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Author(s): François Lescaroux
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Car Ownership in Relation to Income Distribution and Consumers' Spending Decisions

François Lescaroux

Address for correspondence: Dr François Lescaroux, Institut Français du Pétrole, IFP, Economic Studies Department, 1 et 4, avenue de Bois-Préau, 92852 Rueil-Malmaison, France (francois.lescaroux@gdfsuez.com). The views expressed are those of the author and do not necessarily reflect the views of the IFP or GDF SUEZ.

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Abstract

This paper proposes a formal model of per capita private car ownership based on very simple and general assumptions on income distribution and consumers' spending decisions. The author justifies a theoretical S-shaped curve describing changes in ownership as a function of average per capita income, income's dispersion, and the 'cost/utility' ratio of owning a car. He applies the model to a panel of sixty-four countries and explains past variations in their ownership rates. Then, projections are performed to the year 2030. These suggest that important technical and sociological evolutions will be needed to 'meet the challenges of sustainability'.

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1.0 Introduction

The increasing need for mobility at a global level has raised many concerns about the sustainability of our way of living.

From the standpoint of the energy economist, about one half of total oil consumption is used in the transportation sector, where the substitution possibilities are very limited (at least in the medium term). This share should increase in the future as the demand for passenger cars in important emerging countries such as China or India rapidly grows. The surge in oil consumption in the last few years is directly responsible for the oil price hike that has occurred. Moreover, the structural nature of the upward movement in oil demand makes an oil price fall unlikely, unless supply develops even more rapidly. Further, the growing demand for motor fuel puts pressure on the refining sector where the upgrading capacities tend to saturate.

From the environmental economics' point of view, about 25 per cent of global CO_2 emissions from fossil fuels come from the transportation sector alone. The projected growth of this sector raises worries about global warming and clean air because of the limited possibilities of substitution and because of the impossibility of capturing the pollutants. Other important aspects include the need for infrastructure to develop and for intra-city traffic to adapt and avoid congestion. As a consequence, many projections of passenger cars' stocks are performed by national and international institutes (IMF, 2005), as well as individual researchers to help politicians and industrialists in their decision making.

In this paper, we propose a new approach to model the car stock: we justify a formal (non-linear) model of passenger car ownership based on income distribution and consumer spending decisions that can be estimated on a large scale.

In the next section, we present some of the main models of car ownership that have been put forward recently. Then, in Section 3, we explain our theoretical model, derive some properties of its dynamics, and propose a practical approximation to the formal relation; we also mention some advantages of our model compared to the main alternatives and comment on the influence of some determinants of the car ownership rate, such as income inequality or car purchase cost. In Section 4, we concretely apply the model and explain econometrically the car ownership rate in sixty-four countries between 1986 and 1998 as a function of average per capita income, income dispersion, and a country-specific indicator of the 'cost/utility' ratio of owning a car. Section 5 presents the results of the projections of car ownership to the year 2030. Finally, Section 6 summarises our results and we consider some implications of the research.

2.0 Previous Approaches

Almost all the projections of passenger cars' stocks performed rely on S-shaped curves estimated on pooled or panel data, with or without country-specific effects. The most widely used is the Gompertz function (Dargay and Gately, 1997, 1999; Dargay *et al.*, 2007). Letting *Car* denote the long-term equilibrium level of the passenger car ownership rate and letting Y denote real per capita income, it can be written as:

$$Car_t = Car^{\infty} \cdot \exp(\beta_1 \cdot \exp(\beta_2 \cdot \exp(Y_t))), \tag{1}$$

where Car^{∞} is the saturation level and β_1 and β_2 are negative parameters defining the shape of the curve.

Other S-shaped curves have been proposed, such as the log-logistic function used by Lescaroux and Rech (2008). It can be written as:

$$Car_t = \frac{Car^{\infty}}{1 + \exp\{-\lambda \cdot [\ln(Y_t) - \theta]\}}, \tag{2}$$

where λ and θ are two positive parameters defining the shape of the curve.[1]

Finally, the car ownership rate can be modelled with a truncated log-quadratic specification, as in Medlock and Soligo (2002). It is given by:[2]

$$\ln(Car_t) = \rho_1 + \rho_2 \cdot \ln(Y_t) + \rho_3 \cdot \ln(Y_t)^2. \tag{3}$$

The main limit of the forecasts obtained by simulating these various functions has been expressed very clearly — and crudely — by Greenman (1996): 'Forecasting results were found [...] to be very sensitive to the functional form used. The development of these models therefore tended to become an exercise in sophisticated curve fitting without any theoretical guidance as to the appropriate form to use.' To correct for this problem, Greenman proposed a model of car ownership relying on income and automobile diffusion densities that was fitted to data from the UK and Japan.

Another limit of the previous models (that the model proposed by Greenman overcomes) is that they rely just on the mean of the income distribution and do not take into account the shape of its density. The importance of income distribution on passenger car demand has since been confirmed by Storchmann (2005), who showed that 'high inequality leads to a higher car stock in poor countries, while it leads to a smaller car stock in rich countries'.

[1] Button *et al.* (1993) modelled the vehicle ownership rate as a logistic function of time. As the logarithm of per capita income can be approximated locally — and roughly — by a linear time trend, the log-logistic function of per capita income is closely related to the logistic function of time.

[2] Medlock and Soligo also introduce in their panel model the retail price of motor fuel and country-specific effects.

Nonetheless, the detailed data on income distribution and household expenditures for transportation that Greenman's model requires make it difficult to use on a large scale, particularly for emerging countries. On the other hand, the model proposed by Storchmann can be implemented practically for a broad range of countries but, for the sake of simplicity and comparability, it is linear in logarithms, which implies constant elasticities. Such a formulation is at odds with most of the recent literature on passenger car demand and Storchmann acknowledges that this simplification 'will be at the expense of consistency' with an individual model that he constructs first.

3.0 A Formal Model of Car Ownership Based on Income Distribution and Consumers' Spending Decisions

In this paper, we adopt an alternative approach to overcome the problem pointed out by Greenman. We consider a given population and assume that its income distribution is well approximated at time t by the log-normal law, with mean $\overline{Y_t}$ and standard deviation $\beta \cdot \overline{Y_t}$ (many studies have shown that the distribution of per capita income is very well approximated empirically by such a log-normal density; see, for example, Lopez and Servén, 2006). Therefore, the logarithm of Y follows a normal law with mean m and standard deviation σ:

$$\begin{aligned} &\ln(Y) \sim N(m, \sigma), \\ &m = \ln\left(\overline{Y_t}\right) - 0.5 \cdot \ln\left(\beta^2 + 1\right), \\ &\sigma^2 = \ln\left(\beta^2 + 1\right). \end{aligned} \tag{4}$$

Let $f_Y(y, \overline{Y_t}, \beta \cdot \overline{Y_t})$ be the density function of real per capita income, $F_Y(y, \overline{Y_t}, \beta \cdot \overline{Y_t})$ its cumulative distribution function (CDF), $f_U(u)$ the density function of the standard normal distribution, and $F_U(u)$ its CDF. For each individual i in the population, we also consider that owning a car procures a utility U_i. Given y, the income level of the individual and P, the smallest amount of money needed to own and use a car, individual i chooses to buy a car if $P/y \leqslant U_i$ (for each individual, there exists a 'cost/utility' ratio which acts as an income threshold beyond which he chooses to buy a car). Let U, the associated real-valued random variable, have a CDF, F_α, and a density function, f_α.

Then, the probability for an individual to own a car is:

$$\alpha(y) = \text{Proba}\left(\frac{P}{y} \leqslant U\right) = 1 - F_\alpha\left(\frac{P}{y}\right). \tag{5}$$

where α is a strictly increasing function of y, whose value in $y = 0$ is 0 and which tends towards α^∞ when y tends towards infinity, with the saturation level α^∞ being:[3]

$$\alpha^\infty = \int_0^{+\infty} f_\alpha(u) \cdot du. \tag{6}$$

Therefore, the car ownership rate as a function of average per capita income is

$$Car(\overline{Y_t}) = \int_0^{+\infty} \alpha(y) \cdot f_Y(y, \overline{Y_t}, \beta \cdot \overline{Y_t}) \cdot dy. \tag{7}$$

In fact, the utility of owning a car depends on many factors, such as population densities or access to other transport alternatives, which evolve through time as much as do car purchase costs. Consequently, the function α is not time invariant. We do not indicate this inconsistency to lighten the equations but we keep it in mind.

Empirically, it is possible to estimate the function α when household expenditure surveys are available. Greenman (1996) analyses the cases of the UK and Japan, for example. However, for most of the developing countries, these statistics do not exist. Nonetheless, another practical approach is possible. There exists a sequence of simple functions, (α_n), that converges towards α and the convergence is uniform. The car ownership rate can therefore be expressed as:

$$\begin{aligned} Car(\overline{Y_t}) &= \int_0^{+\infty} \left(\lim_{n \to +\infty} \alpha_n(y) \right) \cdot f_Y(y, \overline{Y_t}, \beta \cdot \overline{Y_t}) \cdot dy \\ &= \lim_{n \to +\infty} \left(\int_0^{+\infty} \alpha_n(y) \cdot f_Y(y, \overline{Y_t}, \beta \cdot \overline{Y_t}) \cdot dy \right). \end{aligned} \tag{8}$$

The function $\alpha_n(y)$ can be described by a sequence of real numbers, $\alpha_0, \ldots, \alpha_{n-1}, Y_0, \ldots, Y_{n-1}$:

$$\alpha_n(y) = \sum_{i=0}^{n-2} \alpha_i \cdot \mathbf{1}_{[Y_i;Y_{i+1}]} + \alpha_{n-1} \cdot \mathbf{1}_{[Y_{n-1};+\infty]}, \tag{9}$$

where $\mathbf{1}$ denotes the indicator function ($Y_0 > 0$ and $\alpha_{n-1} = \alpha^\infty$). Define τ_i as:

$$\tau_i(\overline{Y_t}) = \int_{Y_i}^{+\infty} f_Y(y, \overline{Y_t}, \beta \cdot \overline{Y_t}) \cdot dy = 1 - F_U(g_i(Y_t)), \tag{10}$$

[3] The support of U is the extended real line: for some people, the utility of owning a car may be negative (for example, people who cannot drive). Otherwise, the saturation level should be one car per individual.

where

$$g_i(Y_t) = \frac{-\ln(\overline{Y_t}) + \ln(Y_i) + 0.5 \cdot \ln(\beta^2 + 1)}{\sqrt{\ln(\beta^2 + 1)}}. \tag{11}$$

With $\gamma_i = (\alpha_i - \alpha_{i-1})/\alpha^\infty$, $\gamma_0 = \alpha_0/\alpha^\infty$ and by substituting equations (9) and (10) in (8), we obtain:

$$\begin{aligned} Car(\overline{Y_t}) &= \lim_{n \to +\infty} \left(\sum_{i=0}^{n-2} \alpha_i \cdot \int_{Y_i}^{Y_{i+1}} f_Y(y, \overline{Y_t}, \beta \cdot \overline{Y_t}) \cdot dy \right. \\ &\quad \left. + \alpha_{n-1} \cdot \int_{Y_{n-1}}^{+\infty} f_Y(y, \overline{Y_t}, \beta \cdot \overline{Y_t}) \cdot dy \right) \\ &= \lim_{n \to +\infty} \left(\sum_{i=1}^{n-1} (\alpha_i - \alpha_{i-1}) \cdot \int_{Y_i}^{+\infty} f_Y(y, \overline{Y_t}, \beta \cdot \overline{Y_t}) \cdot dy \right) \\ &\quad + \alpha_0 \cdot \int_{Y_0}^{+\infty} f_Y(y, \overline{Y_t}, \beta \cdot \overline{Y_t}) \cdot dy \\ &= \alpha^\infty \cdot \lim_{n \to +\infty} \left(\sum_{i=0}^{n-1} \gamma_i \cdot \tau_i(\overline{Y_t}) \right). \end{aligned} \tag{12}$$

Therefore, the car ownership rate appears as the limit of a sequence of functions Car_n:

$$Car_n(\overline{Y_t}) = \alpha^\infty \cdot \sum_{i=0}^{n-1} \gamma_i \cdot \tau_i(\overline{Y_t}). \tag{13}$$

As a first approximation, Car_n can be approached by:

$$Car_n(\overline{Y_t}) \approx \alpha^\infty \cdot \left[1 - F_U \left(\frac{-\ln(\overline{Y_t}) + \ln\left(\prod_{i=0}^{n-1} Y_i^{\gamma_i} \right) + 0.5 \cdot \ln(\beta^2 + 1)}{\sqrt{\ln(\beta^2 + 1)}} \right) \right]. \tag{14}$$

Let U^* be the truncation of U such that its probability mass is restricted to the sub-interval $[0; +\infty[$. When n increases, $\ln(\prod_i Y_i^{\gamma_i})$ tends towards the expected value of $\ln(P/U^*)$, denoted $\ln(P^*)$. Consequently, the equation relating the car ownership rate to average per capita income can be approximated by:

$$Car(\overline{Y_t}) = \alpha^{\infty} \cdot \left[1 - F_U\left(\frac{-\ln(\overline{Y_t}) + \ln(P^*) + 0.5 \cdot \sigma^2}{\sigma}\right)\right]. \tag{15}$$

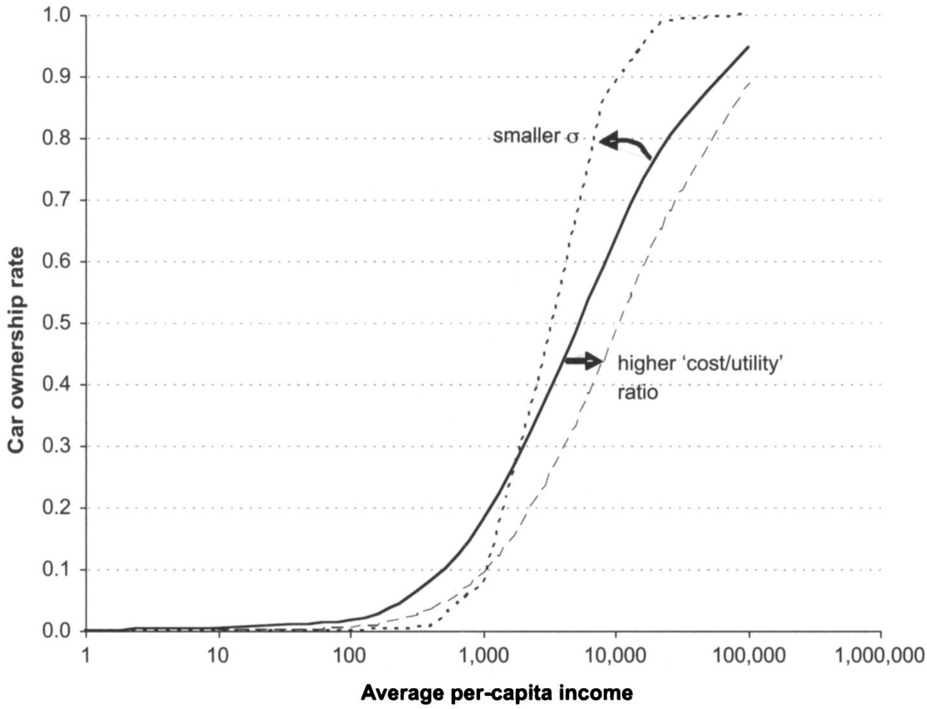
This means that, on average, a share α^{∞} of the population buys a car when its income level exceeds an income threshold P^*. As discussed before, P^* depends on many factors and it varies both through time and from one country to another. Intuitively, we would expect a positive correlation between P^* and average per capita income and a negative correlation between P^* and time. We will explore this possibility further in the empirical part of our work.

The cumulative log-normal distribution model has an important advantage against the log-quadratic and the Gompertz models: its coefficients are directly interpretable. The dispersion of the income distribution acts on the slope of the S-shaped curve while the income threshold acts on the position of the curve along the income axis: the more unequal the distribution of income, the more gentle the slope and the higher the income threshold (that is, the higher the car purchase cost and/or the lower the utility it gives), the most right-translated the curve. Figure 1 shows these influences.

As we will see in the next section, this allows heterogeneity to be introduced between countries in a very simple way. Conversely, the introduction of heterogeneity in the other two models seems rather arbitrary. Indeed, it would not be sensible to estimate a separate equation for each country because the estimation procedure needs observations over the whole range of income; consequently, some parameters need to be common for all countries. However, the parameters in these models are linked and make no sense individually. For example, Medlock and Soligo (2002) let only the intercept vary and Dargay and Gately (1997) let only the parameter which determines the curvature at low-income levels vary, whereas Dargay and Gately (1999) let only the parameter which determines the curvature at high-income levels vary. According to our formal model, such an approach seems artificial because the curvatures at high- and low-income levels are linked and determined mainly by the dispersion of the income distribution[4] (as formulated by Storchmann, 'income inequality tends to move car demand from both sides').

[4] According to equation (15), it should be the only one but we will show later that the income threshold is correlated with per capita income; consequently, the elasticity of the former with respect to the latter also influences both the curvatures at high- and low-income levels.

Figure 1
Influence of the Dispersion and Threshold Parameters on the S-shaped Curve



4.0 Estimation Procedure and Results

We now turn to the empirical application of the formal model. Up to this point, our formal model was close to the 'individual model' of Storchmann (2005). Differences arise in the practical approximation to the theoretical model. Storchmann uses a formulation which is linear in logarithms whereas our approach is non-linear. We consider that equation (15) describes the long-term equilibrium level of the car ownership rate. As in Lescaroux and Rech (2008), the car ownership rate is defined as the number of passenger cars per people aged 15 or more, denoted Car^*,

$$Car_t^* = \alpha^\infty \cdot \left[1 - F_U\left(\frac{-\ln(\overline{Y_t}) + \ln(P^*) + 0.5 \cdot \sigma^2}{\sigma}\right)\right], \qquad (16)$$

and assume a partial adjustment mechanism depending on the rate of change of per capita income:[5]

$$\ln(Car_t) = \ln(Car_{t-1}) + \lfloor \delta_1 + \delta_2 \cdot h(\overline{Y_t}/\overline{Y_{t-1}}) \rfloor \cdot [\ln(Car_t^*) - \ln(Car_{t-1})], \quad (17)$$

where h is a function to be determined and $\overline{Y_t}$ is the average per capita income level ($US2,000).

We chose to restrict α^{∞}, δ_1, and δ_2 as common for all countries. Considering the dispersion parameter σ, it does not need to be estimated. Indeed, in the case of a log-normal distribution, there is a one-to-one relation between the Gini coefficient and the standard deviation of the underlying normal distribution:

$$\text{Gini} = 2 \cdot F_{\text{U}}\left(\sigma \big/ \sqrt{2}\right) - 1. \quad (18)$$

Finally, we allow the income threshold parameter to be country-specific. As this parameter reflects the ratio of the cost of owning a car to the utility it procures, it depends of course on the car purchase costs (including taxes), but it also depends on less easily quantifiable factors, such as the access to other transport alternatives or sociological and cultural factors. Therefore, for the first application of the model, we prefer to consider it as a time-invariant country-specific parameter.

The model to be estimated econometrically thus becomes:

$$\begin{aligned}\ln\left(Car_{i,t}\right) = &\left[1 - \delta_1 - \delta_2 \cdot h\left(\overline{Y_{i,t}}/\overline{Y_{i,t-1}}\right)\right] \cdot \ln(Car_{i,t-1}) \\ &+ \left[\delta_1 + \delta_2 \cdot h\left(\overline{Y_{i,t}}/\overline{Y_{i,t-1}}\right)\right] \\ &\cdot \ln\left[1 - F_{\text{U}}\left(\frac{-\ln\left(\overline{Y_{i,t}}\right) + p_i^* + 0.5 \cdot \sigma_{i,t}^2}{\sigma_{i,t}}\right)\right] \\ &+ \left[\delta_1 + \delta_2 \cdot h\left(\overline{Y_{i,t}}/\overline{Y_{i,t-1}}\right)\right] \cdot \ln(\alpha^{\infty}), \quad (19)\end{aligned}$$

where the subscripts i and t refer respectively to country i and date t and p_i^* stands for $\ln(P_i^*)$.

The most demanding variable in equation (19) is σ because the Gini coefficients are available only for some countries and for a few years. We were nonetheless able to construct a database covering

[5] Lescaroux and Rech (2008) suggest that the speed of adjustment towards the equilibrium level increases with per capita income but they were unable to identify a statistically significant relationship. Dargay *et al.* (2007) show that the sign of the growth rate matters. We pursued this direction using a continuous function of the rate of change of per capita income.

sixty-four countries between 1986 and 1998 (see Appendix 2 for more details). Because of its non-linear nature, equation (19) was estimated using maximum likelihood methods by postulating successively a set of different functions h.

After various experiments, the best specification that we estimated was as follows:

$$\begin{aligned}\ln\left(Car_{i,t}\right) = {} & \left\lfloor 1 - 0.07 \cdot \left(\overline{Y_{i,t}}/\overline{Y_{i,t-1}}\right)^2 \right\rfloor \cdot \ln\left(Car_{i,t-1}\right) \\ & + 0.07 \cdot \left(\overline{Y_{i,t}}/\overline{Y_{i,t-1}}\right)^2 \\ & \cdot \ln\left[1 - F_{\mathrm{U}}\left(\frac{-\ln\left(\overline{Y_{i,t}}\right) + 8.53 + 0.5 \cdot \sigma_{i,t}^2}{\sigma_{i,t}}\right)\right], \end{aligned} \qquad (20)$$

where 8.53 is the median value of $\ln(P_i^*)$. It appeared that the choice of the function h is not crucial for the other parameters and, notably, α^∞ was not statistically different from 1 in all the cases (and still close to 1 when it was significantly different from 1). The detailed estimates of this preliminary specification are reported in Table 1.

The median income threshold is about \$5,500 per capita (\$US2,000), but the dispersion is rather large (see Figure 2). We made a first step towards explaining the level of the income threshold. We evaluated the cross-correlation between the estimated parameters, P_i^*, and the countries' population densities (at the middle of the time sample, in 1995). When data were available, we also evaluated the cross-correlation with car prices (in 2003). The coefficients obtained are 0.34 and 0.41, respectively. This confirms that concentration of population and car purchase costs are important determinants of the car ownership rate. The construction of a cross-section time-series database covering these two indicators and some others (measures of urbanisation or access to other transport alternatives, for example) would enable the 'cost/utility' ratio of owning a car to be modelled explicitly.

Nonetheless, we found that the evolution of the 'cost/utility' ratio as the economy develops is well synthesised, as a first approximation, by the evolution of per capita income. We evaluated the cross-correlation between the income threshold parameter and average per capita income: the coefficient obtained is 0.81 (Figure 2 shows the scatter of points). This is not surprising because the cost of owning a car tends to be positively correlated with per capita income (the rise in standards of living leads to more expensive cars being bought and the greater need for infrastructure leads to more taxes) while the influence of wealth on the utility of owning a car is ambiguous (the urbanisation process and the development of

Table 1
Estimated Parameters of the Car Ownership Model (Equation (20))

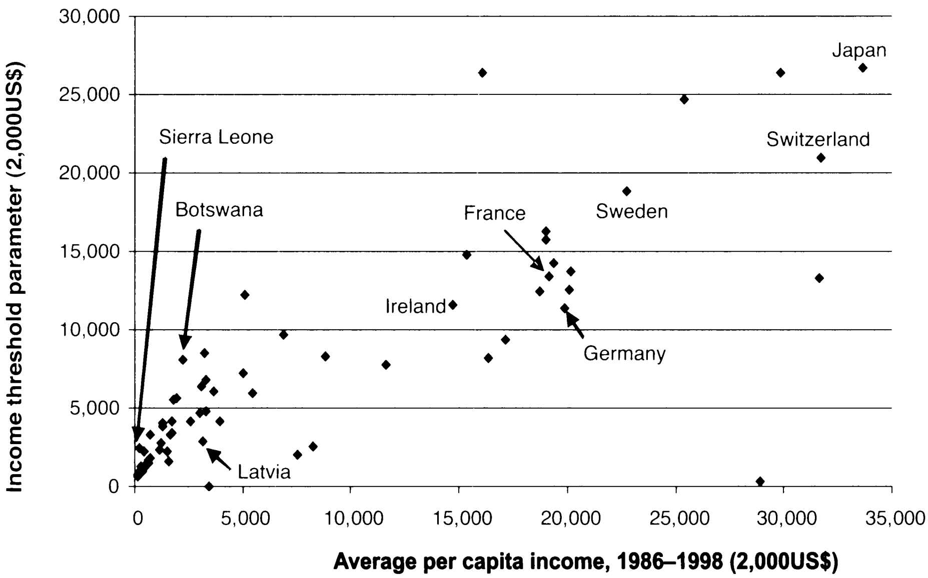
		Coefficient	*z-statistic*			*Coefficient*	*z-statistic*
δ_2		0.07	8.60				
$\ln(P_i^*)$	Algeria	8.15	4.31	$\ln(P_i^*)$	Japan	10.19	3.52
$\ln(P_i^*)$	Argentina	9.18	16.83	$\ln(P_i^*)$	Jordan	8.33	40.39
$\ln(P_i^*)$	Australia	9.15	8.67	$\ln(P_i^*)$	Kenya	7.70	29.29
$\ln(P_i^*)$	Austria	9.44	1.57	$\ln(P_i^*)$	Korea, Rep. of	7.64	1.84
$\ln(P_i^*)$	Bangladesh	7.16	65.73	$\ln(P_i^*)$	Latvia	7.95	66.45
$\ln(P_i^*)$	Belgium	9.43	1.58	$\ln(P_i^*)$	Luxembourg	9.50	0.73
$\ln(P_i^*)$	Botswana	9.00	44.38	$\ln(P_i^*)$	Mexico	8.89	12.04
$\ln(P_i^*)$	Brazil	9.05	61.90	$\ln(P_i^*)$	Morocco	7.76	12.42
$\ln(P_i^*)$	Bulgaria	7.38	10.65	$\ln(P_i^*)$	Mozambique	6.66	261.73
$\ln(P_i^*)$	Burundi	6.58	142.04	$\ln(P_i^*)$	Netherlands	9.69	8.07
$\ln(P_i^*)$	Cameroon	8.10	80.69	$\ln(P_i^*)$	Norway	10.18	5.89
$\ln(P_i^*)$	Canada	9.57	5.55	$\ln(P_i^*)$	Pakistan	7.26	24.13
$\ln(P_i^*)$	Chile	8.71	10.71	$\ln(P_i^*)$	Panama	8.82	15.30
$\ln(P_i^*)$	China	7.18	46.51	$\ln(P_i^*)$	Paraguay	7.69	62.21
$\ln(P_i^*)$	Costa Rica	8.48	10.39	$\ln(P_i^*)$	Peru	8.63	23.76
$\ln(P_i^*)$	Denmark	10.11	5.99	$\ln(P_i^*)$	Portugal	7.83	0.91
$\ln(P_i^*)$	Ecuador	8.32	25.69	$\ln(P_i^*)$	Sierra Leone	7.80	82.93
$\ln(P_i^*)$	Egypt	7.94	11.51	$\ln(P_i^*)$	Singapore	10.18	16.04
$\ln(P_i^*)$	El Salvador	8.61	59.08	$\ln(P_i^*)$	South Africa	8.76	15.00
$\ln(P_i^*)$	Estonia	3.82	0.00	$\ln(P_i^*)$	Spain	8.96	1.94
$\ln(P_i^*)$	Ethiopia	6.47	72.61	$\ln(P_i^*)$	Sri Lanka	7.41	28.03
$\ln(P_i^*)$	Finland	9.67	8.41	$\ln(P_i^*)$	Swaziland	8.25	42.94
$\ln(P_i^*)$	France	9.50	1.59	$\ln(P_i^*)$	Sweden	9.84	4.67
$\ln(P_i^*)$	Germany	9.34	4.16	$\ln(P_i^*)$	Switzerland	9.95	2.39
$\ln(P_i^*)$	Greece	9.03	6.62	$\ln(P_i^*)$	Thailand	8.11	29.54
$\ln(P_i^*)$	Hungary	8.33	17.22	$\ln(P_i^*)$	Turkey	8.33	14.25
$\ln(P_i^*)$	India	6.89	35.71	$\ln(P_i^*)$	Uganda	6.91	53.92
$\ln(P_i^*)$	Indonesia	7.51	42.75	$\ln(P_i^*)$	United Kingdom	9.53	4.57
$\ln(P_i^*)$	Ireland	9.36	3.13	$\ln(P_i^*)$	United States	5.77	0.00
$\ln(P_i^*)$	Israel	9.60	7.21	$\ln(P_i^*)$	Uruguay	8.70	6.99
$\ln(P_i^*)$	Italy	9.01	1.49	$\ln(P_i^*)$	Venezuela	9.41	43.16
$\ln(P_i^*)$	Jamaica	8.46	45.56	$\ln(P_i^*)$	Zimbabwe	7.27	14.49
adj-R^2		0.99		Log likelihood		2596.37	
S.E.		0.099		Observations		768	

public transportation systems tend to lower it but the demand for leisure and travel increases it).

We tried to take into account in the model the link between the income threshold parameter and per capita income. From equation (20), we tried a variety of specifications.[6] The best relationship that we found

[6] We also tried to take into account the temporal decrease of car purchase cost that results from productivity growth in the automobile sector by introducing a time trend in the approximation of $\ln(P_i^*)$, but we could not find a satisfactory specification. This results probably from the shortness of the temporal dimension of our sample.

Figure 2
Per capita Income and 'cost/utility' Ratio of Owning a Car



was as follows:

$$\ln(Car_{i,t}) = \lfloor 1 - \delta_2 \cdot (\overline{Y_{i,t}}/\overline{Y_{i,t-1}})^2 \rfloor \cdot \ln(Car_{i,t-1}) + \delta_2 \cdot (\overline{Y_{i,t}}/\overline{Y_{i,t-1}})^2 \cdot \ln\left[1 - F_{\mathrm{U}}\left(\frac{-\ln(\overline{Y_{i,t}}) + (\gamma \cdot \ln(\overline{Y_{i,t}}) + \beta_i) + 0.5 \cdot \sigma_{i,t}^2}{\sigma_{i,t}}\right)\right], \quad (21)$$

where β_i are country-specific. Table 2 reports the result of the estimation.

Since the estimated value of α is smaller than 1, this is, from Lemma 1 (Appendix 1), a log-concave function of $\ln(\overline{Y_t})$ (as well as equation (20)), which means that the elasticity of car ownership with respect to average per capita income is decreasing (see Appendix 1 for an approximation of the elasticity). This result might be disturbing at first sight because the S-shaped pattern implies that the diffusion process accelerates and then decelerates, but this means that the ratio of the changes, not the elasticity, first increases and then decreases.

As before, α^{∞} was estimated to be statistically no different from 1. This value corresponds to the saturation level estimated by Lescaroux and Rech (2008) but it is bigger than those estimated by Dargay and Gately (1997, 1999) and Medlock and Soligo (2002). The reason for this discrepancy might be the use of different data or it could result from the different S-shaped functions used.

Table 2
Estimated Parameters of the Car Ownership Model (Equation (21))

		Coefficient	*z-statistic*			*Coefficient*	*z-statistic*
δ_2		0.08	7.92	γ		0.37	2.43
β_i	Algeria	5.38	3.01	β_i	Japan	6.40	2.79
β_i	Argentina	5.91	4.16	β_i	Jordan	5.54	4.81
β_i	Australia	5.56	3.37	β_i	Kenya	5.47	5.79
β_i	Austria	5.86	1.46	β_i	Korea, Rep. of	5.29	3.98
β_i	Bangladesh	5.09	5.89	β_i	Latvia	5.15	4.34
β_i	Belgium	5.84	1.05	β_i	Luxembourg	5.85	0.92
β_i	Botswana	6.18	5.17	β_i	Mexico	5.78	4.08
β_i	Brazil	6.03	4.83	β_i	Morocco	5.20	4.43
β_i	Bulgaria	4.73	3.92	β_i	Mozambique	4.77	6.11
β_i	Burundi	4.71	6.31	β_i	Netherlands	6.06	3.39
β_i	Cameroon	5.68	5.70	β_i	Norway	6.38	3.11
β_i	Canada	5.91	2.89	β_i	Pakistan	5.01	5.15
β_i	Chile	5.77	4.20	β_i	Panama	5.85	4.50
β_i	China	5.17	6.17	β_i	Paraguay	5.10	4.70
β_i	Costa Rica	5.56	4.10	β_i	Peru	5.87	4.94
β_i	Denmark	6.37	3.22	β_i	Portugal	4.93	1.56
β_i	Ecuador	5.71	5.14	β_i	Sierra Leone	5.72	6.88
β_i	Egypt	5.31	4.39	β_i	Singapore	6.63	4.19
β_i	El Salvador	5.90	5.23	β_i	South Africa	5.75	4.35
β_i	Estonia	4.60	3.20	β_i	Spain	5.59	1.42
β_i	Ethiopia	4.73	6.49	β_i	Sri Lanka	5.05	5.07
β_i	Finland	6.04	3.47	β_i	Swaziland	5.61	5.08
β_i	France	5.88	1.21	β_i	Sweden	6.14	2.70
β_i	Germany	5.79	2.89	β_i	Switzerland	6.15	1.77
β_i	Greece	5.74	3.48	β_i	Thailand	5.49	4.98
β_i	Hungary	5.31	4.05	β_i	Turkey	5.53	4.45
β_i	India	4.77	5.35	β_i	Uganda	5.03	6.45
β_i	Indonesia	5.15	5.29	β_i	United Kingdom	5.91	2.70
β_i	Ireland	5.89	2.20	β_i	United States	2.29	0.00
β_i	Israel	6.08	3.38	β_i	Uruguay	5.58	3.58
β_i	Italy	5.50	1.18	β_i	Venezuela	6.19	4.67
β_i	Jamaica	5.59	4.59	β_i	Zimbabwe	4.91	4.63
	adj-R^2	0.99			Log likelihood	2597.16	
	S.E.	0.099			Observations	768	

The average adjustment coefficient is 8.6 per cent (with a minimum of 3.9 per cent and a maximum of 12.5 per cent), which means that 90 per cent of full adjustment takes about twenty-six years. Nonetheless, in a country which is not developing, the adjustment process can be less than half as fast. Our adjustment coefficient is much smaller than the value of 0.205 estimated by Medlock and Soligo (2002), close to the value of 0.09 estimated by Dargay and Gately (1999), close to the values of 0.095 (for rising income) and 0.084 (for falling income) estimated by Dargay *et al.*

(2007), and higher than the value of 0.03 estimated by Lescaroux and Rech (2008).[7] The mean and the median income thresholds, $\gamma \cdot \ln(\overline{Y_{i,t}}) + \beta_i$, are about \$8,000 and \$5,600 per capita (\$US2,000), respectively. The lowest value is about \$600 in Ethiopia (maybe because of an important second-hand market)[8] and the biggest values are about \$30,000 in Singapore (because of (a) the quotas established and the booming market for Certificates of Entitlement, and (b) the incredibly high population density) and in Japan.

The model performs remarkably well in (in-sample) dynamic simulation (to save space, the simulations are not reported here; they are available at the URL: http://www.ifp.com/information-publications/etudes-disponibles/car-ownership-simulations). Notably, we are able to reproduce the particular pattern that characterises countries in Eastern Europe (decrease of average per capita income in the aftermath of the fall of the Berlin Wall and simultaneous increase of car ownership) and that results partly from the increase in income inequality.

5.0 Projections of Passenger Car Stocks to the Year 2030

On the basis of assumptions concerning per capita income growth and demographic changes to the year 2030 (see Appendix 2), we used our model of car ownership to project how the car stock could evolve in each country according to different hypotheses regarding variations in income inequality and changes in the 'cost/utility' ratio. By prolonging the actual trends, we first simulate a reference case. Then, we analyse the sensitivity of the projections to changes in the trends observed. These alternative projections are somehow artificial and mainly illustrative of the strong influence of some parameters not considered by most of the other models. Their purpose is to highlight some sources of uncertainty about future developments. A rigorous study of the relationships between per capita income and income inequality and between the income threshold and car purchase costs would be needed to obtain more interesting insights.

[7] Their very slow adjustment process results from the estimation of a common equation for all countries.
[8] Technically, the slowest estimated income threshold is approximately \$450 in the United States. Nonetheless, because of a revision in the way the UN measures the US car stock, our sample begins in 1987; so the US car stock has reached saturation over the whole sample. Consequently, there is not enough variation to estimate accurately the income threshold level and the associated standard deviation is very large. Thus, this value should be considered carefully.

The reference case corresponds to a 'business-as-usual' scenario. On one hand, we assumed that the estimated relationship between the income threshold level and per capita income would remain stable over the whole forecast sample (this means that we do not take into account the possibility that automakers could propose cheap cars designed for developing countries, which would accelerate the expansion of their car stocks). On the other hand, we also considered that the structures of income distribution would stay the same in each country,[9] excepting those in Europe, where we imagined that a standardisation of fiscal policies should cause a kind of partial convergence in the Gini coefficients. On the basis of past data, we postulated five sub-groups of European countries: very egalitarian Scandinavian countries (Denmark, Finland, Norway, and Sweden), very unegalitarian Anglo-Saxon countries (Ireland, UK), egalitarian Continental countries (Austria, Bulgaria, Estonia, Germany, Hungary, Latvia, Luxembourg, Netherlands), unegalitarian Southern countries (Greece, Portugal, Spain) and mixed countries (Belgium, France, Switzerland), halfway between the Continental and the Southern models. The assumptions and results of this projection are reported in Table 3 and Figure 3 summarises the forecasts.[10]

As expected, the projections indicate that the growth rates in both car ownership and car stock should be much larger in poor countries than in rich countries. Particularly, Asian developing countries should enter a period of strong acceleration in the diffusion process of private automobile, with average annual ownership growth rates reaching 11.6 per cent in China, 11.0 per cent in Bangladesh, 9.7 per cent in India, and 5.8 per cent in Indonesia and in Pakistan. Given the significance of these five countries in the present and future world population, they will account for an increase of almost 0.5 billion of cars (that is, more than one half of the total increase for the 64 countries). By 2030, the top six countries for the passenger car stock should be the United States (299 million), China (288 million), India (178 million), Japan (78 million), Germany (60 million) and France (44 million). From 1998 to 2030, the top six countries for the increase in the car stock should be China (+282 million), India

[9] There is a huge literature on income inequality. According to Kuznets (1955), it should first rise and later fall as per capita income increases. Nonetheless, more recent work indicates that this relationship could have weakened or that its capacity to explain variations in income inequality across countries and over time is very limited (Barro, 2000) or that is does not reflect a 'natural' evolution but a purely 'accidental' evolution (Piketty, 2005). Because of this lack of consensus, we prefer to keep the Gini coefficients constant for the base case.

[10] We ascertained that the practical implications of this assumption are very limited: for the EU-15 area, in year 2030, the car stock would be smaller by 4 million cars (about 1.5 per cent of the European stock) with stable Gini coefficients.

Table 3
Assumptions and Projections of Passenger Car Ownership, 1998–2030

	Per capita income (thousands, $US2,000)			Passenger cars per 1,000 people aged 15 or more			Passenger car stock (millions)			Ratio of growth rates: car ownership to per capita income	Population (millions)		
Country	1998	2030	Average annual growth rate (%)	1998	2030	Average annual growth rate (%)	1998	2030	Average annual growth rate (%)		1998	2030	Average annual growth rate (%)
OECD, North America													
Canada	21.2	35.6	1.6	572	757	0.88	13.9	25.1	1.9	0.54	30.1	39.1	0.8
United States	32.7	64.1	2.1	943	997	0.17	203.2	298.6	1.2	0.08	279.0	366.2	0.9
Mexico	5.5	13.5	2.8	157	299	2.04	9.8	30.6	3.6	0.72	96.6	128.1	0.9
OECD, Europe													
Austria	22.7	41.1	1.9	587	850	1.16	3.9	6.3	1.5	0.62	8.1	8.6	0.2
Belgium	20.9	38.1	1.9	534	802	1.28	4.5	7.3	1.5	0.67	10.1	10.8	0.2
Denmark	28.3	51.4	1.9	418	687	1.56	1.8	3.2	1.8	0.83	5.3	5.6	0.2
Finland	21.4	41.7	2.1	481	782	1.53	2.0	3.6	1.8	0.73	5.1	5.5	0.2
France	21.1	38.5	1.9	566	790	1.05	26.8	44.0	1.6	0.55	58.8	66.6	0.4
Germany	22.0	38.9	1.8	604	865	1.13	41.7	59.6	1.1	0.63	82.0	79.3	−0.1
Greece	9.6	20.1	2.3	293	603	2.28	2.7	5.9	2.5	0.97	10.8	11.2	0.1
Hungary	4.1	9.3	2.5	261	627	2.77	2.2	5.0	2.6	1.09	10.3	9.3	−0.3
Ireland	20.9	47.7	2.6	421	791	1.99	1.2	3.6	3.4	0.76	3.7	5.5	1.2
Italy	17.8	31.6	1.8	637	861	0.94	31.4	43.5	1.0	0.52	57.5	57.5	0.0
Luxembourg	39.1	81.4	2.3	706	954	0.94	0.2	0.5	2.1	0.41	0.4	0.6	1.1
Netherlands	21.9	38.3	1.8	463	713	1.36	5.9	10.3	1.7	0.77	15.7	17.1	0.3
Norway	35.9	64.6	1.9	503	766	1.32	1.8	3.4	2.0	0.71	4.4	5.4	0.6
Portugal	9.8	16.8	1.7	543	890	1.56	4.6	8.2	1.8	0.92	10.1	10.6	0.1
Spain	13.4	25.4	2.0	474	771	1.53	16.1	31.3	2.1	0.76	39.9	46.7	0.5
Sweden	24.8	48.1	2.1	527	804	1.33	3.8	6.7	1.8	0.64	8.9	10.0	0.4
Switzerland	33.0	56.6	1.7	578	776	0.93	3.4	5.3	1.4	0.54	7.2	8.1	0.4
Turkey	3.0	6.0	2.2	86	252	3.42	3.8	18.6	5.1	1.57	66.0	92.5	1.1
United Kingdom	23.0	43.4	2.0	506	748	1.23	23.9	41.1	1.7	0.61	58.5	66.2	0.4

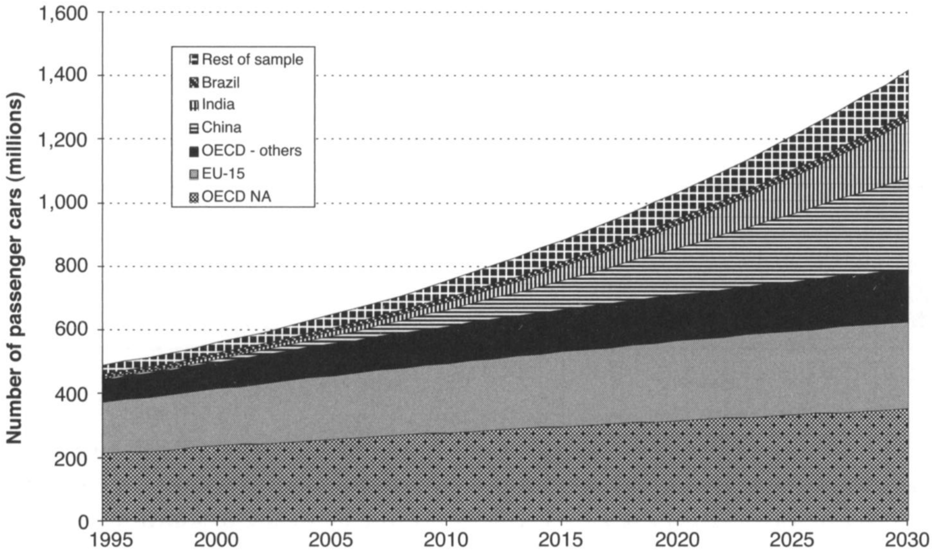
OECD, Pacific													
Australia	19.6	33.3	1.7	650	844	0.82	9.5	17.7	1.9	0.49	18.7	25.3	0.9
Japan	36.7	57.3	1.4	465	737	1.45	49.9	77.7	1.4	1.03	126.4	118.3	−0.2
Korea, Rep. of	9.3	30.2	3.7	210	860	4.51	7.6	36.7	5.1	1.20	46.1	48.4	0.2
South America													
Argentina	8.2	16.0	2.1	196	318	1.53	5.0	12.0	2.7	0.73	36.1	47.5	0.9
Brazil	3.4	6.6	2.1	93	128	1.02	10.8	24.0	2.5	0.49	169.1	236.5	1.1
Chile	4.9	11.4	2.7	115	265	2.63	1.2	4.3	3.9	0.98	15.0	19.8	0.9
Costa Rica	3.9	8.7	2.6	126	296	2.70	0.3	1.4	4.7	1.05	3.7	5.8	1.4
Ecuador	1.4	3.0	2.5	39	92	2.72	0.3	1.2	4.4	1.10	11.9	16.7	1.0
El Salvador	2.1	4.2	2.3	35	92	3.02	0.1	0.6	4.8	1.34	6.0	8.9	1.3
Jamaica	3.1	6.4	2.3	83	237	3.36	0.1	0.5	4.2	1.45	2.5	2.9	0.4
Panama	3.8	8.7	2.6	111	202	1.89	0.2	0.7	3.8	0.73	2.8	4.5	1.4
Paraguay	1.5	2.7	1.9	115	203	1.78	0.4	1.3	4.1	0.93	5.1	8.5	1.6
Peru	2.0	4.6	2.6	40	100	2.91	0.6	2.7	4.6	1.13	24.9	35.6	1.1
Uruguay	6.6	12.4	2.0	234	409	1.76	0.6	1.2	2.3	0.88	3.3	3.6	0.3
Venezuela	5.1	9.8	2.0	92	140	1.32	1.4	4.0	3.3	0.65	23.5	37.1	1.4
Middle East and North Africa													
Algeria	1.7	3.6	2.4	87	188	2.44	1.6	6.5	4.4	1.02	29.6	44.7	1.3
Egypt	1.4	2.9	2.3	37	141	4.24	1.5	11.0	6.4	1.84	64.2	104.1	1.5
Israel	17.6	32.4	1.9	304	521	1.70	1.3	3.7	3.4	0.88	5.8	9.2	1.4
Jordan	1.7	3.7	2.4	72	136	2.00	0.2	0.9	4.7	0.83	4.6	8.6	2.0
Morocco	1.2	2.4	2.1	62	162	3.02	1.1	4.9	4.8	1.42	28.1	39.3	1.1
Asia													
Bangladesh	0.3	0.9	3.3	1	24	10.96	0.1	3.8	13.6	3.36	134.2	217.9	1.5
China	0.8	4.7	5.9	7	239	11.62	6.5	288.2	12.6	1.96	1247.5	1458.4	0.5
India	0.4	1.6	4.3	8	153	9.65	5.1	178.1	11.7	2.24	1009.5	1505.7	1.3
Indonesia	0.8	2.1	3.1	20	122	5.80	2.8	27.3	7.4	1.85	206.0	279.7	1.0
Pakistan	0.5	1.3	3.0	12	74	5.78	0.9	12.8	8.6	1.93	137.7	240.3	1.8
Singapore	19.8	46.3	2.7	129	333	2.99	0.4	1.5	4.3	1.11	3.8	5.2	1.0
Sri Lanka	0.8	2.2	3.3	21	161	6.60	0.3	2.6	7.2	1.99	18.5	20.2	0.3
Thailand	1.9	5.4	3.4	57	219	4.29	2.5	12.6	5.1	1.26	59.4	69.2	0.5

Table 3 Continued

Assumptions and Projections of Passenger Car Ownership, 1998–2030

Country	Per capita income (thousands, $US2,000) 1998	2030	Average annual growth rate (%)	Passenger cars per 1,000 people aged 15 or more 1998	2030	Average annual growth rate (%)	Passenger car stock (millions) 1998	2030	Average annual growth rate (%)	Ratio of growth rates: car ownership to per capita income	Population (millions) 1998	2030	Average annual growth rate (%)
Sub-Saharan Africa													
Botswana	2.7	6.9	3.0	36	102	3.31	0.0	0.2	4.9	1.12	1.7	2.4	1.1
Burundi	0.1	0.2	1.6	2	9	4.73	0.0	0.1	8.4	3.02	6.5	17.2	3.1
Cameroon	0.7	1.3	2.3	13	26	2.21	0.1	0.5	4.9	0.97	15.1	26.9	1.8
Ethiopia	0.1	0.3	2.5	2	3	1.42	0.1	0.3	4.6	0.56	65.8	137.1	2.3
Kenya	0.4	0.8	1.9	14	18	0.77	0.2	0.7	3.7	0.41	29.7	62.8	2.4
Mozambique	0.2	0.5	3.0	5	42	6.57	0.1	0.8	9.0	2.16	17.3	31.1	1.9
Sierra Leone	0.2	0.4	2.9	8	11	1.15	0.0	0.1	3.9	0.39	4.4	9.6	2.5
South Africa	3.0	6.4	2.4	128	186	1.16	3.5	7.2	2.3	0.48	43.8	53.2	0.6
Swaziland	1.3	2.5	2.0	62	97	1.39	0.0	0.1	2.8	0.71	1.0	1.3	0.7
Uganda	0.2	0.5	2.4	4	21	5.30	0.0	0.8	9.1	2.23	23.3	61.5	3.1
Zimbabwe	0.7	0.8	0.4	75	84	0.37	0.5	1.0	2.0	1.02	12.3	16.6	0.9
non-OECD Eastern Europe													
Bulgaria	1.4	7.0	5.1	263	759	3.37	1.8	4.2	2.6	0.66	8.1	6.2	−0.8
Estonia	3.6	20.0	5.5	402	930	2.65	0.5	1.0	2.4	0.49	1.4	1.2	−0.4
Latvia	2.9	17.1	5.7	248	790	3.69	0.5	1.4	3.3	0.65	2.4	2.0	−0.6

Figure 3
Projections of Car Stocks by Major Region



(+173 million), the United States (+95 million),[11] Korea (+29 million), Japan (+28 million) and Indonesia (+25 million).

Nonetheless, as can be seen in Figure 3, the assumptions underlying the projections imply almost a tripling in the total car stock for the sixty-four countries that we consider, from 529 million passenger cars in 1998 to 1,420 million of passenger cars in 2030.[12] Given the actual level of technology and the expected innovations, such an increase seems hardly sustainable in terms of CO_2 emissions and motor fuel demand unless consumers change their driving habits.

It is not easy to compare our projections with those from other sources because of differences in starting date, geographical coverage, and type of vehicle covered. Nonetheless, Table 4 shows for some regions the projected ratios of ownership growth to per capita income growth that synthesise our results (second column) and the results of Dargay *et al.* (DGS), the IEA, and the Sustainable Mobility Project (SMP).[13]

[11] Although the USA is the most mature market, it will remain one of the most dynamic markets because of the sustained population growth.

[12] If we do not consider an increase in the 'cost/utility' ratio as per capita income rises (equation (20)), the total car stock quadruples, to 1,900 million passenger cars, because of the low actual income threshold levels in most of the developing countries. Our approximation of the relationship between the income threshold and per capita income is approximate, but it should provide a better idea of what might happen in the future.

[13] As they are reported in Dargay *et al.* (2007).

Table 4
Comparison of Projected Ratios of Ownership Growth to Per capita Income Growth

	1998–2030 Passenger vehicles	DGS (2007), 2002–30 Total vehicles	IEA (2004), 2002–30 Total vehicles	IEA (2006), 2004–30 Total vehicles	SMP (2004), 2000–30 Light duty vehicles
OECD	0.57	0.42	0.57		0.40
non-OECD	1.84	1.61	1.12		1.13
China	2.03	2.20	1.38	1.96	1.42
India	2.39	1.98	0.39	2.25	1.23
World	1.13*	0.94	0.61	0.86	0.59

* Sixty-four countries.

Overall, our projections indicate a more elastic demand for passenger cars than those of the other sources.[14] Dargay *et al.* explain that the relatively low ratios projected by the SMP result from the assumption of low income-elasticity of ownership. The lack of information about the model used by the IEA prevents the reason for the discrepancy with their projections from being explained. The divergence is very important for non-OECD countries and the world in the 2004 edition. The projections seem closer in the 2006 edition but a closer look indicates that they are not so: the IEA project that the light-duty vehicle stock should climb to 100 million in China (our value is 288 million) and 56 million in India (our value is 178 million) in 2030. Its projected number of light-duty vehicles in use world-wide is close to the passenger car stock that we project for our sample (which excludes Russia and Iran, notably). Yet, these projections rely on almost the same assumptions as ours for income and population growth. The gap between our values and those of Dargay *et al.*, comes mainly from different data sources (as discussed in Lescaroux and Rech) and from the different S-shaped curves used: the Gompertz function implies a lower income-elasticity at low levels of per capita income, which implies a lower ratio for many non-OECD countries (it is nonetheless difficult to compare them as they do not refer to the same stock of vehicles). Similarly, the IMF (2005) projects a growth in total vehicle stock which seems rather weak compared with our projections. Yet, again, its assumptions for income growth are very close to ours (its average world growth rate is 3.6 per cent over 2003–30 and our value is 3.7 per cent over 2005–30)

[14] For the sake of comparison, ownership rates were expressed as a fraction of total population (and not the population aged 15 or more) in this table. Consequently, the reported values do not correspond to the values in Table 3.

and we use the same assumptions for population growth. For most countries, the total vehicle stock that it projects is only slightly greater than the passenger car stock that we project (they estimate that the world total vehicle stock should reach approximately 1,660 million by 2030 and our projections indicate that the passenger car stock for a subset excluding, notably, Russia and Iran should reach 1,420 million by 2030). These low projections of transportation demand probably result from the calibration of the saturation level at 850 vehicles per 1,000 people (as against 1,000 passenger cars per 1,000 people aged 15 or more, according to our estimates) and from the *a priori* assumption of low income-elasticities at low levels of per capita income.

Moreover, our projections already include (at least partially, on the basis of recent experience) the rise in car purchase cost usually associated with a rise in standards of living and they neglect the possibility that automakers could propose cheap cars designed for developing countries. This would accelerate the automobile's diffusion in those countries. The commercialisation at a large scale of low-priced cars such as the one manufactured by Tata would cause a break in the relationship between the 'cost/utility' ratio and per capita income. Somehow artificially, we tried to simulate the impact of such a process for China and India by assuming that their β_i's would decrease smoothly until 2030, when they would be 1 per cent smaller than now. For these two countries alone, the passenger car stocks would reach 302 and 193 million, respectively, over the projection sample. This would imply an increment of approximately 29 million vehicles compared to the reference scenario (that is, almost the size of the Italian car stock in 1998).

Another issue that could affect the development of private transportation worldwide and especially in China is the evolution of income distribution. As a consequence of the very fast economic development in the coastal region, it is actually very unegalitarian. According to some sociologists (Todd and Garrioch, 1989, for example), this seems to be at odds with the nature of the Chinese society. If we were to assume a linear decrease of the Gini coefficient to 0.35 (which is close to the value of the coefficient at the beginning of the 1990s) in 2030, the car stock would be greater by about 20 million. This simulation is purely illustrative and its sole purpose is to highlight the strong influence of income inequality. This point deserves a more systematic analysis which requires the relationship between the mean and the standard deviation of the income distribution to be considered.

Therefore, our modelling of the passenger car stock implies a growth in vehicle ownership (and hence in motor fuel demand if consumers do not adjust their behaviour by buying more efficient vehicles and by driving less) stronger than the growth projected by other sources. The gap is not dramatic in the reference scenario but the alternative simulations suggest that demand could be accelerated by many factors. This raises concerns about the balance between oil supply and demand and about the related CO_2 emissions.

It seems accordingly that both a high rate of technical progress and important sociological changes will be needed to 'meet the challenges of sustainability'. These evolutions could be encouraged now by policies aimed at improving fuel efficiency and reducing the demand for private transportation; otherwise, the adjustment should come soon from the market in the form of a further gasoline price surge.

6.0 Conclusion

In this paper, we have been able to build a formal model of passenger car ownership rate and to propose a practical approximation which works remarkably well in explaining past in-sample evolutions and meets in the long term the desired theoretical properties of the car ownership rate.

Given the distribution of income in a particular population, the formal model explains the car ownership rate as a function of the average per capita income level and a country-specific indicator of the 'cost/utility' ratio of owning a car. When applied over the 1986–98 period to a set of sixty-four countries, the model is able to reproduce past changes in ownership rates. As we do not consider only the average per capita income (as other models do) but also the standard deviation of the income distribution, the model can explain differences in the pattern of growth between egalitarian countries (such as the Scandinavian countries) and less egalitarian countries (such as South American countries), or breaks in the trajectory followed by a particular country when changes occur in the distribution of income (such as in the transition economies). In the present form of the model, the indicators of the 'cost/utility' ratio are estimated, country-specific parameters. It would be desirable to express these parameters as a function of observable indicators in order to evaluate the effects of alternative transportation policies. As a first step in this direction, we showed that the ratios are strongly correlated with car purchase costs and population densities.

We used the estimated model to perform projections to the year 2030. The reference scenario assumes that the relationship between the 'cost/utility' ratio and average per capita income observed in the near past still holds into the future. We project that the total car stock should be about three times greater in 2030 than it was in 1998 (1,420 million passenger cars, excluding, notably, Russia and Iran), but the growth should not be uniform. For example, the Chinese and Indian car stocks should be forty-five times and thirty-five times greater, respectively, than they are and China and India should become the second and the third countries, respectively, for the number of passenger cars. On the other hand, the growth of the car stock in the OECD should come mainly from the USA, and it should be triggered there by population growth only.

We performed some alternative projections to highlight the effects of some socio-economic evolutions already in the tube, such as the diffusion of cheap cars in developing countries, or likely to occur in the coming decades, such as an equalisation of the income distribution in China. These evolutions would lead, more or less, to a stronger growth of the car stock. In particular, a relative fall in car purchase cost would considerably accelerate the diffusion of automobiles in middle-income populations.

Nonetheless, considering the actual levels of fuel consumption per vehicle, the projected growth of the total car stock seems hardly sustainable in terms of oil demand and related CO_2 emissions even in the reference case: in the absence of incentives by the governments that encourage important technical evolutions improving fuel efficiency and sociological evolutions reducing vehicle usage, the adjustment should come from the market in the form of a further gasoline price surge which would cause the same effects.

This work should be pursued by modelling explicitly the 'cost/utility' ratio as a function of economic and geographic factors such as population density or car purchase costs and we are actually working in this direction; one of the main difficulties is to collect the data for some of these variables. It should also be noted that the model proposed here to show the car ownership rate could also be used to model the diffusion in a population of almost any durable good and a variety of services, from televisions and refrigerators to personal computers and internet access. For that matter, a link could easily be drawn from the succession of various S-shaped diffusion curves to Engel's laws, which state how the composition of household budgets evolve as their income rises.

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Appendices

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