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INCOME'S EFFECT ON CAR AND VEHICLE OWNERSHIP, *WORLDWIDE: 1960-2015*

by
Joyce Dargay
&
Dermot Gately

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C.V. STARR CENTER FOR APPLIED ECONOMICS

NEW YORK UNIVERSITY
FACULTY OF ARTS AND SCIENCE
DEPARTMENT OF ECONOMICS
WASHINGTON SQUARE
NEW YORK, NY 10003-6687

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Joyce Dargay
ESRC Transport Studies Unit
Centre for Transport Studies
University College London
Gower Street
London WC1E 6BT

phone: +44 01865 512427
fax: +44 0171 3911586
e-mail: j.dargay@ucl.ac.uk

and

Dermot Gately
Economics Department
New York University
269 Mercer Street
New York, NY 10003

phone: +1 212 998 8955
fax: +1 212 995 3932
e-mail: gatelyd@fasecon.econ.nyu.edu

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This paper makes projections of the growth in the car and total vehicle stock to the year 2015, for OECD countries and a number of developing economies, including China, India, and Pakistan. The projections are based on an econometrically estimated model that explains the growth of the car/population ratio ("car ownership") as a function of per-capita income; a similar model is used for vehicle ownership. The model estimations are based on annual data for 26 countries over the period 1960-92; it is the first study to include countries covering the full range of income levels, from lowest to highest. The models are dynamically specified, so that short- and long-run income elasticities of car and vehicle ownership are estimated. These income elasticities depend upon per-capita income, ranging from about 2.0, for low- and middle-income levels (that is, ownership grows twice as fast as income), down to zero, as ownership saturation is approached for the highest income levels. The similarities and differences among countries are embodied within the model specification, and the implications for the projections are analyzed.

INTRODUCTION

The transportation sector is responsible for over half of world oil consumption and about 30% of the world's total commercial energy consumption. It is also the most rapidly growing sector in terms of energy and particularly oil consumption. Over the past 20 years energy use in the transportation sector increased at an average of 2.7% per year, far more rapidly than any other sector. The annual rate of growth in the OECD (1.8%) -- and particularly in North America -- has been slower than in the rest of the world (4.5%) reflecting the slower income growth and the nearing of saturation of vehicle ownership and use. Growth has been the highest in the fastest growing economies: China, East Asia and parts of Latin America. In the OECD virtually all of the increase in oil demand since the mid-1970s is attributable to transportation, while in the rest of the world the comparable figure is about 45%.

The rapid expansion in the demand for transportation services which underlies the growth in energy demand can be expected to continue over the next two decades as per-capita income continues to grow. Growth will be especially rapid among low- and middle-income countries outside the OECD, whose income growth rates and income elasticities of car and vehicle ownership are expected to be high. Continued rapid growth is also expected for the lower-income OECD countries, and somewhat slower growth for Japan and most of Europe.

The lack of viable alternative fuels for road transportation means that oil demand will continue to increase, as will the associated CO_2 emissions. Because oil demand for road transportation is closely linked with the number of cars and other road vehicles in use, projections of future growth in the vehicle stock can provide an insight into future energy requirements and also to the environmental policy issues which may arise.

This paper presents projections of cars and total vehicles to the year 2015, for 26 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 that relates car and vehicle ownership to per-capita income. Although there are numerous studies of car and vehicle ownership, the focus is either individual countries (e.g., see Mogridge (1983, 1989), Gallez (1994), and Jansson (1989)) or limited groups of countries or regions (e.g., see Button *et al.* (1993), Greenman (1996), and Madre *et al.* (1995)). The data used in these studies vary considerably, from individual household data to aggregate national data. Some are based on models that include the effects of variables other than per-capita income, such as costs or demographic factors. Given the differences in data sources, model specification and methods, it is difficult to compare the results for different countries.

The advantage of the present study is that it applies a single econometric specification to consistent data for a wide range of countries, extending as far back as 1960. The results allow comparison amongst countries and over time, as well as providing projections for car and vehicle ownership for a substantial part of the world's population. The growth in car and vehicle ownership is explained solely as a function of per-capita income. The effects of prices and demographic and geographic factors are ignored within the model, being significantly less important, but they are discussed in Appendix C. Given the historical dominance of per-capita income in determining car and vehicle ownership, this simplification should not detract from the validity of the projections obtained.

The long-run relationship between the car/population ratio ("car ownership") and per-capita income is assumed to be defined by an S-shaped function. The income elasticity increases from below 1.0 at the lowest income levels to above 2.0 as income rises through the middle-income levels, before declining gradually to 0 as saturation is reached at the highest income levels. The model is estimated using time-series data for 20 OECD countries (including Mexico) and 6 less developed economies: China, India, Pakistan, Taiwan, South Korea and Israel.

Section 2 summarizes the historical patterns in the growth of car and vehicle ownership, relative to the growth in per-capita income. Section 3 presents the model to be used in the econometric estimation, and the econometric results are described in Section 4. Section 5 summarizes the projections of car and 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 CAR AND VEHICLE OWNERSHIP, RELATIVE TO GROWTH IN PER-CAPITA INCOME

Different countries' stocks of cars and vehicles and their development over time vary considerably. This is seen in Table 2.1, which summarizes the historical data for the countries covered in this study. The first three columns show the countries included, the abbreviations used in the figures that follow, and the years included in the data samples. The following columns show per-capita GDP (in 1985 US dollars) for 1970 and 1992, as well as the average annual percentage change over this period. The next columns show car ownership levels (defined as the number of cars divided by population) for the two years, the average annual percentage change over the period, and ratio of the average annual growth in car ownership to the average annual growth in per-capita GDP. Similar columns then show analogous data for vehicle ownership (the number of vehicles divided by population).

The variation across countries is apparent. For example, in 1992 ownership varies dramatically. The USA is at the high end, with 560 cars and 750 vehicles per thousand inhabitants. At the low end are China and India, with about 2 cars and 6 vehicles per thousand inhabitants. The average annual growth rates also vary considerably: from 1.2% for cars in the USA (and 1.6% for vehicles) to about 18% for cars (and 16% for vehicles) in South Korea and Taiwan. Relative to growth in per-capita income, the increase in car and vehicle ownership has been greatest in the fastest growing economies, South Korea and Taiwan.

These historical patterns in car and vehicle ownership across countries are illustrated in several figures that follow. Countries are identified in the figures by their abbreviations (codes), which are listed in Table 2.1. Figures 2.1 and 2.2 compare ownership levels between 1970 and 1992. Figures 2.3 and 2.4 show the changes from 1970 to 1992, in both ownership levels and absolute numbers of cars (and vehicles), using logarithmic scales. Figures 2.5 and 2.6 show the changes in ownership levels from 1970 to 1992, relative to the changes in per-capita income, for many of the countries. Figures 2.7 and 2.8 plot average income elasticities (growth-rate ratios: average annual % growth rate of car or vehicle ownership to average annual % growth rate of per-capita income, for 1970-90) versus the average levels of per-capita income over the 1970-90 period.

Table 2.1. Historical data.

Country	Code	Sample	GDP per capita 1985 US dollars			Cars per capita				Vehicles per capita			
			1970	1992	Average annual % change	1970	1992	average annual % change	% change/ % change GDP	1970	1992	average annual % change	% change / % change GDP
Canada	Can	60-92	10.1	16.4	2.2	0.31	0.49	2.1	0.9	0.38	0.62	2.3	1.0
Mexico	Mex	70-92	4.0	6.3	2.1	0.02	0.09	6.1	2.9	0.03	0.13	6.2	3.0
USA	USA	60-92	13.0	17.9	1.5	0.44	0.56	1.2	0.8	0.53	0.75	1.6	1.1
Austria	Astr	70-92	7.5	13.0	2.5	0.16	0.41	4.4	1.7	0.22	0.50	3.9	1.6
Denmark	Dnk	67-92	9.7	14.1	1.7	0.22	0.31	1.6	0.9	0.27	0.37	1.5	0.8
Finland	Fin	60-92	8.1	12.0	1.8	0.15	0.38	4.2	2.3	0.18	0.44	4.2	2.3
France	Fra	60-92	9.2	13.9	1.9	0.24	0.42	2.5	1.3	0.28	0.51	2.7	1.4
Great Britain	GB	60-92	8.5	12.7	1.8	0.21	0.40	2.9	1.6	0.24	0.46	2.9	1.6
Germany	Ger	60-92	9.4	14.7	2.0	0.22	0.44	3.2	1.6	0.26	0.54	3.4	1.7
Greece	Grc	75-92	5.2[1]	6.8	1.6	0.05[1]	0.18	7.9	5.0	0.07[1]	0.26	7.8	4.9
Ireland	Ire	79-92	6.8[2]	9.6	2.7	0.20[2]	0.24	1.4	0.5	0.25[2]	0.32	1.7	0.6
Italy	Ita	60-92	7.6	12.7	2.4	0.19	0.51	4.6	1.9	0.21	0.56	4.6	1.9
Netherlands	NL	70-92	9.2	13.3	1.7	0.19	0.37	3.1	1.9	0.21	0.42	3.1	1.8
Norway	Nor	67-92	8.0	15.5	3.0	0.18	0.38	3.5	1.1	0.22	0.46	3.5	1.1
Portugal	Prt	65-90	3.3	7.5[3]	4.2	0.05	0.16[3]	6.2	1.5	0.06	0.22[3]	6.7	1.6
Spain	Spn	70-92	5.9	9.8	2.4	0.07	0.34	7.3	3.1	0.09	0.41	7.0	3.0
Sweden	Swe	67-92	10.8	14.0	1.2	0.28	0.41	1.7	1.4	0.30	0.45	1.8	1.5
Turkey	Tur	63-92	2.2	3.8	2.5	0.004	0.04	10.6	4.2	0.01	0.05	8.4	3.3
Australia	Astl	65-92	10.8	14.5	1.4	0.31	0.45	1.8	1.3	0.38	0.57	1.8	1.3
Japan	Jpn	60-92	7.3	15.1	3.4	0.08	0.31	6.2	1.8	0.17	0.50	5.0	1.5
China	Chn	65-91	0.7	1.4[4]	3.3	0.0001	0.002[4]	16.5	5.0	0.0006	0.005[4]	11.0	3.3
India	Ind	66-92	0.8	1.3	2.2	0.001	0.003	5.4	2.5	0.002	0.006	5.3	2.4
Israel	Isr	70-89	6.0	9.0[5]	2.1	0.05	0.16[5]	6.5	3.0	0.08	0.20[5]	5.1	2.4
Pakistan	Pak	60-91	1.0	1.4[4]	1.6	0.003	0.01[4]	4.4	2.8	0.004	0.008[4]	4.0	2.5
South Korea	SKo	70-91	1.7	7.3[4]	7.2	0.002	0.06[4]	18.1	2.5	0.004	0.10[4]	16.4	2.3
Taiwan	Twn	66-90	2.2	8.1[3]	6.7	0.003	0.09[3]	17.9	2.6	0.01	0.12[3]	15.5	2.3
OECD[6]			7.8	12.2	2.2	0.18	0.34	4.1	1.9	0.22	0.43	4.0	1.8
LDC[6]			2.1	4.7	3.9	0.01	0.05	11.5	3.0	0.02	0.07	9.5	2.5
ALL[6]			6.5	10.5	2.6	0.14	0.28	5.8	2.3	0.17	0.34	5.3	2.0

[1] 1975. [2] 1979. [3] 1990. [4] 1991. [5] 1989. [6] Unweighted averages of individual countries.

Fig. 2.1 Car Ownership: 1992 vs. 1970

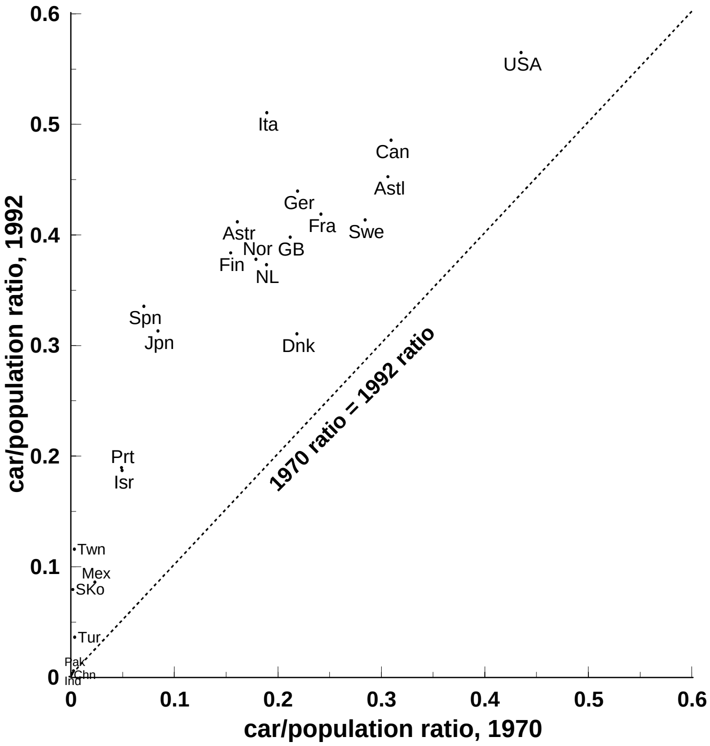


Fig. 2.2 Vehicle Ownership: 1992 vs. 1970

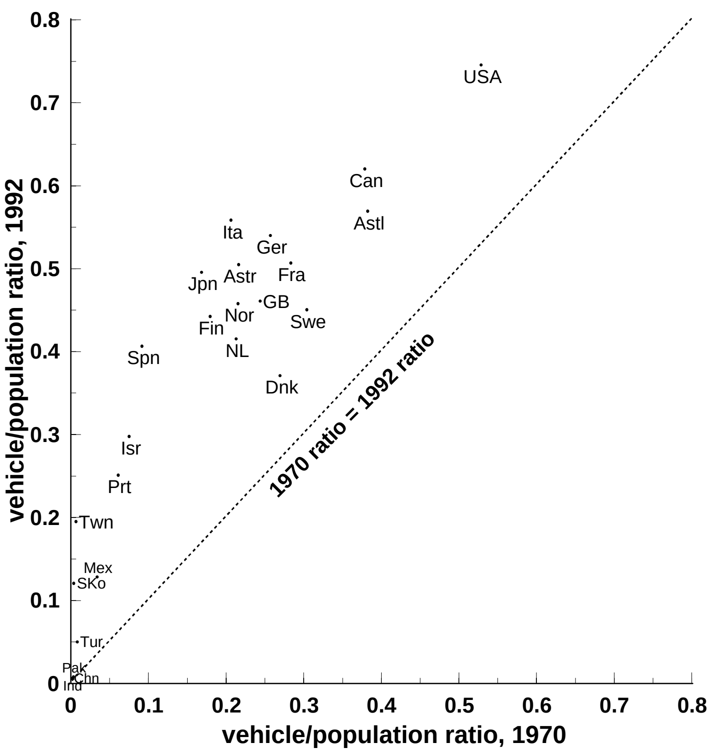


Figure 2.1 shows the changes in car ownership from 1970 to 1992 for all countries in the data sample. Figure 2.2 shows the same for vehicle ownership. Each country's 1970 car/population ratio is plotted on the horizontal, and its 1992 ratio on the vertical. The further a country is above the diagonal, the greater the increase from 1970 to 1992. For example, Italy's 1970 car/population ratio was .19 and by 1992 it had risen dramatically, to .51. South Korea's ratio grew from .002 to .06 over the same period.

All countries experienced significant growth in car and vehicle ownership during this period, from those with the highest income to those with the lowest. For countries such as China, India, and Pakistan, the *percentage* changes were as dramatic as for Italy, even though the levels and the absolute increases were small. The next two graphs, which use logarithmic scales, illustrate these percentage changes.

Fig. 2.3 # Cars & Ownership: 1992 vs. 1970

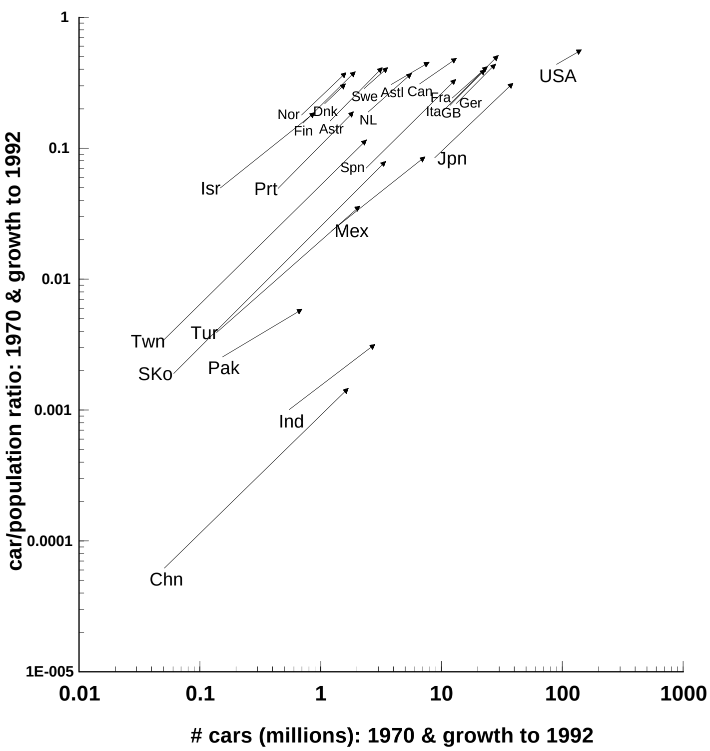
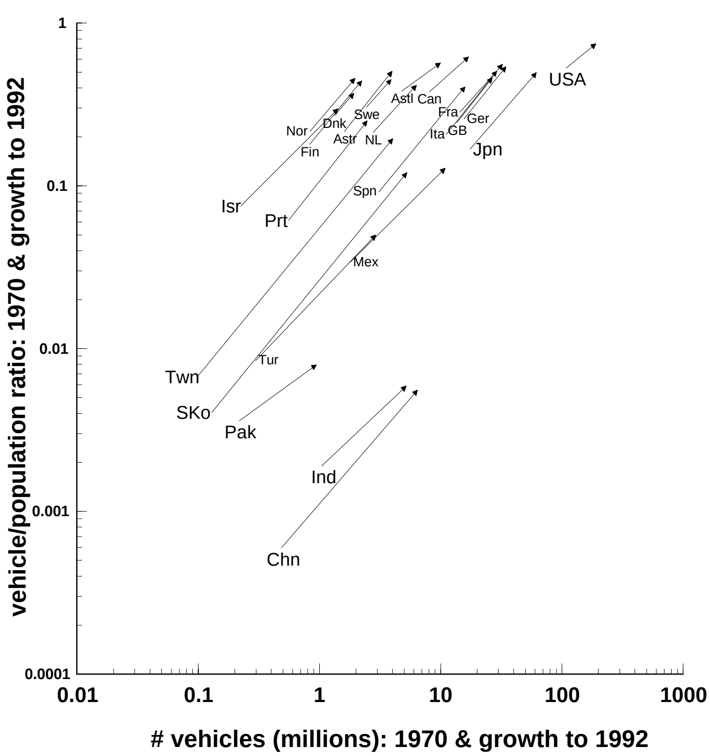


Fig. 2.4 # Vehicles & Ownership: 1992 vs. 1970



The proportionality in growth across countries becomes evident in Figures 2.3 & 2.4, in which we use *logarithmic* scales. These vector graphs plot ownership levels, for both 1970 and 1992, on the vertical axis against the absolute number of cars (vehicles) on the horizontal, for both 1970 and 1992. Each country's vector shows the movement from 1970 to 1992, in the levels of car ownership and in the total number of cars.

The logarithmic scale measures percentage changes: equal horizontal (or vertical) differences measure the same percentage change. Thus we can see that many countries with the lowest 1970 ownership levels experienced the greatest percentage increases by 1992: China, India, Pakistan, South Korea, Turkey and Taiwan.

On the horizontal axis, we can also observe the effects of large populations: although China and India have vehicle/population ratios below .01, their large populations place them among the top ten countries in numbers of vehicles.

Fig. 2.5 Car Ownership vs. GDP, 1970-92

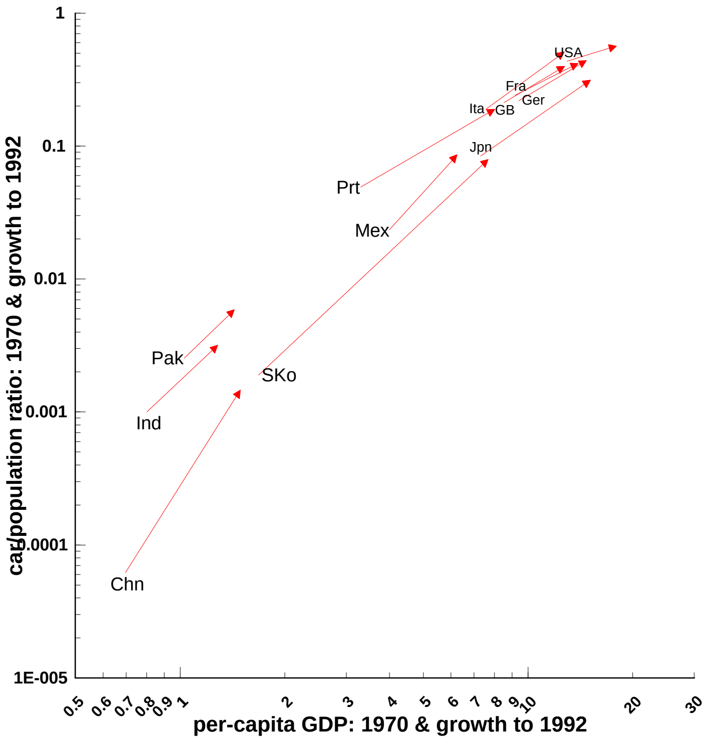
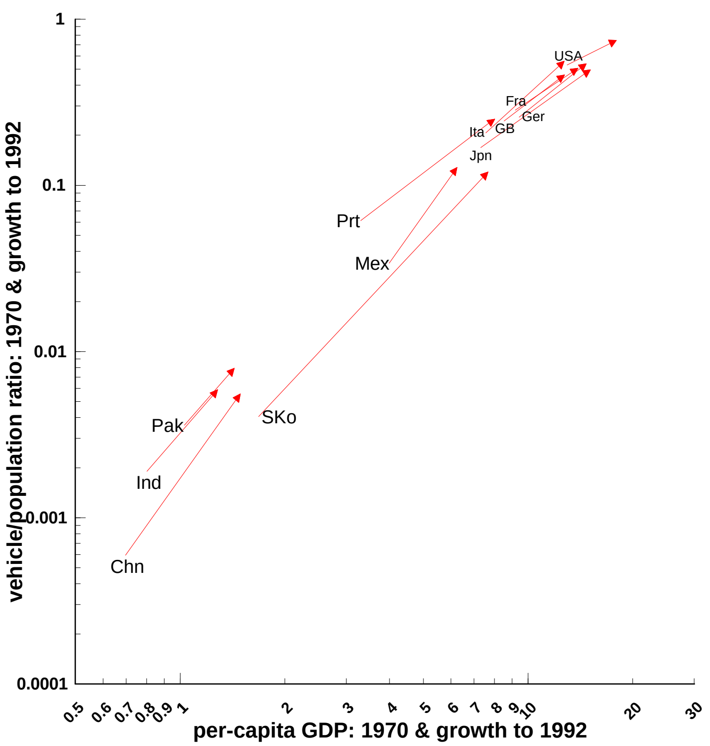


Fig. 2.6 Vehicle Ownership vs. GDP, 1970-92



Figures 2.5 and 2.6 depict the central relationship of this paper: the influence of per-capita income growth upon car and vehicle ownership, respectively. These vector graphs plot the 1970-92 growth in car (vehicle) ownership against the 1970-92 growth in per-capita income. (Only half the countries are shown, in order to allow legibility.) We can observe the clear relationship between ownership and income levels: as income levels increase, car and vehicle ownership increase.

In addition, we can see the variation across countries – both in the absolute levels of car ownership corresponding to given levels of income, and also in the rate of ownership growth compared with income growth. At similar income levels, Portugal's car ownership is twice that of South Korea, and Italy's car ownership is twice that of Japan.

Less dramatic than for cars are the differences in vehicle ownership at various levels of income, as shown in Figure 2.6.

Of course, these vector graphs simplify the actual historical paths. The linear vectors show only (log-) linear movement from 1970 to 1992. But the actual historical paths are not nearly as straight and direct, because income growth rates vary over time (and sometimes are negative), as does the ratio of ownership growth to income growth. A graph of some countries' data can be seen in a graph in the following section (Figure 3.5).

Fig. 2.7 Income Elasticity of Car Ownership vs. Average Income, 1970-90

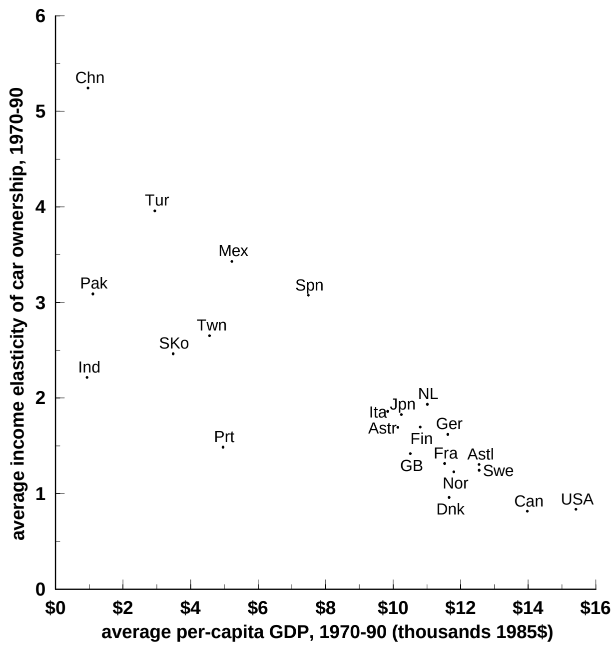
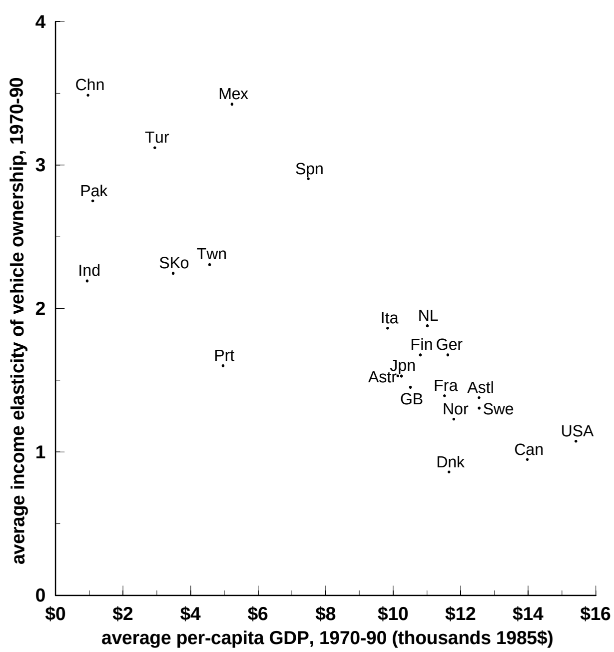


Fig. 2.8 Income Elasticity of Vehicle Ownership vs. Average Income, 1970-90



The ratio of the average annual % growth in ownership to the average annual % growth in per-capita income is a rough measure of the income elasticity of car (or vehicle) ownership.[1] These growth-rate ratios (of ownership growth to income growth over the 1970-90 period) are plotted for each country on the vertical axis of Figures 2.7 & 2.8 (for cars and vehicles respectively), and compared with each country's average income level over this period, on the horizontal axis.

These graphs show that car and vehicle ownership has grown at least twice as fast as income for lower-income countries. That is, the income elasticity of ownership has been much higher than 2.0 for the lowest-income countries.

In addition, the graphs also show that the higher a country's income level the lower is its ratio of ownership growth to income growth. At even higher levels of per-capita income than shown on this graph (at about $30,000), ownership growth (and the income elasticity of ownership) would approach zero, as ownership saturation is reached.

[1] This is a simplification. It ignores the effects on ownership of influences other than income, such as the prices of cars and fuel, demographic changes (an increase in the percentage of adults in the population, or an increase in the labor-force participation of women), etc.

3. THE MODEL

In order to model the relationship between vehicle ownership and per-capita income, illustrated in Figures 2.5 and 2.6 above, we need to find a suitable functional form. It is clear that this relationship is not linear or log-linear, but instead is more accurately represented by some sort of S-shaped curve. Car and vehicle ownership 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. Many of these functional forms have been used to estimate car ownership for individual countries, principally as a function of time, rather than income (see Mogridge, 1983). Some studies have attempted to estimate such models for groups of countries, and have included income as well as other explanatory variables; for example, Button *et al.* (1993) analyzed low-income countries only. But ours is the first study of which we are aware that analyzes the full range of countries, from lowest to highest income, using more than three decades of annual data.

After experimenting with a number of different functional forms, the Gompertz model was chosen for the empirical analysis. The primary justification for this is that it is somewhat 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:

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

where γ is the saturation level and α and β are negative parameters defining the shape, or curvature, of the function.[2] Figure 3.1 depicts an illustrative Gompertz function, similar to what we have estimated econometrically.

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

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

Figure 3.2 depicts the income elasticity of the Gompertz function depicted in Figure 3.1.

[2] The characteristics of the Gompertz function and the interpretation of the parameters are derived in Appendix A.

Fig. 3.1 Illustrative Gompertz function

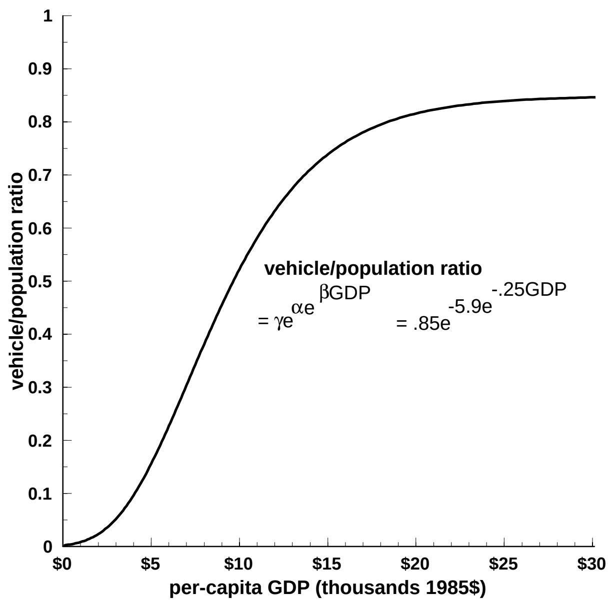
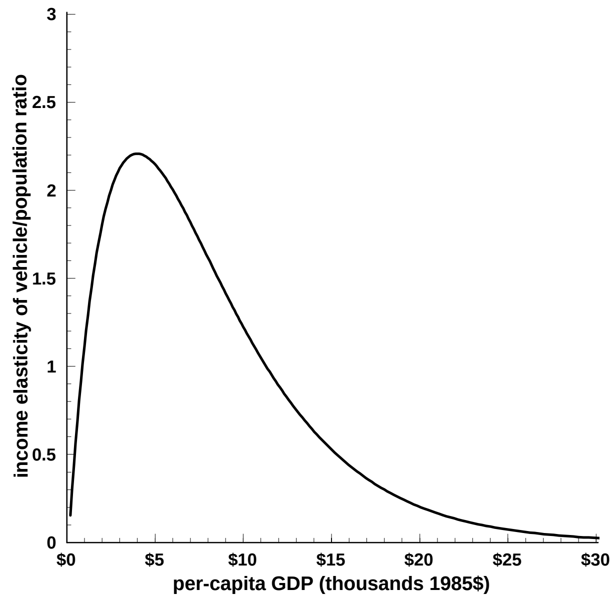


Fig. 3.2 Implied Income Elasticity



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

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

where θ is the speed of adjustment (0 < θ <1). Such lags reflect the slow adjustment of car and 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[3]:

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

[3] By comparison, Button *et al.* (1993) used a quasi-logistic function rather than the Gompertz function (1) that we used, and they incorporated a time-trend in that function rather than our assumption of a partial-adjustment mechanism as in equation (3).

Although it is possible to estimate a separate vehicle (or car) 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 and car 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. Due to the characteristics of the parameters of the Gompertz function and the data sample available, we have chosen to restrict γ, α, and θ to be the same for all countries, and to allow β to be country-specific.

The model to be estimated econometrically thus becomes:

$$V_{it} = \gamma\theta e^{\alpha e^{\beta_i GDP_{it}}} + (1-\theta)V_{it-1} \qquad (5)$$

where the subscript *i* represents country *i*. The long-run income elasticities for each country are

$$\eta_{it}^{LR} = \alpha\beta_i GDP_{it} e^{\beta_i GDP_{it}} . \qquad (6)$$

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

$$\eta_{it}^{SR} = \theta\alpha\beta_i GDP_{it} e^{\beta_i GDP_{it}} . \qquad (7)$$

We are thus estimating a family of long-run Gompertz functions, from pooled time-series cross-section data. We assume that all countries have the same saturation level[4] γ, the same speed of adjustment θ, and the same "low-income" curvature parameter α, but we estimate country-specific values for the "high-income" curvature parameter β_i. Three examples of this family of Gompertz functions are shown in Figure 3.3, and their implied income elasticities in Figure 3.4.

[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. Such saturation levels are also substantially lower than levels that 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?

Fig. 3.3 Gompertz functions with 3 alternative values for β

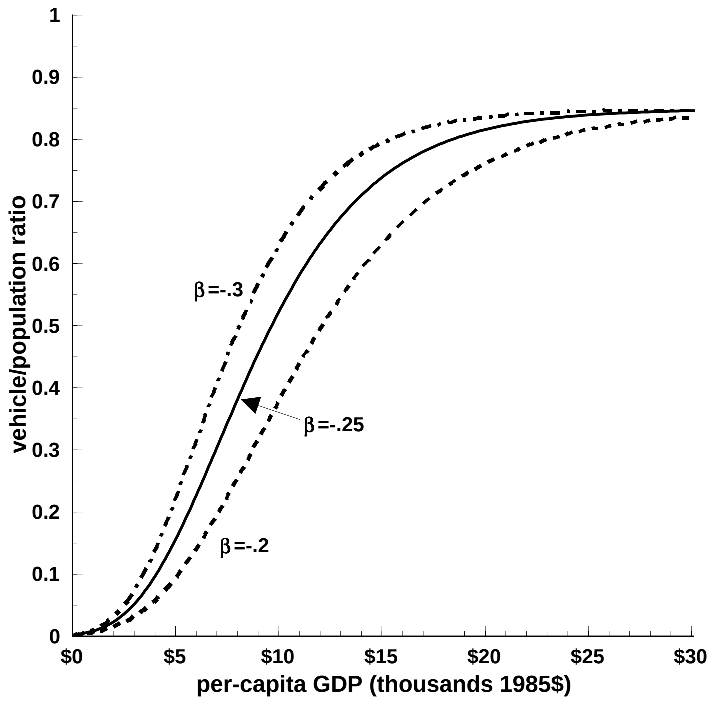


Fig. 3.4 Implied income elasticities for 3 Gompertz functions.

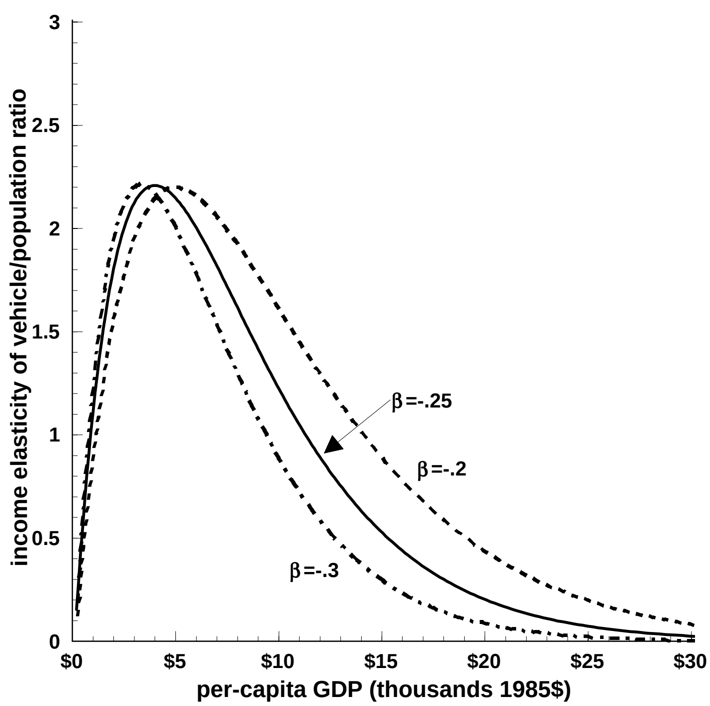


Figure 3.3 depicts the family of Gompertz functions that we are using to estimate the long-run relationship between the vehicle/population ratio and per-capita income. As noted above, we assume that all countries have the same saturation level (γ, equal to .85 in this example). All countries also have the same value of the parameter α (assumed equal to –5.9 in this example). As shown in Appendix A, α determines the maximum income elasticity (at 2.2 in this example, as can be seen in Figure 3.4), which is thus assumed to be the same for all countries, irrespective of β.

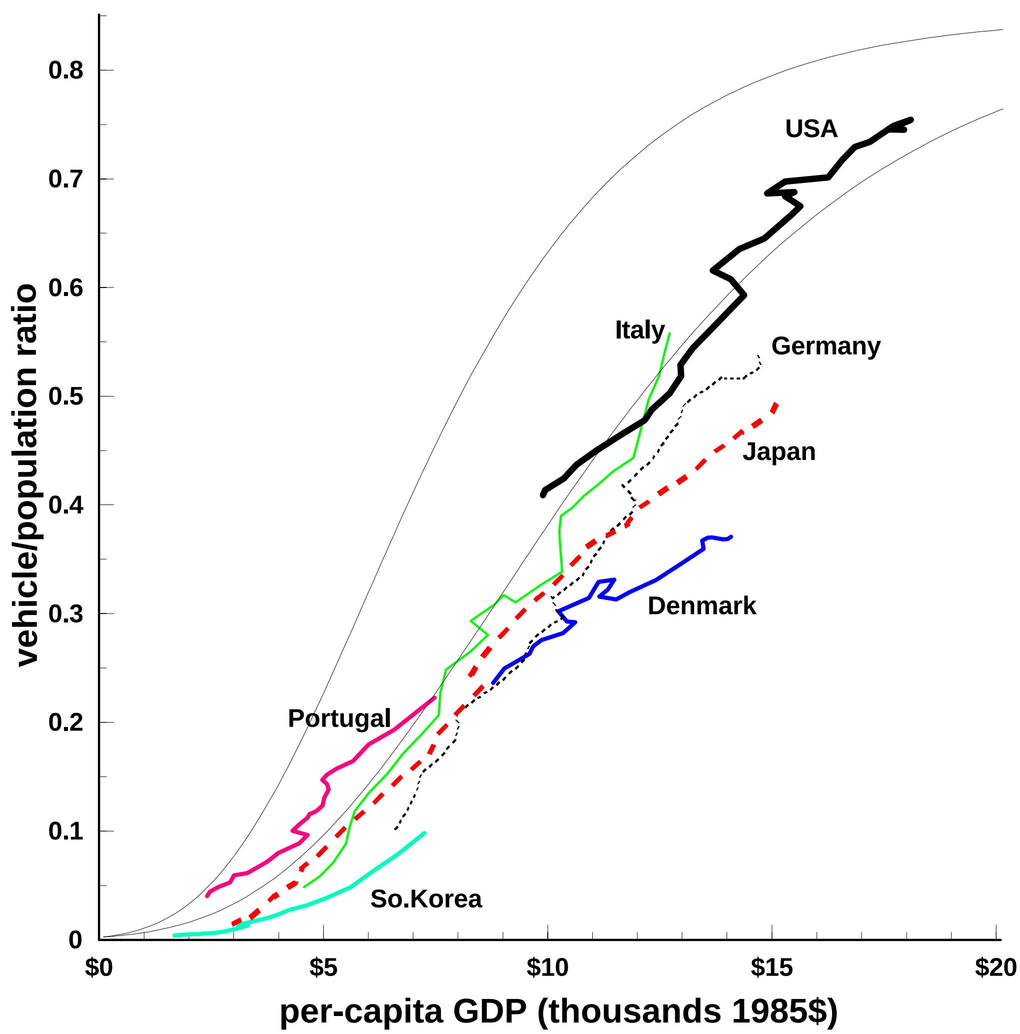
Differences across countries are reflected in the parameter β, where the values here range from –.2 to –.3. The smaller the absolute level of β, the lower is vehicle ownership at any given income level. Of course, since all countries reach vehicle ownership saturation at about .85, eventually these functions converge, at an income level above $30,000.

Figure 3.4 graphs the implied income elasticities for these functions. We see the smaller the absolute level of β, the higher is the income level at which the income elasticity of vehicle ownership peaks. For example, with β= –.3 the income elasticity peaks at a lower income level (about $3000) than it would peak with β= –.2, for which it would peak at about $5000. Likewise, the smaller the absolute level of β, the higher the income level at which the income elasticity falls below 1.0: $9000 for β= –.3 and $14000 for β= –.2.

Figure 3.5 illustrates how the historical data on vehicle ownership and per-capita income for several countries compare with two of this family of Gompertz functions (β= –.3 and β= –.2). However, it must be emphasized that this pair of Gompertz functions represents *long-run* relationships between vehicle ownership and per-capita income, while the actual historical observations of vehicle ownership are not the long-run values corresponding to the contemporaneous levels of per-capita income. Because of this, the historical data would be expected to lie well below the long-run Gompertz functions.

We see important differences among countries, even at the same levels of per-capita income. Some countries' vehicle ownership levels are high relative to their income, such as Portugal and Italy; these would correspond to values of β that are relatively large (in absolute value). Other countries' ownership levels are relatively low: South Korea and Denmark; these would correspond to relatively small values of β.

Figure 3.5. Long-run Gompertz Functions & Historical Data: 1960-92



4. MODEL ESTIMATION

The model described in equation (5) was estimated for the cross-section time-series data for the 26 countries, separately for vehicle ownership and car ownership. The period of estimation varies for the different countries due to data availability. As seen in Table 2.1 in Section 2, the longest series range from 1960 to 1992 and the shortest from 1980 to 1992. On average, there are 27 annual observations per country. As mentioned above, the saturation level, γ, the adjustment coefficient, θ, and α were constrained to be the same for all countries.[5] Due to the non-linear nature of the Gompertz function, the model was estimated using maximum likelihood methods. Because of the vast differences in the population of the countries, in the estimation process, the observations were weighted by their respective populations, so that small counties like Denmark are not given an equal weight with countries like the US or China.

The results of the initial estimation -- with separate β_i for each country -- are shown in Appendix B. For both vehicle and car ownership equations, the estimates of γ, θ and α are of the correct sign, of a reasonable magnitude, and highly significant. The same is generally true for the estimates of β_i, the only exceptions being the *positive* β_i for China, India and Pakistan - the lowest income countries. Since β determines the income level where the income elasticity reaches its maximum value, it is perhaps not surprising that this parameter cannot be estimated purely on the basis of observations of per-capita income well below \$1500, as is the case for the historic data for these three countries.

Using a modified specification, designed to determine β_i more accurately for the low-income countries, it was decided to group China, India, and Pakistan with three other countries with slightly higher incomes: South Korea, Turkey and Mexico. In the initial estimation these latter three countries had the smallest estimated β_i (in absolute value), so the estimates are 'closest' to the positive β_i values obtained for the lowest income countries. In the results presented below, β is thus constrained to be equal for China, India, Pakistan, South Korea, Mexico and Turkey; for all other countries, separate values for β_i are estimated.

The resulting estimates for vehicle and car ownership are shown in Table 4.1. All the estimated parameters are of the expected signs and most are 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.

The adjustment parameter, θ, is estimated to be 0.09, indicating that 9% of the total response to income changes occurs within one year, while 90% of the full adjustment takes approximately 24 years. Adjustment to changes in per-capita income is thus relatively slow. The estimated saturation levels are 0.62 cars and 0.85 vehicles per capita[6]. As expected, the saturation rate is higher for vehicles than for cars, and suggests a saturation of 'other vehicles' of 0.23 per capita. As mentioned earlier, α determines the maximum income elasticity, which for cars is about 2.4. For vehicles, α is slightly smaller in absolute value; consequently the maximum income elasticity is somewhat lower, about 2.2.

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[5] Initially, three alternative models were estimated: 1) with separate αs and βs for each country; 2) restricting β to be the same for all countries, but letting α vary; and 3) restricting α to be the same for all countries, but letting β vary. The third alternative produced the most reasonable results. In earlier work -- Dargay and Gately (1996a and 1996b) -- a variant of the second alternative had been used.

[6] In Dargay and Gately (1996a and 1996b), the estimated saturation levels are 0.69 for cars and 0.99 for vehicles.

Table 4.1. Estimated parameters of car and vehicle ownership models.

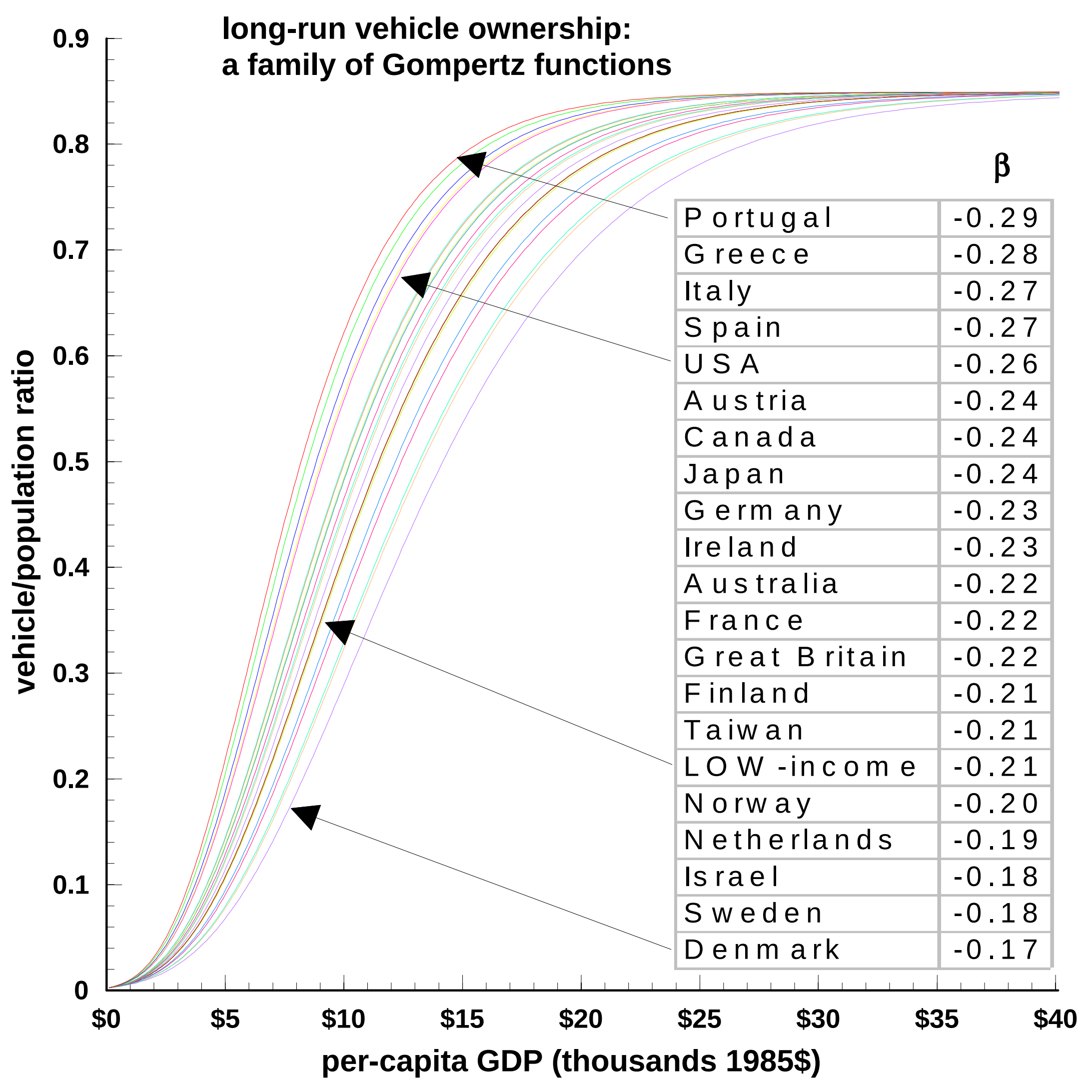
		Cars		Vehicles	
		Coefficient	t-statistic	Coefficient	t-statistic
θ	Speed of adjustment	0.09	11.00	0.08	10.90
γ	Saturation level	0.62	103.66	0.85	83.17
α		-6.42	-27.62	-5.91	-33.79
β	Australia	-0.25	-9.06	-0.22	-9.10
β	Austria	-0.27	-4.71	-0.24	-4.52
β	Canada	-0.26	-12.97	-0.24	-13.00
β	Denmark	-0.20	-3.54	-0.17	-3.15
β	Finland	-0.24	-3.40	-0.21	-3.14
β	France	-0.26	-26.60	-0.22	-27.58
β	Germany	-0.26	-26.94	-0.23	-27.49
β	Great Britain	-0.25	-29.66	-0.22	-29.42
β	Greece	-0.28	-4.52	-0.28	-4.43
β	Ireland	-0.25	-1.63	-0.23	-1.48
β	Israel	-0.20	-1.83	-0.18	-1.54
β	Italy	-0.33	-21.66	-0.27	-23.94
β	Japan	-0.21	-32.23	-0.24	-28.98
β	Netherlands	-0.23	-9.16	-0.19	-8.63
β	Norway	-0.23	-2.60	-0.20	-2.49
β	Portugal	-0.30	-4.33	-0.29	-4.06
β	Spain	-0.30	-20.18	-0.27	-19.07
β	Sweden	-0.23	-5.55	-0.18	-5.40
β	Taiwan	-0.22	-5.08	-0.21	-4.73
β	USA	-0.30	-26.91	-0.26	-27.68
β	LOW*	-0.21	-15.45	-0.21	-16.06
R^2		0.99		0.99	
F-statistic		172364.2		177923.6	
S.E.		0.002967		0.00374	
Log likelihood		2983.08		2826.74	
SSE		0.005731		0.009107	
Observations		675		675	

* LOW includes China, India, Pakistan, South Korea, Mexico and Turkey.

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. For cars, the maximum income elasticity occurs for the different countries at income levels between \$3300 and \$5100 (1985 US\$). For vehicles, we find that β_i are slightly smaller in absolute value than for cars; hence the income levels where the maximum income elasticity is reached are slightly higher -- from \$3500 to \$5900 (1985 US\$).

The estimated long-run relationship between vehicle ownership and per-capita income is illustrated in Figure 4.1, for the different countries. The estimated saturation level of 0.85 vehicles per capita – common for all countries – is apparent. Since α and γ are constrained to be the same for all countries, the differences in the relationship between per-capita income and saturation are determined solely by β_i: the greater the absolute value of β_i, the lower the income required to reach saturation. Vehicle ownership saturation would be approached at the lowest income levels for Portugal, and at the highest income levels for Denmark: 99% of saturation would be reached at an income level (in 1985 \$) of \$22,000 in Portugal and \$38,000 in Denmark. For the USA, 99% saturation would be reached at \$24,000, for the OECD on average at \$26,000, and for the lowest income countries at \$30,000.

Figure 4.1 Estimated Vehicle Ownership Functions



5. PROJECTIONS OF CAR AND VEHICLE OWNERSHIP TO 2015

On the basis of the estimated models for cars and vehicles per capita described above and assumptions concerning population and GDP[7], projections of car and vehicle ownership for the different countries can be made. The assumptions used, and the projections for the year 2015 are presented in Table 5.1. Per-capita income and car and vehicle ownership in 1992 are also given for comparison, as well as the income elasticities for the years 1992 and 2015. The projections for the different countries are illustrated in the figures that follow, which compare the projections for years 2015 and 1992, in the same way that the historical graphs in Section 2 had compared 1992 with 1970.

As indicated earlier, there was in 1992 a vast difference in car and vehicle ownership amongst countries, ranging from less than 0.01 in China, India and Pakistan to levels as high as .56 cars and 0.75 vehicles per capita in the USA. In 2015 the range is even greater - from about 0.01 cars and 0.02 vehicles per capita in Pakistan to .61 cars and 0.82 vehicles per capita in the USA. In the European countries there is also substantial variation, with Turkey having the lowest ownership levels and Italy the highest in both years. Given the assumptions of continuing rapid income growth for South Korea and Taiwan, they will have car and vehicle ownership rates on par with OECD countries within the next 20 years, and higher rates than some of these (Greece, Turkey and Mexico).

There are also enormous differences amongst countries in the growth rates for cars and vehicles over the forecast period. The highest growth rates are in the lowest-income countries, and particularly for those with the highest growth rates of income (China, India, South Korea and Taiwan) and for lower-income OECD countries with high income elasticities (Mexico and Turkey) or high income growth (Ireland and Portugal).

Clearly, the growth rates of the car and vehicle stocks 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 car and vehicle ownership. By 2015 the stocks of cars and vehicles in the OECD are projected to be larger than in 1992 by 48% and 55%, respectively. For the 6 non-OECD countries the stocks are projected to be 760% and 620% higher than in 1992. The implications of these differences in growth are even more apparent when viewed in terms of incremental demand within these 26 countries: the 6 non-OECD countries account for 36% of the projected increase in cars and total vehicles, and China alone for nearly 20%. In 1992 the 20 OECD countries accounted for over 95% of the cars and vehicles of the 26 countries in the sample, but with only 29 % of the total population. By 2015, the OECD countries' share of cars and vehicles will be only 80 % of the total.[8]

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[7] The population projections are taken from UN statistics and the GDP growth rates from World Bank. The GDP projections are for the period up until 2005 and these are assumed to be the same to 2015. Because of the exceptionally high GDP growth projections for China, South Korea and Taiwan (9%, 6.7% and 6.3%), we have assumed growth rates of 75% of the World Bank values for the entire period.

[8] These projections are slightly different from those in Dargay and Gately (1996a and 1996b), which are based on different restrictions on the Gompertz model and higher income growth rates for China, Taiwan, and South Korea.

Table 5.1. Assumptions and projections of car and vehicle ownership, 2015.

Country	Assumptions		Historical Values			Projected Values					Long-run GDP elasticities			
	% Annual growth 1992-2015		GDP / Pop. '85US$	Cars / Pop.	Vehicles / Pop.	GDP / Pop. '85US$	Cars 10^6	Cars / Pop.	Vehicles 10^6	Vehicles / Pop.	Cars		Vehicles	
	Population	GDP / Pop.	1992	1992	1992	2015	2015	2015	2015	2015	1992	2015	1992	2015
Canada	0.97	2.30	16.36	0.49	0.62	27.59	20.3	0.59	27.3	0.80	0.39	0.04	0.48	0.06
Mexico	1.79	1.43	6.25	0.09	0.13	8.67	22.1	0.17	32.3	0.25	2.26	1.89	2.09	1.74
USA	0.91	1.67	17.95	0.56	0.75	26.28	190.8	0.61	259.3	0.82	0.17	0.02	0.24	0.04
Austria	0.30	2.04	12.96	0.41	0.50	20.60	4.7	0.56	6.2	0.74	0.70	0.15	0.81	0.20
Denmark	0.18	2.36	14.09	0.31	0.37	24.10	2.8	0.52	3.5	0.65	1.13	0.27	1.29	0.40
Finland	0.29	2.66	12.00	0.38	0.44	21.95	2.9	0.55	3.7	0.69	1.00	0.16	1.20	0.27
France	0.39	2.23	13.92	0.42	0.51	23.09	36.0	0.57	46.6	0.74	0.61	0.09	0.82	0.18
Great Britain	0.19	2.33	12.72	0.40	0.46	21.60	33.5	0.56	42.8	0.71	0.84	0.15	1.04	0.26
Germany	-0.04	2.43	14.71	0.44	0.54	25.54	36.9	0.58	48.7	0.77	0.54	0.06	0.69	0.10
Greece	0.36	1.68	6.90	0.18	0.26	10.12	3.9	0.35	5.5	0.50	1.80	1.07	1.63	0.95
Ireland	0.66	3.75	9.64	0.24	0.32	22.47	2.1	0.52	2.8	0.68	1.41	0.14	1.39	0.16
Italy	-0.04	2.20	12.72	0.51	0.56	20.99	34.0	0.59	44.0	0.77	0.41	0.05	0.67	0.12
Netherlands	0.40	1.94	13.28	0.37	0.42	20.66	9.0	0.54	11.0	0.66	0.89	0.25	1.16	0.43
Norway	0.38	2.37	15.52	0.38	0.46	26.58	2.7	0.57	3.5	0.74	0.64	0.09	0.84	0.16
Portugal	0.02	3.54	8.02	0.20	0.26	17.85	5.1	0.51	6.7	0.68	1.37	0.16	1.32	0.16
Spain	0.02	2.87	9.80	0.34	0.41	18.79	21.5	0.55	28.0	0.71	1.00	0.13	1.09	0.18
Sweden	0.33	1.38	13.99	0.41	0.45	19.18	4.9	0.53	5.9	0.63	0.87	0.37	1.19	0.64
Turkey	1.48	1.95	3.81	0.04	0.05	5.94	5.7	0.07	8.9	0.11	2.31	2.30	2.13	2.12
Australia	1.13	2.35	14.46	0.45	0.57	24.65	13.1	0.58	17.3	0.76	0.62	0.08	0.75	0.13
Japan	0.21	2.78	15.11	0.31	0.50	28.40	72.2	0.55	101.4	0.78	0.87	0.10	0.57	0.04
China	0.89	5.85	1.49	0.002	0.006	5.39	50.9	0.04	79.3	0.06	1.45	2.34	1.34	2.16
India	1.68	3.82	1.28	0.003	0.006	3.04	15.9	0.01	27.8	0.02	1.32	2.17	1.22	1.99
Israel	1.88	3.35	9.89	0.19	0.22	21.10	3.4	0.46	4.2	0.57	1.73	0.38	1.75	0.48
Pakistan	2.65	2.42	1.43	0.006	0.008	2.48	2.1	0.01	3.8	0.02	1.43	1.99	1.32	1.83
South Korea	0.80	4.20	7.68	0.07	0.11	19.48	21.5	0.41	28.8	0.55	2.08	0.43	1.92	0.40
Taiwan	0.76	4.00	8.99	0.12	0.15	21.49	11.3	0.46	14.7	0.60	1.82	0.28	1.74	0.30
	Mean*	Mean	Mean	Mean	Mean	Mean	Total	Mean	Total	Mean	Mean	Mean	Mean	Mean
OECD	0.50	2.31	2.91	0.35	0.43	21.75	524.1	0.50	705.3	0.66	0.99	0.38	1.07	0.42
LDC	1.44	3.94	5.13	0.06	0.08	12.16	105.2	0.23	158.5	0.30	1.64	1.26	1.55	1.19
ALL	0.72	2.69	10.57	0.28	0.35	18.77	629.3	0.44	863.8	0.58	1.14	0.58	1.18	0.60

*Unweighted averages of the countries included.

Figure 5.1 Car Ownership: 2015 vs. 1992

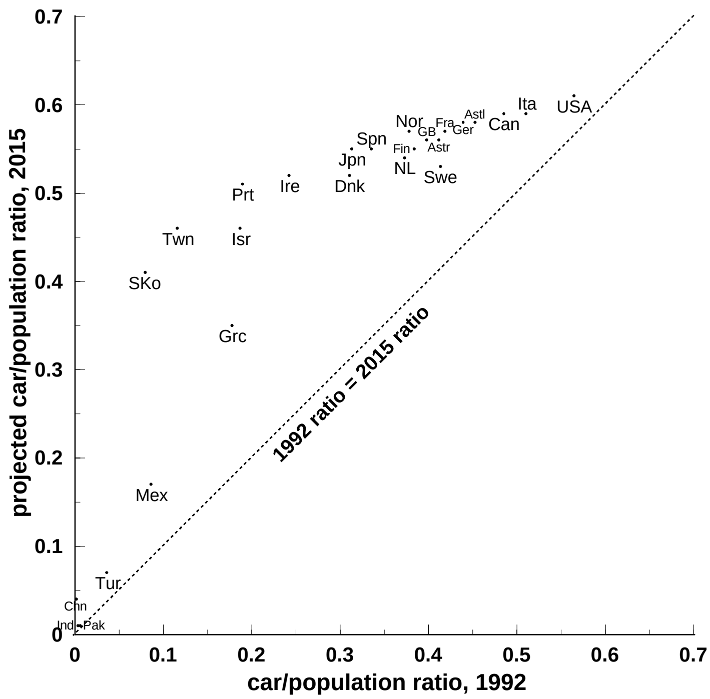
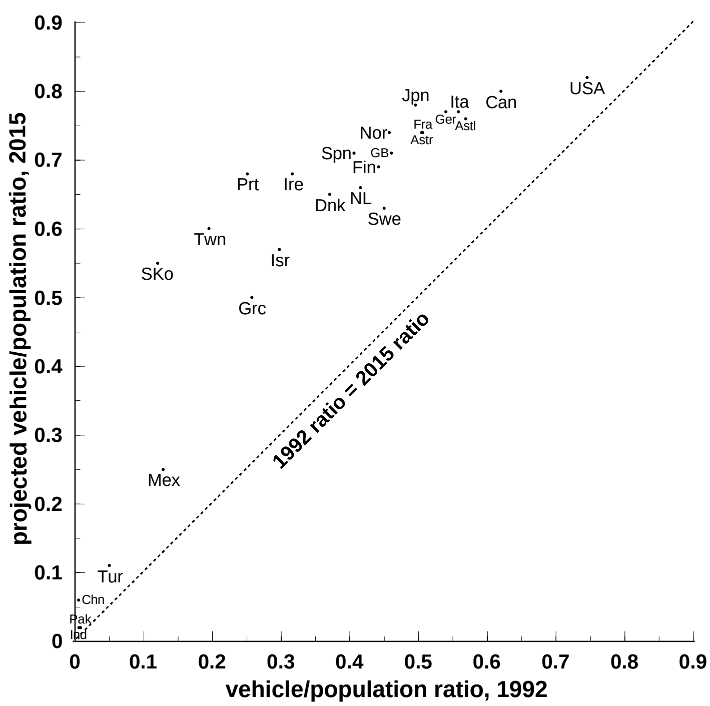


Figure 5.2 Vehicle Ownership: 2015 vs. 1992



Figures 5.1 (& 5.2) plot on the vertical axis the projected 2015 car (and vehicle) ownership level in each country, compared with the 1992 ownership level on the horizontal axis. The greatest absolute increases are projected for the middle-income countries with high rates of income growth: South Korea, Taiwan, Portugal, Israel and Ireland. Ownership saturation is being approached in the USA, where relatively little growth in ownership is projected.

The highest proportional growth is projected for rapidly growing low-income countries, especially China. This is more evident on the few next graphs, in which the scales are logarithmic.

Figure 5.3 # Cars & Ownership: 2015 vs. 1992

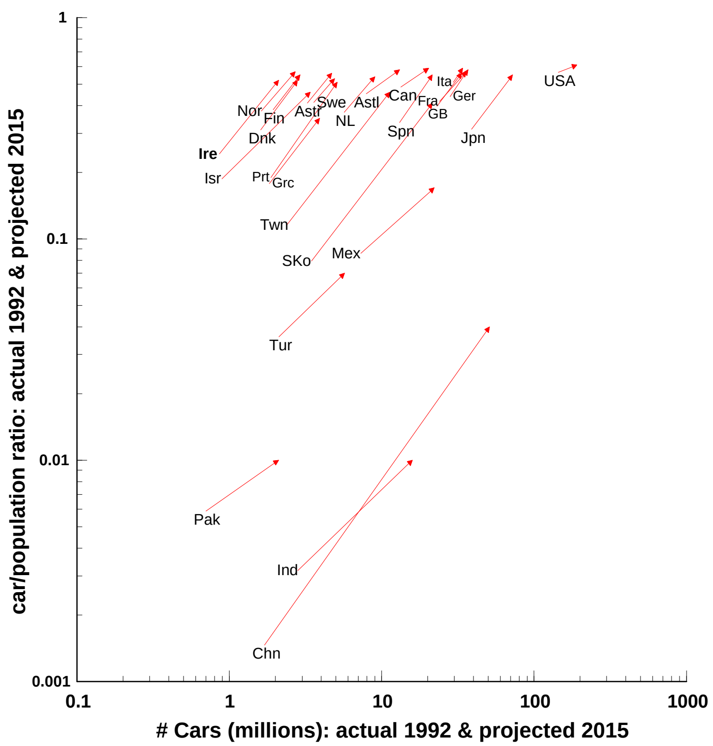
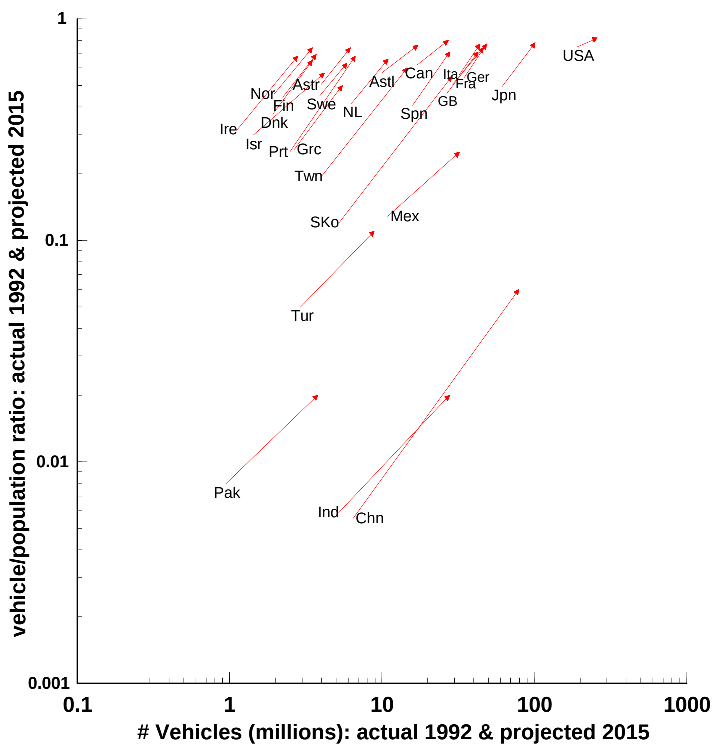


Figure 5.4 # Vehicles & Ownership: 2015 vs. 1992



Figures 5.3 (& 5.4) show the projected growth in ownership on the logarithmic vertical scale and the absolute number of cars (and vehicles) on the logarithmic horizontal scale. The most heavily populated countries, China and India, are projected to have vehicle ownership ratios by year 2015 of only .06 and .02 respectively, yet these imply nearly 80 million vehicles in China and 30 million in India. By 2015, China will have more vehicles than any country except the USA and Japan.

In the USA, the growth of car and vehicle ownership will slow down, as saturation is approached. But the absolute number of cars and vehicles will continue to increase, to 190 and 260 million respectively, due to population growth.

Fig. 5.5 Car Ownership & GDP Growth, 1992-2015

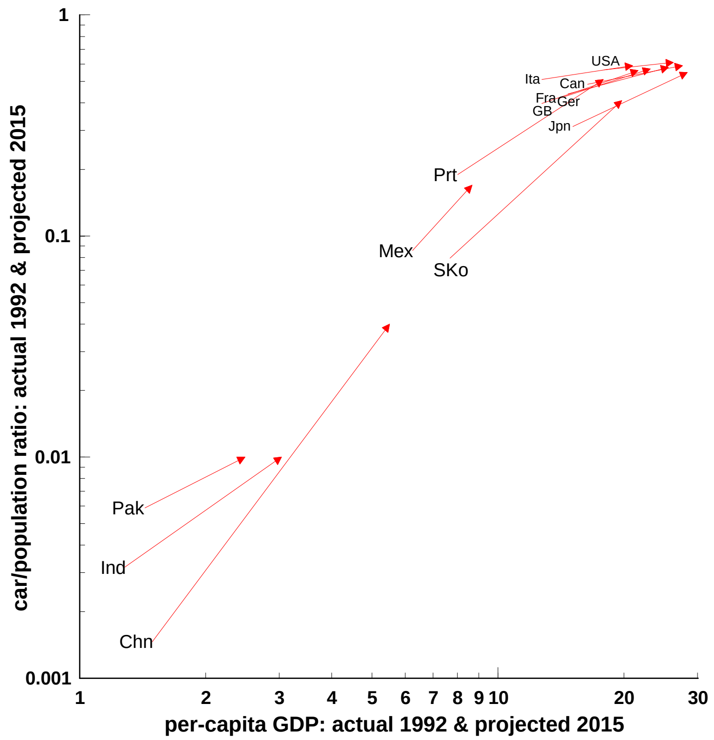
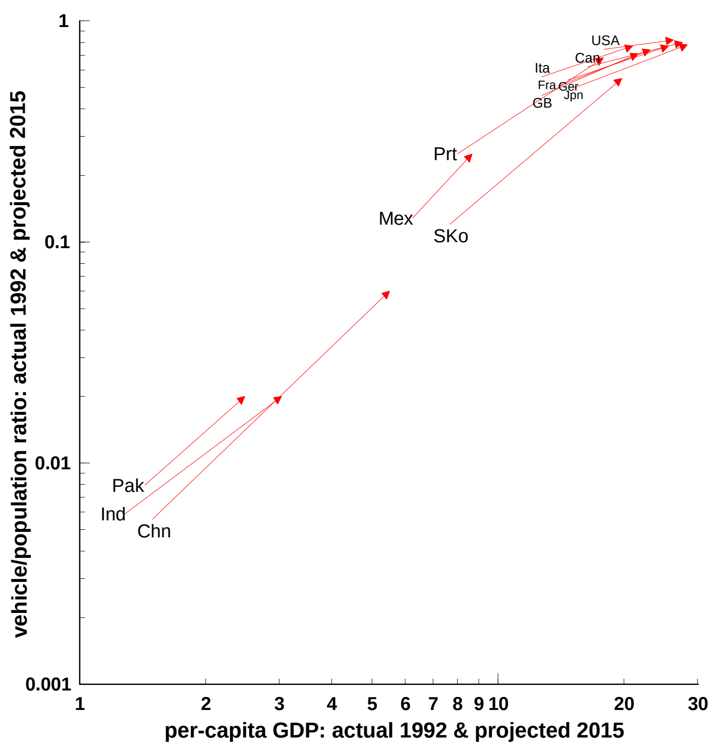


Figure 5.6 Vehicles & GDP Growth, 1992-2015



In Figures 5.5 & 5.6 we see that projected growth in car and vehicle ownership depends upon the assumed growth in income. The more rapid the assumed rate of income growth (e.g. China), the greater the growth in car and vehicle ownership. Ownership growth slows at the highest income levels (e.g. USA), as saturation is approached.

Projections of car ownership are generally similar to those for vehicles. In China, however, car ownership is projected to grow more rapidly than vehicle ownership, for two reasons: one is their extraordinarily low car ownership in 1992; the other is our assumption that all the low-income countries follow a similar path

Figure 5.7 Income Elasticity, 2015 vs. 1992: Cars

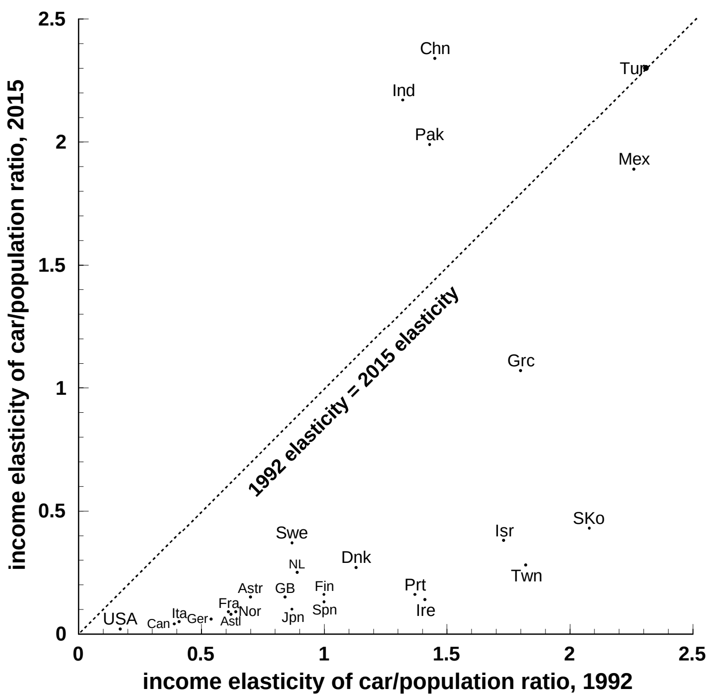
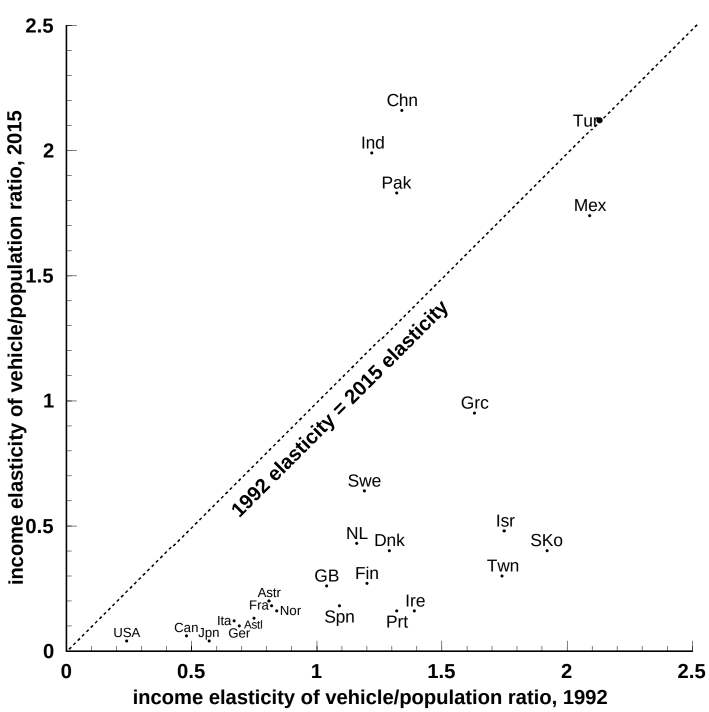


Fig. 5.8 Income Elasticity, 2015 vs. 1992: Vehicles



Figures 5.7 (and 5.8) show the income elasticity of car (and vehicle) ownership – as calculated from equation (6) for each country – for 1992 on the horizontal axis and 2015 on the vertical axis. In most countries, the income elasticity will decline substantially (moving well below the dashed diagonal line) as higher incomes bring about slower growth in vehicle ownership. This is true for virtually all of the OECD countries. It is even true for fast-growing countries such as South Korea and Taiwan, whose ownership growth will decelerate by 2015 as saturation is approached. Their income elasticities of ownership will fall from about 2.0 in 1992 to below 0.5 in 2015.

However, for the lowest income countries (China, India, Pakistan) , whose income levels by 2015 will be in the range of $2000-$5000, the income elasticity of vehicle ownership will actually increase; vehicle ownership will grow nearly twice as fast as income.

For middle-income countries with relatively slow income growth (Turkey, Mexico), the income elasticity will remain high through the year 2015.

Fig. 5.9 Average Income Elasticity of Car Ownership vs. Average Income Level, 1992-2015

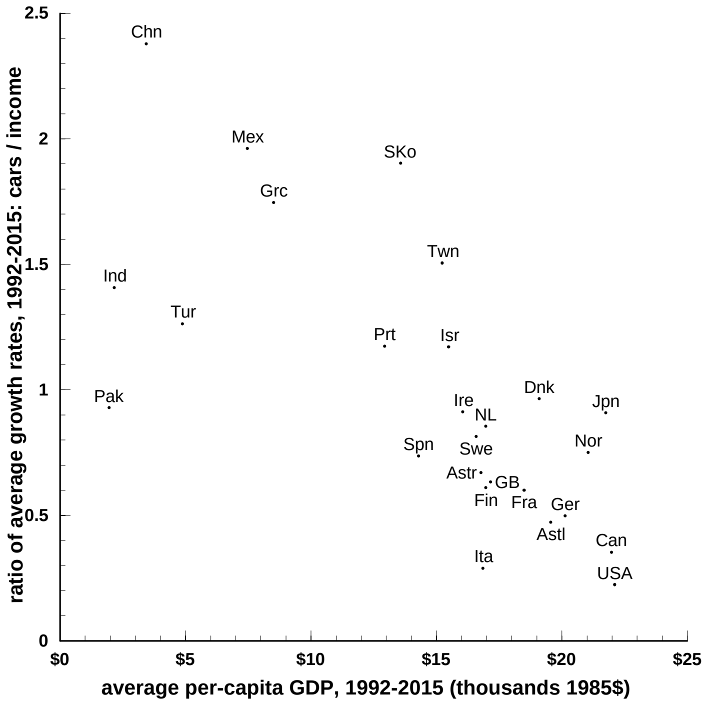
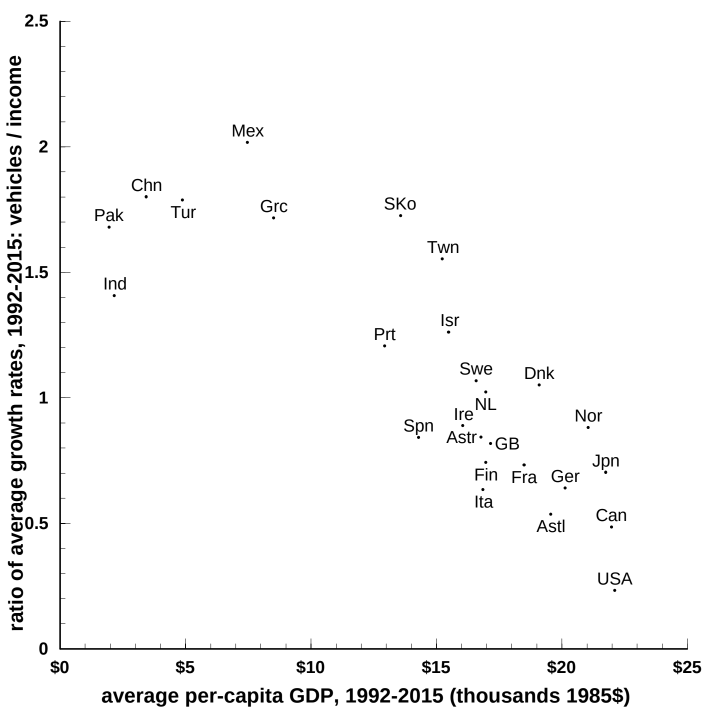


Fig. 5.10 Average Income Elasticity of Vehicle Ownership vs. Average Income Level, 1992-2015



Figures 5.9 and 5.10 – analogous to historical Figures 2.7 and 2.8 – plot on the vertical axis each country's ratio of its average annual % growth in car (vehicle) ownership to its average annual % growth of income, over the period 1992-2015, and on the horizontal its average income level for that period. These graphs show the *average* income elasticity over the period, rather than the starting-year and ending-year income elasticities as shown in Figures 5.7 & 5.8.

These graphs also show that the income elasticity depends upon the country's income level. As in Figure 3.2, we see the effects of increasing income: at the lowest income levels, the income elasticity increases, then it reaches a maximum at a per-capita income of about $5000, then it steadily declines..

It is instructive to compare these income elasticity estimates with others in the literature, such as those by Button *et al.* (1993). They estimated income elasticities for five groups of the lowest income countries. As the low-income groups' average incomes increase, so do the estimated income elasticities: from 0.57 to 1.16. These estimates are lower than ours (and lower than suggested by Figs. 2.7 & 2.8), perhaps a consequence of the low saturation levels assumed. But their increase is consistent with our specification (as in Figure 3.2). Also consistent with our specification is the conclusion by Tanner (1983), in work mainly on industrialized countries that income elasticities decline as countries' incomes increase.

Figures 5.11 and 5.12 show

both historical growth in ownership (1970–92) and projected growth to year 2015, as a function of per-capita income. For legibility, only four countries are shown: China, South Korea, Japan and the USA. The solid-line vectors plot the countries' history, and the dashed-line vectors plot the projected growth.

China's path closely follows that of South Korea. This results from our assumption that China follows the same long-run ownership function as South Korea (together with India, Pakistan, Mexico and Turkey). But it travels that path to 2015 more slowly than did South Korea in 1970-92. We project that China's vehicle/ population ratio will grow at 10% annually, which is slower than the 16% annual growth experienced by South Korea (and much slower than Japan's 24% annual growth in 1960-73). In fact, were China's vehicle ownership to grow at 16% annually, by the year 2015 China would have as many vehicles as the USA, 260 million – rather than the 80 million we have projected.

Yet there are some differences in growth patterns among countries, as would be expected from the familial differences that are shown in Figure 4.1. For a given income level, South Korea's ownership levels lag behind those of Japan, and Japan's lag behind those of the USA. At the highest income levels, however, there is convergence: all countries eventually reach the same saturation level.

6. CONCLUSIONS

For most of the OECD countries, we expect convergence of car and vehicle ownership levels over the next two decades, to levels that are close to saturation. For the USA this implies relatively little increase from its current, high levels of ownership. For Japan and most of Europe, however, it implies a continuation of the substantial increases in ownership that have occurred over the past quarter-century. Beyond those increases of the next two decades, however, there will be relatively little additional growth in ownership, as saturation is approached in the majority of OECD countries.

The most rapid growth within the OECD in car and vehicle ownership will occur in those OECD countries with relatively low incomes but with high rates of income growth, such as Portugal, Greece, and Ireland. Moreover, that ownership growth will continue beyond the next two decades, as these countries' per-capita incomes catch up with the rest of Europe.

Similarly rapid growth in income and vehicle ownership can be expected to continue in South Korea, Taiwan, and Israel. Yet eventually their ownership growth will decelerate, as their per-capita income levels and vehicle ownership levels approach those of the OECD countries.

For the lowest income countries – China, India, and Pakistan – car and vehicle ownership will grow about twice as rapidly as per-capita income, for the entire period of the next two decades. But given the very low ownership levels from which these countries are starting, their ownership levels will *still* be very low after two decades of relatively rapid growth. For China, whose per-capita income growth (assumed to be 5.85% annually) is expected to be higher than that of India and Pakistan, we project that by 2015 its per-capita income will be about $5400 (1985$), and its ownership rates will be .036 for cars and .056 for vehicles. Given the huge population of China, this implies 50 million cars and nearly 80 million vehicles, which would make it the third largest country in terms of vehicles, after the USA and Japan. This growth will continue at a high level beyond the next two decades, so it is inevitable that China within three decades would have more vehicles than Japan, and eventually more than the USA.

Very rapid growth rates in the vehicle/population ratio are not unusual when a country is starting from low levels, and this rapid growth can be sustained for two decades. In South Korea over the period 1970-91, the vehicle/population ratio grew at an average annual rate of 16%, from .004 to .10. Similarly, during the 1960-73 period, Japan's vehicle/population ratio grew at an average annual rate of 24%, increasing the ratio from .01 to .23. Over the same period, the vehicle/population ratio grew at an average annual rate of 19% in Spain (from .01 to .14), and 14% in Italy (from .05 to .26).

If the vehicle/population ratio in China were to grow at such rapid rates – even faster than the 10% average annual rate that we are projecting – then its vehicle stock could easily surpass that of Japan by 2015, and perhaps be as large as in the USA. For example, if China's vehicle/population ratio were to grow until the year 2015 at the same rate at which South Korea's grew during the 1970-91 period (16% annually), then China's vehicle/population ratio would increase from .006 in 1992 to .18 in 2015. At that rate, by 2015 China would have the same number of vehicles as the USA -- about 260 million.

There is, of course, a substantial amount of uncertainty in such projections. Among the types of uncertainty are the following:

- growth rates in per-capita income could be significantly different from what we have assumed;
- the income elasticities of car and vehicle ownership, and their changes over time, could differ from what we have estimated in our equation specification;
- 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), other changes in government policies regarding transportation, and demographic changes (such as an increase in the percentage of adults in the population, or increased female labor-force participation), and cross-country differences in population density or road availability; these variables are discussed in Appendix C.

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 car and vehicle ownership. As per-capita income grows, so will car and vehicle ownership. Our specification provides a simple yet powerful analysis of this relationship, using historical data for more than three decades and 26 countries, over a wide range of per-capita income levels and a range of growth rate experience.

APPENDIX A:

CHARACTERISTICS OF THE GOMPERTZ FUNCTION

The Gompertz equation for long-run vehicle ownership, V*, as a function of per-capita income (GDP) can be written as:

$$V^* = \mathrm{G}(GDP) = \gamma e^{\alpha e^{\beta GDP}} \qquad \text{(A1)}$$

where α and β are negative values. The parameter γ defines the saturation level, since for $\beta < 0$, $Lim_{GDP \to \infty} \mathrm{G}(GDP) = \gamma$.

The parameter α determines the value of the Gompertz function at GDP=0, i.e.

$$V^*\big|_{GDP=0} = \gamma e^{\alpha} \ . \qquad \text{(A2)}$$

Since the saturation level γ cannot be equal to 0, the value of the Gompertz function approaches 0 as α increases negatively.

The long-run elasticity of the Gompertz function (A1) is calculated by appropriate differentiation as:

$$\eta^{LR} = \alpha \beta \, GDP \, e^{\beta GDP} \ . \qquad \text{(A3)}$$

By setting the derivative of the elasticity with respect to GDP equal to 0, we can derive the value of income, GDP_{ME}, for which the elasticity is at its maximum value. We find

$$GDP_{ME} = -1/\beta \ . \qquad \text{(A4)}$$

Given the relationship between β and GDP_{ME}, the maximum elasticity is determined by the parameter α as

$$\eta^{M} = -\alpha e^{-1} = -0.3678\alpha \ . \qquad \text{(A5)}$$

APPENDIX B

Table B1. Estimated parameters of car and vehicle ownership models, assuming separate β_i for each of the 26 countries

		Cars		Vehicles	
		Coefficient	t-statistic	Coefficient	t-statistic
θ	speed of adjustment	0.13	12.75	0.11	11.71
γ	saturation level	0.64	86.75	0.89	65.37
α		-4.18	-19.41	-4.26	-19.34
β	Australia	-0.19	-12.40	-0.18	-11.12
β	Austria	-0.20	-6.27	-0.19	-5.49
β	Canada	-0.19	-17.41	-0.18	-15.47
β	China	1.08	1.01	0.24	3.63
β	Denmark	-0.15	-4.30	-0.13	-3.55
β	Finland	-0.18	-4.33	-0.16	-3.63
β	France	-0.19	-26.28	-0.17	-22.74
β	Germany	-0.19	-26.48	-0.17	-22.81
β	Great Britain	-0.18	-25.87	-0.17	-22.17
β	Greece	-0.19	-4.48	-0.21	-4.44
β	Ireland	-0.18	-1.88	-0.18	-1.64
β	India	0.30	4.06	0.19	2.93
β	Israel	-0.14	-1.84	-0.13	-1.51
β	Italy	-0.24	-24.17	-0.20	-21.22
β	Japan	-0.15	-25.13	-0.18	-22.96
β	Mexico	-0.13	-10.95	-0.14	-11.41
β	Netherlands	-0.18	-11.38	-0.15	-9.51
β	Norway	-0.17	-3.49	-0.15	-3.01
β	Pakistan	0.11	0.63	0.09	0.47
β	Portugal	-0.20	-4.25	-0.21	-3.94
β	South Korea	-0.12	-5.64	-0.15	-6.61
β	Spain	-0.22	-20.12	-0.21	-17.30
β	Sweden	-0.17	-7.34	-0.14	-6.26
β	Taiwan	-0.13	-4.21	-0.14	-4.04
β	Turkey	-0.10	-2.84	-0.12	-3.11
β	USA	-0.22	-28.26	-0.21	-24.03
R^2		0.99		0.99	
F-statistic		155910.7		153040.2	
S.E.		0.002827		0.003655	
Log likelihood		3018.21		2844.89	
SSE		.005164		.00863	
Observations		675		675	

APPENDIX C:
Other Variables Influencing Vehicle Ownership

The model described in the paper makes a simple assumption, that car and vehicle ownership rates are determined by per-capita income levels, with relatively minor differences across countries. One common aspect among countries is that ownership levels will converge when high income levels are reached; these common saturation levels are estimated at .62 cars and .85 vehicles per capita. A more complex model might well incorporate the effects of other variables that influence the growth of car and vehicle ownership. In this Appendix we discuss several of these variables:

- cost variables, both the fixed costs of purchase and ownership, and also the variable costs of operation;
- demographic variables, such as the age structure of the population and its change over time; in particular, we examine differences across countries in the adult/population ratio – the fraction of the population that is of driving age and thus are potential car and vehicle owners;
- population density, measured either by population per square kilometer (KM) or by the fraction of a country's population that is urbanized; these variables might be employed to explain the common observation that vehicle ownership in densely populated mega-cities with excellent systems of mass transportation (Tokyo, Hong Kong, New York, London) is much lower than would be expected given their relatively high income levels;
- road density, measured by the length of roads (in KM) divided either by land area or by population.

Analyzing the effects of any of these variables, however, is made difficult because of inadequate data, both across countries and over time.

C1. Costs of Ownership

On an individual or household level, decisions regarding car ownership are determined not only by income and socio-demographic factors, but also by the costs involved. The main components of these costs can be categorized as the fixed costs of owning a car, which are independent of the extent to which the car is used, and the variable costs, which are determined by the distances driven. In addition to the actual purchase price and associated taxation, the fixed costs include insurance, road tax, vehicle licensing fees and garaging fees. The variable costs are the expenditures relating directly to car use: fuel costs, maintenance and repairs, oil, parking fees, tolls and other road use charges. In addition to the 'price' of car ownership, the price of substitutes are of relevance: the availability and costs associated with alternative transport modes. In comparing the costs of different modes, some notion of 'generalized' costs is required which takes into account the time and convenience costs as well as the economic costs.

The effects of all of these costs will also be reflected in car ownership on an aggregate or national level. Changes in these costs within a country will effect the growth of car ownership over time, and differences in these costs amongst countries will partially explain variation in ownership levels. Many of these costs are influenced by transportation, energy, environmental, or fiscal policies, such as vehicle taxation, road tax, vehicle licensing fees, fuel taxes, parking charges and road user fees. Other costs are determined by more general economic considerations, such as differences in pre-tax car and fuel prices amongst countries, and the higher costs of parking and insurance in densely populated areas. The availability and cost of alternative transport modes is primarily determined by the economic viability of providing a convenient public transit system, which will be more probable in densely-populated urban areas, but also by national and local transportation policy.

There is a reasonable amount of empirical evidence to support the relationship between car ownership and 'costs'. Some early work, mostly for the US, is summarized in Mogridge (1983), which suggests an elasticity of car ownership with respect to the price of cars that is in excess of –1 (in absolute value). Uri (1982) estimates the elasticity of car ownership in the US with respect to costs (using a price comprised of the price of cars and the price of gasoline) to be about -0.8. Also for the US, Pritchard and DeBoer (1995) show that car registrations are sensitive to insurance costs (with an elasticity of around -0.5) and that gasoline taxes have a small but significantly negative influence on registrations. For Great Britain, Dargay and Goodwin (1994) estimate an elasticity of car ownership with respect to running costs of -0.6, and to purchase costs of -0.4, based on aggregate national data. In a more recent study based on individual household data for the same country, Dargay and Vythoulkas (1997) find the elasticity with respect to running costs to be -0.5 and to purchase costs of -0.3.

Unfortunately, we are not aware of any studies that statistically examine the effects of costs on car ownership for such diverse countries as included in this paper. Although there is some empirical evidence of cost differences across countries (see Jansson and Cardebring, 1989), there is far too little data to allow comparisons of the effects over time for the full range of countries that we analyze.

C2. The Adult/Population Ratio

Differences across countries or over time in the adult/population ratio can affect the fraction of population that are of driving age, and thus are potential owners of cars and vehicles. The higher the fraction of the population that are adults, the higher is the fraction of potential owners of vehicles. This variable has been shown in Gately (1990) to have been important in partly explaining the rapid growth of US gasoline demand from the mid-1960's through the late 1970's: the relatively rapid growth in the number of drivers during this period, as the large cohort of baby-boomers became adults.

Figure C1. Adult/Population Ratio, 1970 vs. 1990

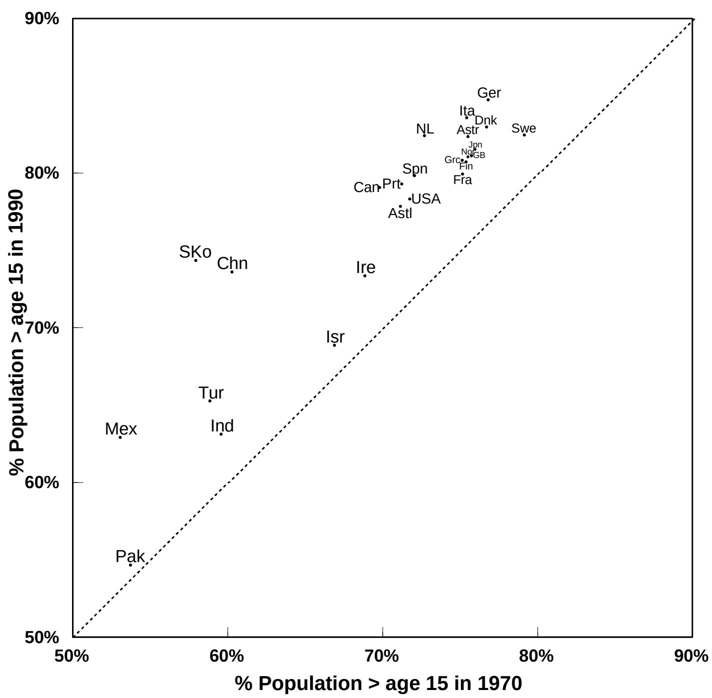


Figure C1 shows the differences among countries and the changes over time in the adult/population ratio, as measured by the fraction of the population that is above age 15. OECD countries, especially Japan and most of Europe, have "older" populations (higher fractions of adults) than the rest of the world. But in all countries shown in Figure C1, the fraction of the population above age 15 has increased from 1970 to 1990: all countries are above the dashed diagonal line. Those countries furthest above the diagonal (South Korea, China, and Mexico) have had the greatest change in the age composition of their population, due to significant declines in their birth rates. A few countries have experienced little change in age composition: Pakistan and Israel.

To the degree that differences in the age composition of the population persist across countries or over time, these will affect the growth rates of car and vehicle ownership, as well as the ultimate levels of saturation. In our model, however, such differences are ignored.

C3. Population Density

Another difference across countries that could influence car and vehicle ownership is population density. As noted above, it is often observed that in densely populated urban areas with good systems of mass transportation (Tokyo, Hong Kong, New York, and London) the vehicle/population ratio is lower than would be expected given the relatively high levels of per-capita income. Yet incorporating such considerations is not simple, and even the measurement of population density across countries and over time is difficult.

One issue is whether to measure density by dividing population by a country's *total* land area or only by its *habitable* land area. Certainly, if much of a country consists of frozen tundra, desert, or mountainous areas, then using its total land area as the denominator would be misleading. Thus the ratio of population to *habitable* land would be a better measure, but we do not have such data.[9] Hence we shall use the ratio of population per square kilometer of total land.

A different measure of population density is the fraction of the population that is urbanized. For example, although Australia has a very low population per sq. KM, it is one of the most highly urbanized countries in the world. Conversely for India and China.

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[9] Although data exists for "agricultural land area", it is not a good proxy for habitable land, for several reasons: it measures actual not potential agricultural land, and thus varies over time; it excludes heavily populated but non-agricultural areas; it also excludes forests and woodlands, which are habitable although not agricultural.

Fig. C2. Population Density: % Urbanized vs. Population per sq. KM

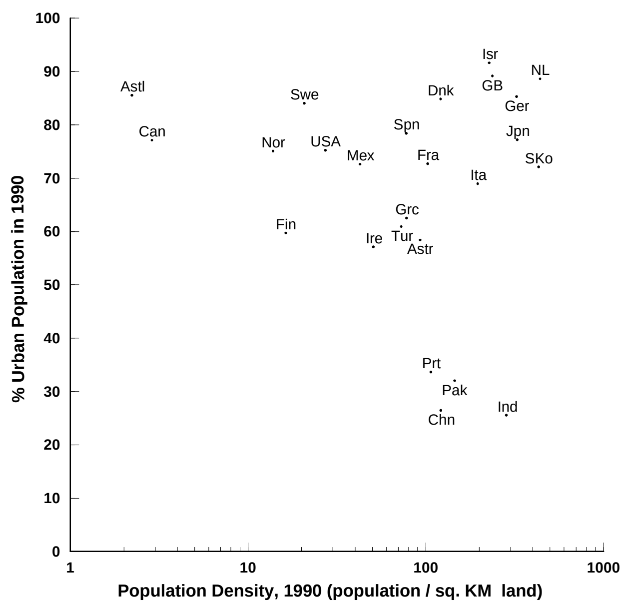
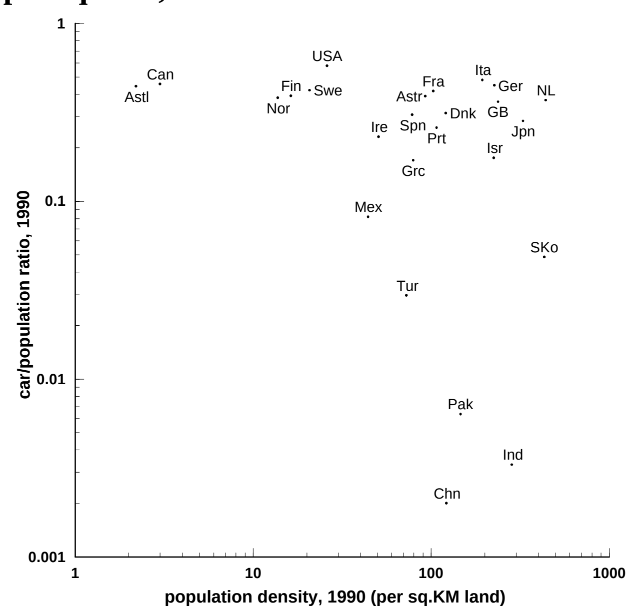


Figure C2 plots each country's 1990 percentage urbanized (on the vertical scale), and its 1990 population per square KM of total land area (on the horizontal, using a logarithmic scale). These two variables are quite different measures of population density. In the upper left, we see Australia and Canada, which have very low population per sq. KM, but are relatively urbanized countries. In the lower right, we see Portugal, Pakistan, China, and India; these have high population per sq. KM but are relatively rural.

Let us now illustrate the correlation (or lack thereof) between car ownership and population density. Figure C3 compares car ownership (on the vertical, logarithmic scale) with population per sq. KM (on the horizontal, logarithmic scale), for each of these countries in 1990.

None of the measures of population density described here would be very useful as additional explanatory variables. Although there clearly are some obvious examples of very densely populated mega-cities with excellent mass transportation that have relatively low ownership rates for cars and vehicles, we do not believe that omitting an explanation for these anomalies will undermine our analysis substantially.

Figure C3. Car Ownership vs. Population per sq. KM, 1990



C4. Road Density

The next variable we examine is the availability of roads, relative either to land area or to population. It might be argued that the availability of a good network of roads would encourage car and vehicle ownership, and that the lack of good roads would discourage ownership. Of course, the effects can work both ways: as car and vehicle ownership expands, that generates political support for improving the network of roads.

Figure C4. Road Availability, per sq. KM and per capita, 1990

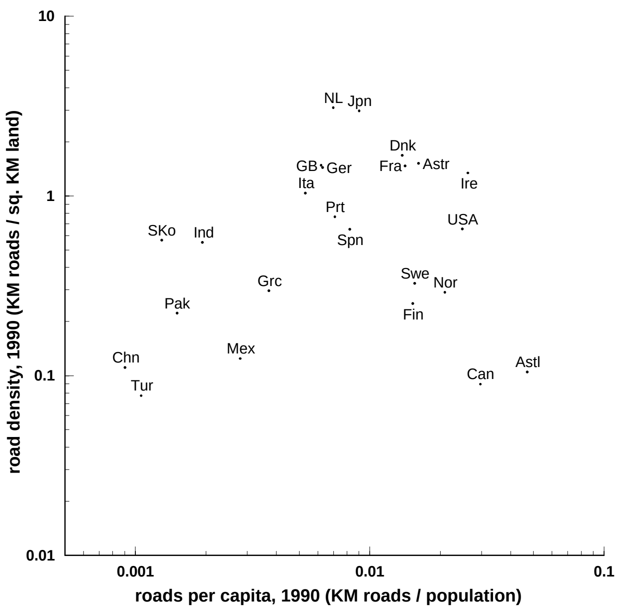


Figure C5. Cars and roads per capita, 1990

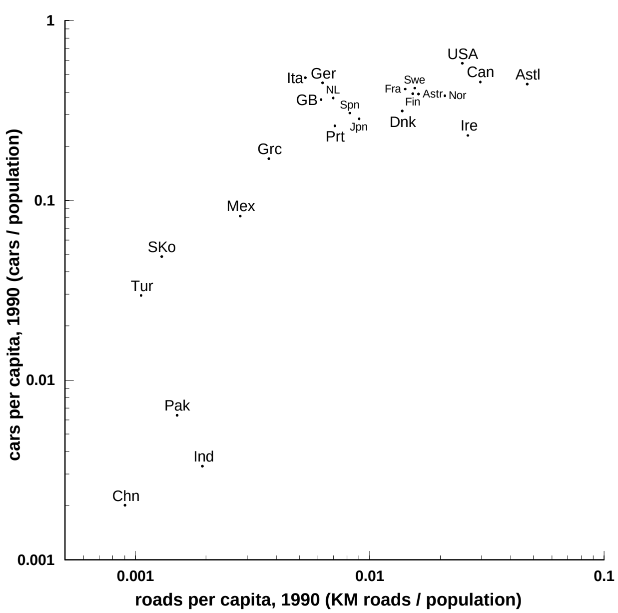


Figure C4 plots, for each country in 1990, its road density (KM roads per sq. KM land) on the vertical axis, and its roads (KM) per capita on the horizontal axis. Both scales are logarithmic, in order to allow for the very large differences among countries. On the vertical scale, we see that Netherlands and Japan have the most dense network of roads, while China, Turkey, Canada and Australia have the least dense. Yet Australia and Canada have the highest per-capita road length (on the horizontal scale). The range across countries on both scales, from highest to lowest, is about 15 to 1.

Figure C5 compares cars per capita with roads per capita, across countries for 1990. Both scales are logarithmic: cars per capita on the vertical, and roads per capita on the horizontal. For a given level of car ownership, there is a wide range of road densities across countries, especially for higher-income countries. Roads per capita seem to be largely a function of geography: what percentage of the country is densely populated. Some of the least densely populated (Australia, Canada, and the USA) have the highest level of roads per capita, while those most densely populated have much lower levels: Italy, Germany, Great Britain, Netherlands, and Japan. Similarly, the population density of France is only half that of Italy and Germany, and its roads-per-capita is considerably greater.

Yet there are important differences between countries with similar population densities. Japan and South Korea, for example, have similar population densities, but South Korea's per-capita road length is only one-tenth that of Japan.

Figure C6. Cars and roads per capita, 1965-90

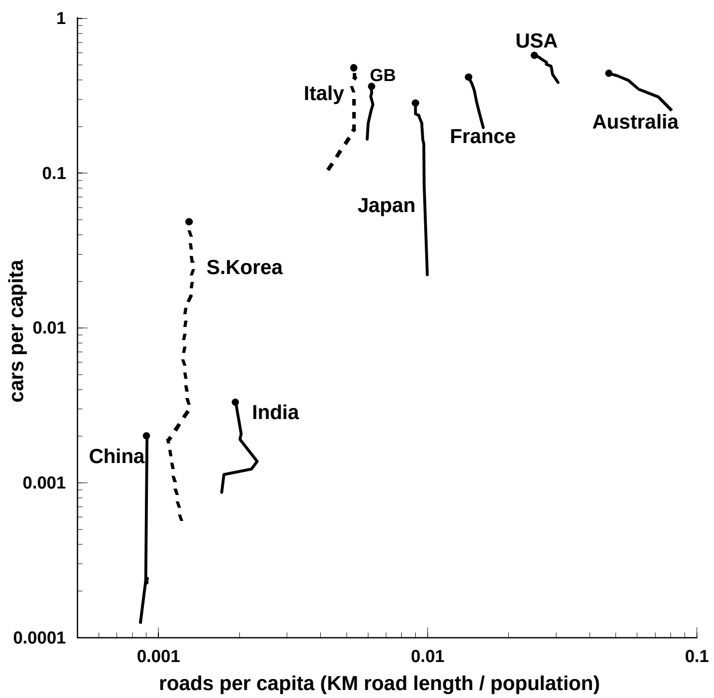


Figure C6 extends over time the comparison of cars and roads per capita, for several countries. Each country's time-path starts in 1965 and ends in 1990 (denoted by a circular marker).

There are important differences not only among countries but also in their paths over time. While car ownership has increased in all countries shown, since 1965 roads-per-capita has increased substantially only in Italy. It has remained roughly constant in China, South Korea, India, and Great Britain. The four other OECD members shown -- Japan, France, USA, and Australia -- had much higher roads-per-capita in 1965 than the other countries, but that advantage has declined since then, both relatively and absolutely, even as car ownership has increased.[10]

South Korea has been able to expand car ownership rapidly since 1965 (and even China, in relative terms), yet roads-per-capita have increased very little. Roads-per-capita in both South Korea and China are only about one-tenth that of Japan – suggesting significant value for improved road networks. But rapid development of highway infrastructure would be needed for South Korea and China to have by 2015 even just the road density that Italy had in 1965. South Korea would have to increase its roads-per-capita by more than 10% annually for two decades in order to match the current level of Japan, and by more than 7% annually to match the level of Italy. Even faster growth rates would be needed for China to reach the current levels of Japan or Italy by 2015.

For all the variables discussed in this Appendix, there are substantial differences across countries, of at least one order of magnitude. Undoubtedly these differences will affect different countries' car and vehicle ownership, and their growth over time. A more complex model including such variables – if the data were available – might explain historical patterns more clearly, and generate better projections of future growth.

Yet we believe that our relatively simple model of car and vehicle ownership, using only per-capita income, provides substantial explanatory power.

[10] The way in which road length is measured by this data may be misleading. In some countries (and perhaps all), no distinction is made between roads of different capacity or quality. Hence if an unpaved country road is improved to a six-lane divided highway, there is no change in its length as measured by these data – even though the improved road has three times as many traffic lanes, can carry at least three times as much traffic, and at much higher speeds.

DATA SOURCES

Vehicle Registrations, Car Registrations, 1960-92
    Source: Motor Vehicle Manufacturers Association, *World Motor Vehicle Data*.
Real Income: Gross Domestic Product (GDP), 1960-92
    Source: Penn World Tables
Population, 1960-1992; Total Land Area 1990; % Urban Population 1990;
    % Population > age 15, 1970 and 1990;
    Source: United Nations
Road Length, 1965-92
    Source: International Road Federation

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