Topic area: D 1

Paper Number: 4124

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Title:

MODELLING GLOBAL VEHICLE OWNERSHIP

Abstract:

This paper presents projections of the growth in the vehicle stock over the next two decades for 82 countries at different levels of economic development, from the lowest (China, India, and Pakistan) to the highest (the US, Japan, and Europe). The projections are based on a dynamic econometric model which uses a Gompertz function to specify the relationship between per capita vehicle ownership and per-capita income, or GDP. Pooled time-series and cross-section data are employed to empirically estimate the income elasticities and saturation levels for different countries. The saturation level is allowed to vary amongst countries as a function of population density. In addition, the issue of symmetry of response to rising and falling income is examined. The asymmetric specification used 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.

Keywords: transport modelling, car ownership, demand elasticities, vehicle ownership

Method of Presentation: OHP

1 INTRODUCTION

This paper examines the trends in the growth of the stock of road vehicles in a large sample of countries over the past decades and presents projections of its development over the next 25 years. It employs an S-shaped function - the Gompertz function - to estimate the relationship between the vehicle stock and income, or GDP. Pooled time-series and cross-section data are employed to empirically estimate the saturation level and income elasticities for different countries. 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 in different time perspectives 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 follows earlier work by the same authors (Dargay and Gately, 1996, 1999), which was based on a sample of 26 countries - 20 OECD countries and 6 LDCs - for the period up until 1992, and projections were made to the year 2015.

The current study extends our earlier work in three ways. Firstly, the data set is extended in time - to 1997 in most instances - and is more comprehensive. In addition to the original 26 countries, 56 countries are included, so that for the year 1997, 86% of the world population and 96% of the total vehicle stock is represented. The comprehensiveness of the data set and particularly the inclusion of a large number of developing countries provide a high degree of variation in both income and the vehicle stock. This allows more precise estimates of the relationship between income and the number of vehicles at various stages of economic development.

Secondly, the assumption of a common saturation level for all countries is relaxed. In our previous study, the estimated saturation level was constrained to be the same for all countries, and differences in vehicle ownership between countries at the same income level were accounted for by allowing saturation to be reached at different income levels. There are, of course, a number of reasons why saturation, itself, may be different for different countries. Many of these have to do with transport policy. The existence of reliable public transport alternatives, 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. Other factors which can be thought to influence the saturation level have to do with the demographics of the different countries. A higher proportion of urban population would reduce the demand for vehicles, while larger land areas would increase distances travelled by individuals and for goods and thus require a greater number of vehicles. In this study we attempt to account for these demographic differences by specifying the saturation level as a function of a rough measure of population density: the number of inhabitants per square kilometre.[1] Since population density may change over time, the saturation level will vary over time as well as across countries.

[1] Although we also have data on the proportion of the population living in urban areas, we are unable to use this variable since we have no information on its future development.

The third extension we make to our earlier study concerns the assumption of symmetry in the response of the vehicle stock to rising and falling income. Although there is little doubt that increasing income leads to a higher vehicle ownership, less is understood about the effect of declining income. Given the longevity of the vehicle stock, habit persistence etc. one might expect that reductions in income would not necessarily 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. In most countries real per capita GDP falls in at least one year over the observation period, and in many LDCs, GDP falls in a number of years.

Traditional demand modelling is based on the implicit assumption that demand responds symmetrically to rising and falling income, as well as all other explanatory variables. There are few empirical studies which address the asymmetry issue. An exception is a study by Dargay (2000) of household car ownership in the UK, which employs decomposition techniques to separately estimate elasticities with respect to rising and falling income. The results indicate that car ownership responds more strongly to rising than to falling income – there is a 'stickiness' in the downward direction. In the current study, we employ a rather different technique. In order to account for possible asymmetry, the demand function is specified in such a manner that adjustment to falling income is allowed to be different from that to rising income. This 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.

Section 2 summarises the data used for the analysis, and explores the historical patterns of the vehicle stock 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 summarises the projections for vehicle ownership, based upon assumed growth rates of per-capita income in the various countries. Section 6 presents conclusions.

2 HISTORICAL PATTERNS IN THE GROWTH OF ROAD VEHICLES

Table 1-a and 1-b lists the countries included in the analysis and the observation sample for each of the countries, along with some of the data. The first 26 countries - from Australia to the US - are those included in our previous studies, while the remainder of the 82 countries are new to this analysis. The maximum observation period for which we have data for all variables - the number of road vehicles, GDP, population and population density - is from 1960 to 1997. This is generally the case for the OECD countries included in the first 26. For the non-OECD countries, with the exception of China, India, Pakistan and Israel, the data sample is much smaller, but generally from around 1989 or 90 to 1996.

Also included in the tables are the data for 1996, as well as the average annual percentage change in these variables from 1990 to 96. This short period was chosen for comparative purposes, simple because we have data for most countries over this period. From the Tables we see that there is considerable variation amongst countries. The number of vehicles per capita ranges from a maximum of 0.78 in the US to 0.01 or less in many of the poorest countries. The OECD countries generally have between 30 and 70 vehicles per capita. The only exceptions are the lowest income countries - Mexico, Turkey and Korea. The variation is greater in the non-OECD countries, where the number of vehicles per capita ranges from less than 0.01 in many countries to 0.41 in Kuwait.

Table 1-a. Historic Data.

	Data	Vehicles per capita	GDP per capita 85US$	Population millions	Vehicles millions	Vehicles per capita	GDP per capita 85US$	Population	Vehicles
		1996				Average annual % change 1990-96			
Australia	65-96	0.60	16202	18.3	11.0	0.8	1.9	1.2	2.0
Austria	70-97	0.56	13555	8.1	4.5	2.7	1.1	0.7	3.4
Canada	60-96	0.59	17102	30.0	17.5	-1.1	-0.1	1.3	0.2
China	65-96	0.01	2209	1215.4	10.5	9.0	8.9	1.1	10.3
Denmark	67-96	0.39	15452	5.3	2.0	0.8	1.8	0.4	1.2
Finland	60-97	0.44	13187	5.1	2.2	-0.5	-1.1	0.5	0.0
France	60-97	0.52	14338	58.4	30.6	0.7	0.5	0.5	1.2
Germany	60-96	0.68	15163	81.9	56.1	4.8	0.9	0.5	5.3
Greece	75-96	0.31	7252	10.5	3.3	3.9	1.2	0.5	4.4
India	66-96	0.01	1557	945.6	6.6	5.3	3.5	1.8	7.2
Ireland	79-96	0.34	12727	3.6	1.2	2.1	5.4	0.6	2.7
Israel	70-97	0.24	11160	5.7	1.4	3.6	3.1	3.4	7.1
Italy	60-96	0.55	13152	57.4	31.8	1.1	0.9	0.2	1.3
Japan	60-96	0.55	15836	125.8	68.7	2.6	1.7	0.3	2.9
Korea, Rep.	70-97	0.21	9795	45.5	9.6	17.6	6.6	1.0	18.8
Mexico	70-96	0.14	6099	92.7	13.1	2.7	0.8	1.8	4.5
Netherlands	70-97	0.41	14222	15.5	6.4	0.1	1.5	0.6	0.8
Norway	67-97	0.47	17959	4.4	2.1	0.4	3.2	0.5	0.9
Pakistan	60-97	0.01	1504	125.4	1.2	3.1	1.3	2.5	5.7
Portugal	65-97	0.36	8419	9.9	3.6	8.3	2.0	0.1	8.4
Spain	60-97	0.45	10307	39.3	17.7	3.3	1.2	0.2	3.5
Sweden	60-97	0.45	14544	8.8	4.0	-0.3	-0.2	0.5	0.2
Turkey	63-97	0.06	4127	62.7	3.5	5.0	1.6	1.9	7.0
UK	60-97	0.47	14006	58.8	27.7	0.5	1.0	0.4	0.8
United States	60-96	0.78	19410	265.2	206.0	0.5	1.2	1.0	1.5
Indonesia	90-96	0.02	2628	197.2	4.4	5.8	4.9	1.7	7.6
Brazil	90-96	0.08	4225	161.5	12.8	-1.8	0.7	1.5	-0.3
Nigeria	94-96	0.01	956	114.6	1.4	-1.0	-0.3	3.0	1.9
Philippines	90-96	0.03	1813	71.9	2.1	19.8	0.5	2.3	22.6
Thailand	89-96	0.10	5108	60.0	6.2	14.4	6.1	1.3	15.8
Iran	90-95	0.04	3718	59.9	2.5	3.5	1.5	1.6	5.2
Egypt	89-96	0.03	2024	59.3	1.8	0.7	1.0	2.1	2.8
Congo,Dem. Rep.	90-96	0.03	214	45.3	1.4	5.6	-8.9	3.2	9.1
South Africa	90-96	0.14	3173	39.9	5.7	0.3	-0.4	2.1	2.4
Colombia	93-96	0.04	3756	39.3	1.4	-1.9	2.6	2.0	1.0
Poland	89-97	0.25	4705	38.6	9.6	6.8	3.5	0.2	7.0
Argentina	89-96	0.15	6042	35.2	5.4	-2.7	4.3	1.3	-1.4
Tanzania	90-96	0.00	458	30.5	0.1	-1.3	-2.0	3.0	1.7
Algeria	93-96	0.05	2583	28.7	1.5	16.7	-0.1	2.3	10.5

Kenya	89-96	0.01	913	27.9	0.4	0.7	0.0	2.9	3.6

Table 1-b. Historic Data.

	Sample	Vehicles per capita	GDP per capita 85US$	Population millions	Vehicles millions	Vehicles per capita	GDP per capita 85US$	Population	Vehicles
				1996		Average annual % change 1990-96			
Sudan	90-96	0.01	985	27.2	0.3	5.0	4.5	2.0	7.1
Morocco	90-96	0.05	2305	26.8	1.3	4.4	1.2	1.9	6.3
Peru	93-96	0.12	2568	23.9	2.9	-1.7	5.5	1.8	0.9
Romania	89-96	0.12	1790	22.6	2.8	9.7	-0.7	-0.4	9.2
Venezuela	93-96	0.09	6415	22.3	2.0	-2.1	1.0	2.3	1.2
Malaysia	93-97	0.17	7235	21.1	3.5	5.0	5.9	2.5	7.6
Sri Lanka	89-96	0.01	2594	18.3	0.3	-5.6	3.6	1.2	-4.4
Syria	90-96	0.03	4866	14.5	0.4	1.6	3.8	3.0	4.7
Chile	89-96	0.11	6048	14.4	1.6	5.3	5.7	1.6	7.0
Cote d'Ivoire	90-96	0.03	1132	13.9	0.5	5.4	-1.1	3.0	8.6
Cameroon	90-96	0.01	932	13.6	0.2	3.0	-4.5	2.8	5.9
Ecuador	89-96	0.04	2882	11.7	0.5	4.0	0.8	2.2	6.3
Zimbabwe	92-96	0.03	1226	11.2	0.4	-2.1	2.3	2.4	1.3
Guatemala	93-96	0.02	2354	10.2	0.2	-2.6	1.3	2.7	1.3
Hungary	89-97	0.27	4933	10.2	2.8	4.4	-1.4	-0.3	4.1
Belgium	89-97	0.47	13889	10.2	4.8	1.7	0.8	0.3	2.1
Zambia	90-96	0.03	657	9.2	0.2	10.5	-0.8	2.9	13.6
Tunisia	89-96	0.06	3171	9.1	0.6	5.0	1.4	1.8	6.9
Senegal	90-96	0.01	1136	8.6	0.1	4.3	-0.1	2.6	7.0
Bulgaria	89-97	0.23	4920	8.4	2.0	6.2	-3.8	-0.7	5.5
Dominican Rep.	90-96	0.05	2513	8.0	0.4	-7.4	2.5	1.9	-5.6
Bolivia	90-96	0.05	1854	7.6	0.4	2.4	1.9	2.4	4.9
Haiti	93-96	0.01	609	7.3	0.1	-2.2	-2.7	2.1	1.0
Switzerland	89-97	0.50	15503	7.1	3.5	0.3	-1.0	0.9	1.2
Honduras	89-96	0.03	1362	5.8	0.2	7.7	-0.2	3.0	10.9
El Salvador	90-97	0.08	2113	5.8	0.4	14.8	2.5	2.1	17.2
Benin	90-96	0.01	1033	5.6	0.0	18.9	2.0	2.9	22.4
Paraguay	93-96	0.02	2142	5.0	0.1	-2.5	-0.4	2.7	1.4
Nicaragua	89-96	0.03	1457	4.6	0.1	7.5	2.0	2.9	10.6
Jordan	90-96	0.07	3139	4.3	0.3	2.2	1.2	5.3	7.6
New Zealand	90-96	0.56	12495	3.7	2.1	0.6	1.4	1.7	2.3
Costa Rica	89-96	0.12	3722	3.4	0.4	6.2	1.0	1.9	8.2
Uruguay	90-97	0.16	5663	3.2	0.5	2.9	3.5	0.7	3.7
Panama	90-96	0.10	3481	2.7	0.3	5.7	3.2	1.8	7.7
Congo, Rep.	90-96	0.02	2160	2.6	0.1	1.9	-0.4	2.9	4.8
Jamaica	93-96	0.05	2433	2.5	0.1	-0.9	-0.9	0.9	0.5
Oman	90-95	0.14	7881	2.2	0.3	1.5	0.5	4.9	6.5
Kuwait	93-95	0.41	14300	1.7	0.7	-4.9	0.7	-3.7	-6.1
Trinidad&Tobago	93-96	0.11	7782	1.3	0.1	-0.8	2.8	0.8	0.4
Gabon	90-96	0.04	3823	1.1	0.0	2.8	-0.6	2.7	5.5
Luxembourg	89-96	0.60	19245	0.4	0.2	2.6	2.8	1.4	4.1
Iceland	89-96	0.52	13547	0.3	0.1	-0.1	0.2	1.0	0.9

The following column shows per-capita GDP in constant US dollars expressed in international prices, base year 1985.[2] Clearly, the variation in per capita income is very wide - from $456 in Tanzania to over $19000 in the US 1996. The next two columns show population and the total number of vehicles per country. As expected, the US is responsible for a very large share of vehicles, 30% of the total, while accounting for only 5% of the population of the countries included.

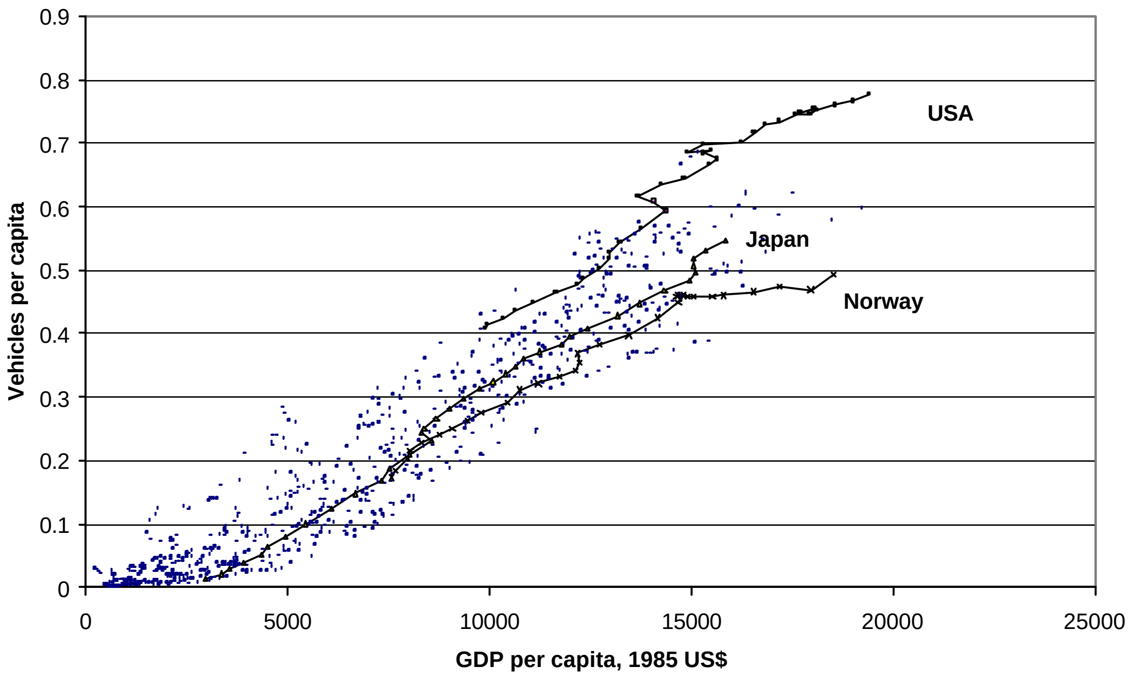
The average annual rates of change of these variables over the period 1990 to 1996 are shown in the final four columns. Again, the variation across countries is apparent. Vehicles per capita increased by about10% per year or more in The Philippines, Thailand, Korea, China, Algeria, Zambia, El Salvador and Benin, while most OECD countries experienced growth rates of less than 2%. In some countries, vehicles per capita declined over the period, but the absolute number of vehicles has risen in all but two instances. In addition, many countries have experienced a decline in real per capita GDP.

The relationship between vehicles per capita and GDP per capita is shown in the scatter diagram in Figure 1. All available data is plotted for all countries over time. Although the individual countries cannot be distinguished, the general pattern can be gleaned. The number of vehicles rises slowly at the lowest income levels, increases more quickly in the $5000 to $15000 range, after which the growth rate begins to decline. In other words, the relationship appears to follow an S-shaped curve. Clearly there is a large variation in the number of vehicles per capita for any given income level. Some of this variation has to do with the fact that the observed vehicle-GDP observations are not in equilibrium. The number of vehicles in a given year is determined not only by current income, but also by past income. Some of the variation, however, is a result of differences in the individual countries - differences in transport policy, prices, or the demographic factors referred to earlier.

The data for three countries - the USA, Japan and Norway - are illustrated by lines joining the annual data points. We see that the development has been rather different in the three countries: the US has the largest number of vehicles per capita and Norway the lowest at all comparable income levels. The majority of OECD countries, lie in between the two, as exemplified by Japan. The highest income countries give some idea of the level of vehicle saturation. There is a suggestion that this may not be the same for all countries, but that there may be a range in saturation levels.

[2] The GDP per capita series is constructed from the Penn World Tables (through 1992), then using World Bank growth rates through 1997.

Figure 1. The relationship between vehicles per capita and GDP per capita.



3. THE MODEL

As illustrated above, the relationship between vehicle ownership and per-capita income appears to be represented by an S-shaped curve. This implies that the number of vehicles (per capita) increases slowly at the lowest income levels, and then more rapidly as income rises, finally to slow 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 in allowing different curvatures at low- and high-income levels.

Letting *V** denote the long-run equilibrium level of the vehicle/population ratio, and letting GDP denote per-capita income, the Gompertz model can be written as:

$$V_t^* = g\, e^{a\, e^{b\, GDP_t}} \qquad (1)$$

where γ is the saturation level and α and β are negative parameters defining the shape, or curvature, of the function. Figure 2 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:

$$h_t^{LR} = ab\,GDP_t\, e^{b\,GDP_t} \qquad (2)$$

Figure 3 shows the income elasticity for various income levels of the Gompertz function depicted in Figure 2.

Figure 2 Illustrative Gompertz function

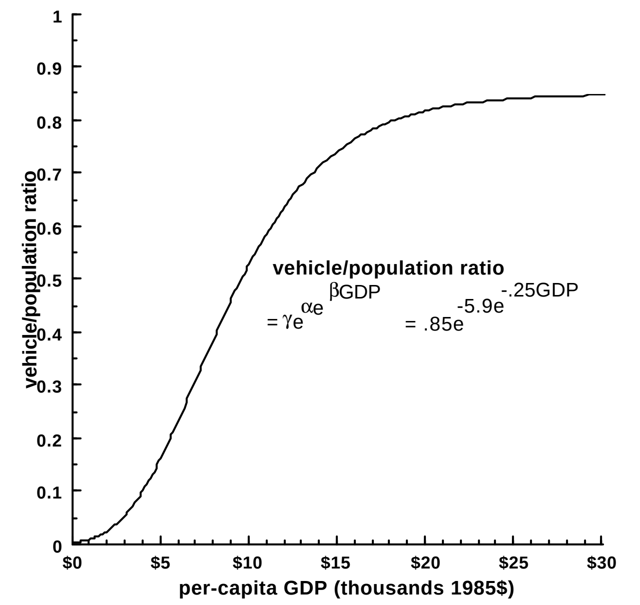
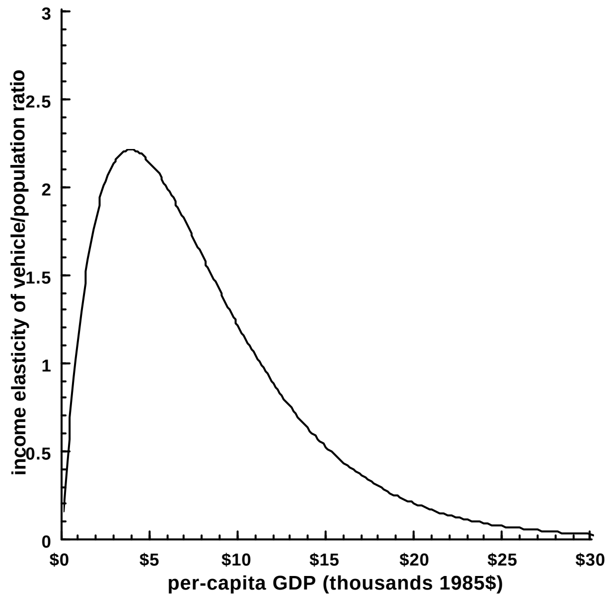


Figure 3 Implied Income Elasticity



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:

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

where θ is the speed of adjustment (0 < θ <1). Such lags reflect the slow adjustment of vehicle ownership to increased income: the necessary buildup 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:

$$V_t = gq\, e^{a\, e^{b\, GDP_t}} + (1-q)V_{t-1} \qquad (4)$$

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, γ, requires observations on vehicle ownership which are nearing saturation. Analogously, the parameter α which determines the value of the Gompertz function at GDP=0 necessitates observations on very low income and ownership levels. It would not be sensible, for example, to estimate the saturation level, γ, for low-income countries separately, as 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 only 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 modelled simultaneously.

In our earlier studies based on a smaller sample of countries, we restricted γ, α, and θ to be the same for all countries, and allowed only β to be country specific. Thus we assumed a common saturation level for all countries, and differences in between countries reflected by the income at which saturation is reached.[3] In this paper we relax this restriction by specifying the saturation level to be a function of population density, and thus vary amongst countries. Since the population density of each country changes over time as population changes, the saturation level varies over time as well as across countries. The saturation level for country *i* at time *t* is specified as:

$$g_{it} = \bar{g} + l \ PD_{it} \qquad (5)$$

where the population density (population per square km), PD, is normalised so that $\bar{g}$ is the mean saturation level of the data sample.

The dynamic specification in equations (3) and (4) assumes that the response to a fall in income is equal but opposite to 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 our countries have experienced negative as well as positive per capita GDP growth over the period, it is important that we take such asymmetry into consideration. To do so, the adjustment coefficient relating to periods of falling income, q_F , is allowed to be different from that to rising income, q_R. The estimated equation is:

$$V_t = g\,(q_R D_R + q_F D_F)\, e^{a e^{b\, GDP_t}} + (1 - q_R D_R - q_F D_F) V_{t-1} \qquad (6)$$

where $D_R = 1$ if $GDP_t - GDP_{t-1} > 0$ and $= 0$ otherwise
and $D_F = 1$ if $GDP_t - GDP_{t-1} < 0$ and $= 0$ otherwise.

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 vehicle ownership probably does not decline at the same rate when income falls as it increases when income rises, we would expect $q_R > q_F$. The hypothesis of asymmetry can be tested statistically from the estimates of q_R and q_F. If they are not

[3] It can be shown, that the level of GDP at which x % of saturation is reached is calculated as Ln(Ln(x)/α))/β.

statistically different from each other, symmetry cannot be rejected and the model reverts to the traditional case.

The model to be estimated econometrically form the pooled data sample becomes:

$$V_{it} = (\bar{g} + l PD_{it})(q_R D_R + q_F D_F) e^{a e^{b_i GDP_{it}}} + (1 - q_R D_R - q_F D_F) V_{it-1} \quad (7)$$

where the subscript *i* represents country *i*. The adjustment parameters, q_R and q_F , and the parameters α and λ are constrained to be the same for all countries, while β is allowed to be country specific. The long-run income elasticities for each country are calculated as

$$h_{it}^{LR} = a\, b_i GDP_{it} e^{b_i GDP_{it}} \, . \quad (8)$$

The short-run income elasticities are also determined by the adjustment parameter, θ, and are

$$h_{it}^{SR} = q\, a\, b_i GDP_{it} e^{b_i GDP_{it}} \, . \quad (9)$$

where $q = q_R$ for income increases and $q = q_F$. for income decreases.

3 MODEL ESTIMATION

The model described in equation (7) was estimated for the cross-section time-series data for the 82 countries. The period of estimation varies for the different countries due to data availability, as shown in Table 1. Because of the inclusion of the lagged dependent variable as an explanatory variable, the initial observation for each country is lost. In all, we have 1123 observations. As mentioned above, the mean saturation level, $\bar{g}$, the adjustment coefficients, q_R and q_F, and α were constrained to be the same for all countries. Due to the non-linear nature of the Gompertz function, the model was estimated using maximum likelihood methods.

The initial estimation allowed separate β_is for each country. Although the resulting parameters were of the correct sign and of a reasonable magnitude, many of the β_is for the countries with few observations were not statistically significant. The countries with non-significant βs were then grouped on the basis of the magnitudes of the initial estimates of β, and the model was re-estimated constraining the βs to be the same for the countries in each group. The resulting estimates are shown in Table 2. A total of 53 parameters are estimated, including 48 betas. All the estimated parameters are of the expected signs (θs and γ positive and α, λ and βs negative) and highly significant. From the R^2 values and F-statistics, we see the model explains the data very well. However, this is to be expected in a model containing a lagged dependent variable.

Table 2. Estimation results of the Gompertz model for vehicles per capita.

	coefficient	t-statistic		coefficient	t-statistic		coefficient	t-statistic
θ_R	0.12	14.2						
θ_F	0.07	9.8						
$\bar{g}$	0.80	111.8						
λ	-0.0077	-17.6						
α	-5.90	-28.2						
β			β			β		
Australia	-0.20	-18.4	Korea, Rep.	-0.26	-17.3	Indonesia	-0.23	-7.8
Austria	-0.23	-8.5	Mexico	-0.20	-24.3	Brazil	-0.19	-12.4
Canada	-0.19	-27.0	Netherlands	-0.24	-9.9	Philippines	-0.45	-6.3
China	-0.17	-7.1	Norway	-0.17	-5.0	Thailand	-0.28	-15.4
Denmark	-0.16	-5.6	Pakistan	-0.22	-2.1	Iran	-0.19	-4.3
Finland	-0.18	-5.9	Portugal	-0.29	-8.7	Congo,DR	-2.67	-2.2
France	-0.21	-39.6	Spain	-0.25	-30.6	South Africa	-0.35	-8.1
Germany	-0.24	-36.3	Sweden	-0.17	-11.0	Poland	-0.43	-18.6
Greece	-0.27	-8.6	Turkey	-0.22	-10.0	Argentina	-0.19	-8.0
India	-0.20	-5.5	UK	-0.22	-35.6	Algeria	-0.36	-3.0
Ireland	-0.20	-2.9	United States	-0.23	-45.0	Peru	-0.41	-3.2
Israel	-0.18	-3.5	Switzerland	-0.18	-3.2	Malaysia	-0.22	-8.6
Italy	-0.26	-34.0	New Zealand	-0.21	-1.9	Chile	-0.21	-3.8
Japan	-0.27	-31.2	Belgium	-0.23	-4.4	Hungary	-0.37	-5.1
						Bulgaria	-0.34	-3.7
Sudan	-0.36	-2.8	Tanzania	-0.25	-1.9	Romania	-0.79	-7.1
Morocco			Ecuador			Cote d'Ivoire		
Zimbabwe			DominicanRep			Zambia		
Bolivia			Jordan					
Honduras			Uruguay					
El Salvador			Congo, Rep.					
Nicaragua			Kuwait					
Nigeria	-0.31	-3.7	Colombia	-0.13	-2.3	Sudan	-0.36	-2.8
Egypt			Sri Lanka			Morocco		
Kenya			Syria			Zimbabwe		
Cameroon			Guatemala			Bolivia		
Senegal			Paraguay			Honduras		
Haiti			Oman			El Salvador		
Benin			Trinidad			Nicaragua		
Costa Rica			&Tobago					
Panama			Gabon					
Jamaica			Luxembourg					
			Iceland					
Adjusted R2	.99987		Sum of sq. errors	.01865		Log likelihood	4586.1	

The adjustment parameter, θ, is estimated to be 0.12 for rising income, but only 0.7 for falling income. Testing for the equality of the θs results in F-statistic of 61, so that symmetry is clearly rejected. The vehicle stock thus declines less when income falls, than when income rises. When income rises, 12% of the complete adjustment occurs in one year, but when income falls only 7% of the long-term adjustment occurs in one year. The estimated mean saturation level is 0.80

vehicles per capita. The coefficient of population density is negative and statistically significant, indicating that the saturation level declines with increasing population density.

The value of α determines the maximum GDP elasticity, which in this case is estimated to be -2.1. Saturation is reached at different income levels for different countries, because 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. According to the estimates, the maximum income elasticity generally occurs for the different countries at income levels between \$3000 and \$6000 (1985 US\$). The values of α and β also determine the GDP level at which vehicle saturation is reached. The estimates imply that, on average, 99% of saturation is reached at a GDP level of around \$28000 (85 US) per capita.

4 PROJECTIONS OF CAR AND VEHICLE OWNERSHIP TO 2025

On the basis of the estimated models and assumptions concerning population and GDP growth, projections of car and vehicle ownership for the different countries can be made. The assumptions (Table 3) used are based on projections from the 2000 IEA World Energy Outlook for the years 1997 to 2020. We assume the same growth rates will hold until 2025. Population density is assumed to grow at the same rate as population.

Table 3. Assumptions concerning growth rates for the period 1997 to 2025.

	Real GDP	Population	GDP per capita
OECD North America	2.1	0.7	1.38
OECD Europe	2.1	0.2	1.88
OECD Pacific	1.7	0.1	1.59
Transition Economies	3.2	0.7	2.45
China	5.2	0.7	4.37
East Asia	4.2	1.1	3.02
India	4.9	1.2	3.59
South Asia	4.7	1.4	3.20
Brazil	2.5	1.1	1.38
Latin America	3.2	1.3	1.86
Africa	2.9	2.1	0.78
Middle East	3.2	2.6	0.58

Tables 4-a and 4-b show the resulting vehicle projections for the year 2025 for the individual countries as well as some of the other relevant estimates. For the year 2000, the estimated long-run GDP elasticity ranges from 0.2 in the US to 2.2 in a number middle-income countries, with rapid growth. For the majority of OECD countries, the elasticity is less than unity, and in all countries the elasticity will decline over time as income increases due to the nature of the Gompertz function.

The projections for vehicles per capita for 2025 and its average annual growth rate from 2000 to 2025 are given in the next two columns. As indicated earlier, there was in 1996 a vast difference in vehicle ownership amongst countries, ranging from less than 0.01 vehicles per capita in many of the poorest countries to 0.78 in the USA. In 2025 the range is even greater - from 0.01 vehicles per capita in some of the lowest African countries to 0.87 vehicles per capita in the USA. In the

European countries the variation is declining, but Turkey remains at a relatively low vehicle intensity.

Table 4-a. GDP elasticities, vehicle projections for 2025 and saturation levels.

	Long-run GDP Elasticity	Vehicles per capita	Average annual growth, %	Vehicles millions	Saturation vehicles per capita
	2000	2025	2000-2025	2025	2025
Mean all countries	1.5	0.3	2.2	16.2	0.8
Australia	0.7	0.84	1.05	16.03	0.91
Austria	0.7	0.78	1.03	6.65	0.83
Canada	0.6	0.85	1.04	31.13	0.91
China	1.7	0.10	8.87	151.89	0.79
Denmark	1.0	0.71	1.82	3.97	0.81
Finland	1.1	0.77	1.88	4.20	0.90
France	0.8	0.77	1.21	47.48	0.83
Germany	0.5	0.70	0.21	61.02	0.72
Greece	1.5	0.61	2.31	6.80	0.85
India	1.5	0.03	5.56	42.01	0.56
Ireland	0.9	0.78	2.17	3.02	0.87
Israel	1.6	0.29	0.25	3.43	0.47
Italy	0.6	0.72	0.81	43.95	0.75
Japan	0.3	0.64	0.43	82.47	0.65
Korea, Rep.	0.9	0.43	1.74	26.70	0.42
Mexico	2.0	0.37	3.40	50.04	0.86
Netherlands	0.5	0.52	0.72	8.58	0.54
Norway	0.7	0.84	1.60	3.89	0.90
Pakistan	1.5	0.03	4.74	6.62	0.72
Portugal	1.1	0.71	1.97	7.44	0.83
Spain	1.0	0.75	1.58	31.07	0.85
Sweden	1.1	0.76	1.76	7.14	0.90
Turkey	2.2	0.21	4.35	18.62	0.83
UK	0.6	0.68	1.02	42.25	0.71
United States	0.2	0.87	0.33	283.73	0.89
Indonesia	2.0	0.14	6.44	37.81	0.80
Brazil	2.2	0.13	2.26	29.98	0.89
Nigeria	1.3	0.01	0.26	2.57	0.73
Philippines	2.2	0.20	6.59	20.21	0.65
Thailand	2.0	0.51	5.17	41.95	0.79
Iran	2.1	0.06	1.33	7.81	0.85
Egypt	2.0	0.05	1.86	5.90	0.83
Congo,Dem. Rep.	1.9	0.04	0.97	3.17	0.89
South Africa	2.1	0.18	1.11	13.33	0.87
Colombia	1.9	0.06	2.26	3.29	0.87
Poland	1.3	0.67	2.99	31.52	0.80
Argentina	2.1	0.33	3.01	16.65	0.90
Tanzania	0.6	0.01	0.46	0.29	0.86
Algeria	2.2	0.12	2.52	6.44	0.90
Kenya	1.3	0.01	0.23	0.64	0.84

Table 4-b. GDP elasticities, vehicle projections for 2025 and saturation levels.

	Long-run GDP Elasticity	Vehicles per capita	Average annual growth, %	Vehicles millions	Saturation Vehicles per capita
	2000	2025	2000-2025	2025	2025
Sudan	1.5	0.02	1.45	0.97	0.90
Morocco	2.1	0.09	1.86	4.17	0.83
Peru	2.1	0.29	3.29	9.98	0.89
Romania	2.0	0.44	4.40	12.08	0.82
Venezuela	2.2	0.20	3.26	6.41	0.89
Malaysia	1.7	0.64	4.24	18.76	0.84
Sri Lanka	1.6	0.04	4.11	1.01	0.59
Syria	2.0	0.05	1.54	1.53	0.79
Chile	2.0	0.41	4.07	8.57	0.89
Cote d'Ivoire	2.2	0.12	3.18	3.07	0.85
Cameroon	1.3	0.01	0.65	0.34	0.87
Ecuador	2.1	0.12	3.70	2.04	0.87
Zimbabwe	1.7	0.03	0.06	0.57	0.87
Guatemala	1.4	0.02	1.09	0.33	0.80
Hungary	1.5	0.64	3.07	7.84	0.81
Belgium	0.6	0.63	0.90	6.75	0.66
Zambia	1.9	0.04	1.42	0.64	0.90
Tunisia	2.2	0.10	1.52	1.62	0.83
Senegal	1.5	0.02	1.00	0.29	0.85
Bulgaria	1.8	0.55	3.20	5.57	0.84
Dominican Rep.	2.0	0.08	2.60	0.97	0.73
Bolivia	2.1	0.11	3.34	1.23	0.91
Haiti	1.0	0.01	0.50	0.08	0.61
Switzerland	0.9	0.69	1.11	5.20	0.77
Honduras	1.8	0.05	2.22	0.46	0.85
El Salvador	2.1	0.10	2.20	0.84	0.59
Benin	1.4	0.02	1.79	0.16	0.84
Paraguay	1.4	0.02	0.66	0.17	0.90
Nicaragua	1.9	0.06	3.05	0.42	0.87
Jordan	2.1	0.07	0.46	0.66	0.83
New Zealand	1.0	0.78	1.17	3.03	0.90
Costa Rica	2.1	0.30	3.20	1.51	0.84
Uruguay	1.9	0.46	3.41	2.13	0.89
Panama	2.1	0.28	3.59	1.09	0.87
Congo, Rep.	1.8	0.03	1.69	0.16	0.90
Jamaica	2.1	0.09	2.73	0.35	0.65
Oman	2.2	0.15	0.59	0.72	0.90
Kuwait	0.6	0.69	1.09	2.56	0.75
Trinidad&Tobago	2.2	0.20	2.54	0.38	0.64
Gabon	1.8	0.04	0.54	0.08	0.91
Luxembourg	1.0	0.69	0.69	0.30	0.78
Iceland	1.6	0.63	0.91	0.17	0.91

There are also enormous differences amongst countries in the growth rates for vehicles over the forecast period. The highest growth rates are noted for the Asian countries as a result of the rapid assumed income growth. In general, the growth rates of vehicle intensity are far greater for the low-income countries than for the OECD – due both to faster growth in per-capita income and to higher income elasticities of vehicle ownership.

Comparing the projected number of vehicles in 2025 with those of 1996 (Table 1), we find a substantial increase in all countries. Because of the rapid growth in vehicles per capita and its large population, by 2025 China will be second to the US in total vehicles. The saturation levels, in terms of vehicles per capita for the 2025 are shown in the final column. Since these are dependent on population density, they are not constant over time but will decline as population increases. In 2025, the mean saturation level for all countries is estimated to be 0.8 vehicles per capita, with a range for the individual countries from 0.42 in Korea to 0.91 in Australia. The mean value is slightly lower that the common saturation level of 0.85 reported in Dargay and Gately (1999).[4]

The projections for the total number of vehicles by world region are shown in Figure 4. These indicate that Asia[5] will overtake both the US & Canada and OECD-Europe[6] within the next 25 years, while OECD-Europe will approach the US and Canada. OECD countries, in general, will be approaching saturation, while other regions will continue to experience rapid growth. The growth rate will be highest in Asia, followed by Latin America. In comparison, growth will be far slower in Africa and the Middle East.

Figure 4. Projections of road vehicles for world regions to 2025.

[4] In contrast, Button *et al*. (1993), which uses data only from low-income countries, sorted into five groups based on per-capita income and car ownership, assumes *different* saturation levels of car ownership for the five groups, which range from 0.3 to 0.45. These levels are substantially lower than those we find here. Such levels have long been exceeded by several OECD countries, yet it is never explained why countries in Latin America, Africa, and Asia – once they had achieved incomes similar to many OECD countries' 1990 incomes – would *not* have comparable levels of car ownership. On what other goods would they be spending those incomes instead?

[5] Here Korea is included in Asia and Japan in OECD Pacific.

[6] Transition economies of Eastern Europe are not included.

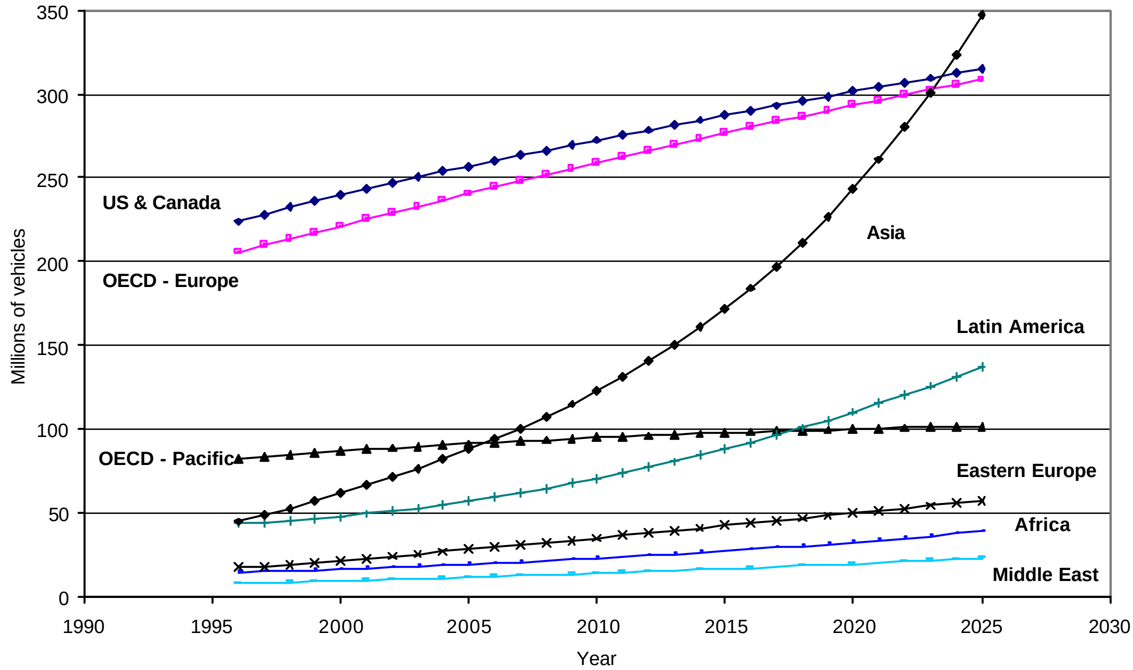
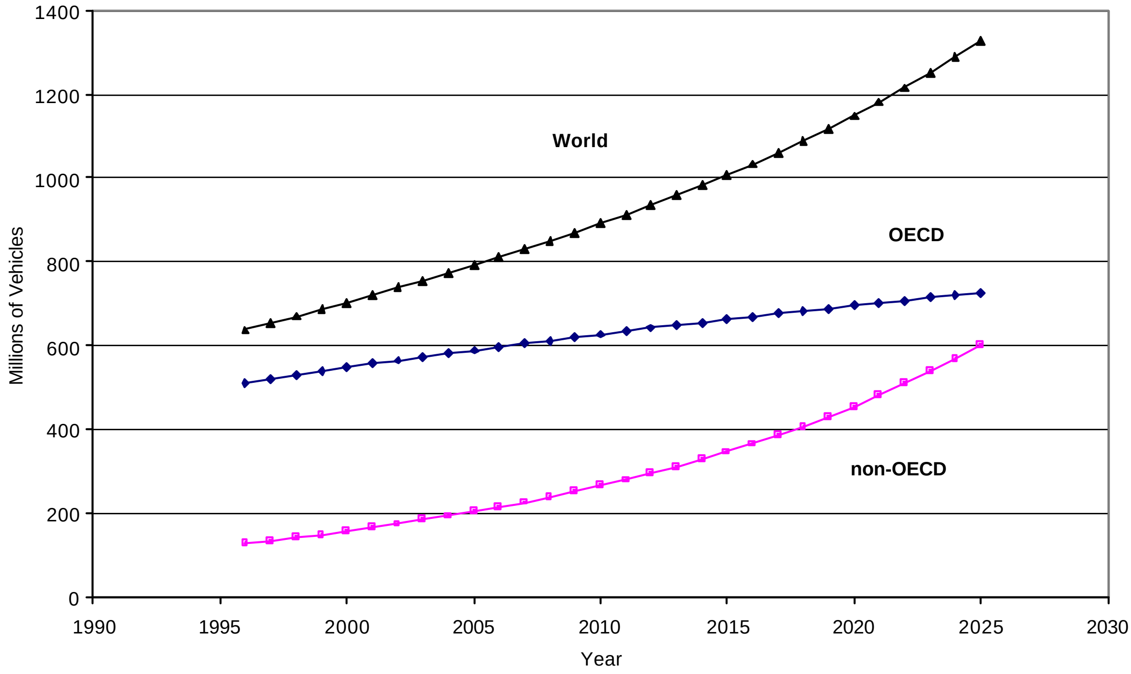


Figure 5 shows the projections for the total world vehicle stock, and that for OECD and non-OECD countries. The projections suggest a doubling of world vehicle stocks over the next 25 years. Over the same period, growth in the OECD will be only 40% while the number of vehicles in non-OECD countries will more than quadruple. Of the countries in our sample, today, the OECD countries account for nearly 80% of the vehicles, but with only 18 % of the total population. By 2025, the OECD countries' share of vehicles will be reduced to slightly more than half the total of our world sample, while they will account for around 15% of the population

Figure 5. Projections of road vehicles for OECD and non-OECD countries to 2025.



5 CONCLUSIONS

In the previous sections we have seen how projections of road vehicles can be obtained by estimating a dynamic Gompertz model on the basis of historical data for a wide range of countries. Our specification provides a simple yet powerful analysis of this relationship, using historical data for 82 countries, for periods up to nearly 4 decades, over a wide range of per-capita income levels and a range of growth rate experience. Apart from the projections presented in the previous section, our main conclusions can be summarised as follows:

- The Gompertz function provides a statistically valid representation of the relationship between the number of vehicles per capita and GDP per capita;
- Dynamics are important: adjustment of the vehicle stock to income changes does not occur instantaneously, but slowly over time;
- The relationship between vehicles and income is not symmetric in the short run: the response to falling income is less rapid than the response to rising income;
- There is evidence that the saturation level of vehicles per capita declines as population density increases.

There is, of course, a substantial amount of uncertainty in any projections so long into the future. Among the types of uncertainty in this study are the following:

- The growth rates in per-capita income and/or population could be significantly different from what we have assumed;
- the income elasticities, their changes over time and the saturation levels, could differ from what we have estimated in our model;
- there could be significant effects of non-income variables that we have omitted from our model, such as price effects (via changes the price of vehicles and/or fuels), changes in

government policies regarding transportation, and other demographic changes (such as an increase in the percentage of adults in the population, increased female labour-force participation, the proportion of the population living in urban conurbations).

However, these uncertainties should not detract from the fundamental point of this paper: there exists a strong historical relationship between the growth of per-capita income and the growth of the number of vehicles per capita. As per-capita income grows, so will the number of vehicles, at least until saturation is reached. Although many high-income countries will be approaching saturation over the next decades, on a global level, there is still a long way to go. This clearly has implications for the demand for motor fuels, for congestion and for the environment.

ACKNOWLEDGEMENTS

The authors are grateful for support from the Economic and Social Research Council of the UK and the C V Starr Center for Applied Economics at New York University.

DATA SOURCES

Vehicles: Motor Vehicle Manufacturers Association, *World Motor Vehicle Data*, World Bank.
Real Income: Gross Domestic Product (GDP 1985 US$ purchasing power parity): Penn World Tables, World Bank
Population, Population Density: World Bank
Projections of GDP per capita and population: IEA World Energy Outlook 2000.

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