06160)		

*Figures in the parenthesis are standard errors and L stands for logarithm

Table 8: Estimated Cointegrating Vector for (LPCNR, LPERCAPGDP, LRELATIVEREALP)

LPCNR	LPERCAPGDP	LRELATIVEREALP	Trend	Constant
1.000000	-1.172552	-0.052490	-0.009835	5.928002
	(0.14022)	(0.04136)		

*Figures in the parenthesis are standard errors and L stands for logarithm

Table 9: Long Run Price and Income Elasticity of Traffic Volume per Car (TVPC) and Per Capita New Registration (PCNR)

Variables	Income Elasticity	Elasticity w.r.t. relative real price of petrol
TVPC	1.23	-0.81
PCNR	1.17	0.05

Table 10: Estimated VECM for the set of variables (LTVPCCAR, LPERCAPGDP, LRELATIVEREALP)

Explanatory Variables	D(LTVPCCAR)	D(LPERCAPGDP)	D(LRELATIVEREALP)
E(-1)	-0.469417 (-3.00028)	0.034013 (0.50061)	-1.052016 (-3.71090)
D(LTVPCCAR (-1))	0.385435 (2.07337)	-0.007562 (-0.09367)	-0.255126 (-0.75742)
D(LPERCAPGDP(-1))	-1.732207 (-3.02625)	-0.332616 (-1.33812)	-0.113514 (-0.10945)
Trend	0.000871 (0.99566)	0.000819 (2.15767)	-0.000894 (-0.56397)
Adj. R-squared	0.276117	0.044218	0.318512

Note: L stands for logarithm, E (-1) indicates the adjustment factor, figures in the parenthesis shows t-values and D stands for first difference.

Table 11: Estimated VECM for the set of variables (PCNR, PERCAPGDP, RELATIVEREALP)

Explanatory Variables	D(LPCNR)	D(LPERCAPGDP)	D(LRELATIVEREALP)
E(-1)	-0.168831 (-1.44874)	0.341182 (1.76214)	2.837064 (3.08579)
D(LPCNR(-3))	0.310589 (1.40501)	-0.447645 (-1.21883)	-1.177292 (-0.67505)
D(LRELATIVEREALP(-1))	-0.028638 (-1.20213)	-0.031527 (-0.79655)	-0.222416 (-1.18342)
Intercept	0.009040 (2.24002)	0.007283 (1.08626)	-0.017721 (-0.55660)
Trend	0.0000464 (0.15619)	0.001022 (2.07190)	-0.003572 (-1.52445)
Adj. R-squared	0.513955	0.056438	0.128633

Note: L stands for logarithm; E (-1) indicates the adjustment factor, figures in the parenthesis show t-values and D stands for first difference.

Table 12: Road Transport Default CO_2 Emission Factors (in kg/TJ)

Fuel	Lower	Upper
Motor Gasoline	67500	73000
Gas/Diesel Oil	72600	74800

Source: Adopted from table 3.2.1, Chapter 3, p 3.16, Mobile Combustion, 2006 IPCC Guidelines for National Greenhouse Gas Inventories