Vehicle Ownership and Income Growth, Worldwide: 1960-2030

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Abstract:

The speed of vehicle ownership expansion in emerging market and developing countries has important implications for transport and environmental policies, as well as the global oil market. The literature remains divided on the issue of whether the vehicle ownership rates will ever catch up to the levels common in the advanced economies. This paper contributes to the debate by building a model that explicitly models the vehicle saturation level as a function of observable country characteristics: urbanization and population density. Our model is estimated on the basis of pooled time-series (1960-2002) and cross-section data for 45 countries that include 75 percent of the world's population. We project that the total vehicle stock will increase from about 800 million in 2002 to over 2 billion units in 2030. By this time, 56% of the world's vehicles will be owned by non-OECD countries, compared with 24% in 2002. In particular, China's vehicle stock will increase nearly twenty-fold, to 390 million in 2030. This fast speed of vehicle ownership expansion implies rapid growth in oil demand.

Keywords: vehicle ownership, transport modeling, oil market.
JEL Classification: O12 - Microeconomic Analyses of Economic Development;
R41 - Transportation: Demand, Supply, and Congestion;
Q41 – Energy Demand and Supply.

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1. INTRODUCTION

Economic development has historically been strongly associated with an increase in the demand for transportation and particularly in the number of road vehicles. This relationship is also evident in the developing economies today. Surprisingly, very little research has been done on the determinants of vehicle ownership in developing countries. Typically, researchers make assumptions about vehicle saturation rates (IEA, 2005, or OPEC, 2004), which are very much lower than the vehicle ownership already experienced in the most of the wealthier countries. Because of this, their forecasts of future vehicle ownership in currently developing countries are much lower than would be expected by comparison with developed countries when these were at comparable income levels.

This paper empirically estimates the saturation rate for different countries, by formalizing the idea that vehicle saturation levels may be different across countries. Given data availability, we limit ourselves to the influence of demographic factors, urban population and population density. A higher proportion of urban population and greater population density would encourage the availability and use of public transit, and could reduce the distances traveled by individuals and for goods transportation. Thus countries that are more urbanized and densely populated could have a lower need for vehicles. In this study we attempt to account for these demographic differences by specifying a country's saturation level as a function its population density and proportion of the population living in urban areas. There are, of course, a number of other reasons why saturation may vary amongst countries. For example, the existence of reliable public transport alternatives and the use of rail for goods transport may reduce the saturation demand for road vehicles. Alternatively, investment in a comprehensive road network will most likely increase the saturation level. Such factors, however, are difficult to take into account, as they would require far more data than are available for all but a few countries.

This paper examines the trends in the growth of the stock of road vehicles (at least 4 wheels) for a large sample of countries since 1960 and makes projections of its development through 2030. It employs an S-shaped function – the Gompertz function – to estimate the relationship between vehicle ownership and per-capita income, or GDP. Pooled time-series and cross-section data are employed to estimate empirically the responsiveness of vehicle ownership to income growth at different income levels. By employing a dynamic model specification, which takes into account lags in adjustment of the vehicle stock to income changes, the influence of income on the vehicle stock over time is examined. The estimates are used, in conjunction with forecasts of income and population growth, for projections of future growth in the vehicle stock.

The study builds on the earlier work of Dargay and Gately (1999), who estimated vehicle demand in a sample of 26 countries - 20 OECD countries and 6 developing countries – for the period 1960 to 1992, and projected vehicle ownership rates until 2015.

The current study extends that work in four ways. Firstly, we relax the 1999 paper's assumption of a common saturation level for all countries. In our previous study, the estimated saturation level was constrained to be the same for all countries (at about 850 vehicles per thousand people); differences in vehicle ownership between countries at the same income level were accounted for by allowing saturation to be reached at different income levels.

Secondly, the data set is extended in time to 2002 and adds 19 countries (mostly non-OECD countries) to the original 26; these 45 countries comprise about three-fourths of world population. The inclusion of a large number of non-OECD countries – more than one-third of the countries, with three-fourths of the sample's population – provides a high degree of variation in both income and vehicle ownership. This allows more precise estimates of the relationship between income and vehicle ownership at various stages of economic development. In addition, the model is used for countries not included in the econometric analysis to obtain projections for the "rest of the world".

The third extension we make to our earlier study concerns the assumption of symmetry in the response of vehicle ownership to rising and falling income. Given habit persistence, the longevity of the vehicle stock and expectations of rising income, one might expect that reductions in income would not lead to changes in vehicle ownership of the same magnitude as those resulting from increasing income. If this is the case, estimates based on symmetric models can be misleading if there is a significant proportion of observations where income declines. This is the case in the current study, particularly for developing countries. In most countries, real per capita income has fallen occasionally, and in Argentina and South Africa it has fallen over a number of years. In order to account for possible asymmetry, the demand function is specified so that the adjustment to falling income can be different from that to rising income. Specifically, the model permits the short-run response to be different for rising and falling income without changing the equilibrium relationship between the vehicle stock and income. The hypothesis of asymmetry is then tested statistically.

Finally, the fourth extension is to use the projections of vehicle growth to investigate the implications for future transportation oil demand. This is based on a number of simplifying assumptions and comparisons are made with other projections.

Section 2 summarizes the data used for the analysis, and explores the historical patterns of vehicle ownership and income growth. Section 3 presents the Gompertz model used in the econometric estimation, and the econometric results are described in Section 4. Section 5 summarizes the projections for vehicle ownership, based upon assumed growth rates of per-capita income in the various countries. Section 6 presents the implications for the growth of highway fuel demand. Section 7 presents conclusions.

2. HISTORICAL PATTERNS IN THE GROWTH OF VEHICLE OWNERSHIP

Table 1 summarizes the various countries' historical data[1] in 1960 and 2002, for per-capita income (GDP), vehicle ownership, and population. Comparisons of the data for 1960 and 2002 are graphed below (in Section 5, we present similar graphic comparisons between 2002 and the projections for 2030).

The relationship between the growth of vehicle ownership and per-capita income is highly non-linear. Vehicle ownership grows relatively slowly at the lowest levels of per-capita income, then about twice as fast as income at middle-income levels (from $3,000 to $10,000 per capita), and finally, about as fast as income at higher income levels, before reaching saturation at the highest levels of income. This relationship is shown in Figure 1, using annual data over the entire period 1960-2002 for the USA, Germany, Japan and South Korea; in the background is an illustrative Gompertz function that is on average representative of our econometric results below. Figure 2 shows similar data for China, India, Brazil and South Korea – with the same Gompertz function, but using logarithmic scales. Figure 3 shows the illustrative Gompertz relationship between vehicle ownership and per-capita income, as well as the income elasticity of vehicle ownership at different levels of per-capita income.

[1] All OECD countries are included, excepting Portugal and the Slovak Republic. Portugal was excluded because we could not get vehicles data that excluded 2-wheeled vehicles, and the Slovak Republic because comparable data were unavailable for a sufficiently long period. Among the non-OECD countries with comparable data, we excluded Singapore and Hong Kong because their population density was 10 times greater than any of the other countries, and we excluded Colombia because of implausible 25% annual reductions in vehicle registrations in 1994 and 1997.

Table 1. Historical Data on Income, Vehicle Ownership and Population, 1960-2002

			per-capita GDP (thousands, real, PPP)			Vehicles per 1000 population			Total Vehicles (millions)			ratio of growth rates: Veh.Own. to per-cap. GDP	Population, 2002		
Country	Code	first data year (if not 1960)	1960 or first year	2002	Average annual growth rate	1960 or first year	2002	Average annual growth rate	1960 or first year	2002	Average annual growth rate		millions	density per sq.KM	% urbanized
OECD, North America															
Canada	Can		10.4	26.9	2.3%	292	581	1.6%	5.2	18.2	3.0%	0.72	31	3	79
United States	USA		13.1	31.9	2.1%	411	812	1.6%	74.4	233.9	2.8%	0.76	288	31	78
Mexico	Mex		3.7	8.1	1.9%	22	165	4.9%	0.8	16.7	7.5%	2.58	101	53	75
OECD, Europe															
Austria	Aut		8.1	26.3	2.8%	69	629	5.4%	0.5	5.1	5.8%	1.91	8	97	68
Belgium	Bel		8.2	24.7	2.7%	102	520	4.0%	0.9	5.3	4.3%	1.48	10	315	97
Switzerland	Che		15.4	27.7	1.4%	106	559	4.0%	0.6	4.0	4.8%	2.89	7	184	67
Czech Republic	Cze	1970	8.9	13.6	1.3%	82	390	5.0%	0.8	4.0	5.1%	3.79	10	133	75
Germany	Deu		9.0	23.5	2.3%	73	586	5.1%	5.1	48.3	5.5%	2.20	83	236	88
Denmark	Dnk		10.6	25.9	2.1%	126	430	3.0%	0.6	2.3	3.4%	1.38	5	127	85
Spain	Esp		4.8	19.3	3.3%	14	564	9.2%	0.4	22.9	9.9%	2.74	41	82	78
Finland	Fin		7.4	24.3	2.9%	58	488	5.2%	0.3	2.5	5.6%	1.82	5	17	59
France	Fra		8.5	23.7	2.5%	158	576	3.1%	7.2	35.3	3.9%	1.26	61	108	76
Great Britain	GBr		9.7	23.6	2.1%	137	515	3.2%	7.2	30.6	3.5%	1.50	59	246	90
Greece	Grc		4.5	16.1	3.1%	10	422	9.4%	0.1	4.6	10.1%	3.03	11	82	61
Hungary	Hun	1963	4.2	12.3	2.8%	15	306	8.1%	0.1	3.0	8.1%	2.87	10	110	65
Ireland	Ire		5.3	29.8	4.2%	78	472	4.4%	0.2	1.9	5.2%	1.05	4	57	60
Iceland	Isl		8.3	26.7	2.8%	118	672	4.2%	0.0	0.2	5.4%	1.50	0.3	3	93
Italy	Ita		7.2	23.3	2.8%	49	656	6.4%	2.5	37.7	6.7%	2.25	57	196	67
Luxembourg	Lux		10.9	42.6	3.3%	135	716	4.0%	0.05	0.3	4.7%	1.23	0.4	173	92
Netherlands	Nld		9.6	25.3	2.3%	59	477	5.1%	0.7	7.7	5.9%	2.19	16	477	90
Norway	Nor		7.7	28.1	3.1%	95	521	4.1%	0.3	2.4	4.7%	1.33	5	15	75
Poland	Pol		4.0	9.6	2.1%	8	370	9.5%	0.2	14.4	10.3%	4.51	39	127	63
Sweden	Swe		10.2	25.4	2.2%	175	500	2.5%	1.3	4.5	3.0%	1.15	9	22	83
Turkey	Tur		2.5	6.1	2.1%	4	96	7.7%	0.1	6.4	10.0%	3.62	67	90	67
OECD, Pacific															
Australia	Aus		10.4	25.0	2.1%	266	632	2.1%	2.7	12.5	3.7%	0.99	20	3	91
Japan	Jpn		4.5	23.9	4.1%	19	599	8.6%	1.8	76.3	9.4%	2.12	127	349	79
Korea	Kor		1.4	15.1	5.8%	1.2	293	13.9%	0.03	13.9	15.7%	2.40	48	483	83
New Zealand	NZL		11.1	19.6	1.4%	271	612	2.0%	0.6	2.4	3.2%	1.45	4	15	86
Non-OECD, South America															
Argentina	Arg	1962	9.7	9.6	-0.05%	55	186	3.1%	0.9	7.1	5.4%	-67.8	38	13	88
Brazil	Bra	1962	2.7	7.1	2.5%	20	121	4.6%	1.0	20.8	7.8%	1.87	171	21	82
Chile	Chl	1962	1.8	9.2	4.2%	17	144	5.4%	0.1	2.2	7.5%	1.29	16	21	86
Dominican Rep.	Dom	1962	2.3	6.0	2.4%	7	118	7.3%	0.02	1.0	10.7%	3.04	9	178	67
Ecuador	Ecu	1969	1.7	2.9	1.6%	9	50	5.2%	0.03	0.7	10.1%	3.16	13	46	64
Non-OECD, Africa and Middle East															
Egypt	Egy	1963	1.2	3.5	2.8%	4	38	6.0%	0.1	2.5	8.4%	2.16	68	67	43
Israel	Isr	1961	3.3	17.9	4.2%	25	303	6.2%	0.1	1.9	9.3%	1.49	6	318	92
Morocco	Mar	1962	2.1	3.6	1.3%	17	59	3.2%	0.2	1.8	6.0%	2.44	30	66	57
Syria	Syr		1.2	3.1	2.4%	6	35	4.1%	0.03	0.6	7.5%	1.71	17	92	52
South Africa	Zaf	1962	6.7	8.8	0.7%	66	152	2.1%	1.1	6.9	4.7%	3.17	45	37	58
Non-OECD, Asia															
China	Chn	1962	0.3	4.3	6.5%	0.38	16	9.8%	0.2	20.5	12.0%	1.51	1285	137	38
Chinese Taipei	Twn	1974	3.8	18.5	5.0%	14	260	9.5%	0.2	5.9	12.4%	1.89	23	701	81
Indonesia	Idn		0.7	2.9	3.3%	2.1	29	6.4%	0.2	6.2	8.6%	1.93	216	117	43
India	Ind		0.9	2.3	2.3%	1.0	17	6.8%	0.4	17.4	9.1%	2.92	1051	353	28
Malaysia	Mys	1967	2.2	8.1	3.8%	25	240	6.7%	0.2	5.9	9.6%	1.77	25	74	59
Pakistan	Pak		0.9	1.8	1.8%	1.7	12	4.7%	0.1	1.7	7.4%	2.57	145	188	34
Thailand	Tha		1.0	6.2	4.4%	4	127	8.7%	0.1	8.1	11.0%	1.98	64	121	20
Sample (45 countries)			**3.4**	**8.6**	**2.3%**	**53**	**166**	**2.8%**	**118**	**728**	**4.4%**	**1.21**	**4346**	**68**	**48**
Other Countries			**2.2**	**3.1**	**0.8%**	**5**	**45**	**5.2%**	**4**	**83**	**7.4%**	**6.73**	**1891**	**28**	**45**
OECD Total			**8.1**	**22.12**	**2.4%**	**150**	**550**	**3.1%**	**115**	**617**	**4.1%**	**1.30**	**1127**	**34**	**78**
Non-OECD Total			**1.4**	**3.6**	**2.3%**	**4**	**39**	**5.6%**	**9**	**195**	**7.5%**	**2.39**	**5110**	**53**	**41**
Total World			**3.1**	**7.0**	**2.0%**	**41**	**130**	**2.8%**	**122**	**812**	**4.6%**	**1.41**	**6237**	**48**	**47**

Figure 1. Vehicle Ownership and Per-Capita Income for USA, Germany, Japan, and South Korea, with an Illustrative Gompertz Function, 1960-2002

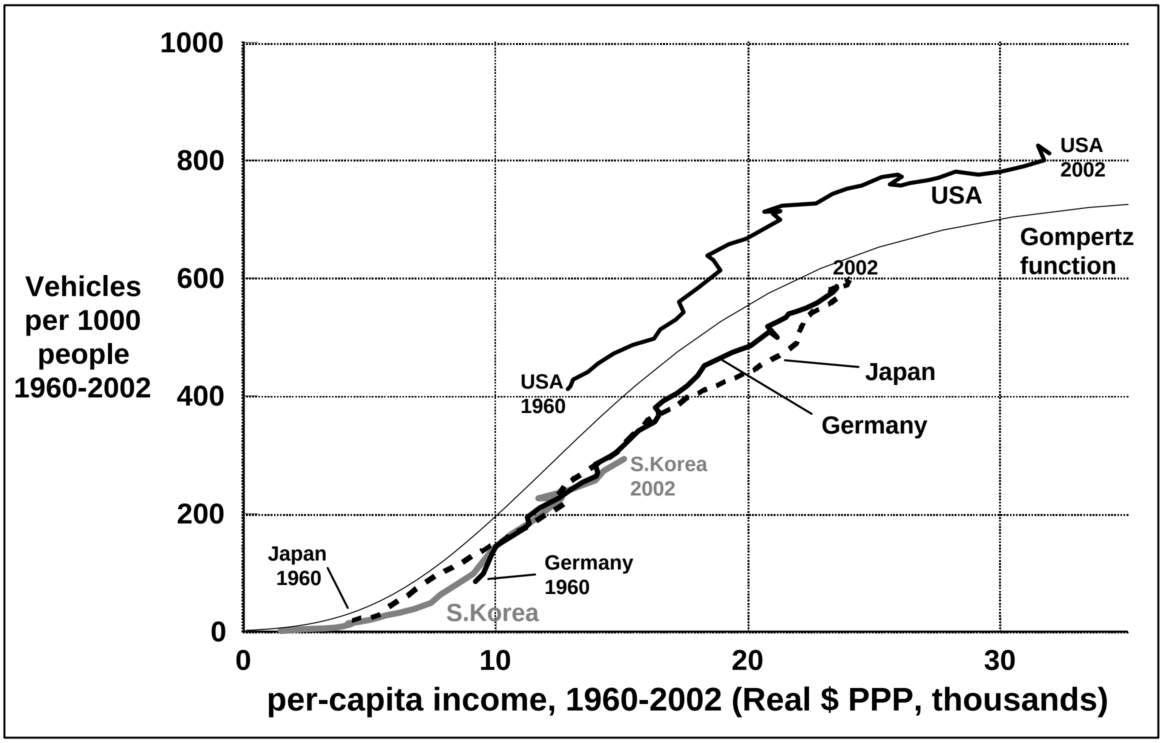
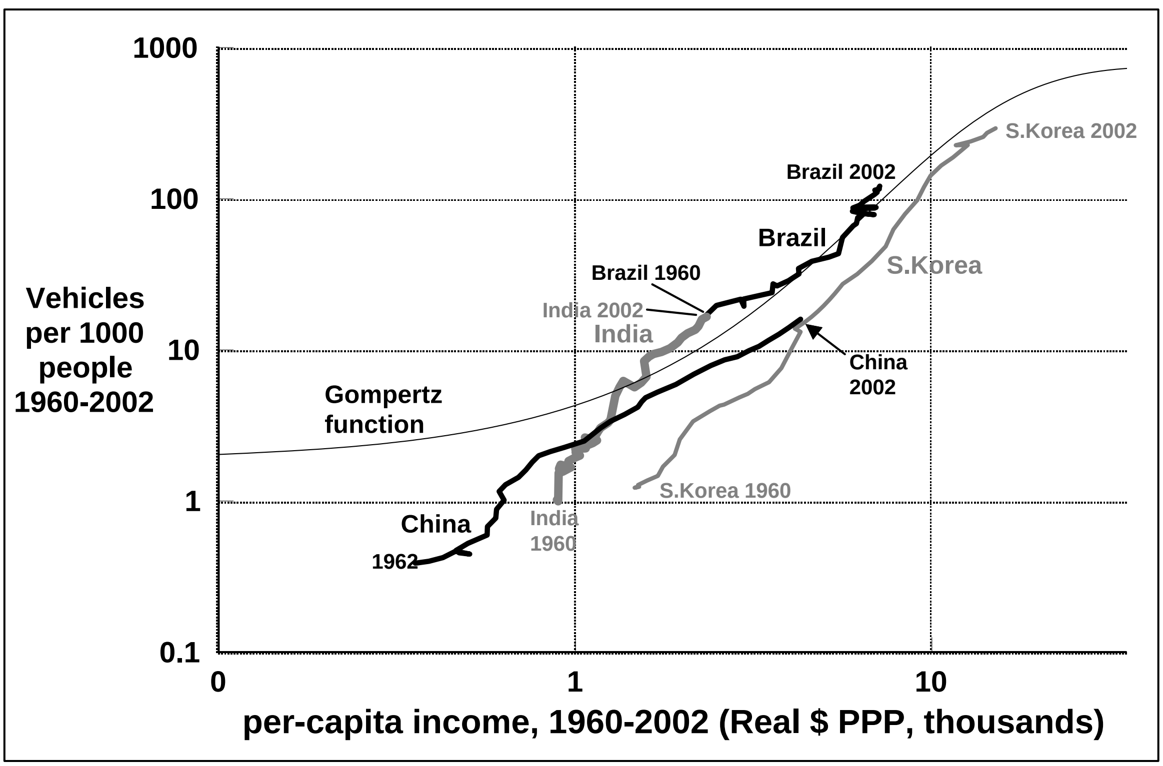


Figure 2. Vehicle Ownership and Per-capita Income for South Korea, Brazil, China, and India, with the Same Illustrative Gompertz Function, 1960-2002



3. THE MODEL

As illustrated above, we represent the relationship between vehicle ownership and per-capita income by an S-shaped curve. This implies that vehicle ownership increases slowly at the lowest income levels, and then more rapidly as income rises, and finally slows down as saturation is approached. There are a number of different functional forms that can describe such a process—for example, the logistic, logarithmic logistic, cumulative normal, and Gompertz functions. Following our earlier studies, the Gompertz model was chosen for the empirical analysis, because it is relatively easy to estimate and is more flexible than the logistic model, particularly by allowing different curvatures at low- and high-income levels.[2]

Letting *V** denote the long-run equilibrium level of vehicle ownership (vehicles per 1000 people), and letting GDP denote per-capita income (real 1995 $ Purchasing Power Parity), the Gompertz model can be written as:

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

where γ is the saturation level (measured in vehicles per 1000 people) and α and β are negative parameters defining the shape, or curvature, of the function. Figure 3.1 depicts an illustrative Gompertz function, similar to what we have estimated econometrically.

The implied long-run elasticity of the vehicle/population ratio with respect to per-capita income is not constant, due to the nature of the functional form, but instead varies with income. The long-run income elasticity is calculated as:

$$\eta_t^{LR} = \alpha\beta GDP_t e^{\beta GDP_t} \tag{2}$$

This elasticity is positive for all income levels, because α and β are negative. The elasticity increases from zero at GDP=0 to a maximum at GDP=$-1/\beta$, then declines to zero asymptotically as saturation is approached. Thus β determines the per-capita income level at which vehicle ownership becomes saturated: the larger the β in absolute value, the lower the income level at which vehicle ownership flattens out. Figure 3.2 shows the income elasticity for various income levels of the Gompertz functions depicted in Figure 3.1.

[2] See Dargay-Gately (1999) for a simpler model, using a smaller set of countries. Previous work in summarized in Mogridge (1983), which discusses vehicle ownership being modelled by various S-shaped functions of time, rather than of per-capita income.

Fig. 3.1 Illustrative Gompertz function

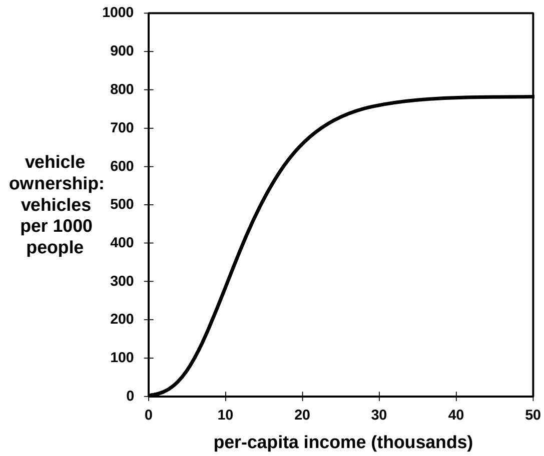
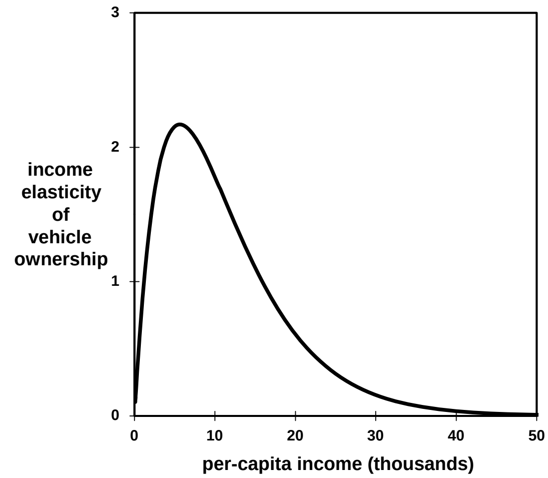


Fig. 3.2 Implied Income Elasticity



We assume that the Gompertz function (1) describes the *long-run* relationship between vehicle ownership and per-capita income. In order to account for lags in the adjustment of vehicle ownership to per-capita income, a simple partial adjustment mechanism is postulated:

$$V_t = V_{t-1} + \theta\,(V_t^* - V_{t-1}) \qquad (3)$$

where V is actual vehicle ownership and θ is the speed of adjustment ($0 < \theta < 1$). Such lags reflect the slow adjustment of vehicle ownership to increased income: the necessary build-up of savings to afford ownership; the gradual changes in housing patterns and land use that are associated with increased ownership; and the slow demographic changes as young adults learn to drive, replacing their elders who have never driven. Substituting equation (1) into equation (3), we have the equation:

$$V_t = \gamma\theta\, e^{\alpha e^{\beta GDP_t}} + (1-\theta)V_{t-1} \qquad (4)$$

In Dargay and Gately (1999), we had assumed that only the coefficients β_i were country-specific, while all the other parameters of the Gompertz function were the same for all countries: the saturation level γ, the speed of adjustment θ, and the coefficient α. Thus, differences between countries were reflected in the curvature parameters β_i , which determined the income level for each country at which the common level of saturation is reached. In this paper we relax this restriction of a common saturation level. Instead, we assume that the maximum saturation level will be that estimated for the USA, denoted γ_{MAX} . Other countries that are more urbanized and more densely populated than the

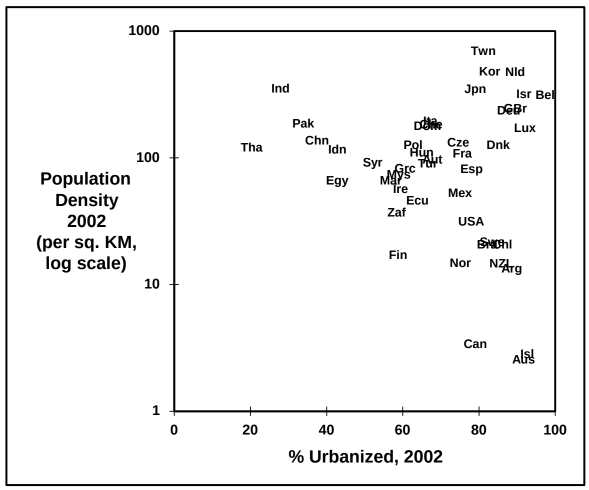
USA will have lower saturation levels. The saturation level for country *i* at time *t* is specified as:[3]

$$
\begin{aligned}
\gamma_{it} &= \gamma_{MAX} + \lambda \overline{D}_{it} + \varphi \overline{U}_{it} \\
&\quad \textit{where} \\
\overline{D}_{it} &= D_{it} - D_{USA,t} \quad \textit{if} \quad D_{it} > D_{USA,t} \\
&= 0 \quad \textit{otherwise} \\
&\quad \textit{and} \\
\overline{U}_{it} &= U_{it} - U_{USA,t} \quad \textit{if} \quad U_{it} > U_{USA,t} \\
&= 0 \quad \textit{otherwise}
\end{aligned} \tag{5}
$$

where λ and φ are negative.

Figure 4 plots the 2002 data on population density and urbanization. The most urbanized and densely populated countries are in Western Europe and East Asia: Netherlands, Belgium, Germany, Great Britain, Japan and South Korea. Some countries are highly urbanized but not densely populated, such as Australia and Canada. Others are densely populated but not highly urbanized, such as China, India, Pakistan, Thailand, and Indonesia.

Figure 4. Countries' Population Density and Urbanization, 2002



The dynamic specification in equations (3) and (4) assumes that the response to a fall in income is equal but opposite the response to an equivalent rise in income. As mentioned earlier, there is a good deal of evidence that this may not be the case, and that assuming symmetry may lead to biased estimates of income elasticities. Since many of the countries in the sample have experienced negative as well as positive per-capita income growth over the period (especially Argentina and South Africa), it is important that we take such asymmetry into consideration.[4] To do so, the adjustment coefficient relating to periods of falling income, θ_F , is allowed to be different from that to rising income, θ_R. This is done by creating two dummy variables defined as:

[3] Population density and urbanization are normalised by taking the deviations from their means over all countries and years in the data sample. Since population density and urbanization vary over time, so too does the saturation level.

[4] This issue had been addressed previously in Dargay (2001).

$$R_{it} = 1 \ \ if \ \ GDP_{it} - GDP_{it-1} > 0 \ and = 0 \ otherwise$$
$$F_{it} = 1 \ \ if \ \ GDP_{it} - GDP_{it-1} < 0 \ and = 0 \ otherwise \tag{6}$$

and replacing θ in (4) with:

$$\theta = \theta_R R_{it} + \theta_F F_{it} \tag{7}$$

This specification does not change the equilibrium relationship between the vehicle stock and income given in equation (1), nor the long-run income elasticities. Only the rate of adjustment to equilibrium is different for rising and falling income, so that the short-run elasticities and the time required for adjustment will be different. Since it is likely that vehicle ownership does not decline as quickly when income falls as it increases when income rises, we would expect $\theta_R > \theta_F$. The hypothesis of asymmetry can be tested statistically from the estimates of θ_R and θ_F. If they are not statistically different from each other, symmetry cannot be rejected and the model reverts to the traditional, symmetric case.

Substituting (5) and (7) into (4), the model to be estimated econometrically from the pooled data sample becomes:

$$V_{it} = (\gamma_{MAX} + \lambda \overline{D}_{it} + \varphi \overline{U}_{it})(\theta_R R_{it} + \theta_F F_{it}) e^{\alpha e^{\beta_i GDP_{it}}} + (1 - \theta_R R_{it} - \theta_F F_{it}) V_{it-1} + \varepsilon_{it} \tag{8}$$

where the subscript *i* represents country *i* and ε_{it} is random error term. The adjustment parameters, θ_R and θ_F , and the parameters α, $\bar{\gamma}$, φ and λ are constrained to be the same for all countries, while β_i is allowed to be country-specific, as is each country's saturation level from equation (5). The long-run income elasticities for each country are calculated as

$$\eta_{it}^{LR} = \alpha \beta_i GDP_{it} e^{\beta_i GDP_{it}} \tag{9}$$

which are the same as in the symmetric model (2). The short-run income elasticities are also determined by the adjustment parameter, θ, and are

$$\eta_{it}^{SR} = \theta \alpha \beta_i GDP_{it} e^{\beta_i GDP_{it}} \ . \tag{10}$$

where $\theta = \theta_R$ for income increases and $\theta = \theta_F$ for income decreases.

The rationale for pooling time-series data across countries is the following. Although it is possible, in theory, to estimate a separate vehicle ownership function for each country, the short time periods and relatively small range of income levels that are available for each country make such an approach untenable. Reliable estimation of the saturation level requires observations on vehicle ownership which are nearing saturation.

Analogously, estimation of the parameter α, which determines the value of the Gompertz function at the lowest income levels, necessitates observations for low income and ownership levels. Thus it would not be sensible to estimate the saturation level for low-income countries separately, because vehicle ownership in these countries is far from saturation. Similarly, one could not estimate the lower end of the curve, i.e. the parameter α, on the basis of data only for high-income countries with high vehicle-ownership, unless historic data were available for many years in the past. For these reasons, we use a pooled time-series cross-section approach, with all countries being modeled simultaneously.

We had considered utilizing additional explanatory variables in the model, such as the cost of vehicle ownership, or the price of gasoline.[5] However, the unavailability of data for a sufficient number of countries and periods prevented such an attempt.

[5] Storchmann (2005) uses fuel price, the fixed cost of vehicle ownership, and income distribution – but not per-capita income – to explain vehicle ownership across countries. His data set includes more countries (90) but only a short time series, 1990-1997.

4. MODEL ESTIMATION

The model described in equation (8) was estimated for the cross-section time-series data for the 45 countries. The period of estimation is generally from 1960 to 2002, but is shorter for some countries due to early data being unavailable (see Table 1). In all, we have 1838 observations. In order to allow larger countries to have more influence on the estimated coefficients, the observations were weighted with population. As mentioned above, the maximum saturation level, γ_{MAX} , the speed-of-adjustment coefficients, θ_R and θ_F, and the lower-curvature parameter α were constrained to be the same for all countries. The upper-curvature parameters β_i were estimated separately for each country. The model was estimated using iterative least squares.

The resulting estimates are shown in Table 2. A total of 51 parameters are estimated, including 45 country-specific β_i. All the estimated coefficients are of the expected signs: θ_R , θ_F , and γ_{MAX} are positive and α, λ, φ and β_i are negative. All coefficients are statistically significant, except for the β_i coefficients for Luxembourg, Iceland, Ecuador, and Syria. From the Adjusted R^2, we see the model explains the data very well; however, this is to be expected in a model containing a lagged dependent variable.

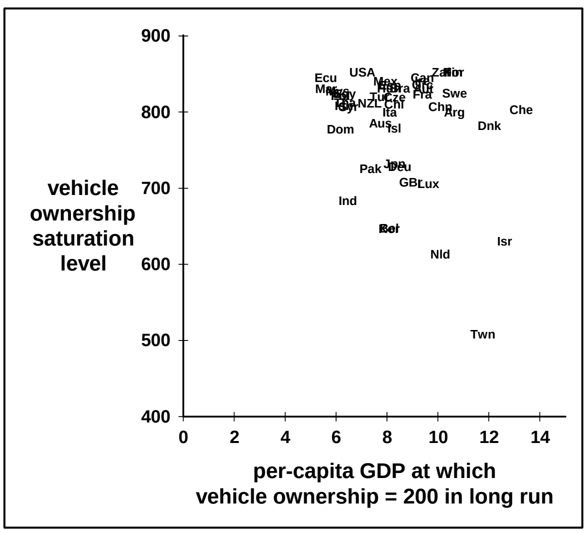
The estimated adjustment parameter is larger for rising income than for falling income, 0.095 versus 0.084. Testing the equality $\theta_R = \theta_F$ yields an F-statistic of 4.76 (with probability value=0.03) so that symmetry is rejected. This implies that the vehicle stock responds less quickly when income falls than when income rises. With increasing income, 9.5% of the complete adjustment occurs in one year, but when income falls only 8.4% of the long-term adjustment occurs in one year. Thus a fall in per-capita income reduces vehicle ownership about 11% less in the short run (1-year) than an equivalent rise in income increases vehicle ownership. The long-run elasticity is the same for both income increases and decreases.

Table 2. Estimated Coefficients of Equation (8)

		coef.	P-value		
Speed of adjustment θ					
income increases		0.095	0.0000		
income decreases		0.084	0.0000		
max. saturation level γ_{max}		852	0.0000		
population density λ		-0.000388	0.0000		
urbanization φ		-0.007765	0.0001		
alpha α		-5.897	0.0000		
Country	Code	beta coef.	P-value	**vehicle ownership saturation**	**per-capita GDP (in thousands) at which vehicle ownership = 200**
OECD, North America					
Canada	Can	-0.15	0.00	845	9.4
United States	USA	-0.20	0.00	852	7.0
Mexico	Mex	-0.17	0.00	840	7.9
OECD, Europe					
Austria	Aut	-0.15	0.00	831	9.4
Belgium	Bel	-0.20	0.00	647	8.1
Switzerland	Che	-0.11	0.00	803	13.3
Czech Republic	Cze	-0.17	0.00	819	8.3
Germany	Deu	-0.18	0.00	728	8.5
Denmark	Dnk	-0.12	0.00	782	12.0
Spain	Esp	-0.17	0.00	835	8.1
Finland	Fin	-0.13	0.00	852	10.6
France	Fra	-0.15	0.00	823	9.4
Great Britain	GBr	-0.17	0.00	707	8.9
Greece	Grc	-0.15	0.00	836	9.4
Hungary	Hun	-0.17	0.00	831	8.1
Ireland	Ire	-0.15	0.01	841	9.4
Iceland	Isl	-0.17	0.87	779	8.3
Italy	Ita	-0.18	0.00	800	8.1
Luxembourg	Lux	-0.16	0.78	706	9.6
Netherlands	Nld	-0.16	0.00	613	10.1
Norway	Nor	-0.13	0.00	852	10.6
Poland	Pol	-0.23	0.00	821	6.2
Sweden	Swe	-0.13	0.00	825	10.6
Turkey	Tur	-0.18	0.00	820	7.7
OECD, Pacific					
Australia	Aus	-0.19	0.00	785	7.7
Japan	Jpn	-0.18	0.00	732	8.3
Korea	Kor	-0.20	0.00	646	8.1
New Zealand	NZL	-0.19	0.01	812	7.3
Non-OECD, South America					
Argentina	Arg	-0.13	0.00	800	10.6
Brazil	Bra	-0.17	0.00	831	8.5
Chile	Chl	-0.17	0.00	810	8.3
Dominican Rep.	Dom	-0.24	0.02	777	6.2
Ecuador	Ecu	-0.25	0.13	845	5.6
Non-OECD, Africa and Middle East					
Egypt	Egy	-0.22	0.00	824	6.3
Israel	Isr	-0.13	0.00	630	12.6
Morocco	Mar	-0.25	0.00	830	5.6
Syria	Syr	-0.22	0.22	807	6.5
South Africa	Zaf	-0.14	0.00	852	10.1
Non-OECD, Asia					
China	Chn	-0.14	0.00	807	10.1
Chinese Taipei	Twn	-0.16	0.00	508	11.7
Indonesia	Idn	-0.23	0.00	808	6.3
India	Ind	-0.24	0.00	683	6.5
Malaysia	Mys	-0.23	0.00	827	6.0
Pakistan	Pak	-0.21	0.01	725	7.3
Thailand	Tha	-0.22	0.00	812	6.3
Adjusted R-squared		0.999821			
Sum of Squared Residuals		0.038947			

The estimated maximum saturation level is 852 vehicles per 1000 people – for the USA and for those countries which are less urbanized and less densely populated: Finland, Norway, and South Africa. The coefficients for population density and urbanization are both negative and statistically significant, indicating that the saturation level declines with increasing population density and with increasing urbanization. The lowest saturation levels among the large countries are for Netherlands, Belgium, Germany, Great Britain, Japan, South Korea and India. Figure 5 plots each country's estimated saturation level and the income level at which it would reach vehicle ownership of 200 vehicles per 1000 people. The latter measures reflects the country's curvature parameter β_i. Some countries would reach vehicle ownership of 200 quickly, at relatively low income levels (USA, India, Indonesia, Malaysia), while others would reach it more slowly, at much higher income levels (China, Netherlands, Denmark, Israel, Switzerland).

Fig. 5 Countries' Estimated Vehicle Ownership Saturation Levels and Income Levels at which Vehicle Ownership = 200.



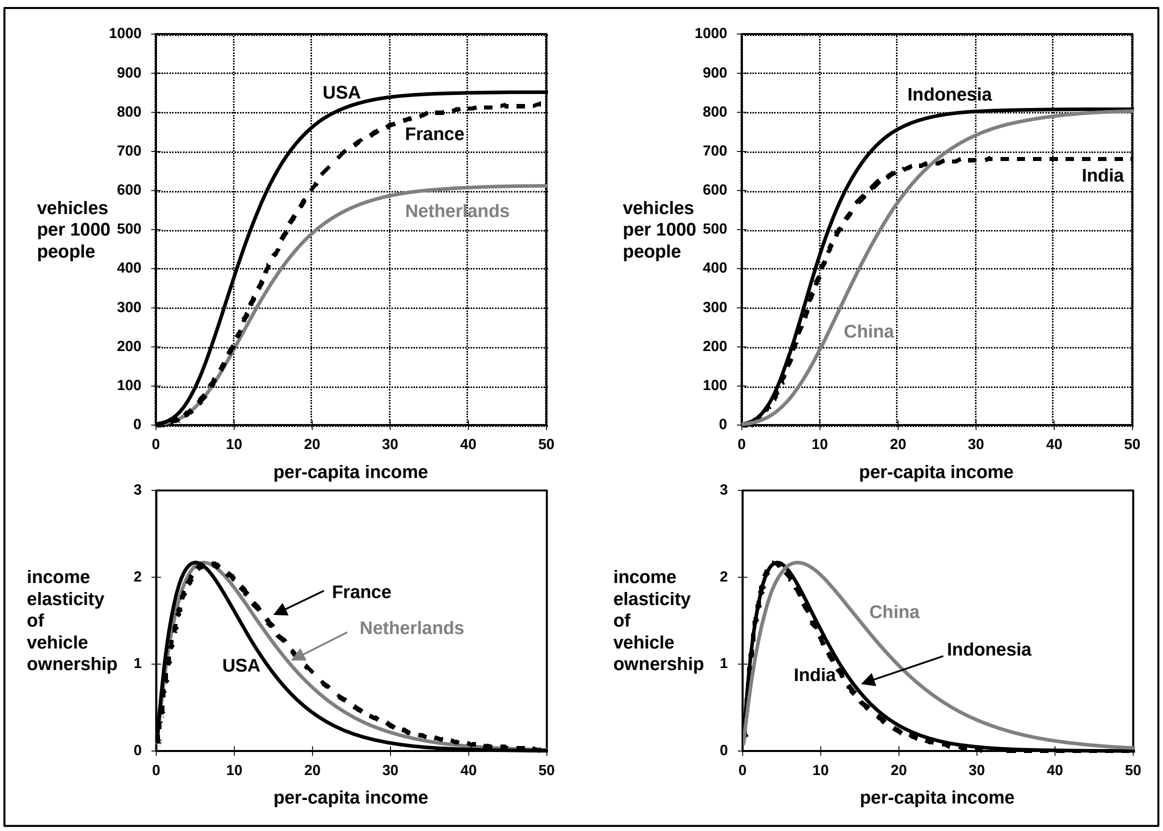
The value of α determines the maximum income elasticity of vehicle ownership rates[6], which in this case is estimated to be 2.1. The value of β_i determines the income level where the common maximum elasticity is reached: the smaller the β_i in absolute value, the greater the per-capita income at which the maximum income elasticity occurs – for the different countries respectively, at income levels between $4,000 and $9,600. The vehicle ownership level at which the maximum income elasticity occurs is about 90 vehicles per 1000 people. The values of α and β_i also determine the income level at which vehicle saturation is reached. The estimates imply that 99% of saturation is

[6] The maximum elasticity is derived by setting the derivative of the long-run elasticity with respect to GDP equal to zero, solving for the value of GDP where the elasticity is a maximum and replacing this value of GDP (=-1/β) in the original elasticity formula. This gives a maximum elasticity of $-\alpha e^{-1} = -0.367\alpha$.

reached, for the different countries respectively, at a per-capita income level of between $19,000 and $46,000.

The graphs in Figure 6 illustrate the cross-country differences in saturation levels and low-income curvature for 6 selected countries. Countries can differ in their saturation level, or their low-income curvature (measured by income level at which vehicle ownership of 200 is reached), or both. USA and France have similar saturation levels but different low-income curvatures: USA reaches 200 vehicle ownership at per-capita income of $7,000 while France reaches it at $9,400. France and Netherlands reach 200 vehicle ownership at similar income levels, but France has a much higher saturation level (823) than does Netherlands (613). Similarly, India and Indonesia have similar low-income curvatures – reaching vehicle ownership of 200 at about $6,500 – but India's saturation level (683) is lower than Indonesia's (808) because India is more urbanized and has higher population density. By contrast, China reaches vehicle ownership of 200 more slowly (at about $10,000) than India but it has a higher saturation level.[7]

Fig. 6 Long-run Gompertz Functions for Six Selected Countries, and the Implied Income Elasticity of Vehicle Ownership



[7] Although China is more urbanized than India, it has much lower population density as we have measured it, using land area. Since much of western China is virtually uninhabitable, it would have been preferable to use *habitable* land area rather than *total* land area when calculating population density, but such data are unavailable. This would have the effect of lowering China's estimated saturation level to something closer to that of India (683). The effect of this on China's projections is discussed in the next section.

5. PROJECTIONS OF VEHICLE OWNERSHIP TO 2030

On the basis of assumptions concerning future trends in income, population and urbanization, the model projects vehicle ownership for each country.[8] These are shown in Table 3 and graphed in figures that follow.

Within the OECD countries, projected growth in vehicle ownership is relatively slow, about 0.6% annually, because many of these countries are approaching saturation. The only exceptions to slowly growing vehicle ownership in the OECD are Mexico and Turkey, whose vehicle ownership will grow faster than income. However, due to population growth, the annual growth rate for total OECD vehicles is somewhat higher, at 1.4%. For the USA, we project only a slight increase in vehicle ownership (from 812 to 849 per 1000 people) but a large absolute increase in the total vehicle stock of 80 million, due to population growth of nearly 1% annually. This 80 million *increase* for the USA is larger than the projected 2030 *total* of vehicles in any European country, and is almost as large as the total number of vehicles in Japan.

For the non-OECD countries[9], we project much faster rates of growth: vehicle ownership growth of about 3.5% annually, and total vehicles growth of 6.5% annually – four times the rate for the OECD. The most rapid growth is in the non-OECD economies with high rates of income growth, and per-capita income levels ($3,000 to $10,000) at which the income elasticity of vehicle ownership is the highest. China has by far the highest growth rate of vehicle ownership, 10.6% annually, followed by India (7%) and Indonesia (6.5%). By 2030, China will have 269 vehicles per 1000 people – comparable to vehicle ownership levels of Japan and Western Europe in the early 1970's – and it will have more vehicles than any other country: 24% more vehicles than the USA. China's vehicle ownership is projected to grow rapidly for two reasons: (1) its projected high growth rate for per-capita income during 2002-2030, 4.8% (which is actually much slower than its recent rapid growth), and (2) vehicle ownership is growing 2.2 times as fast as per-capita income, as it passes through the middle level of per-capita income ($3,000 to $10,000) with the highest income-elasticity of vehicle ownership. Similarly for India and

[8] Population density is assumed to grow at the same rate as population. Projections for urbanization are obtained by estimating a model relating urbanization to per-capita income and lagged urbanization for all countries over the sample period and creating forecasts on the basis of this model and the projected per-capita income values. The model used and the estimates obtained are available upon request.

[9] For the "Other" (non-sample) countries in the rest of the world, we projected vehicle ownership from our estimated Gompertz function's parameters, adapted to this "Other" group's characteristics. In 2002 this group had per-capita income of about $3000 and owned 44 vehicles per 1000 people. We estimated the group's β_i coefficient by regressing the sample countries' β_i values against the levels of per-capita income at which the respective countries had 44 vehicles per 1000 people; this produced a value of β_i=-0.21 for "Other" countries. Using the sample countries' median saturation value (812), we assumed 2.5% annual per-capita income growth for "Other" countries, and projected their vehicle ownership to 2030.

Indonesia, whose per-capita income is not projected to grow as fast as China's, but whose vehicle ownership is projected to grow nearly twice as fast as per-capita income.

The faster growth of total vehicles in the non-OECD countries will more than double their share of world vehicles – from 24% in 2002 to 56% by 2030. Non-OECD countries will acquire over three-fourths of these additional vehicles – nearly 30% will be from China alone. By 2030, there will be 2.08 billion vehicles on the planet, compared with 812 million in 2002; this total is 2.5 times greater than in 2002.

The *historical* results shown in the left graphs of Figure 7 indicate quite rapid growth in vehicle ownership within the OECD, and in many non-OECD countries as well, over the period 1970-2002, when their vehicle ownership doubles or triples. In many countries, vehicle ownership frequently grew *twice* as fast as per-capita income, and in a few countries more than twice as fast. Such large income-elasticities for vehicle ownership (two or higher) are consistent with the non-linear Gompertz function we have estimated, for countries whose per-capita income is increasing through the middle-income range of $3,000 to $10,000.

The *projected* results, in the right graphs of Figure 7, show that most OECD countries' vehicle ownership growth will decelerate in the future, growing at a rate lower than per-capita income. However, the non-OECD countries whose per-capita income is increasing through the middle-income range will experience growth in vehicle ownership that is at least as rapid as their growth in per-capita income. In some of the largest countries, vehicle ownership will grow *twice* as rapidly as per-capita income – in China, India, Indonesia, and Egypt.

Figure 8 compares these historical and projected ratios of vehicle ownership growth to per-capita income growth. Figure 9 summarizes the historical and projected changes in total vehicles.

Table 3. Projections of Income and Vehicle Ownership, 2002-2030

Country	Code	per-capita GDP (thousands, real, PPP) 2002	per-capita GDP 2030	per-capita GDP Average annual growth rate	Vehicles per 1000 population 2002	Vehicles per 1000 population 2030	Vehicles per 1000 population Average annual growth rate	Total Vehicles (millions) 2002	Total Vehicles 2030	Total Vehicles Average annual growth rate	ratio of growth rates: Veh.Own. to per-cap. GDP	Population (millions) 2002	Population 2030	Population Average annual growth rate
OECD, North America														
Canada	Can	26.9	46.2	2.0%	581	812	1.2%	18.2	30.0	1.8%	0.62	31	37	0.6%
United States	USA	31.9	56.6	2.1%	812	849	0.2%	234	314	1.1%	0.08	288	370	0.9%
Mexico	Mex	8.1	19.3	3.1%	165	491	4.0%	16.7	65.5	5.0%	1.26	101	134	1.0%
OECD, Europe														
Austria	Aut	26.3	49.8	2.3%	629	803	0.9%	5.1	6.4	0.8%	0.38	8	8	-0.1%
Belgium	Bel	24.7	45.3	2.2%	520	636	0.7%	5.3	6.7	0.8%	0.33	10	11	0.1%
Switzerland	Che	27.7	54.3	2.4%	559	741	1.0%	4.0	4.9	0.7%	0.41	7	7	-0.3%
Czech Republic	Cze	13.6	40.2	4.0%	390	740	2.3%	4.0	7.1	2.1%	0.59	10	10	-0.2%
Germany	Deu	23.5	38.1	1.7%	586	705	0.7%	48.3	57.5	0.6%	0.38	83	82	0.0%
Denmark	Dnk	25.9	46.7	2.1%	430	715	1.8%	2.3	3.9	1.9%	0.86	5	5	0.1%
Spain	Esp	19.3	39.0	2.5%	564	795	1.2%	22.9	31.7	1.2%	0.48	41	40	-0.1%
Finland	Fin	24.3	46.1	2.3%	488	791	1.7%	2.5	4.2	1.8%	0.75	5	5	0.0%
France	Fra	23.7	41.2	2.0%	576	779	1.1%	35.3	50.3	1.3%	0.54	61	65	0.2%
Great Britain	GBr	23.6	43.1	2.2%	515	685	1.0%	30.6	44.0	1.3%	0.47	59	64	0.3%
Greece	Grc	16.1	33.0	2.6%	422	725	2.0%	4.6	7.7	1.8%	0.75	11	11	-0.1%
Hungary	Hun	12.3	40.0	4.3%	306	745	3.2%	3.0	6.4	2.7%	0.75	10	9	-0.5%
Ireland	Ire	29.8	54.0	2.1%	472	812	2.0%	1.9	3.9	2.7%	0.91	4	5	0.7%
Iceland	Isl	26.7	49.5	2.2%	672	768	0.5%	0.2	0.3	1.0%	0.21	0	0	0.5%
Italy	Ita	23.3	44.5	2.3%	656	781	0.6%	37.7	40.2	0.2%	0.27	57	52	-0.4%
Luxembourg	Lux	42.6	63.8	1.4%	716	706	-0.1%	0.3	0.4	1.1%	-0.04	0	1	1.1%
Netherlands	Nld	25.3	42.3	1.8%	477	593	0.8%	7.7	10.2	1.0%	0.42	16	17	0.2%
Norway	Nor	28.1	47.5	1.9%	521	805	1.6%	2.4	4.0	1.9%	0.83	5	5	0.3%
Poland	Pol	9.6	30.7	4.2%	370	746	2.5%	14.4	27.4	2.3%	0.60	39	37	-0.2%
Sweden	Swe	25.4	48.1	2.3%	500	777	1.6%	4.5	7.0	1.6%	0.69	9	9	0.0%
Turkey	Tur	6.1	14.1	3.0%	96	377	5.0%	6.4	34.7	6.2%	1.67	67	92	1.2%
OECD, Pacific														
Australia	Aus	25.0	47.6	2.3%	632	772	0.7%	12.5	18.4	1.4%	0.31	20	24	0.7%
Japan	Jpn	23.9	42.1	2.0%	599	716	0.6%	76.3	86.6	0.5%	0.31	127	121	-0.2%
Korea	Kor	15.1	39.0	3.5%	293	609	2.6%	13.9	30.5	2.8%	0.77	48	50	0.2%
New Zealand	NZL	19.6	39.1	2.5%	612	786	0.9%	2.4	3.5	1.3%	0.36	4	4	0.4%
Non-OECD, South America														
Argentina	Arg	9.6	25.5	3.6%	186	489	3.5%	7.1	23.8	4.4%	1.0	38	49	0.9%
Brazil	Bra	7.1	15.9	2.9%	121	377	4.1%	20.8	83.7	5.1%	1.43	171	222	0.9%
Chile	Chl	9.2	23.7	3.4%	144	574	5.1%	2.2	11.7	6.1%	1.47	16	20	0.9%
Dominican Rep.	Dom	6.0	13.6	3.0%	118	448	4.9%	1.0	5.1	5.9%	1.65	9	11	1.0%
Ecuador	Ecu	2.9	7.0	3.1%	50	182	4.7%	0.7	3.2	5.6%	1.50	13	17	0.9%
Non-OECD, Africa and Middle East														
Egypt	Egy	3.5	6.6	2.3%	38	142	4.9%	2.5	15.5	6.7%	2.09	68	109	1.7%
Israel	Isr	17.9	25.9	1.3%	303	454	1.5%	1.9	4.1	2.7%	1.10	6	9	1.3%
Morocco	Mar	3.6	7.5	2.7%	59	228	4.9%	1.8	9.7	6.3%	1.83	30	43	1.3%
Syria	Syr	3.1	4.9	1.6%	35	80	3.0%	0.6	2.3	4.9%	1.89	17	29	1.8%
South Africa	Zaf	8.8	18.6	2.7%	152	395	3.5%	6.9	16.7	3.2%	1.27	45	42	-0.3%
Non-OECD, Asia														
China	Chn	4.3	16.0	4.8%	16	269	10.6%	20.5	390	11.1%	2.20	1285	1451	0.4%
Chinese Taipei	Twn	18.5	46.2	3.3%	260	477	2.2%	5.9	13.6	3.1%	0.66	23	29	0.8%
Indonesia	Idn	2.9	7.3	3.4%	29	166	6.5%	6.2	46.1	7.4%	1.89	216	278	0.9%
India	Ind	2.3	6.2	3.5%	17	110	7.0%	17.4	156	8.1%	1.98	1051	1417	1.1%
Malaysia	Mys	8.1	19.8	3.2%	240	677	3.8%	5.9	23.8	5.1%	1.16	25	35	1.3%
Pakistan	Pak	1.8	3.4	2.2%	12	29	3.2%	1.7	7.8	5.6%	1.48	145	272	2.3%
Thailand	Tha	6.2	18.3	3.9%	127	592	5.7%	8.1	44.6	6.3%	1.43	64	75	0.6%
Sample (45 countries)		**8.6**	**18.3**	**1.8%**	**166**	**316**	**1.5%**	**728**	**1765**	**3.2%**	**0.85**	**4346**	**5379**	**0.8%**
Other Countries		**3.0**	**6.0**	**1.7%**	**44**	**112**	**2.2%**	**83**	**315**	**4.9%**	**1.34**	**1891**	**2820**	**1.4%**
OECD Total		**22.3**	**41.6**	**1.5%**	**548**	**713**	**0.6%**	**617**	**908**	**1.4%**	**0.42**	**1127**	**1272**	**0.4%**
Non-OECD Total		**3.6**	**9.1**	**2.2%**	**38**	**169**	**3.6%**	**195**	**1172**	**6.6%**	**1.61**	**5110**	**6927**	**1.1%**
Total World		**7.0**	**14.1**	**1.7%**	**130**	**254**	**1.6%**	**812**	**2080**	**3.4%**	**0.94**	**6237**	**8199**	**1.0%**

Figure 7. Growth in Vehicle Ownership and Per-Capita Income, Historical and Projected

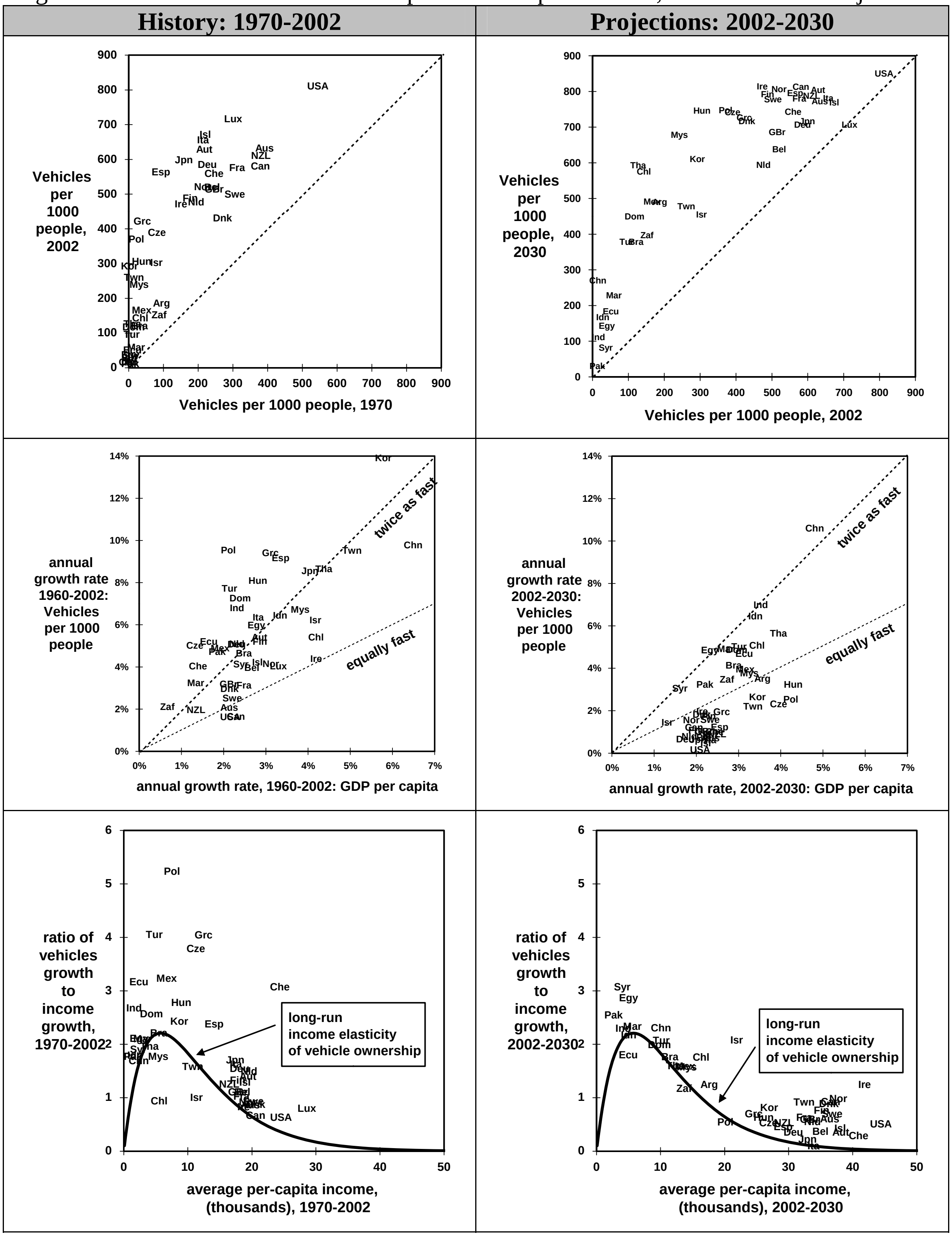
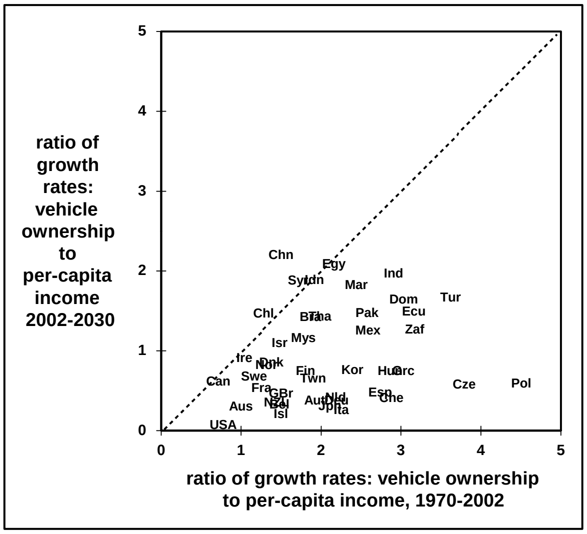
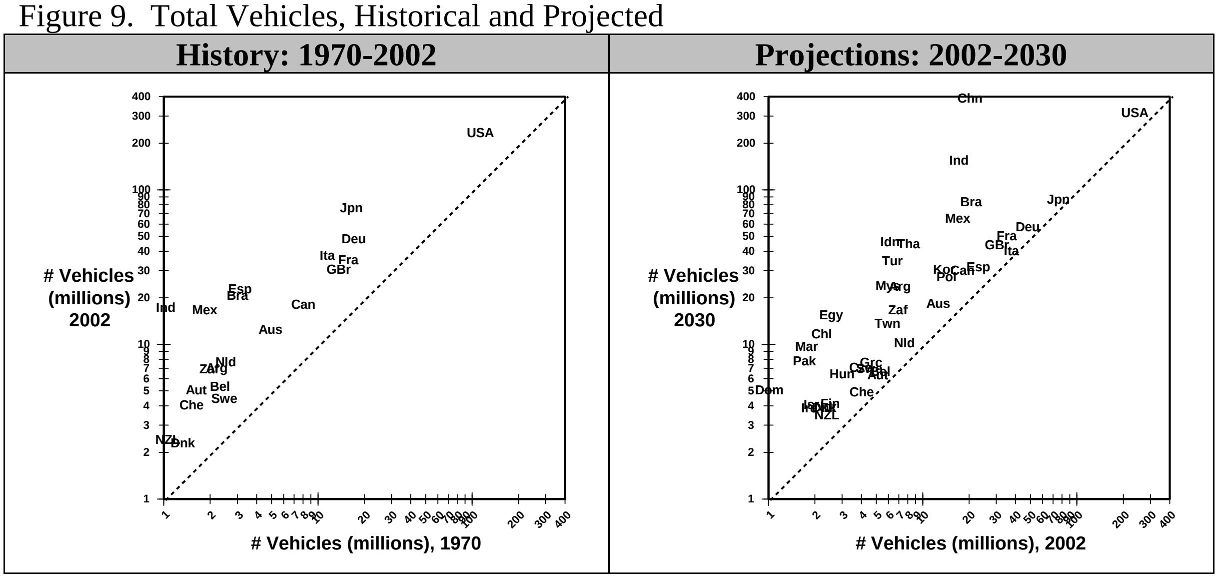


Figure 8. Ratio of Growth Rate of Vehicle Ownership to Growth Rate of Per-Capita Income, Historical and Projected



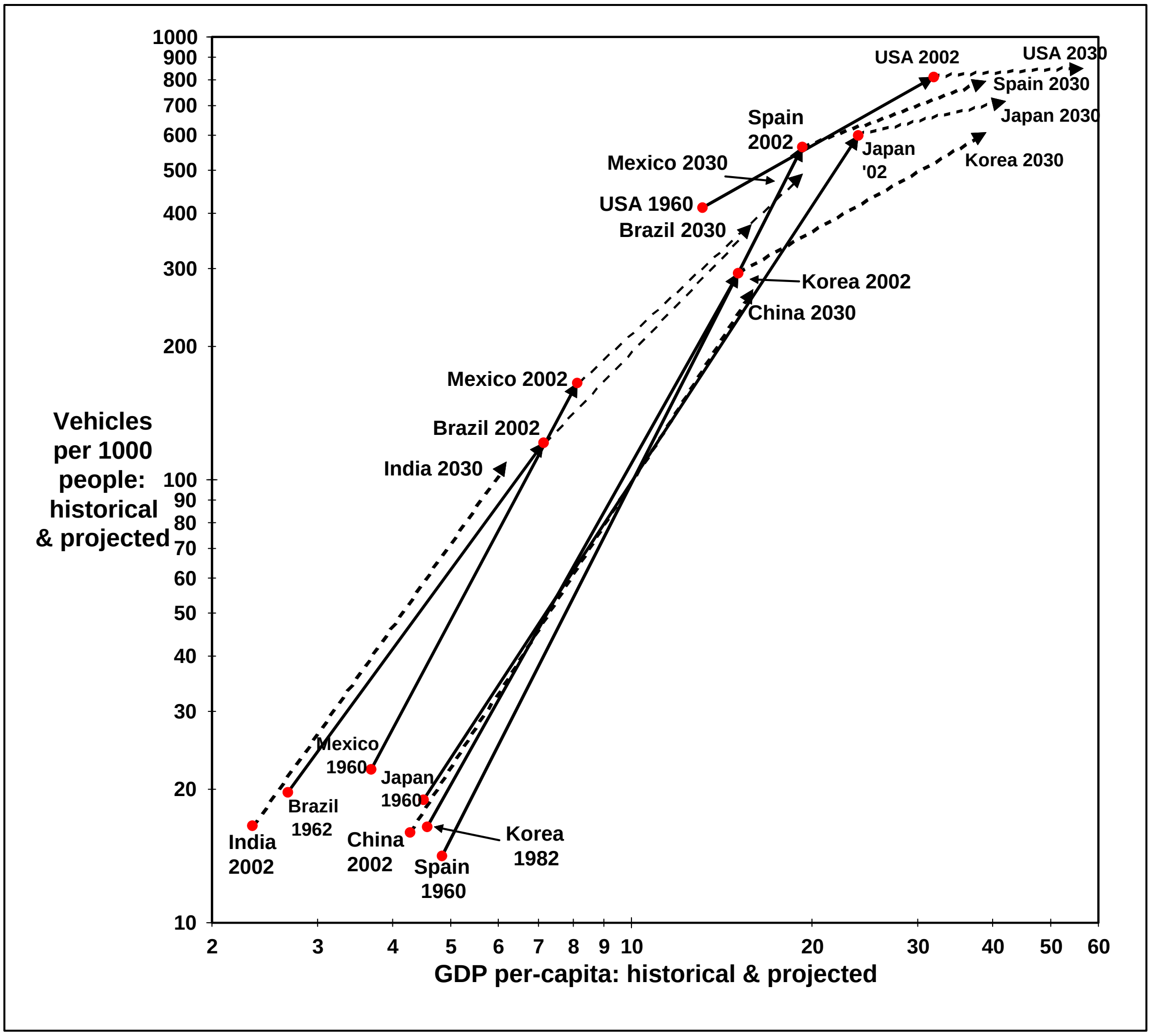
About half the countries experienced *historical* growth rates of vehicle ownership that are at least twice as high as the growth of per-capita income, and almost every country has had its vehicle ownership growing faster than per-capita income since 1970. However, for almost all countries the *projected* ratio of vehicle ownership growth to per-capita income growth will be lower than the *historical* ratio (below the diagonal in Figure 8). Yet there are important differences between OECD and non-OECD countries. For every OECD country except Mexico and Turkey, the projected ratio will be lower than 1. But for almost every non-OECD country, the projected ratio will be higher than 1; and this ratio will be as high as 2 for China, India, Indonesia, Egypt, Syria, and Morocco – countries whose per-capita income will be passing through the middle-income range of $3,000 to $10,000, within which vehicle ownership grows twice as fast as per-capita income. Only when per-capita income levels rise above $15,000 can we expect vehicle ownership to grow no faster than per-capita income.

Figure 9. Total Vehicles, Historical and Projected



By 2030, the six countries with the largest number of vehicles will be China, USA, India, Japan, Brazil, and Mexico. China is projected to have nearly 20 times as many vehicles in 2030 as it had in 2002. This growth is due both to its high rate of income growth and the fact that its per-capita income during this period is associated with vehicle ownership growing more than twice as fast as income.

Figure 10. Projected Growth for China and India, compared with Historical and Projected Growth for USA, Japan, South Korea, Brazil, Mexico, and Spain.



Let us put into historical context the rapid growth that we are projecting for China. In 2002, China's vehicle ownership was 16 per 1000 people, similar to that of India, but at a higher per-capita income. This rate of vehicle ownership was comparable to the rate in 1960 for Japan, Spain, Mexico and Brazil, and in 1982 for South Korea. We project that China's vehicle ownership will rise to 269 by 2030, increasing 2.2 times faster than its growth rate for per-capita income[10]. This projection for China, as its per-capita income increases from $4,300 to $16,000, is comparable to the 1960-2002 experience of Japan, Spain, Mexico and Brazil, and since 1982 for South Korea. Although these other countries' per-capita incomes grew at different rates historically (slower in Brazil and Mexico, faster in Spain, Japan, and South

[10] As noted above, we assume China's per-capita income will grow at 4.8% annually (see Appendix A for details; the long-term growth rate between 2020-2030 is assumed at 4.1% annually, this is one percentage point *lower* than the assumptions used in DoE's *International Energy Outlook 2004*).

Korea), their *ratios* of growth in vehicle ownership to per-capita income growth over the 1960-2002 period were *at least as high as* the 2.2 that we project for China.[11]

Figure 11. Total Vehicles, 1960-2030

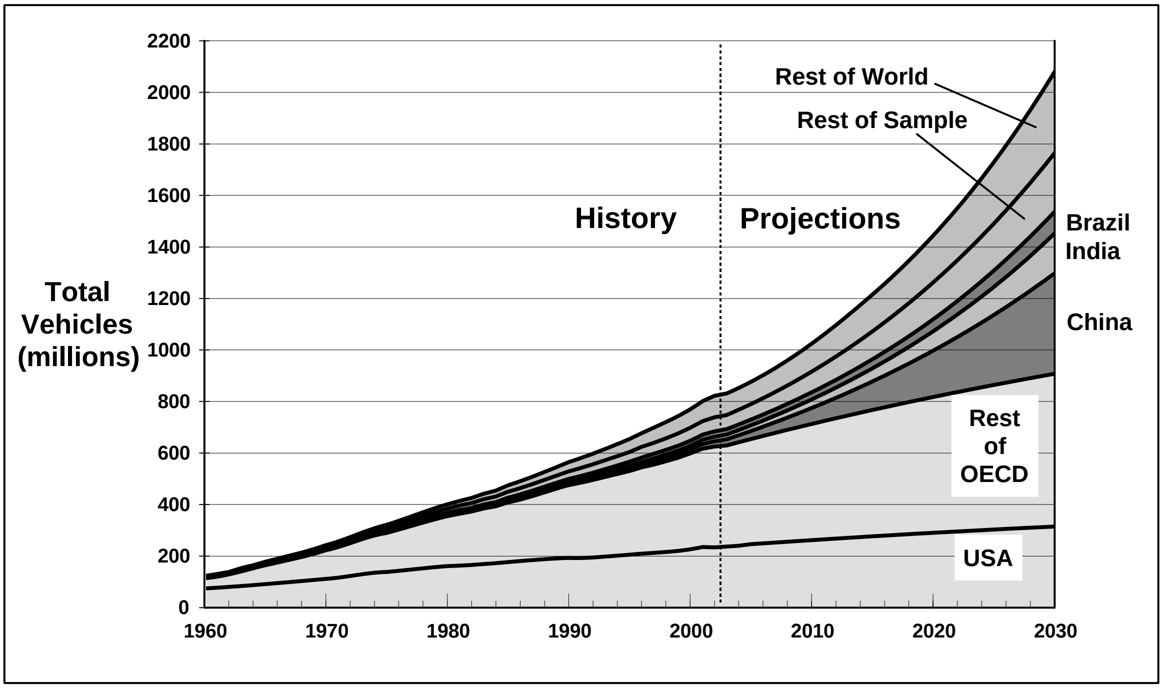


Figure 11 summarizes historical and projected regional values for total vehicles. The world stock of vehicles grew from to 122 million in 1960 to 812 million in 2002 (4.6% annually), and is projected to increase further to 2.08 billion by 2030 (3.4% annually). The implications for highway fuel use are discussed in Appendix B.

Figure 12. Regional Shares of the Absolute Increase in GDP and Total Vehicles, 2002-2030

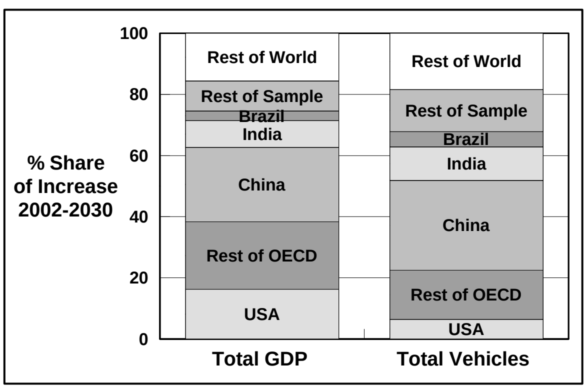


Figure 12 shows the non-OECD's disproportionately high growth in Total Vehicles relative to GDP during 2002-2030. While the OECD countries will produce about 38 % of the increase in GDP, they will contribute only 23% to the increase in Total Vehicles.

[11] As observed in the previous section , China's estimated saturation level for vehicle ownership (807) is higher than that for India (683). This is because China's population density is only one-third of India's, given the fact that we divide population by land area rather than *habitable* land area (90% of China's population lives in only 30% of the land area). If we used India's lower saturation level for China, our projections for China in 2030 would be vehicle ownership of 228 rather than 269 vehicles per 1000 people, and 331 million total vehicles rather than 390 million. This would represent a reduction in the annual growth rate of vehicle ownership from 10.6% to 10.0%; the ratio to growth in per-capita income would be 2.07 rather than 2.2.

Comparisons of our vehicle ownership projections with those of others in the literature indicate that our projections ("D-G-S") are higher, especially for the non-OECD countries[12]. Button, Ngoe, and Hine (1983) focused on low-income countries and *assumed* a saturation level of between 300 and 450 cars per 1000 people. They project ownership rates for only a selection of countries, two of which are included in our sample: Pakistan and Malaysia. For these two countries, they projected a doubling of cars from 1986 and 2002, but historical data show that vehicles have more than tripled over this time period. Hence their projections seem unrealistically low – the likely result of the low saturation levels that are assumed.

More comprehensive projections for OECD and non-OECD regions are provided by IEA(2004) to year 2030 and OPEC(2004) to year 2025. Comparisons with our projections are complicated by differences in income growth rates assumed. Hence we compare the projected ratios of average annual growth rate of vehicle ownership to average annual growth rate of per-capita income for 2002-2030; see Table 4.

Table 4. Projected Ratios of Vehicle Ownership Growth to Per-capita Income Growth, 2002-2030: Comparison of D-G-S Projections with IEA(2004) and OPEC(2004)

Region	D-G-S	IEA(2004)	OPEC(2004)
OECD	0.42	0.57	0.39
Non-OECD	1.61	1.12	0.97
China	2.20	1.38	1.28
India	1.98	0.39	
Egypt	2.09	1.21	
World	0.94	0.61	0.57

The respective ratios for the OECD are relatively similar across the three studies. For the Non-OECD countries, however, our projected ratios are substantially higher than those of IEA(2004) and OPEC(2004). For the world as a whole, we project that vehicle ownership will grow almost as rapidly as per-capita income, while IEA(2004) and OPEC(2004) project that it will grow only about six-tenths as rapidly. For the slower projections of Non-OECD growth in OPEC(2004), the explanation appears to be a low saturation level for developing countries' vehicle ownership (425) that was *assumed*: see Brennand (2006). Such a saturation level for vehicle ownership (425) is even lower than upper range of the *car* saturation level (450)

[12] Mogridge (1989) revised an earlier saturation estimate of 660 vehicles per 1000 people for Great Britain, increasing it to 900. Such a saturation level is much higher than our estimate for Great Britain (707), and higher even than our saturation estimate for the USA (852). For comparison, we project vehicle ownership for Great Britain to increase from 515 in 2002 to 685 vehicles per 1000 people in 2030. Additionally, Exxon Mobil (2005) makes projections of "light duty" vehicles (cars and light trucks) for selected regions expressed as average annual growth rates from 2000 to 2030. Specifically, these projections are 1.2% for North America, 0.9% for Europe, and 4.7% for Asia-Pacific (both OECD and non-OECD countries). Our projected growth rates for *total* vehicles (including buses and heavy trucks) are higher for all three regions: 1.7% for North America, 1.6% for Europe, and 6.1% for Asia Pacific.

assumed by Button *et al* (1983). As for the projections of IEA(2004), details of the underlying model are not provided.

To sum up these comparisons, the considerably lower projections of non-OECD vehicle ownership in Button *et al* (1983) and in OPEC (2004) are due to the *assumption* of significantly lower saturation levels for those regions. This assumption leaves unexplained why developing countries – once they had achieved incomes similar to many OECD countries – would *not* have comparable levels of vehicle ownership. On what other goods would consumers in developing countries be spending their incomes instead?

6. IMPLICATIONS FOR PROJECTIONS OF HIGHWAY FUEL DEMAND

Projections of increasing vehicle ownership suggest that highway fuel use may also increase significantly. However, the rate of increase in highway fuel demand depends upon the changes over time in fuel use per vehicle as vehicle availability increases.

Figure 13. Gasoline per Vehicle and Vehicle Ownership for Selected Countries, 1971-2002

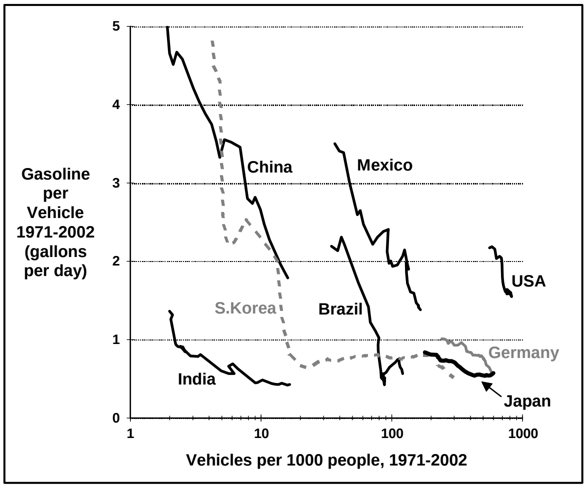


Figure 13 summarizes, for several large countries, the 1971-2002 relationship between *gasoline* per vehicle and vehicle ownership[13]. At the lowest levels of vehicle ownership, fuel use per vehicle is relatively high; a relatively small number of vehicles (mostly buses and trucks) are used intensively. As vehicle ownership grows, more cars and other personal vehicles are available, although used less intensively than buses and trucks, so that fuel use per vehicle declines.

Highway fuel use per vehicle also changes over time for other reasons than vehicle availability, namely vehicle usage, and fuel efficiency. With a given vehicle stock, fuel price and income can affect vehicle usage (distance driven) in a given year. Fuel-efficiency improvements can reduce fuel use per vehicle, as it takes less fuel to travel a given distance.

Based on judgment and historical patterns, OPEC (2004) makes assumptions about different regions' rates of decline in highway fuel per vehicle. Using those projected rates of decline[14] together with our projected growth rates for total vehicles, we project that world consumption of highway fuel will grow by 2.5% annually by 2030: 0.9% in the OECD and 5.2% in the rest of the world. By comparison, OPEC (2004) projects 2000-2025 annual growth in world highway fuel of 1.9%. Our higher rate of growth in highway fuel is due to higher projections of the vehicle stock. If instead we were to assume slower projected rates of decline in fuel per vehicle – closer to those experienced in 1990-2000 (-0.1% for OECD, -2% for China and South Asia, -1% for other non-OECD) – then world highway fuel consumption would grow at 2.8% annually.

[13] The ratio of gasoline consumption to total vehicles is an imperfect measure of highway fuel use per vehicle, because some vehicles use diesel fuel instead of gasoline, and some gasoline is not used by vehicles. We use only gasoline consumption because we have no data for diesel fuel consumption for non-OECD countries, or for OECD countries before 1993.

[14] OPEC (2004) projects the following annual rates of decline for highway fuel per vehicle: OECD North America: -0.5%, OECD Europe: -0.6%, OECD Pacific: -0.4%, China: -2.1%, Southeast Asia: -0.9%, South Asia: -2.2%, Latin America: -0.7%, Africa and Middle East: -1.4%. We use estimates of these regions' highway fuel per vehicle from Brennand (2006) to calculate highway fuel consumption in 2002.

7. CONCLUSIONS

We use a comprehensive data set covering 45 countries over 1960-2002 to explain historical patterns in the vehicle ownership rates as an S-shaped, Gompertz function of per-capita income. Our model specification exploits the similarity of response in vehicle ownership rates to per-capita income across countries over time, while allowing for cross-country variation in the speed of vehicle ownership growth and in ownership saturation levels.

The relationship between vehicle ownership and per-capita income is highly non-linear. The income elasticity of vehicle ownership starts low but increases rapidly over the range of $3,000 to $10,000, when vehicle ownership increases twice as fast as per-capita income. Europe and Japan were at this stage in the 1960's. Many developing countries, especially in Asia, are currently experiencing similar developments and will continue to do so during the next two decades. When income levels increase to the range of $10,000 to $20,000, vehicle ownership increases only as fast as income. At very high levels of income, vehicle ownership growth decelerates and slowly approaches the saturation level. Most of the OECD countries are at this stage now.

We project that the world's total vehicle stock will be 2.5 times greater in 2030 than in 2002, increasing to more than two billion vehicles. Non-OECD countries' share of total vehicles will rise from 24% to 56%, as they acquire over three-fourths of the additional vehicles. China's vehicle stock will increase nearly twenty-fold, to 390 million by 2030 – more vehicles than the USA – even though its rate of vehicle ownership (about 270 vehicles per 1000 people) will be only at levels experienced by Japan and Western Europe in the mid-1970's, and by South Korea in 2001. As in most countries, vehicle ownership in China, India, Indonesia and elsewhere will grow twice as rapidly as its per-capita income, as these countries pass through middle-income levels of $3,000 to $10,000 per capita. By 2030, vehicle ownership in virtually all the OECD countries will have reached saturation, but in most of Asia it will still only be at 15% to 45% of ownership saturation levels.

Finally, our results suggest that the future strong growth in the vehicle stock in developing countries will lead to significant increases in oil demand from the transport sector. We project annual worldwide growth in highway fuel demand to be in the range of 2.5% to 2.8%.

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APPENDIX A: Data Sources

This appendix provides further details on the datasets used in the analysis of vehicle ownership.

Vehicle ownership data are primarily from the *United Nations Statistical Yearbook*. The data for a few country-years are from the national statistical offices.

Historical data on Purchasing-Power-Parity (PPP) adjusted gross domestic product are from the OECD's *SourceOECD* database. The data are expressed in thousands of 1995 PPP-adjusted dollars. Where necessary, the series were spliced with real GDP data from IMF's *World Economic Outlook* database using the assumption that growth in the PPP GDP rate equals real GDP growth.

Data on the real GDP growth projections for 2005-09 are from the IMF's *World Economic Outlook*. For 2010-30, the main data source is the U.S. Department of Energy (DoE) *International Energy Outlook April 2004*. An adjustment was made to the DoE's growth projection for China and India. In both cases, the long-term growth rates were reduced by 1 percentage point (specifically for China, the growth rate is 5 percent annually over 2010-14, 4.4 percent over 2015-2019, and 4.1 percent over 2020-2030; for India, the growth rate assumption is 4.3 during 2010-2014, 4.1 percent during 2015-2019, and 3.9 during 2020-2030). This adjustment was made to reduce the PPP-weighted world growth rate to its historical average of about 3.5 percent a year. This adjustment may create a downward bias in our vehicles projection if, in the future, world GDP growth will turn out to be higher than the historical average.

The data on urbanization and land area are from the World Bank's *World Development Indicators* database. Urbanization is expressed in percentage points and land area is expressed in square kilometers. The data on population, including projections, are from the United Nations database (median scenario). Population density was calculated by dividing total population by land area; it is measured by persons per square kilometer.