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, transport oil demand
JEL Classification: 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 (with at least 4 wheels, including cars, trucks, and buses). 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, analyses such as IEA(2004) or OPEC(2004) make assumptions about vehicle saturation rates – maximum levels of vehicle ownership (vehicles per 1000 people) – 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

Country	Code	first data year (if not 1960)	per-capita income (thousands, 1995 $ PPP)			Vehicles per 1000 population			Total Vehicles (millions)			ratio of growth rates: Veh.Own. to per-cap. income	Population, 2002		
			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

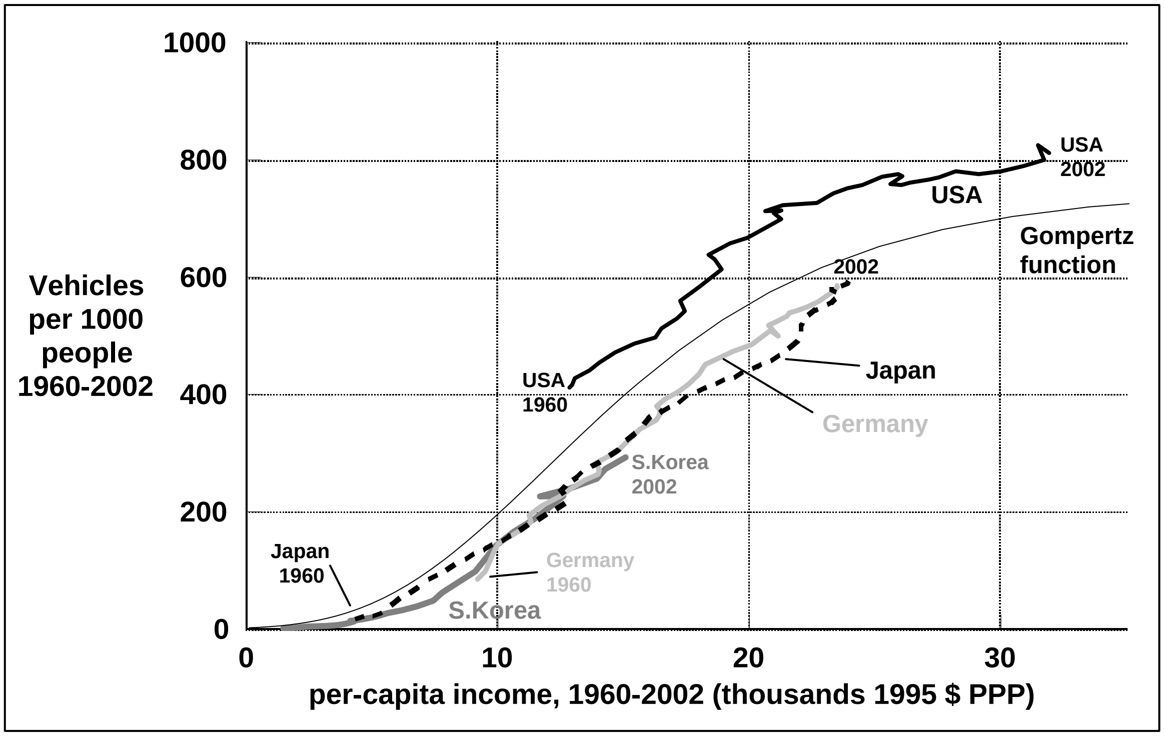
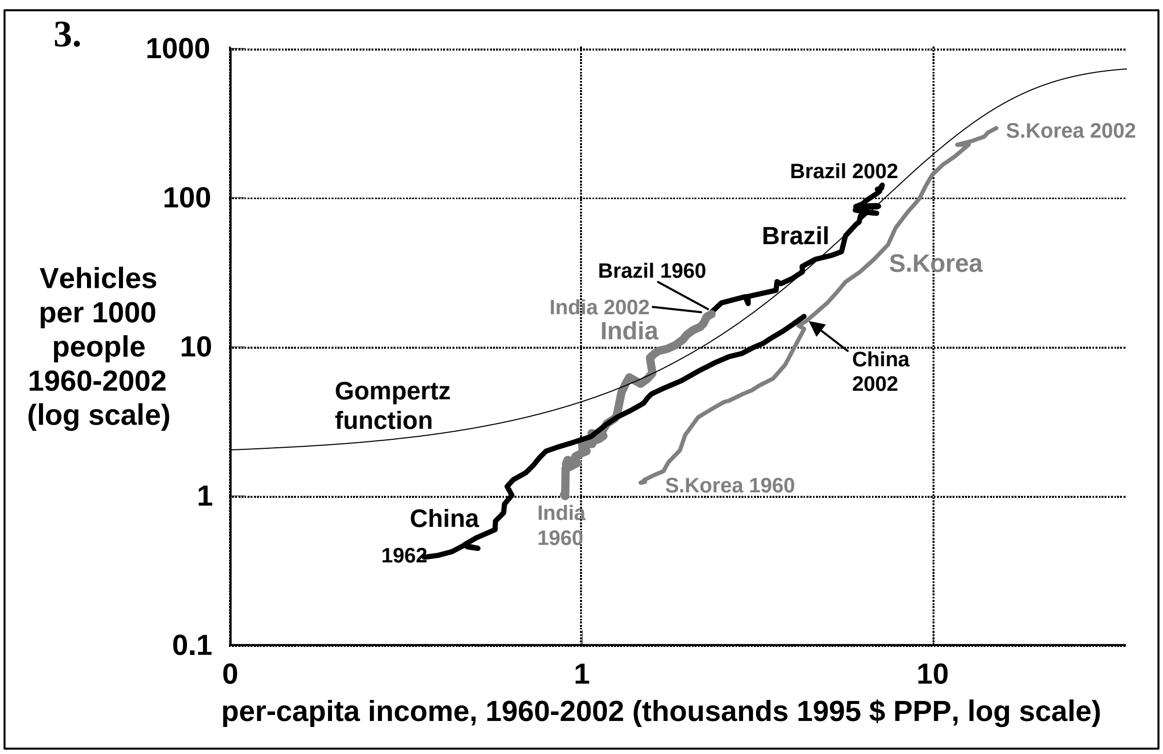


Figure 2. Vehicle Ownership and Per-capita Income for South Korea, Brazil, China, and India, with the Same Illustrative Gompertz Function, 1960-2002



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 (expressed in real 1995 dollars evaluated at Purchasing Power Parities), the Gompertz model can be written as:

$$V_t^* = \gamma e^{\alpha e^{\beta GDP_t}} \qquad (1)$$

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.

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:

$$\eta_t^{LR} = \alpha\beta GDP_t \, e^{\beta GDP_t} \qquad (2)$$

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/β, 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 depicts an illustrative Gompertz function, similar to what we have estimated econometrically, together with the implied income elastictity for all income levels[3].

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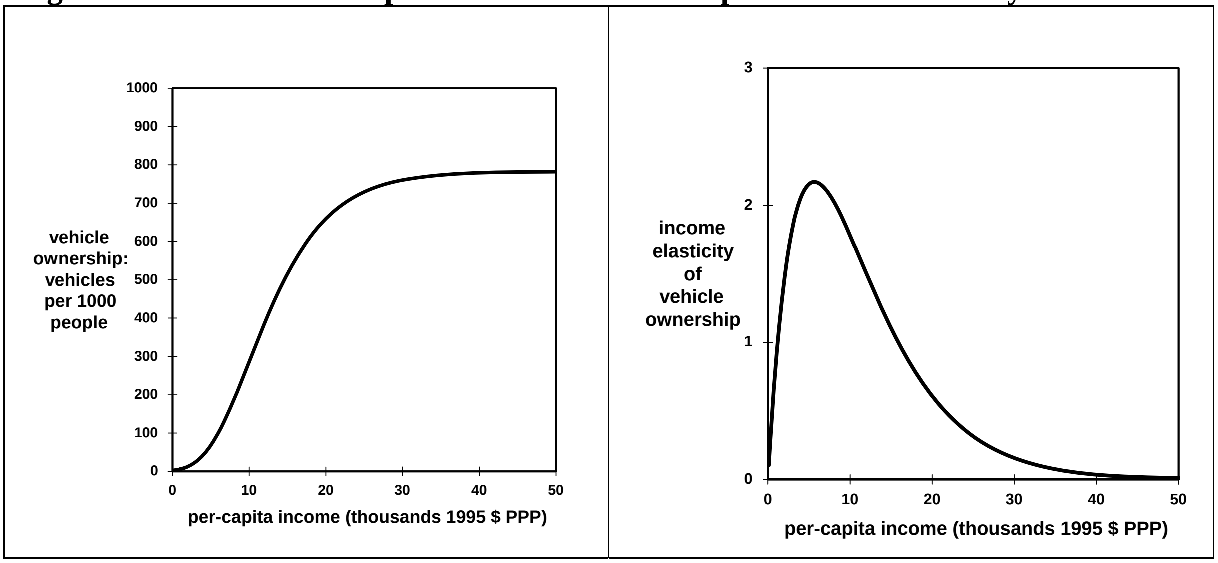
[2] See Dargay-Gately (1999) for a simpler model, using a smaller set of countries. Earlier analyses are summarized in Mogridge (1983), which discusses vehicle ownership being modelled by various S-shaped functions of time, rather than of per-capita income, some with saturation and some without. Medlock and Soligo (2002) employ a log-quadratic function of per-capita income.

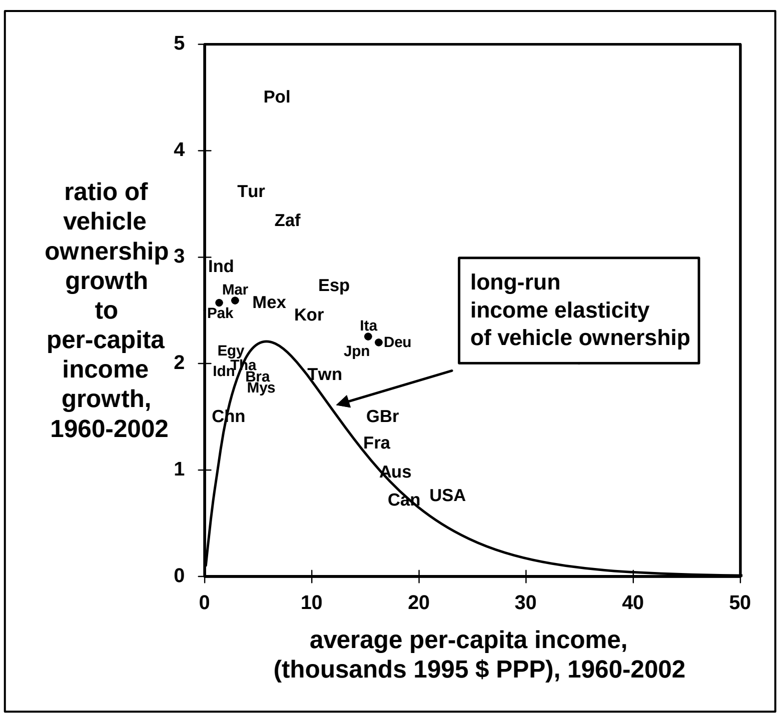
[3] As discussed below, there can be differences across countries in the saturation levels of a country's Gompertz function and its income elasticity. Figure 3 plots an illustrative function for the median country's saturation level. Differences across countries are illustrated in Figure 6.

Figure 3. Illustrative Gompertz function and its implied income elasticity



Shown in Figure 4 are the historical ratios of vehicle ownership growth to per-capita income growth (which approximates the income elasticity), compared to the countries' average level of per-capita income (for the largest countries, with population above 20 million in 2002). Also graphed is the income elasticity of vehicle ownership for our illustrative Gompertz function. One can observe the pattern across countries of the income elasticity increasing at the lowest levels of per-capita income, then peaking in the per-capita income range of $5,000 to $10,000, followed by a gradual decline in the income elasticity at higher income levels.

Figure 4. Historical Ratios of Vehicle Ownership Growth to Income Growth, by Levels of per-capita Income:1960-2002



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 < θ <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 in that paper 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 (620 cars and 850 vehicles per 1000 people). 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:[4]

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

4 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.

where λ and φ are negative, and D_{it} denotes population density and U_{it} denotes urbanization in country *i* at time *t*..

Figure 5. Countries' Population Density and Urbanization, 2002

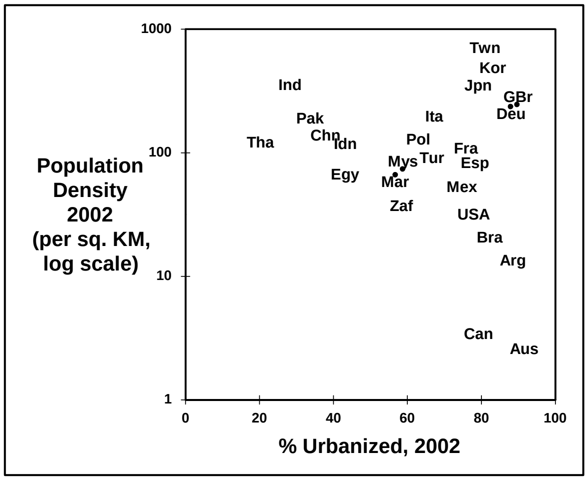


Figure 5 plots the 2002 data on population density and urbanization, for countries with population greater than 20 million. The most urbanized and densely populated countries are in Western Europe and East Asia: Germany, Great Britain, Japan and South Korea. Some countries are highly urbanized but not densely populated, such as Australia and Canada. Others are densely populated but not highly urbanized, such as China, India, Pakistan, Thailand, and Indonesia.

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 evidence that this may not be the case, and that assuming symmetry may lead to biased estimates of income elasticities. Many of the countries in the sample have experienced periods of negative changes in per-capita income, some for several years, such as Argentina and South Africa, whose experience is graphed in Figure 6. Thus it is important that we take such asymmetry into consideration.[5] 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:

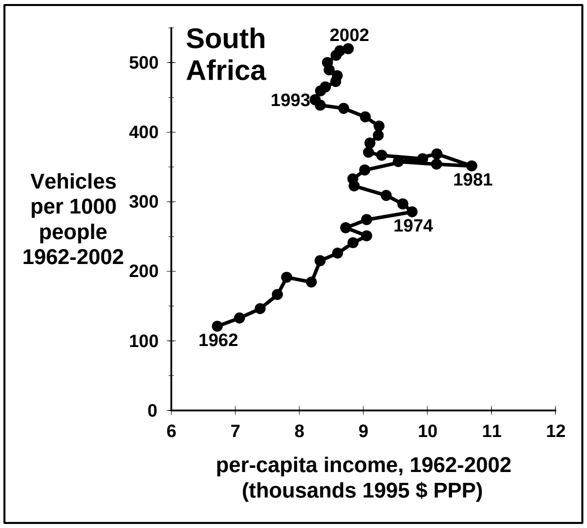
$$\begin{aligned} R_{it} &= 1 \;\; if \;\; GDP_{it} - GDP_{it-1} > 0 \; and = 0 \; otherwise \\ F_{it} &= 1 \;\; if \;\; GDP_{it} - GDP_{it-1} < 0 \; and = 0 \; otherwise \end{aligned} \tag{6}$$

and replacing θ in (4) with:

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

[5] Note that this asymmetry differs from the *long-run* asymmetric *price* responsiveness of oil demand, used in papers by Dargay, Gately and Huntington: see Gately-Huntington (2002); an alternative approach has been proposed by Griffin and Schulman (2005). The asymmetry used here relates to the *short-run* income elasticity and affects the speed of adjustment, while the long-run elasticities are symmetric..

Figure 6. Asymmetric Response of Vehicle Ownership to Increases and Decreases in Income: South Africa, 1962-2002.



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[6], 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:

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

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, γ_{MAX} , 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

$$\eta_{it}^{LR} = \alpha \beta_i GDP_{it} e^{\beta_i GDP_{it}} \quad (9)$$

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

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

[6] In the graph for South Africa, vehicle ownership does not decline when income falls; it continues increasing, albeit more slowly, because of the long lags of adjusting vehicle ownership to extended periods of increasing income.

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.[7] However, the unavailability of data for a sufficient number of countries and periods prevented such an attempt.

[7] 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. Medlock and Soligo (2002), with a smaller set of countries, utilize the price of highway fuel to model the cross-country fixed effects within a log-quadratic approximation of vehicle ownership.

4. MODEL ESTIMATION

The model described in equation (8) was estimated for the pooled cross-section time-series data on vehicle ownership 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. Several alternative specifications were also estimated – respectively dropping from the equation population density, or urbanization, or asymmetry; these results are compared with our standard specification, and with those of Dargay-Gately (1999), in Appendix B.

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.

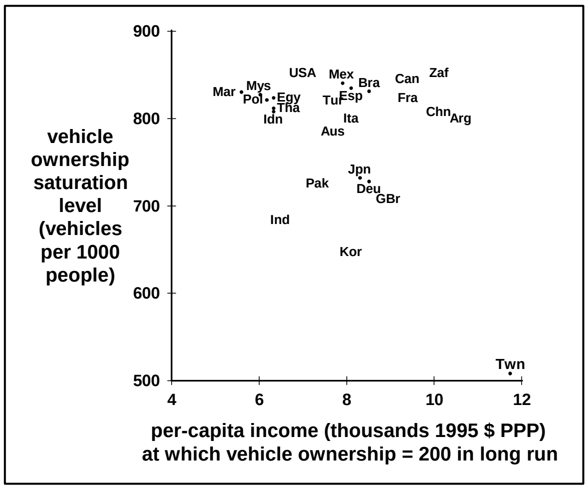
The vehicle saturation levels vary across countries — from a maximum of 852 for the USA (and for Finland, Norway, and South Africa) to a minimum of 508 for Chinese Taipei. All the OECD countries have saturation levels above 700 except for the most urbanized and densely populated: Netherlands (613), Belgium (647), and South Korea (646). Similarly, most of the Non-OECD countries have saturation levels in the range of 700 to 800 vehicles per 1000 people.

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	**beta coef.**	**P-value**	**vehicle ownership saturation (per 1000 people)**	**per-capita income (thousands 1995 $ PPP) at which vehicle ownership = 200**
OECD, North America				
Canada	-0.15	0.00	845	9.4
United States	-0.20	0.00	852	7.0
Mexico	-0.17	0.00	840	7.9
OECD, Europe				
Austria	-0.15	0.00	831	9.4
Belgium	-0.20	0.00	647	8.1
Switzerland	-0.11	0.00	803	13.3
Czech Republic	-0.17	0.00	819	8.3
Germany	-0.18	0.00	728	8.5
Denmark	-0.12	0.00	782	12.0
Spain	-0.17	0.00	835	8.1
Finland	-0.13	0.00	852	10.6
France	-0.15	0.00	823	9.4
Great Britain	-0.17	0.00	707	8.9
Greece	-0.15	0.00	836	9.4
Hungary	-0.17	0.00	831	8.1
Ireland	-0.15	0.01	841	9.4
Iceland	-0.17	0.87	779	8.3
Italy	-0.18	0.00	800	8.1
Luxembourg	-0.16	0.78	706	9.6
Netherlands	-0.16	0.00	613	10.1
Norway	-0.13	0.00	852	10.6
Poland	-0.23	0.00	821	6.2
Sweden	-0.13	0.00	825	10.6
Turkey	-0.18	0.00	820	7.7
OECD, Pacific				
Australia	-0.19	0.00	785	7.7
Japan	-0.18	0.00	732	8.3
Korea	-0.20	0.00	646	8.1
New Zealand	-0.19	0.01	812	7.3
Non-OECD, South America				
Argentina	-0.13	0.00	800	10.6
Brazil	-0.17	0.00	831	8.5
Chile	-0.17	0.00	810	8.3
Dominican Rep.	-0.24	0.02	777	6.2
Ecuador	-0.25	0.13	845	5.6
Non-OECD, Africa and Middle East				
Egypt	-0.22	0.00	824	6.3
Israel	-0.13	0.00	630	12.6
Morocco	-0.25	0.00	830	5.6
Syria	-0.22	0.22	807	6.5
South Africa	-0.14	0.00	852	10.1
Non-OECD, Asia				
China	-0.14	0.00	807	10.1
Chinese Taipei	-0.16	0.00	508	11.7
Indonesia	-0.23	0.00	808	6.3
India	-0.24	0.00	683	6.5
Malaysia	-0.23	0.00	827	6.0
Pakistan	-0.21	0.01	725	7.3
Thailand	-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 largest countries are for Germany, Great Britain, Japan, South Korea and India[8]. Figure 7 plots for each country (with population greater than 20 million in 2002) the 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).

Figure 7. Countries' Estimated Vehicle Ownership Saturation Levels and Income Levels at which Vehicle Ownership = 200.



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[8] In Medlock-Soligo (2002), there is *much* wider cross-country variation in vehicle-ownership saturation levels estimated – nearly tenfold, from lowest (China) to highest (USA). Their estimated ownership-saturation levels (for *passenger* vehicles only) range from 600 in the USA and Italy, 400-500 in the most of the OECD, 150-200 in Mexico, Turkey, S. Korea and most of Non-OECD Asia, but less than 100 for China. This large variability is due to the fact that saturation levels in the Medlock-Soligo model are closely related to the estimated fixed effects— therefore, the calculated saturation levels do not take into account as much cross-country information as in our framework. For comparison, our estimated ownership-saturation levels estimates are almost all within 10% of the average saturation level. Only those countries that are most urbanized and densely populated have estimated saturation levels that are substantially lower; the lowest saturation level (Twn) is 60% of the highest (USA). At the other extreme, there was no cross-country variation in vehicle ownership saturation levels in Dargay-Gately (1999), which assumed a shared saturation level across countries that was estimated to be 850 vehicles (652 cars) per 1000 people.

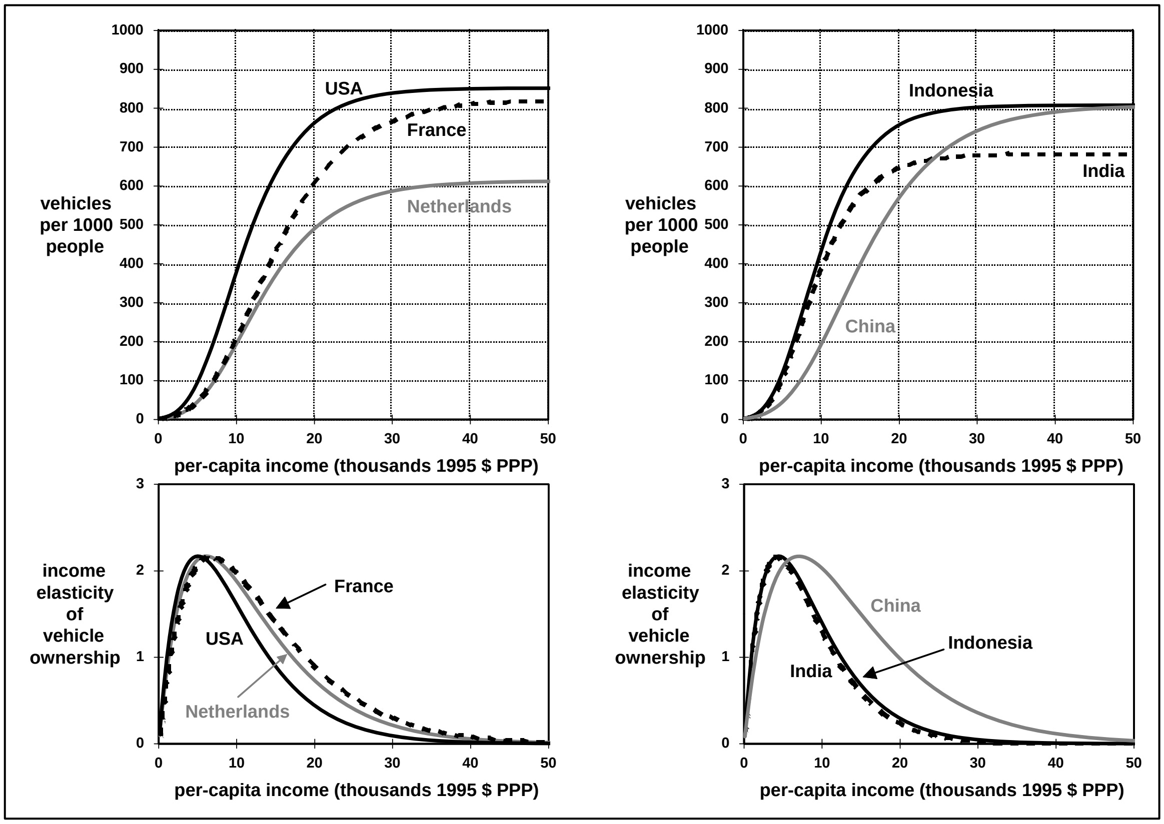
The value of α determines the maximum income elasticity of vehicle ownership rates[9], which in this case is estimated to be 2.1. The value of β_i determines the income level where the common maximum elasticity is reached: the smaller the β_i in absolute value, the greater the per-capita income at which 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 reached, for the different countries respectively, at a per-capita income level of between $19,000 and $46,000.

The graphs in Figure 8 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.[10]

[9] 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 ($=-1/\beta$) in the original elasticity formula. This gives a maximum elasticity of $-\alpha e^{-1} = -0.367\alpha$.

[10] 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.

Figure 8. Long-run Gompertz Functions for Six Selected Countries, and the Implied Income Elasticity of Vehicle Ownership



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.[11] These are shown in Table 3.

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 OECD growth rate for total 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[12], 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 Indonesia, whose per-capita income is not projected to grow as

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[11] 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.

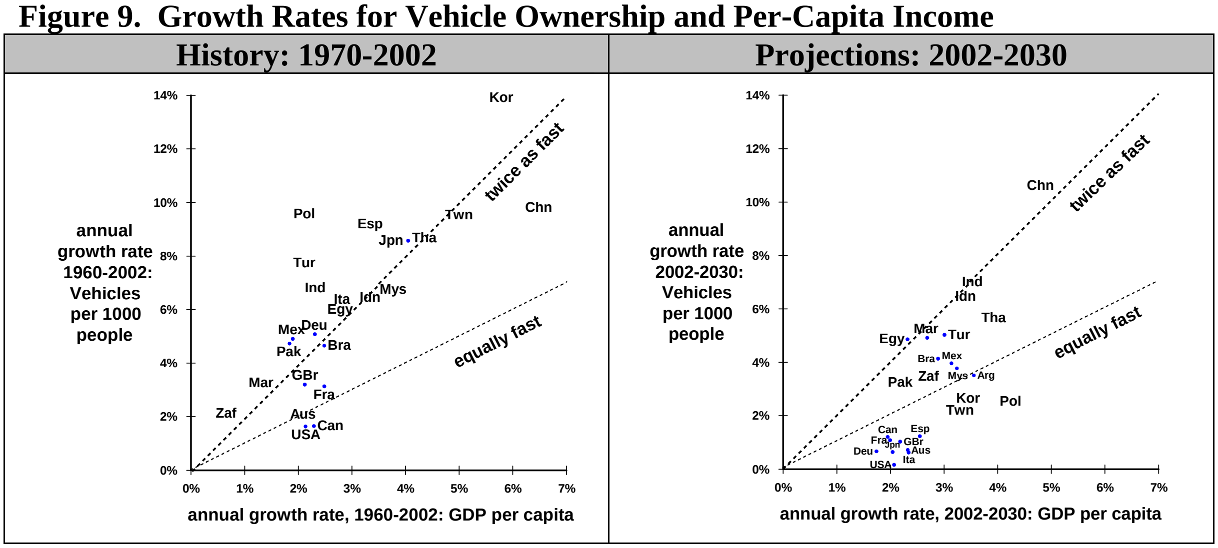
[12] For the "Other" (non-sample) countries in the rest of the world, we projected vehicle ownership from our estimated Gompertz function's parameters, adapted to this "Other" group's characteristics. In 2002 this group had per-capita income of about $3000 and owned 44 vehicles per 1000 people. We estimated 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 1.7% annual per-capita income growth for "Other" countries, and projected their vehicle ownership to 2030.

fast as China's, but whose vehicle ownership also 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.

Shown in Figure 9 (for the countries with population above 20 million in 2002) are the *historical* growth rates in vehicle ownership and per-capita income (1970-2002), and the *projected* growth rates for 2002-2030. The *historical* results for 1970-2002 show that vehicle ownership in most countries 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 to 2030 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 9. Growth Rates for Vehicle Ownership and Per-Capita Income



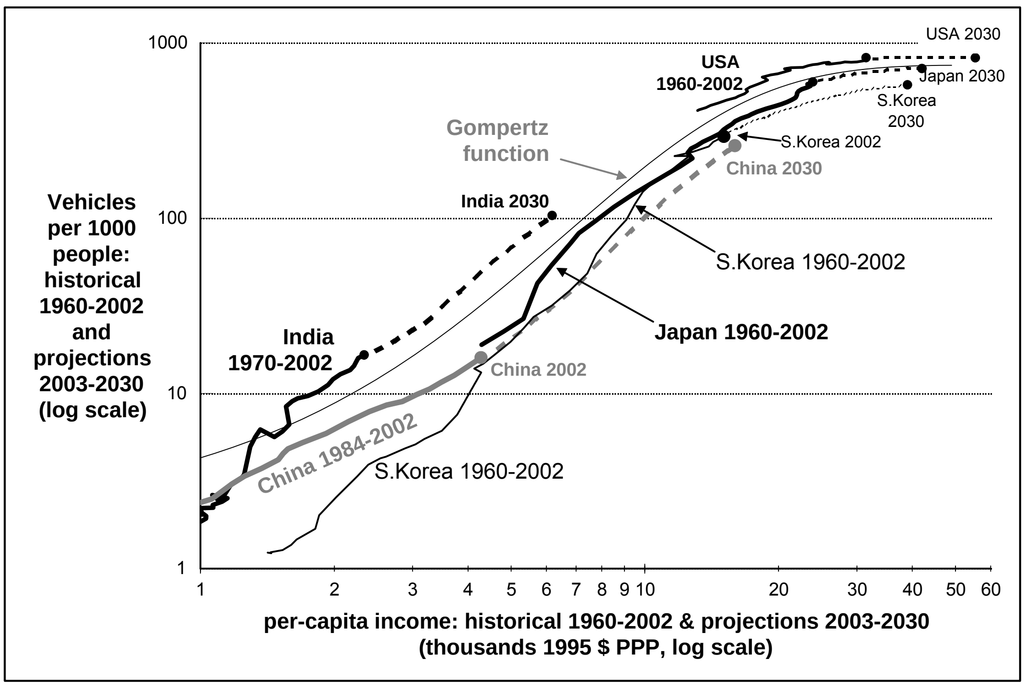
By 2030, the six countries with the largest number of vehicles will be China, USA, India, Japan, Brazil, and Mexico. China is projected to have nearly 20 times as many vehicles in 2030 as it had in 2002. This growth is due both to its high rate of income growth and the fact that its per-capita income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

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

Country	per-capita income (thousands, 1995 $ PPP) 2002	2030	Average annual growth rate	Vehicles per 1000 population 2002	2030	Average annual growth rate	Total Vehicles (millions) 2002	2030	Average annual growth rate	ratio of growth rates: Veh.Own. to per-cap. Income	Population (millions) 2002	2030	Average annual growth rate
OECD, North America													
Canada	26.9	46.2	2.0%	581	812	1.2%	18.2	30.0	1.8%	0.62	31	37	0.6%
United States	31.9	56.6	2.1%	812	849	0.2%	234	314	1.1%	0.08	288	370	0.9%
Mexico	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	26.3	49.8	2.3%	629	803	0.9%	5.1	6.4	0.8%	0.38	8	8	-0.1%
Belgium	24.7	45.3	2.2%	520	636	0.7%	5.3	6.7	0.8%	0.33	10	11	0.1%
Switzerland	27.7	54.3	2.4%	559	741	1.0%	4.0	4.9	0.7%	0.41	7	7	-0.3%
Czech Republic	13.6	40.2	4.0%	390	740	2.3%	4.0	7.1	2.1%	0.59	10	10	-0.2%
Germany	23.5	38.1	1.7%	586	705	0.7%	48.3	57.5	0.6%	0.38	83	82	0.0%
Denmark	25.9	46.7	2.1%	430	715	1.8%	2.3	3.9	1.9%	0.86	5	5	0.1%
Spain	19.3	39.0	2.5%	564	795	1.2%	22.9	31.7	1.2%	0.48	41	40	-0.1%
Finland	24.3	46.1	2.3%	488	791	1.7%	2.5	4.2	1.8%	0.75	5	5	0.0%
France	23.7	41.2	2.0%	576	779	1.1%	35.3	50.3	1.3%	0.54	61	65	0.2%
Great Britain	23.6	43.1	2.2%	515	685	1.0%	30.6	44.0	1.3%	0.47	59	64	0.3%
Greece	16.1	33.0	2.6%	422	725	2.0%	4.6	7.7	1.8%	0.75	11	11	-0.1%
Hungary	12.3	40.0	4.3%	306	745	3.2%	3.0	6.4	2.7%	0.75	10	9	-0.5%
Ireland	29.8	54.0	2.1%	472	812	2.0%	1.9	3.9	2.7%	0.91	4	5	0.7%
Iceland	26.7	49.5	2.2%	672	768	0.5%	0.2	0.3	1.0%	0.21	0	0	0.5%
Italy	23.3	44.5	2.3%	656	781	0.6%	37.7	40.2	0.2%	0.27	57	52	-0.4%
Luxembourg	42.6	63.8	1.4%	716	706	-0.1%	0.3	0.4	1.1%	-0.04	0	1	1.1%
Netherlands	25.3	42.3	1.8%	477	593	0.8%	7.7	10.2	1.0%	0.42	16	17	0.2%
Norway	28.1	47.5	1.9%	521	805	1.6%	2.4	4.0	1.9%	0.83	5	5	0.3%
Poland	9.6	30.7	4.2%	370	746	2.5%	14.4	27.4	2.3%	0.60	39	37	-0.2%
Sweden	25.4	48.1	2.3%	500	777	1.6%	4.5	7.0	1.6%	0.69	9	9	0.0%
Turkey	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	25.0	47.6	2.3%	632	772	0.7%	12.5	18.4	1.4%	0.31	20	24	0.7%
Japan	23.9	42.1	2.0%	599	716	0.6%	76.3	86.6	0.5%	0.31	127	121	-0.2%
Korea	15.1	39.0	3.5%	293	609	2.6%	13.9	30.5	2.8%	0.77	48	50	0.2%
New Zealand	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	9.6	25.5	3.6%	186	489	3.5%	7.1	23.8	4.4%	1.0	38	49	0.9%
Brazil	7.1	15.9	2.9%	121	377	4.1%	20.8	83.7	5.1%	1.43	171	222	0.9%
Chile	9.2	23.7	3.4%	144	574	5.1%	2.2	11.7	6.1%	1.47	16	20	0.9%
Dominican Rep.	6.0	13.6	3.0%	118	448	4.9%	1.0	5.1	5.9%	1.65	9	11	1.0%
Ecuador	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	3.5	6.6	2.3%	38	142	4.9%	2.5	15.5	6.7%	2.09	68	109	1.7%
Israel	17.9	25.9	1.3%	303	454	1.5%	1.9	4.1	2.7%	1.10	6	9	1.3%
Morocco	3.6	7.5	2.7%	59	228	4.9%	1.8	9.7	6.3%	1.83	30	43	1.3%
Syria	3.1	4.9	1.6%	35	80	3.0%	0.6	2.3	4.9%	1.89	17	29	1.8%
South Africa	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	4.3	16.0	4.8%	16	269	10.6%	20.5	390	11.1%	2.20	1285	1451	0.4%
Chinese Taipei	18.5	46.2	3.3%	260	477	2.2%	5.9	13.6	3.1%	0.66	23	29	0.8%
Indonesia	2.9	7.3	3.4%	29	166	6.5%	6.2	46.1	7.4%	1.89	216	278	0.9%
India	2.3	6.2	3.5%	17	110	7.0%	17.4	156	8.1%	1.98	1051	1417	1.1%
Malaysia	8.1	19.8	3.2%	240	677	3.8%	5.9	23.8	5.1%	1.16	25	35	1.3%
Pakistan	1.8	3.4	2.2%	12	29	3.2%	1.7	7.8	5.6%	1.48	145	272	2.3%
Thailand	6.2	18.3	3.9%	127	592	5.7%	8.1	44.6	6.3%	1.43	64	75	0.6%
Sample (45 countrie	**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 Tota	**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%**

Figures 10 and 11 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[13]. 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 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.[14]

Figure 10. Historical and Projected Growth for China, India, South Korea, Japan and USA: 1960-2030



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[13] As noted above, we assume China's per-capita income will grow at an average annual rate of 4.8% (see Appendix A for details). This is lower than the 5.6% growth rate for 2003-2030 that is assumed in DoE's *International Energy Outlook 200*6.

[14] 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.

Figure 11. Projected Growth for China and India, compared with Historical and Projected Growth for USA, Japan, South Korea, Brazil, Mexico, and Spain.

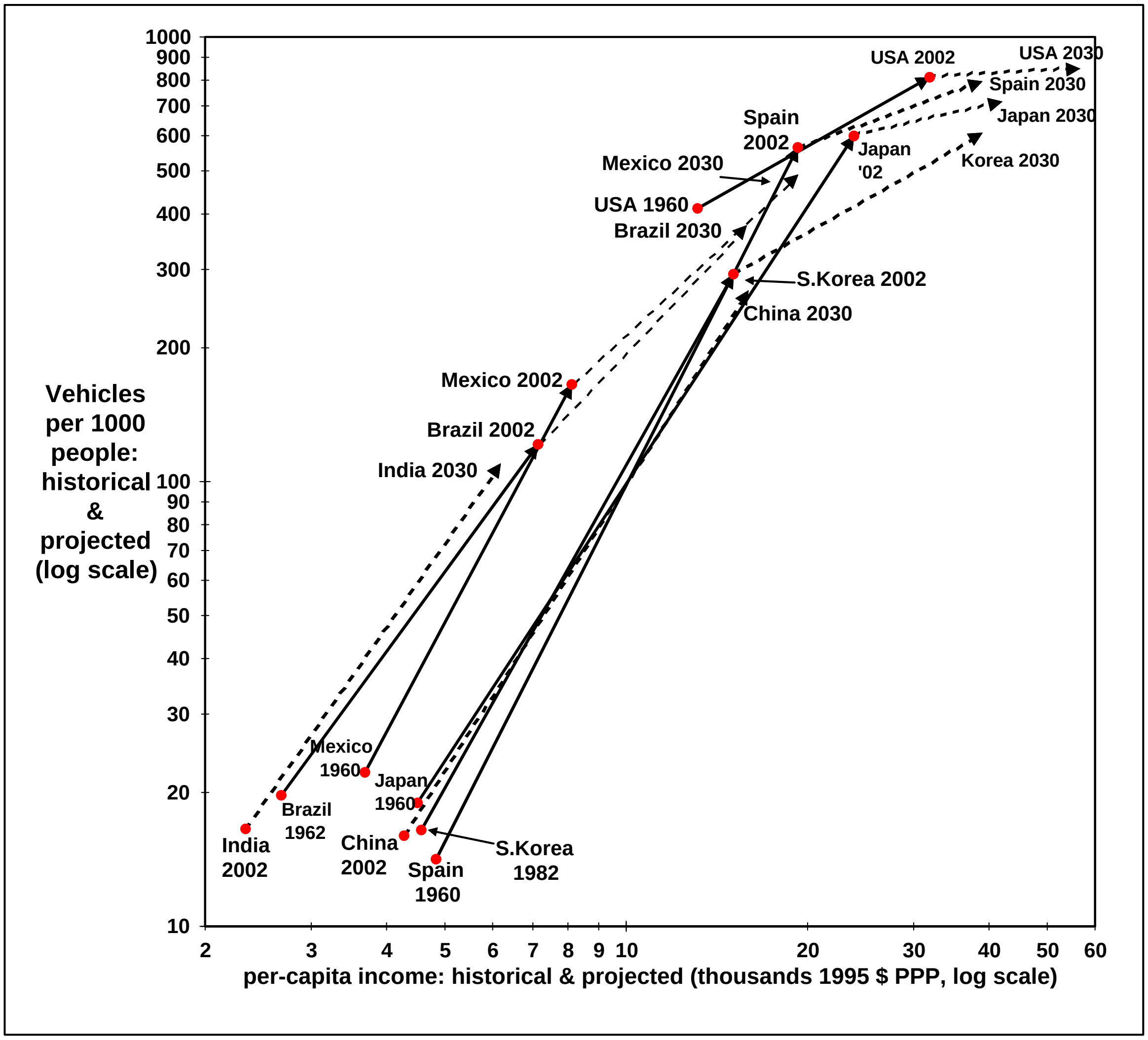


Figure 12. Total Vehicles, 1960-2030

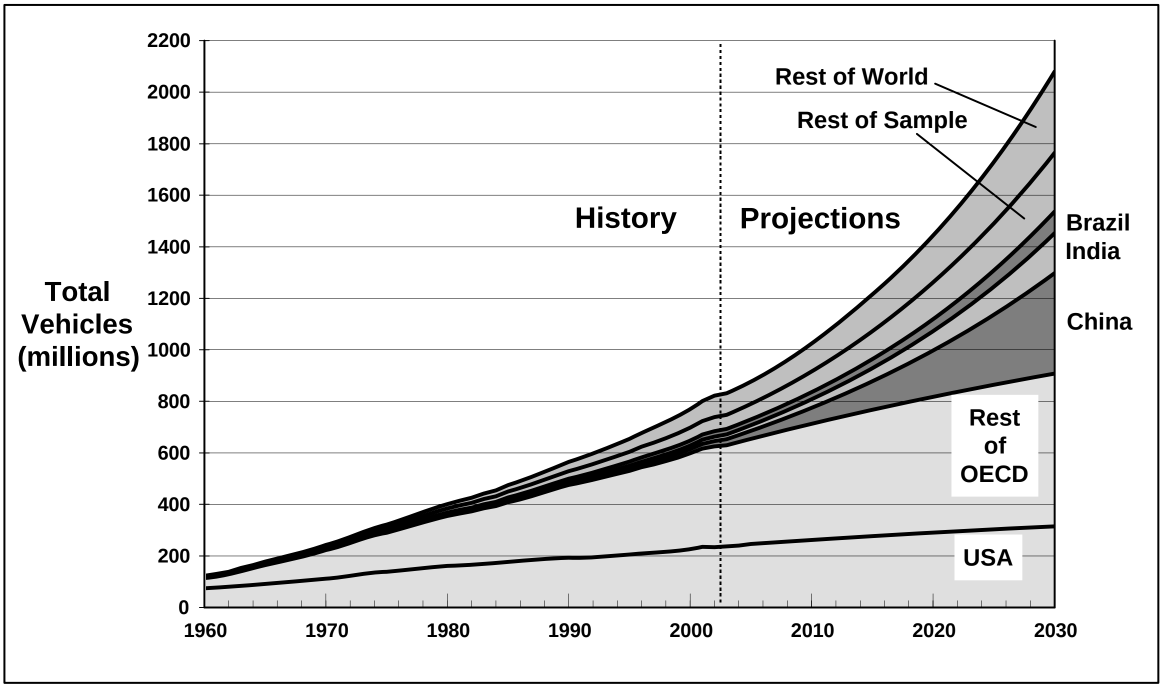


Figure 12 summarizes historical and projected regional values for total vehicles. The world stock of vehicles grew from 122 million in 1960 to 812 million in 2002 (4.6% annually), and is projected to increase further to 2.08 billion by 2030 (3.4% annually). The implications for highway fuel use are discussed in the following section.

Figure 13. Regional Shares of the Absolute Increase in Income and Total Vehicles, 2002-2030

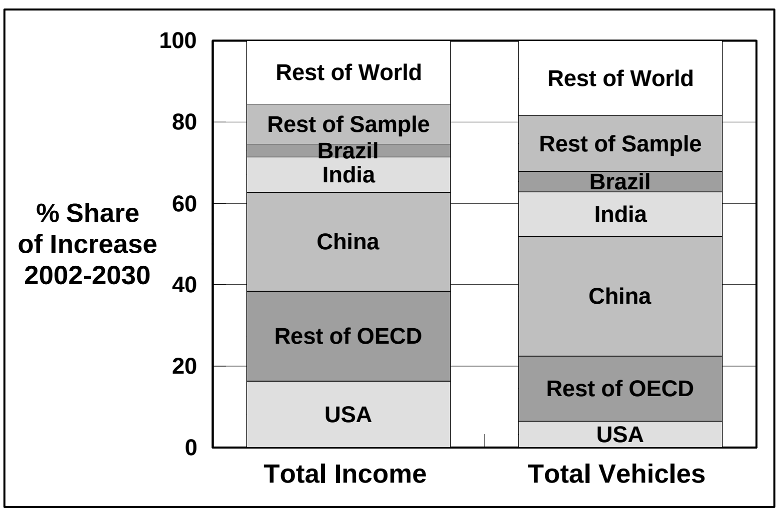


Figure 13 shows the non-OECD's disproportionately high share of additional Total Vehicles relative to their share of additional Total Income during 2002-2030. The non-OECD countries will produce 62% of the absolute increase in Total Income, but will constitute 77% of the increase in Total Vehicles.

5.1 Comparison to Previous Studies

Our vehicle ownership projections for the OECD are comparable to others in the literature, but are much higher for non-OECD countries. Since comparisons among projections are complicated by differences in income growth rates assumed, 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. Table 4 compares our projections (D-G-S) with those of IEA (2004), IEA (2006), OPEC (2004), the Sustainable Mobility Project (SMP, 2004), Button *et al.* (1993) and Medlock-Soligo(2002).

Table 4. Projected Ratios of Vehicle Ownership Growth to Per-capita Income Growth, 2002-2030

Region	D-G-S to 2030	IEA(2004) to 2030	IEA(2006) to 2030	OPEC(2004) to 2025	SMP(2004) to 2030	Medlock & Soligo(2002): 1995-2015	Button *et al.* (1993) 2000-2025
OECD	0.42	0.57		0.39	0.40		
Non-OECD	1.61	1.12		0.97	1.13		
China	2.20	1.38	1.96	1.28	1.42	2.02	
India	1.98	0.39	2.25		1.23	2.89	
Indonesia	1.89					2.94	
Malaysia	1.16					1.96	0.92
Pakistan	1.48					4.00	0.73
Thailand	1.43					2.63	
World	0.94	0.61	0.86	0.57	0.59		

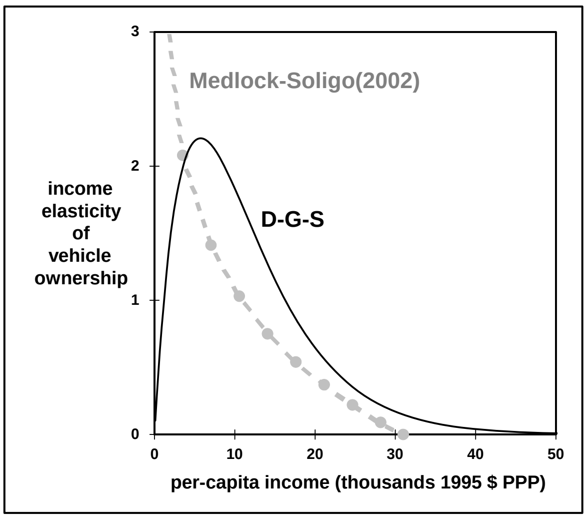
The respective ratios for the OECD are similar across the studies. However, for the Non-OECD countries, our projected ratios are substantially higher than those of all the others[15] – except Medlock-Soligo (2002), which is discussed separately below. For the world as a whole, we project that vehicle ownership will grow almost as rapidly as per-capita income, while IEA (2004)[16], OPEC (2004) and SMP (2004) project that it will grow only about six-tenths as rapidly.

[15] Exxon Mobil (2005) projections to 2030 for OECD Europe and North America are similar to those in Table 4: growth in "light duty" vehicles (cars and light trucks) about half as rapid as income growth. However, for Asia-Pacific (both OECD and non-OECD combined) they project 4.7% annual growth in "light duty" vehicles, while we project 6.1% annual growth in total vehicles for those countries, using comparable income growth assumptions. Details of the underlying model are not provided. Wilson *et al.* (2004), using the Dargay-Gately(1999) model, make projections for China and India that are similar to ours: (car) ownership growth twice as rapid as per-capita income.

[16] The latest IEA projections, IEA (2006), are much closer to ours than to IEA (2004); details of the underlying models are not provided.

Lower projections of Non-OECD vehicle ownership by OPEC (2004) and SMP (2004) can be explained by their *assumption* of low saturation levels and low income-elasticities of vehicle ownership. For OPEC (2004), the developing countries' vehicle ownership saturation level was assumed to be 425 vehicles per 1000 people[17] – considerably lower than our saturation estimates of 700 to 800 for most countries. For SMP (2004), the relatively low projections of non-OECD vehicle ownership are due to their *assumption* of relatively low income-elasticity of vehicle ownership (1.3) for low-to-middle levels of per-capita income (through which most Non-OECD countries will be passing in the next two decades) – which is one-third lower than our estimated income elasticity for those income levels. SMP (2004) assumes similarly low income-elasticities of vehicle ownership for *all* income levels, which implies much lower saturation levels than we have estimated.

Figure 14. Comparison of Income Elasticities



The highest projected ratios for low-income Non-OECD Asian countries are those of Medlock-Soligo (2002). They employ a log-quadratic functional specification, which has an income-elasticity of vehicle ownership that is very high at the lowest levels of per-capita income but which declines rapidly as per-capita income increases (Figure 14). However, the data in Figure 4 suggest that the income-elasticity of vehicle ownership follows a non-monotonic pattern: increasing over the lowest income levels and decreasing over higher income levels, but remaining above 1.0 for income levels in the range of $3,000 to $15,000.

To sum up these comparisons, the considerably lower projections of non-OECD vehicle ownership in OPEC (2004) and SMP (2004) are due to their *assumption* of significantly lower income-elasticities and saturation levels of vehicle ownership for these regions. Such assumptions raise the important question of why developing countries – once they achieve levels of per-capita income within the range of OECD countries over the past few decades – would *not* have comparable levels of vehicle ownership. On what other goods would consumers in developing countries be spending their incomes instead?

[17] See Brennand (2006). Similarly low saturation levels were assumed by Button *et al.* (1993), for *car* ownership (300 to 450 cars per 1000 people). By contrast, Dargay-Gately(1999) estimated saturation levels of 620 cars (and 850 vehicles) per 1000 people. Button *et al.* (1993) made car ownership projections for ten low-income countries, two of which are included in our sample: Pakistan and Malaysia. They also made projections for 1986-2000, which underestimated by 50% the ratio of car ownership growth to per-capita income growth that actually occurred from 1986 to 2000 for these two countries.

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 15. Gasoline Usage and Vehicle Ownership for Selected Countries, 1971-2002

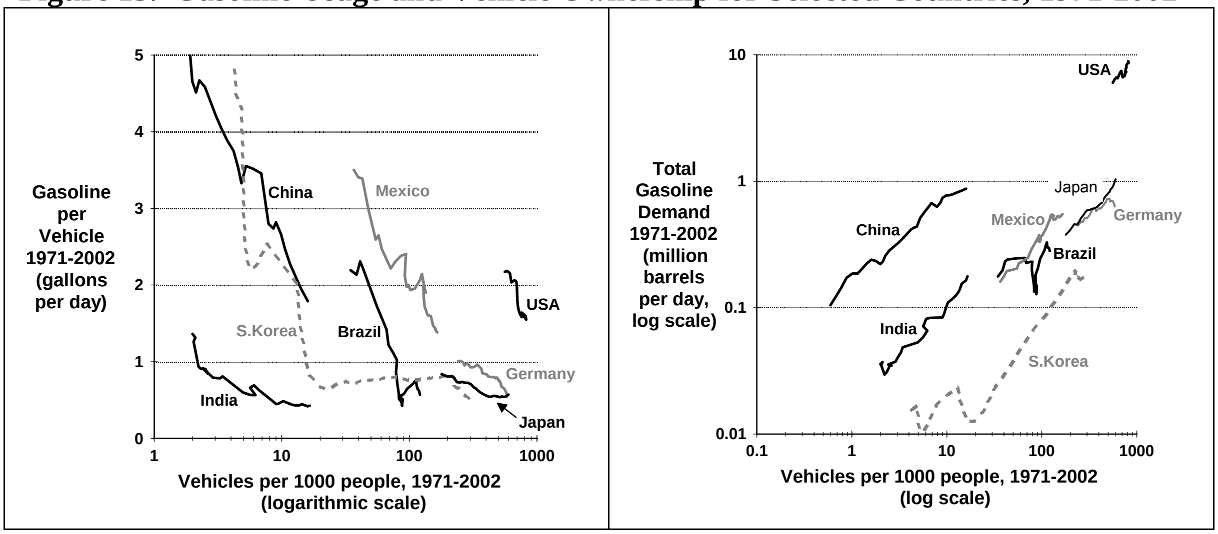


Figure 15 summarizes, for several large countries, the 1971-2002 relationship between *gasoline* usage[18] and vehicle ownership, both per-vehicle (left graph) and total (right graph). At the lowest levels of vehicle ownership, fuel use per vehicle is relatively high; a relatively small number of vehicles (mostly buses and trucks) are used intensively. As vehicle ownership grows, more cars and other personal vehicles are available; these additional vehicles are used less intensively than buses and trucks, so that fuel use per vehicle declines, while total use grows.

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[19]

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[18] 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. Some recent reductions in German gasoline usage reflect fuel-switching to diesel and in Brazil reflect the use of ethanol.

[19] 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:

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.

If our high projected long-term growth rates of highway fuel demand turn out to be correct, this may test the ability of producers to increase production. Given limited incentives for the OPEC countries to increase production quickly (Gately, 2004), as well as restrictions on investment in many countries, it is not clear whether there will be enough oil in the market to match rising demand at prices typical over the past several decades. If prices indeed turn out to be considerably higher than in the past, highway fuel demand will grow more slowly than our projections, due to lower use of vehicles, higher fuel efficiency, use of alternative fuels such as bio-diesel and possibly also due to reduced vehicle ownership rates. This last effect would not be captured by our partial equilibrium model of vehicle ownership. However, our results clearly support the view that, with current policies, oil demand will continue to rise significantly over the coming decades and there are significant risks that the oil market balances will often be tight; see IMF (2005) for a detailed discussion.

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

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-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.

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.

Our results also 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 up to 2.5-2.8%. Our work has a number of other broad policy implications. For example, developing countries will face the challenge of building the infrastructure (roads, bridges, fuel delivery, etc.) needed to support the growth in vehicle ownership. Moreover, many of the environmental concerns associated with the greater use of vehicles could presumably be strengthened by our projections, especially since future vehicle ownership growth will mostly take place in developing countries that have so far been able to deal with the environmental issues less successfully than advanced economies (World Bank, 2002). However, while the historical patterns in vehicle ownership rates suggest that growing wealth is a powerful determinant of vehicle demand, policymakers may be able to slow the expansion of the vehicle stock through tax policies, promotion of public transport, and appropriate urban planning – an important area for future research.

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APPENDIX A: Data Sources

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

Data on vehicles (at least 4 wheels, including cars, trucks, and buses) 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 income data from IMF's *World Economic Outlook* database using the assumption that growth in the PPP GDP rate equals real income growth.

Data on the real income 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 income 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 income 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.

APPENDIX B: Alternative Specifications

This appendix compares in the results of our Reference Case with four alternative specifications of the vehicle ownership equation:

- Reference Case but without using Population Density;
- Reference Case but without using Urbanization;
- Reference Case but without allowing for Asymmetric Income Responsiveness;
- Common Saturation Levels: Dargay-Gately(1999), Symmetric Income Response.

Table B1 displays the estimated values for all coefficients (except country-specific β_i) and their Probability Values, as well as the Adjusted R^2 and Sum of Squared Residuals. Also shown are projections of Total Vehicles in 2030 (millions), for all countries with more than 10 million vehicles, as well as World totals – assuming the same projected level for non-sample "Other" countries (315 million) across all specifications.

The econometric results are similar across all specifications. All the coefficients have the expected sign and are statistically significant (except for country-specific β_i for some of the smaller countries, as in Table 2). All have comparable summary statistics: high Adjusted R^2 and low Sums of Squared Residuals.

Projections of Total Vehicles in 2030 for the World are very similar across specifications, although country-specific projections may differ by more, especially for those countries with extreme values of density or urbanization. World totals within 2% of the Reference Case are projected by the specifications which exclude (respectively) Density or Urbanization or Income Asymmetry. The largest differences from the Reference Case result from the Common Saturation specification (Dargay-Gately 1999); world projections that are 95% of Reference Case, with OECD projections higher (103%) and Non-OECD projections lower (89%). Compared with the differences across projections in Table 4, however, these alternative specifications generate remarkably similar projections.

Table B1. Econometric Results and Projections from Alternative Specifications

	Alternative Specifications									
	Reference Case		X-Density		X-Urbanization		X-Asymmetry		Common Saturation	
asymmetric income response	**yes**		**yes**		**yes**		**no**		**no**	
population density	**yes**		**no**		**yes**		**yes**		**no**	
urbanization	**yes**		**yes**		**no**		**yes**		**no**	
	coef.	P-value	coef.	P-value	coef.	P-value	coef.	P-value	coef.	P-value
Speed of adjustment θ										
income increases	0.095	0.00	0.080	0.00	0.093	0.00	0.098	0.00	0.075	0.00
income decreases	0.084	0.00	0.066	0.00	0.083	0.00	0.098		0.075	
max. saturation level γ_{max}	852	0.00	853	0.00	852	0.00	852	0.00	852	0.00
population density λ	-0.000388	0.00			-0.000476	0.00	-0.000400	0.00		
urbanization φ	-0.007765	0.00	-0.015297	0.00			-0.007445	0.00		
alpha α	-5.897	0.00	-5.613	0.00	-5.814	0.00	-5.912	0.00	-5.362	0.00
Adjusted R-squared	0.999825		0.999825		0.999828		0.999828		0.999820	
Sum of Sq. Residuals	0.038947		0.039843		0.039229		0.039039		0.041131	

	Total Vehicles 2030 (millions)	Total Vehicles 2030 (millions)	Total Vehicles 2030 (millions)	Total Vehicles 2030 (millions)	Total Vehicles 2030 (millions)
OECD, North America					
Canada	30.0	29.6	30.2	30.1	29.7
United States	314.4	314.3	314.4	314.4	313.8
Mexico	65.5	63.3	64.8	65.5	60.5
OECD, Europe					
Germany	57.5	59.2	59.4	57.4	64.1
Spain	31.7	31.9	31.7	31.8	31.8
France	50.3	51.2	49.9	50.3	50.9
Great Britain	44.0	45.6	45.6	44.0	49.9
Italy	40.2	42.2	39.7	40.2	42.1
Netherlands	10.2	11.9	10.3	10.2	12.7
Poland	27.4	27.6	27.1	27.4	27.2
Turkey	34.7	34.0	34.1	34.6	32.3
OECD, Pacific					
Australia	18.4	17.0	19.7	18.5	19.5
Japan	86.6	96.7	84.6	86.3	97.1
Korea	30.5	36.1	29.8	30.3	37.5
Non-OECD, South America					
Argentina	23.8	22.3	23.9	24.0	22.1
Brazil	83.7	78.1	83.9	83.7	76.1
Chile	11.7	11.0	11.8	11.7	11.0
Non-OECD, Africa and Middl					
Egypt	15.5	14.6	15.1	15.5	13.5
South Africa	16.7	15.8	16.5	16.8	15.1
Non-OECD, Asia					
China	390.2	349.8	376.5	392.0	309.8
Chinese Taipei	13.6	20.1	12.2	13.4	20.2
Indonesia	46.1	42.7	44.7	46.1	38.7
India	155.5	142.1	147.4	155.8	123.4
Malaysia	23.8	23.9	23.6	23.8	23.4
Thailand	44.6	44.5	43.9	44.7	43.1
Sample (45 countries)	**1765**	**1723**	**1739**	**1767**	**1663**
Other Countries	**315**	**315**	**315**	**315**	**315**
OECD Total	**908**	**927**	**908**	**907**	**937**
Non-OECD Total	**1172**	**1112**	**1146**	**1175**	**1041**
Total World	**2080**	**2038**	**2054**	**2082**	**1978**

	Total Vehicles: % of Reference Case	Total Vehicles: % of Reference Case	Total Vehicles: % of Reference Case	Total Vehicles: % of Reference Case
Sample (45 countries)	97.6%	98.5%	100.1%	94.2%
Other Countries	100.0%	100.0%	100.0%	100.0%
OECD Total	102.1%	100.0%	99.9%	103.2%
Non-OECD Total	94.8%	97.7%	100.2%	88.8%
Total World	98.0%	98.7%	100.1%	95.1%