A CROSS-COUNTRY COMPARISON OF HOUSEHOLD CAR OWNERSHIP
– A Cohort Analysis –

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This paper analyses household car ownership behaviours in seven countries characterised by different economic and cultural contexts: France, Italy, Japan, the Netherlands, Poland, UK and USA. An Age-Cohort-Period model is used to account for the effects of the stage in life cycle, of a differentiated access of successive generations to the car, and of the impact of the current economic context.

It appears that differences between countries and regions can be attributed to three main factors: the history of car ownership development, the level of economic development, and population density. Thus, the USA, where car diffusion started earlier than elsewhere (before World War II), seems closer to saturation than the other countries. Indeed, the differences between cohorts are narrower and the sensitivity to changes in economic factors is weaker in the case of American households. As shown by long-term projections, this proximity to saturation should result in a lower growth of the car fleet in the USA compared to the rest of the countries considered. Besides, unlike the other countries, this evolution would essentially be due to an increase in the number of households.

At the other extreme, Poland has the lowest car ownership levels, but these are continuing to grow and the gaps between successive generations do not stabilise, reflecting a catching up phenomenon after the period of transition from a rationed economy to a free market economy. The influence of economic affluence is also evidenced by a comparison between two Italian macro-regions: car ownership rates are lower, and income sensitivity is stronger, in the South and the Islands than in the North and the Centre. Although car diffusion reduced the gap between the two regions in terms of the proportion of motorised households, at least for the more recent generations, the South and the Islands are still lagging in terms of the level of car ownership per household. Closing this gap should depend on the evolution of incomes.

Finally, the more densely populated countries (Japan and the Netherlands) record lower car ownership levels than the other industrialised countries.

Key Words: Household car ownership, Age-Cohort-Period model, Cross-country comparison, Long term projections

Men resemble the times more than they do their fathers.
Arab proverb

1. INTRODUCTION

The development of the automobile, favoured by the growth of incomes and improvements in the quality of road networks, has given a formidable impulse to personal mobility. By improving accessibility to almost every place in terms of money costs as well as time, the car permitted the lengthening of the distance between the home and places of diverse activities. Urban sprawl, in turn, combined with the dynamics of the labour market (e.g. the increasing share of women at work), increased the need for additional vehicles in a household. Thus, the car became the transport mode with the strongest growth in most countries: first in North America (between the two World Wars), then in Western Europe (after World War II), and nowadays in Central and Eastern Europe (since the economic transition) as well as in South-East Asia and emerging countries. This evolution resulted in a steady growth of national car fleets and in the dominant share of the automobile as compared to other passenger transport modes.

In this paper, we analyse household car ownership behaviours in seven countries: France, Italy, Japan, the Netherlands, Poland, the United Kingdom and the United States. This allows us to appreciate the evolution of behaviours in contexts that are economically and culturally diverse and characterised by different historical developments of car ownership. The case of Poland permits con-
trasting a less developed economy compared to the other countries considered, making a transition from a centrally planned (and rationed) economy to a free market economy. The influence of the level of economic affluence is also examined in the Italian case by comparing two macro-regions, the first being formed of the richer regions of the North and Centre, and the second grouping the South and the Islands (Sicily and Sardinia).

An Age-Cohort-Period model is used to account for the effects of the stage in life cycle, of a differentiated access of successive generations to the car, and of the impact of the current economic context.

The next section presents the methodology. Then, the results of the analysis of the number of cars per household are shown: a comparison at national level as well as between the two Italian macro-regions defined above. In the fourth section, vehicle fleets of four countries are projected, based on the estimated age and cohort effects and on demographic projections (to 2010 or 2020). A summary of the main findings concludes the paper.

2. A DEMOGRAPHIC APPROACH

2.1 Why a demographic approach to car ownership?

Individual motorisation rates (i.e. average numbers of cars per adult) continue to grow in most industrialised countries\(^*\). Such a tendency questions the relevance of a priori saturation thresholds of traditional models of projection based upon extrapolation at an aggregate level of a logistic growth curve, taking inspiration in models of diffusion of epidemics (e.g. Tanner’s work\(^1\)). Saturation thresholds fixed a priori in car ownership forecasting models have regularly been exceeded. This is due to the development of multi-motorisation (urban cars, vans, etc.), particularly in the United States where, on average per household, the number of vehicles exceeded the number of driving license holders in 2001\(^*\). Moreover, even in a period of collapse of the new car market, the lengthening lifetime and holding duration of cars minimises the impact of recession on households’ motorisation level. In France, the average age of a vehicle stabilised at approximately 6 years between 1985 and 1991, and then increased to reach 6.6 years in 1995, 7.1 years in 1999 and 7.3 years in 2002. The mean duration of car holding fluctuated around 3.8 years between 1985 and 1992 and then grew to 4.4 years in 1999 and 4.5 years in 2002\(^3,7\). Not only do the threshold estimates depend on the observation periods used, they may also differ significantly according to the error structure assumed\(^8\). Besides, car ownership growth curves (fraction of motorised households as a function of time) are the result of product diffusion as well as of the influence of economic factors such as the growth of incomes. Statistical decomposition of observed growth curves into the relative contribution of each component proves to be impossible with only time series data\(^9\). Because of their sigmoid form, observed growth curves are frequently interpreted as reflecting a diffusion process such as learning by contagion. In particular, when the curve is logistic it is considered as characterising a “simple epidemic” diffusion, i.e. with no effect of economic factors. Analysing growth curves of several durable goods on a series of cross-sections, Bonus\(^9\) shows that in the presence of diffusion by learning, an asymmetric growth curve is more likely. Yet, the hypothesis underlying a logistic curve is that growth is symmetric, the inflection point taking place “at halfway between the two asymptotes, which correspond respectively to 0 and maximal level S of ownership”\(^10\). Therefore, observation of a logistic curve does not indicate the presence of diffusion by learning but rather its absence.

As to models calibrated on cross-sectional data to estimate long-term relationships, they rely on the hypothesis that the observed data correspond to an equilibrium, i.e. all households have completely adjusted to every change in the factors that are relevant to their behaviour\(^11,1\). This is not the case in practice. It is therefore necessary to study car ownership in a context of historical development, accounting explicitly for the history of automobile diffusion\(^13\).

Most life cycle profiles of car ownership show changes through time, under the combined influence of the replacement of generations and of the evolution of factors linked to the general economic environment such as standards of living, consumer tastes, and supply. Figure 1 shows the evolution of the average number of cars per adult in France, by birth generation of household reference person. The observations relate to the years 1980, 1985, 1990 and 1995. On one hand, one can see the differences in motorisation levels according to age: linking all points pertaining to the same survey year, one obtains what could be interpreted as a motorisation profile over the life cycle (such a profile is shown for 1985 by the bold line). The number of cars per adult increases and

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\(^*\) See, e.g. Demand Descriptors of Passenger Transport, Deliverable D5 of SCENARIOS, a project funded by the European Commission under the Transport RTD Programme of the 4th Framework Programme, October 1997.


\(^3\) For a comprehensive review of car ownership models, see e.g. the survey by de Jong et al.\(^12\).
reaches a maximum when the head of household is aged between 35 and 39 years and then decreases (the decline being faster after the age of 55-59 years). On the other hand, comparison of the motorisation levels of successive cohorts at the same age shows differences that can be explained, at least partly, by a differentiated access to the automobile for the different generations at their respective times.

Hence, the use of aggregate time-series is not relevant, since they do not take into account the heterogeneity across individuals. The use of only one cross-section of individual data is not sufficient either, since the heterogeneity of behaviours over time is not accounted for.

The demographic approach follows successive generations over time. Cohorts are formed by grouping households by period of birth of the head (or reference person). Supported by the “parallelism” of life cycle profiles associated to the different cohorts, an analysis scheme founded on an additive mechanism of the age and generation effects is used. Economic indicators (notably, of income and prices) are introduced in order to identify the effect of the current economic context. This approach has several advantages. Indeed, it accounts for the dynamic heterogeneity of individual behaviours and “endogenises” the process of diffusion. Moreover, it takes into account the influence of economic factors on ownership decisions as well as the effects of demographic changes (replacement of generations, population size and age structure) on the formation of macro-economic quantities (in this case, automobile fleets). Finally, its use for long-term projections rests on quite reliable variables (demographic projections are sufficiently stable).

### 2.2 Three linked dimensions of time

The longitudinal perspective highlights the impact on behaviours of three linked dimensions of time:
- **age**, which indicates the importance of the *stage in life cycle* through the effect of biological change (with age) on needs and aptitudes, of family size and age composition (number of adults, presence or absence of children), of the number of working persons, etc. Different demands and constraints characterise each stage in the life cycle. Members of families at the same stage see their behaviours subject to roughly the same pressures and constraints, so that the variability of behaviours of households located at the same stage tends to be lower than that between different stages.

However, one has to keep in mind that age is an imperfect indicator of stage in life cycle. Individuals (or families) can attain the same stage at different ages: for example, duration of studies, existence and duration of military service, cultural norms and financial resources influence the decisions to get married or to have children. Some individuals will even not pass a particular phase of development, like getting married or having children.

Ryder has shown the high potential of the concept of cohort in understanding change, and advocated its adoption not only in demography (his own discipline) but also in the social and behavioural sciences in general; and
- the period, which reflects the impact of the global socio-economic context (levels of incomes and prices), of supply and of new consumption habits like infatuation for diesel cars or certain types of vehicles (e.g. SUVs or urban cars).

Evaluation of the effect of stage in life cycle furnishes a standard profile indicating the change of motorisation rates with age. Introduction of generation effects allows placing this profile in a historical perspective, taking into account the effects of diffusion linked to the evolution of life styles, of institutional constraints, of consumers’ needs, or of characteristics of supply. Finally, accounting for period effects permits measuring the effects of temporary or permanent changes in the global economic environment on behaviours.

2.3 The Age-Cohort-Period model

This approach requires data describing an element of a household’s (or an individual’s) behaviour (here an indicator of car ownership) and allowing the follow-up of different cohorts over a long enough period. They can be obtained from a panel (refreshed more or less frequently), or more often from a series of independent cross sections by the method of pseudo-panels.\(^{18}\)

Let us note \(y_{c,t}\) a measure of this behaviour (e.g. the number of cars per household) in period \(t\) for households the reference persons of which belong to cohort \(c\) defined by their birth year. An exact relation links an age \(a\) and a cohort \(c\) in a period \(t\):

\[
c = t - a .
\]

The Age-Cohort-Period decomposition is written:

\[
y_{c,t} = \sum_a \alpha_a A(a) + \sum_c \alpha_c C(c) + \sum_t \beta_t P(t) + \varepsilon_{c,t}
\]

where \(A(a)\), \(C(c)\), and \(P(t)\) are dummy variables for age \(a\), cohort \(c\) and period \(t\), respectively, and \(\varepsilon_{c,t}\) is an error term. \(\alpha_a\) and \(\alpha_c\) are the coefficients of the dummy variables for age \(a\) and cohort \(c\), respectively; \(\beta_t\) is the coefficient of the dummy variable for period \(t\). Economic factors can be accounted for explicitly by introducing, instead of period dummies, economic variables (income or total expenditure, and real prices):

\[
y_{c,t} = \sum_a \alpha_a A(a) + \sum_c \alpha_c C(c) + \beta_t \ln \text{INC}(t) + \beta_p \ln \text{PRICE}(t) + \varepsilon_{c,t}
\]

where IN\(C\) is the income variable and PR\(ICE\) is an index of relative price influencing motorisation (purchase cost, of both new and second-hand cars, or total cost). \(\beta_t\) and \(\beta_p\) are the coefficients of the income and price variables, respectively. This semi-logarithmic specification allows accounting for the fact that the sensitivity of car ownership behaviour to income and price variations is likely to diminish as the stock of vehicles owned increases. Indeed, the estimated elasticity of car ownership \(y\) with respect to variable \(x\) in period \(t\) is given by the expression \(\tilde{\eta}_{x,t}(t) = \beta_x / \gamma_x\), where \(\beta_x\) is the estimated coefficient of \(x\) and \(\gamma_x\) is the average car ownership in \(t\). In the tables synthesising the period effects, elasticity estimates pertain to the last observation year for each country.

The exact multicollinearity due to equation (1) makes it impossible to identify all the model’s coefficients without imposing restrictions. A dummy variable is thus dropped during estimation: age dummies cover the life cycle, whereas generation dummies characterise all cohorts except one, noted \(c_0\), which acts as a “reference generation” and with respect to which differences are estimated. Thus, each coefficient \(\alpha\) can be interpreted as a gap between the cohort \(c\) and the “reference generation” \(c_0\). Moreover, the set of age coefficients can be interpreted as the life cycle motorisation profile for the “reference generation”.

Introducing economic variables, we obtain a fixed effects model, with the particularity that the data are intrinsically “incomplete”, the different cohorts not being observed at the same ages at the same periods. A drawback of the fixed effects specification is that the accuracy of the estimated coefficients of these variables (at individual level) is often poor. The reason is that the sole variability accounted for in their estimation is that which remains after removing the variability between individuals and the variability between ages.\(^{19}\) Yet, income is highly correlated with age and the differences between generations can also be large. Furthermore, needs along the life cycle are heterogeneous, as illustrated by Table 1 in the case of French households.

Among young households, car ownership grows faster than income. It also increases rapidly when the head of household is about 50 (grown-up children acquiring their first car while they still live with their parents). For households with the oldest heads, the number of cars per adult decreased during a period where income per consumption unit grew because of real increase of retirement pensions.

The income variables are therefore introduced at the aggregate level. This comes down to assume that incomes grow at the same rate for all cohorts (national average progression). So, differences between cohorts appear only through the intercept (age and generation effects).
A CROSS-COUNTRY COMPARISON OF HOUSEHOLD CAR OWNERSHIP – A Cohort Analysis –

A. BERRI

Nevertheless, the use of an aggregate indicator is consistent with the interpretation of period effects as those of the global economic context which households face. Moreover, in carrying out projections, hypotheses about the evolution of economic factors (income growth and price changes) relate to aggregate quantities (in general).

### 3. A COMPARATIVE ANALYSIS OF CAR OWNERSHIP BEHAVIOURS

Most of the data used come from national household expenditure surveys: each year from 1977 to 1994 for the United Kingdom; each year from 1985 to 1994 and 1996 for Italy; in 1979, 1984, 1989 and 1994 for Japan; in 1987-90, 1992 and 1994-97 for Poland; for the USA**, from 1980 to 1989, except 1982-83 (where only urban households were surveyed) and 1986 for which the data are incomplete. In the case of French households, the data are from the Consumer Confidence Survey (Enquête de Conjuncture Auprès des Ménages) of INSEE, 1977-94.

#### Table 1 Variations of income and motorisation by generation in France (% 92-94/77-79)

<table>
<thead>
<tr>
<th>Generation of birth</th>
<th>Age*</th>
<th>Motorisation (cars/adult)</th>
<th>Income/CU** (1980 prices)</th>
<th>Apparent elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>From</td>
<td>To</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1901-05</td>
<td>75</td>
<td>90</td>
<td>-33%</td>
<td>+1%</td>
</tr>
<tr>
<td>1906-10</td>
<td>70</td>
<td>85</td>
<td>-16%</td>
<td>+22%</td>
</tr>
<tr>
<td>1911-15</td>
<td>65</td>
<td>80</td>
<td>-8%</td>
<td>+18%</td>
</tr>
<tr>
<td>1916-20</td>
<td>60</td>
<td>75</td>
<td>+3%</td>
<td>+12%</td>
</tr>
<tr>
<td>1921-25</td>
<td>55</td>
<td>70</td>
<td>+9%</td>
<td>+10%</td>
</tr>
<tr>
<td>1926-30</td>
<td>50</td>
<td>65</td>
<td>+17%</td>
<td>+21%</td>
</tr>
<tr>
<td>1931-35</td>
<td>45</td>
<td>60</td>
<td>+20%</td>
<td>+33%</td>
</tr>
<tr>
<td>1936-40</td>
<td>40</td>
<td>55</td>
<td>+8%</td>
<td>+33%</td>
</tr>
<tr>
<td>1941-45</td>
<td>35</td>
<td>50</td>
<td>+1%</td>
<td>+21%</td>
</tr>
<tr>
<td>1946-50</td>
<td>30</td>
<td>45</td>
<td>+4%</td>
<td>+8%</td>
</tr>
<tr>
<td>1951-55</td>
<td>25</td>
<td>40</td>
<td>+28%</td>
<td>+3%</td>
</tr>
<tr>
<td>1956-60</td>
<td>20</td>
<td>35</td>
<td>+93%</td>
<td>+18%</td>
</tr>
</tbody>
</table>

All households            +32%                       +17%                       1.88

Source: Based on Table 1 in Berri and Madre20. Calculations on data from the Consumer Confidence Survey (Enquête de Conjuncture Auprès des Ménages) of INSEE, 1977-94.

* For each birth cohort, middle of age range in the observation periods 1977-79 and 1992-94.

**Consumption Unit (Oxford scale: 1 for household head, 0.7 for each other person aged 14 years or more, 0.5 for each child of less than 14 years).

Note: The numbers in parentheses are either of “wrong” sign or too large, because the numbers of observations in the corresponding cells are too small. This is the case of the oldest and youngest cohorts. The large variations in motorisation may be experienced by only a few observed households, but are not necessarily due to the corresponding variations in income. For instance, a reduction in car ownership may occur following a decrease in family size or because of an inability to drive.

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* Material from the Family Expenditure Survey is Crown copyright; has been provided by the Central Statistical Office (CSO) through the Economic and Social Research Council (ESRC) Data Archive; and has been used by permission. Neither the CSO nor the ESRC Data Archive bears any responsibility for the analysis or interpretation of the data reported here.

** The US data used in this study were made available by the Inter-university Consortium for Political and Social Research. The Consumer Expenditure Survey was conducted by the U.S. Department of Labor, Bureau of Labor Statistics (BLS). The data was reorganized for household-level analysis by Julie A. Nelson, University of California, Davis. Neither the original source or collectors of the data, nor the organizer or distributors of the data bear any responsibility for the analyses or interpretations presented here.

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The history of automobile diffusion is different in
LONG-TERM DYNAMICS (PART 2)

Fig. 2 Number of cars per household – USA (1980, 1984 and 1989)

Fig. 3 Number of cars per household – Netherlands (1985, 1990 and 1995)

Fig. 4 Number of cars per household – Japan (1979, 1984, 1989 and 1994)
Europe compared to North America, and in capital regions in comparison with the provinces. For instance, in the early 1950’s, the level of motorisation in Québec was three times as high as it was in France.

3.2 A cross-country comparison

Because data are not as detailed for Japan and the Netherlands as for the other countries, the generations were grouped in such a way that comparisons would be possible. Thus, the oldest generation includes all households whose heads were born before 1910. Likewise, the last age group embodies households whose heads were aged 75 years or more. Households the heads of which are less than 20 years old were not included in the analysis. They do not represent a complete and homogeneous cohort, owing to the fact that children leave the home of their parents at different ages, depending on the period, the social group, the duration of schooling, and the job market. Age and cohort effects are estimated by means of dummy variables by five-year brackets. The reference generation is that born between 1936 and 1940.

The effect of (real) incomes is accounted for through total expenditure per capita for France and Japan, total expenditure per household for Italy and the United Kingdom, household final consumption per capita for Poland, and for the United States through disposable income per capita (in previous year, car ownership being observed during the first quarter of each year). The price variable is a relative index of car prices, whether new or second-hand. For Japan, only the income factor is taken into account. Neither income nor price variables were introduced in the case of the Netherlands, the number of observation points being too small to estimate their effects.

The model is estimated by least squares. The heteroskedasticity of errors due to variations in the cell sizes is corrected for by weighting the data by \( \sqrt{n_c} \), where \( n_c \) is the number of observations for cohort \( c \), except in the cases of Japan and the Netherlands where the cell sizes are unavailable.

Logit regression in the case of Poland

In the case of Polish households, the number of cars per household is almost identical to the proportion of motorised households because of the low rate of multi-motorisation (in general, less than 3%). Use of either of the two indicators as a dependent variable gives rise to erroneous estimates of the motorisation rate by age for some cohorts. Thus, the share of motorised households can be negative at some ages (this is the case for the oldest generations) or greater than 1 (mainly for the more recent cohorts)! This is due to the large gaps observed between the different generations, with very low, if not zero, motorisation rates for the oldest ones. Gaps with respect to these old cohorts are widening with the strong progression of car ownership after the period of transition (Figs. 6 and 7).

To palliate this deficiency of the linear probability model (prediction of probabilities or proportions outside \([0, 1]\)), a logit transformation is operated on the dependent variable:
LONG-TERM DYNAMICS (PART2)

Coding tilts the tails of the distribution so as to show a significant variation among the small or the large proportions much better than can allow the sole examination of the proportions themselves. Indeed, whereas a proportion can take values between 0 and 1, \( L \) takes values between \(-\infty\) and \(+\infty\), where \( L = 0 \) (i.e. \( y/(1-y) = 1 \)) corresponds to a proportion equal to 0.5. At the “middle” of the distribution (proportions around 0.5), proportions and logits show similar results.22

A drawback of the transformation resides in the exclusion of extreme values (0 and 1). Among the 635 observations available for estimation over the period under study, 84 display a proportion of motorised households (and hence a number of cars per household) equal to zero. Restricting the analysis to ages between 20 and 90 years, we are left with 528 observations for estimation.

The error term is again heteroskedastic, not only due to changing cell sizes, but also because inside each group \( c \) the number of “successes” (e.g. number of motorised households) follows a binomial distribution for which \( y_c \) depends on the values of explanatory variables.22 The variance of error \( \varepsilon_c \) is approximately equal to

\[
V(\varepsilon_c) = \frac{1}{n_c y_c(1-y_c)},
\]

where \( n_c \) is the number of observations of group \( c \) and \( y_c \) is the probability of “success” (e.g. of being motorised) for a member of the group.23 If the size \( n_c \) is sufficiently large, the binomial distribution can be approximated by the normal distribution as follows:22

\[
\varepsilon_c \sim N \left( 0, \frac{1}{n_c Y_c(1-y_c)} \right).
\]

The model is estimated by least squares and the heteroskedasticity of errors corrected for by weighting the data by \( \sqrt{n_c y_c(1-y_c)} \), where \( n_c \) is the number of observations for cohort \( c \) and \( y_c \) is the observed proportion. The car ownership age profile simulated for a given cohort is obtained by an anti-logarithmic transformation of the logits of the motorisation indicator by age estimated for this cohort:

\[
y_c = \frac{1}{1 + \exp(-L_c)},
\]

where \( L_c \) is the logit of \( y_c \).

In the case of a logit transformation of the dependent variable, the elasticity of car ownership \( y \) with respect to variable \( x \) in period \( t \) is estimated by \( \frac{\hat{\beta}_x(t)}{(1-y_t)\hat{\beta}_y} \), where \( \hat{\beta}_x \) is the estimated coefficient of \( x \) and \( \hat{\beta}_y \) is the average car ownership in \( t \). Again, the sensitivity to changes in the explanatory variable diminishes as the average car ownership level increases.

The figures represented on the following graphs are the levels of car ownership simulated by the model, i.e. obtained from the estimated coefficients of age and cohort dummies. To save space, this is illustrated in Table 2 with estimation results for one country, namely Poland.

Let us first consider, on the example of the generation 1936-40, how the number of cars per household varies along the life cycle (Fig. 8).

At all stages of the life cycle, this indicator is higher (respectively, lower) in the US (respectively, in Poland) than in the other countries. Apart from Poland, the lowest motorisation levels are observed in Japan for young households and in the Netherlands for old ones; France and the UK show very close patterns. In all cases, the average number of cars increases at the beginning of life...
cycle, reaches a maximum and then declines. The maximum is attained when the age of household head is 45 to 49 years in France, the UK and USA, about 55 years in Italy, the Netherlands and Poland, and around 60 years in Japan. This maximum is about 1.7 cars per household in the USA, 1.4 in Italy, 1.3 in the UK and Japan, 1.2 in France, 1.1 in the Netherlands, and slightly less than 0.4 in Poland. At old age, the number of cars per household is about the same in France, Japan and the UK (about 0.8 when the head is 70-74 years old and 0.7 when aged 75 years and more).

The low car ownership levels recorded by the Netherlands and Japan compared to the other industrialised countries may partly be attributed to their higher population density. Indeed, the number of inhabitants per km$^2$ in 1995 was as high as 456 in the Netherlands and 333 in Japan, compared with 243 in the UK, 195 in Italy, 127 in Poland, 106 in France, and only 29 in USA. The impact of population density operates through the availability of alternatives to the car, notably public transport, in densely populated urban areas. Moreover, congestion

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Table 2  Age and cohort effects – Poland

<table>
<thead>
<tr>
<th>Age</th>
<th>Coeff.</th>
<th>Std error</th>
<th>Cars per household (cohort 1936-40)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-24</td>
<td>-2.469</td>
<td>0.136</td>
<td>0.078</td>
</tr>
<tr>
<td>25-29</td>
<td>-1.914</td>
<td>0.119</td>
<td>0.129</td>
</tr>
<tr>
<td>30-34</td>
<td>-1.397</td>
<td>0.105</td>
<td>0.198</td>
</tr>
<tr>
<td>35-39</td>
<td>-1.038</td>
<td>0.092</td>
<td>0.262</td>
</tr>
<tr>
<td>40-44</td>
<td>-0.781</td>
<td>0.079</td>
<td>0.314</td>
</tr>
<tr>
<td>45-49</td>
<td>-0.629</td>
<td>0.063</td>
<td>0.348</td>
</tr>
<tr>
<td>50-54</td>
<td>-0.483</td>
<td>0.046</td>
<td>0.381</td>
</tr>
<tr>
<td>55-59</td>
<td>-0.470</td>
<td>0.047</td>
<td>0.385</td>
</tr>
<tr>
<td>60-64</td>
<td>-0.498</td>
<td>0.066</td>
<td>0.378</td>
</tr>
<tr>
<td>65-69</td>
<td>-0.704</td>
<td>0.083</td>
<td>0.331</td>
</tr>
<tr>
<td>70-74</td>
<td>-0.854</td>
<td>0.107</td>
<td>0.299</td>
</tr>
<tr>
<td>75+</td>
<td>-0.954</td>
<td>0.138</td>
<td>0.278</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cohort</th>
<th>Coeff.</th>
<th>Std error</th>
<th>Cars per household at age 35-39**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1910</td>
<td>-1.891</td>
<td>0.170</td>
<td>0.051</td>
</tr>
<tr>
<td>1911-15</td>
<td>-1.878</td>
<td>0.150</td>
<td>0.051</td>
</tr>
<tr>
<td>1916-20</td>
<td>-1.622</td>
<td>0.123</td>
<td>0.065</td>
</tr>
<tr>
<td>1921-25</td>
<td>-1.099</td>
<td>0.095</td>
<td>0.106</td>
</tr>
<tr>
<td>1926-30</td>
<td>-0.635</td>
<td>0.073</td>
<td>0.158</td>
</tr>
<tr>
<td>1931-35</td>
<td>-0.285</td>
<td>0.055</td>
<td>0.210</td>
</tr>
<tr>
<td>1936-40</td>
<td>0</td>
<td></td>
<td>0.262</td>
</tr>
</tbody>
</table>


* In the case of a logit transformation, the simulated car ownership age profile for the reference cohort is obtained by applying equation (7) to the age coefficients. This profile is represented in Figure 8.

** For each cohort, the simulated car ownership level at the age of 35-39 is obtained by adding its coefficient (set to zero for the reference cohort) and the coefficient of the dummy variable for age 35-39, and applying equation (7). The results are represented in Figure 9.

---

Fig. 8  Number of cars per household along the life cycle: generation 1936-40

---

The corresponding figures in 1985 are as follows: 427 for the Netherlands, 321 for Japan, 235 for the UK, 192 for Italy, 122 for Poland, 100 for France, and 26 for USA.
problems in these areas may lead to lower car ownership and use. This effect is evidenced in the case of homogeneous French zones, defined by the population size of the urban area and distance from the centre of the urban area\textsuperscript{25-26}. Car ownership and use are lower in densely populated urban centres than in peripheral and rural zones. Differences in behaviour appear through demographic characteristics (age and cohort) as well as the impact of economic factors.

Gaps between generations can be seen from their motorisation levels simulated by the model for the same age (35-39), at different points in time (Fig. 9).

As noted in the examples of Paris and Montreal\textsuperscript{27}, there seems to be a generation with maximum motorisation rates in almost all the countries under review: at the same age, those born after 1950 have fewer cars in the UK and in France, while in Japan there is almost no difference between generations born after 1955. As one could expect, the most motorised generation in USA was born earlier (in the 1930s). Compared to this most motorised generation, the cohort born during the second half of the 1960s has at its disposal 0.48 car less in USA\textsuperscript{*}, 0.17 less in France, and 0.1 less in the UK. The gap between the most motorised generation and the generations born at the beginning of the century is larger than the gap between recent cohorts (the difference is less marked in the US where car ownership developed 20 years earlier than in Western Europe). The low motorisation level of young generations as compared to older cohorts, shown in the cases of France, Italy, UK and USA, may be explained by, notably, the lengthening of duration of studies or of unemployment (e.g. difficulty to find a first job after completion of studies). The case of Poland is different because car ownership developed much later (in the 1990s) than in the other countries. On that account, the number of cars per household is still higher among new generations.

Concerning period effects, total expenditure elasticity is much lower in USA (0.15) and Japan (0.26) than in France and Italy (0.42), Poland (0.46) or UK (0.58). Sensitivity to variations in purchase prices of vehicles is higher in Italy than in the other countries (Table 3). As mentioned above, income and price elasticities are likely to weaken as the level of motorisation increases. This is illustrated in the case of Poland which experienced a rapid development of car ownership after the period of transition: the number of cars per household increased from 0.24 in 1987 to 0.31 in 1992 and 0.43 in 1996. The income elasticity decreased from 0.61 in 1987 to 0.55 in 1992 and 0.46 in 1996. Likewise, the purchase price elasticity decreased in absolute value over the period (-0.26 in 1987, -0.24 in 1992 and -0.20 in 1996).

3.3 A comparison between two Italian macro-regions

Italian regions display different levels of economic development and wealth, particularly between the North and the South\textsuperscript{28-29}. Thus, the gross domestic product of the North represents more than twice that of the South (€542 billion against €237 billion, in 1996), whereas the gap in terms of population between the two regions is narrower (25.834 million against 20.850 million as of 1\textsuperscript{st} January 2001). The Centre region shows an intermediate...
Table 3  Income and price effects

<table>
<thead>
<tr>
<th></th>
<th>Adjusted R²</th>
<th>Total expenditure</th>
<th>Purchase price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coeff.</td>
<td>Std. deviation</td>
<td>Elasticity</td>
</tr>
<tr>
<td>France</td>
<td>0.948</td>
<td>0.462</td>
<td>0.055</td>
</tr>
<tr>
<td>Italy</td>
<td>0.976</td>
<td>0.464</td>
<td>0.076</td>
</tr>
<tr>
<td>Poland</td>
<td>0.916</td>
<td>0.795</td>
<td>0.125</td>
</tr>
<tr>
<td>UK</td>
<td>0.934</td>
<td>0.562</td>
<td>0.075</td>
</tr>
<tr>
<td>Japan</td>
<td>0.979</td>
<td>0.280</td>
<td>0.104</td>
</tr>
<tr>
<td>USA</td>
<td>0.826</td>
<td>0.187</td>
<td>0.194</td>
</tr>
</tbody>
</table>

Notes: (1) The adjusted R² is that of the regression including an intercept.
(2) Elasticities are estimated for the last observation period (1989 in the case of USA, 1994 for France, Japan and UK, and 1996 for Italy and Poland).
(3) 95% confidence intervals for elasticities are given between square brackets. Only one bound of an interval is mentioned if the other bound presents a wrong sign (given the accuracy of the estimate).
(4) For USA, the period effects estimates are of poor accuracy, and hence can show a wrong sign (indicated by the symbol **).
(5) In the case of Poland, the coefficients are those of a regression in which the dependent variable is a transformation of the motorisation indicator. But, the elasticity is that of the indicator itself.

Fig. 10 Number of cars per household along the life cycle: generation 1936-40 – Italian regions

The unemployment rate is much higher in the South (in 2000, 21.0% to compare with 4.7% in the North and 8.3% in the Centre).

These differences are likely to induce disparities between regions in terms of household car ownership. Comparison of two macro-regions brings to light differences in terms of level of motorisation as well as its temporal diffusion with the replacement of generations. The first macro-region consists of the North and the Centre of the country, and the second group is the South and the Islands (Sicily and Sardinia).

As shown by the example of the generation 1936-40, the number of cars per household is higher in the North and the Centre than in the South irrespective of the age of the reference person (Fig. 10). The gap is maximal between 50 and 60 years. This is also the age at which car ownership is the highest for households of the two regions. Since car ownership in the South and the Islands culminates at 1.1 car per household, the difference is essentially due to the extent of multi-motorisation. Besides the level of income and the number of driving license holders, the differences in terms of multi-motorisation can be explained to a large extent by differences in the number of working persons per household. Indeed, although activity rates (ratio of the working force to the population aged 15 years or more) of men are close, the rate of women is lower in the South as compared to the North and the Centre²⁸.

Whether in the north or in the south, the generations born after 1945 do not display differences of motorisation at the same age (Fig. 11). However, the gap between

Fig. 11 Generation gaps: number of cars per household at 35-39 years – Italian regions

²⁸ In 2000, the activity rates of women were of 40.8% in the North, 37.3% in the Centre, and only 28.4% in the South. Those of men were of 62.9% in the North, 60.5% in the Centre, and 60.4% in the South.
households of the two macro-regions does not shrink among the young cohorts, as observed in the case of the percentage of motorised households. This persistent gap is attributable to differences in multi-motorisation.

Although car diffusion in the South and the Islands allowed reducing the gap from the North and the Centre in terms of the proportion of motorised households, at least among the most recent generations, there is still scope for progression in levels of motorisation per household. This progression should depend on the evolution of incomes. As a matter of fact, households living in the South and the Islands are more sensitive to changes in income than those of the North and Centre (Table 4). Thus, the elasticity is 0.5 against 0.3 for the number of cars per household. Sensitivity to vehicle prices is of the same order of magnitude in the two parts of the country (-0.5).

4. Long term projections of car fleets

Based on the estimations presented above, car fleets were projected to the years 2010 and 2020. We present the results for the countries for which projections of the household population were available when these calculations were made for the SCENES project: until 2010 for Japan and the USA, and until 2020 for France and the Netherlands. Here, we confine ourselves to projections based solely on demographic effects (i.e. based on models including only age and cohort dummies), because it has not been possible to consider alternative hypotheses of evolution of economic variables for all the countries.

4.1 Long term projection using the demographic approach

The demographic approach provides us with a tool for long term projections of the car fleet that is both flexible and robust, in that it avoids fixing saturation thresholds, is able to account for the effects of economic as well as demographic factors, and utilises quite reliable variables (population projections).

The projection procedure relies on:

- the estimation of a standard profile of automobile ownership along the life cycle, and its projection for each of the successive cohorts, on the basis of the effects of age and generation and according to scenarios of evolution of the economic factors considered; and

- the projection of the population (of individuals or households) in levels and in structure by age, allowing to account for purely demographic phenomena like ageing which is foreseeable in most industrialised countries.

Thus, as shown by Table 5, a general characteristic of the expected evolutions in the four countries considered is the decrease of the share of the young population (less than 40 years old) and the increase of the old population (60 years and older). The same tendency would be at work as to the structure of the household population by age of the head, as shown by the following graph in the case of the Netherlands (Fig.12).

4.2 Car fleet projections

For each projection year, the number of cars per household is estimated for each age group (of reference person), and then combined with the corresponding number of households to obtain the fleet. Based on the homogenisation of behaviours among recent cohorts (more and more narrow gaps), it is assumed that the profile of the last observed cohort (in the 1960’s) applies for the following generations.

Figure 13 shows the age motorisation profiles for Dutch households (one point every five years from 1985 to 2020). Only cohorts for which there are at least two observations are represented. The observed points (at

<table>
<thead>
<tr>
<th></th>
<th>Adj. R²</th>
<th>Total expenditure</th>
<th>Purchase price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coef.</td>
<td>Std. dev.</td>
<td>Coef.</td>
</tr>
<tr>
<td>North &amp; Centre</td>
<td>0.967</td>
<td>0.328</td>
<td>-0.610</td>
</tr>
<tr>
<td>South &amp; Islands</td>
<td>0.961</td>
<td>0.508</td>
<td>-0.501</td>
</tr>
</tbody>
</table>


Notes: (1) The adjusted R² is that of the regression including an intercept.
(2) Elasticities are estimated for the last observation period (1996).
(3) 95% confidence intervals for elasticities are given between square brackets.

SCENES stands for “Modelling and methodology for analysing the interrelationship between external developments and European transport”, a project funded by the European Commission under the Transport RTD programme of the 4th Framework Programme.

** The sources for demographic projections are the Institut National de la Statistique et des Etudes Economiques (INSEE, France), Statistics Netherlands, the Bureau of the Census (USA), and the Ministry of Health and Welfare (Japan).
most three for a given cohort: 1985, 1990 and 1995) are linked by segments in bold. The oldest cohorts are present only with observed values, whereas the youngest appear only in projection. The cohorts born after 1970 cannot be distinguished on the graph: they are assumed to have the same profile as the generation 1966-70.

Besides, one can note the very good simulation of the profile by age of household head for 1995, the last observation year (Table 6).

For France, the fleet projections for each age group of household head are the product of three quantities (number of cars per adult, number of adults per household, number of households); their sum gives the total fleet. For Japan, the Netherlands and the United States, the fleets (at the disposal) of households are obtained by multiplying the number of vehicles per household by the number of households for each age group of the head, and then by summing over all age groups.

The projections (as of 1st January, like for demographic projections) are adjusted so as to correspond to the global fleet*, that is including the vehicles (at the disposal) of households the age of the reference person of which has not been accounted for in the estimations (less than 20 years or greater than the maximum age considered), and the vehicles of firms and institutions. The adjustment consists in multiplying the projected series by the ratio of the observed fleet as of 1st January 1995 (Table 7) to the fleet projected for the same period. This simple procedure is justified by the fact that, firstly the proportion of the fleet held by households is predominant and remains globally stable and, secondly the proportion at the disposal of households whose head is very young (less than 20 years) or very old (in general, more than 85 years) is marginal.

The following tables show for each country the projected fleet as well as the corresponding number of households and the average number of vehicles per household estimated from these global figures.

The growth rates of the fleets and their decomposition into the growth of the number of households and the growth of the number of vehicles per household are given in logarithmic differences: \( \ln(y/x) = \ln y - \ln x \). A remarkable property of this measure is its symmetry, i.e. its value (in absolute terms) does not depend on the point of comparison used. It is also additive, i.e. the sum of two successive relative variations gives the relative variation

---

### Table 5  Evolution of the population age structure from 1995 to 2020 (%)

<table>
<thead>
<tr>
<th>Year</th>
<th>0-19</th>
<th>20-29</th>
<th>30-39</th>
<th>40-49</th>
<th>50-59</th>
<th>60-69</th>
<th>70-79</th>
<th>80+</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>1995</td>
<td>26.1</td>
<td>14.8</td>
<td>15.0</td>
<td>14.4</td>
<td>9.7</td>
<td>9.6</td>
<td>6.2</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>23.5</td>
<td>12.9</td>
<td>13.3</td>
<td>14.0</td>
<td>13.4</td>
<td>10.2</td>
<td>7.5</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>2020</td>
<td>22.5</td>
<td>11.8</td>
<td>12.7</td>
<td>12.9</td>
<td>13.3</td>
<td>12.3</td>
<td>8.7</td>
<td>5.8</td>
</tr>
<tr>
<td>Netherlands</td>
<td>1995</td>
<td>24.4</td>
<td>15.9</td>
<td>16.4</td>
<td>15.0</td>
<td>10.6</td>
<td>8.5</td>
<td>6.1</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>23.7</td>
<td>11.8</td>
<td>13.2</td>
<td>15.8</td>
<td>13.8</td>
<td>11.3</td>
<td>6.6</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>2020</td>
<td>21.8</td>
<td>12.5</td>
<td>11.9</td>
<td>12.8</td>
<td>15.0</td>
<td>12.5</td>
<td>9.0</td>
<td>4.4</td>
</tr>
<tr>
<td>Japan</td>
<td>1995</td>
<td>22.9</td>
<td>15.0</td>
<td>12.7</td>
<td>15.6</td>
<td>13.4</td>
<td>11.0</td>
<td>6.3</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>19.7</td>
<td>11.0</td>
<td>14.4</td>
<td>13.0</td>
<td>12.7</td>
<td>13.9</td>
<td>9.6</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td>2020</td>
<td>18.9</td>
<td>9.9</td>
<td>11.3</td>
<td>14.7</td>
<td>13.1</td>
<td>12.3</td>
<td>12.0</td>
<td>7.8</td>
</tr>
<tr>
<td>USA</td>
<td>1995</td>
<td>28.7</td>
<td>14.1</td>
<td>16.8</td>
<td>14.3</td>
<td>9.4</td>
<td>7.6</td>
<td>5.9</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>27.4</td>
<td>13.8</td>
<td>12.5</td>
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<td>13.7</td>
<td>9.5</td>
<td>5.4</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>2020</td>
<td>26.4</td>
<td>13.3</td>
<td>13.0</td>
<td>11.6</td>
<td>12.5</td>
<td>11.8</td>
<td>7.2</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Sources: For France and the Netherlands, projections by Eurostat (1995-2050; base scenario); for the United States, the Census Bureau; for Japan, the Ministry of Health and Welfare (data obtained from the International Data Base of the U.S. Census Bureau).

---

![Fig. 12 Structure of the household population in the Netherlands: 1995-2020](image-url)
LONG-TERM DYNAMICS (PART 2)

between the two extreme values. Moreover, the relative change in a product is the sum of the relative changes in the two terms of the product. For instance, the relative change in the value of a quantity of an item is equal to the relative change in the quantity plus the relative change in the price (see the Annex for a more detailed presentation).

Percentages of logarithmic differences, $100 \times \ln \left( \frac{y}{x} \right)$, are noted $L\%$.

The car fleets should continue to grow but less and less rapidly: five-year growth rates diminish regularly (Tables 8 to 11).

The strongest increase between 1995 and 2010 should be recorded by Japan ($41L\%$, which is equivalent to $50\%$) and the lowest by the United States ($16L\%$, that is to say $18\%$). The Netherlands and France should experience a growth of intermediate magnitude with quite close rates ($25\%$ and $27\%$, respectively).

However, decomposition of the growth rates shows that the differences between countries are essentially due to differences in the evolution of the motorisation rate. Indeed, the number of households should grow at a similar pace in each of the countries (about $14 L\%$, or $15\%$, between 1995 and 2010). On the other hand, the number of vehicles per household should strongly increase in Japan (about $30\%$), due to the replacement of poorly motorised generations by others that are much more so (Fig. 9). On the contrary, this rate should remain almost stable in USA. Again, France and the Netherlands are in an intermediate position, with very close patterns though their car ownership levels differ (they are higher for French households).

\[ e^{0.405} - 1 = 0.4993 - 0.50, \text{ that is } 50\%. \]

\[ \frac{e^{0.405} - 1}{e^{0.405} + 1} = 0.50. \]

Table 6 Age profiles of the number of cars per household – Netherlands (1995)

<table>
<thead>
<tr>
<th>Age group</th>
<th>Observed</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-24</td>
<td>0.61</td>
<td>0.61</td>
</tr>
<tr>
<td>25-29</td>
<td>0.87</td>
<td>0.88</td>
</tr>
<tr>
<td>30-34</td>
<td>1.00</td>
<td>0.98</td>
</tr>
<tr>
<td>35-39</td>
<td>1.06</td>
<td>1.02</td>
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<tr>
<td>40-44</td>
<td>1.14</td>
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<td>45-49</td>
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<tr>
<td>50-54</td>
<td>1.03</td>
<td>1.16</td>
</tr>
<tr>
<td>55-59</td>
<td>0.90</td>
<td>1.07</td>
</tr>
<tr>
<td>60-64</td>
<td>0.71</td>
<td>0.89</td>
</tr>
<tr>
<td>65-69</td>
<td>0.58</td>
<td>0.72</td>
</tr>
<tr>
<td>70-74</td>
<td>0.39</td>
<td>0.57</td>
</tr>
<tr>
<td>75+</td>
<td>0.39</td>
<td>0.39</td>
</tr>
</tbody>
</table>

Table 7 Automobile fleets observed in 1990 and 1995

<table>
<thead>
<tr>
<th>Source</th>
<th>1990</th>
<th>1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>23,010,000</td>
<td>24,900,000</td>
</tr>
<tr>
<td>Netherlands</td>
<td>5,371,366</td>
<td>5,883,851</td>
</tr>
<tr>
<td>Japan</td>
<td>32,621,046</td>
<td>42,678,430</td>
</tr>
<tr>
<td>USA*</td>
<td>186,731,066</td>
<td>197,374,942</td>
</tr>
</tbody>
</table>

*The fleet statistics in the USA are those of registrations (automobiles and trucks). Since 1985, vans, mini-vans and utility vehicles are no longer classified as passenger cars but as trucks.

\[ \text{Table 13 Motorisation profiles (observed and projected)} \]
As shown by Table 12, the projections for 2000 and 2005 prove to be very close to the observed figures, with projection errors of about 2% or less in general (it is even almost nil in 2005 for the Netherlands!). In the case of USA, the gap is slightly larger: -3% in 2000 and -6% in 2005. This underestimation is mainly...
due to a strong increase of the number of trucks (among which are pick-ups, vans, mini-vans and utility vehicles) compared to passenger cars (Table 13). Though this increase is largely attributable to companies (which own the bulk of trucks), households also contribute to this increase through the development of multi–motorisation and the tendency to a specialisation of vehicles owned by purpose.

5. CONCLUSIONS

From the foregoing analyses, it appears that differences between countries or regions can be explained by three main factors:

- the history of car ownership development: the United States, where automobile diffusion started before World War II, seems closer to saturation than Western Europe or Japan, a fortiori Poland where motorisation rates continue to grow rapidly. Indeed, the differences between generations are smaller and the sensitivity to the evolution of economic factors is lower in USA. As shown by long-term projections, this proximity to saturation should result in a lower growth of the car fleet in the USA compared to the rest of the countries considered. Besides, unlike the other countries, this evolution would essentially be due to an increase in the number of households;

- the level of economic development: Poland has the lowest motorisation rates among the countries under review, but these rates continue to grow and the gaps between generations do not stabilise, reflecting a phenomenon of catching-up after the period of transition from a centrally planned and rationed economy to a free market economy. The influence of economic affluence is also evidenced in the case of Italian regions: motorisation rates are lower and sensitivity to income is stronger in the South and the Islands than in the North and the Centre. Although the diffusion of the car reduced the gap between the two parts of the country in terms of the proportion of motorised households, at least for the more recent generations, the South and the Islands are still lagging in terms of level of car ownership per household. Closing this gap should depend on the evolution of incomes;

- population density: the Netherlands and Japan, where density is the highest, record over almost the whole life cycle lower motorisation rates than the other industrialised countries. In Japan, the maximum level of car ownership occurs later in the life cycle, as compared to what prevails in the remaining countries. This last point might be explained by a late motorisation, but which gradually grows as the size of the family increases.

REFERENCES


ACKNOWLEDGEMENTS

Access to the data used in this work has been made possible thanks to the help of many colleagues: Joyce Dargay (University of Leeds) for the UK, Toshiyuki Yamamoto (Nagoya University) for Japan, Rico Konen and Andrés de Jong (Statistics
LONG-TERM DYNAMICS (PART2)

Consider a change in two steps \( x \to y \to z \). \( H(y|x) \) is additive if and only if
\[
H(z/y) = H(y/x) + H(z/y).
\]
Putting \( z = x \), one sees that an additive indicator is necessarily symmetric. In addition, if one puts \( y/x = p \), \( z/y = q \) and \( z/x = r \), the previous equation becomes
\[
H(r) = H(p \cdot q) = H(p) + H(q).
\]
It follows that only additive indicators have the property that the relative variation of a product is equal to the sum of the respective relative variations of the two terms of the product. Hence, only an additive indicator allows solving the problems pointed out above.

It turns out that the only continuous (at least at one point) indicators of relative difference that are additive (and therefore symmetric) are positive multiples of the logarithmic difference:
\[
H(x/y) = c \ln(y/x), \quad c > 0.
\]
To retain only indicators that behave approximately as \( H_1(y|x) = (y-x)/x = (y|x)-1 \) when \( (y|x) \approx 1 \), it is further required from a “good” indicator to be normalised in the following sense:
\[
\lim_{s \to 0} H_1(s) = \lim_{s \to 0} \frac{H(s) - H(1)}{s - 1} = H'(1) = 1,
\]
in which case \( c = 1 \).

This normalisation permits, on one hand, eliminating the scale effect due to the arbitrary constant \( c > 0 \) and, on the other hand, linking every indicator of relative difference to the indicator \( H_1 \), for its common use and intuitiveness as well as for its validity as approximation of the relative difference when \( x \) and \( y \) are close. The authors note that among non-normalised indicators only some multiples of the logarithmic difference have an established position in scientific usage.

The logarithmic difference is therefore the sole indicator of relative difference to be symmetric, additive and normalised.

By analogy with the habitual presentation of relative differences in percentages, it is proposed to call logarithmic variations (or differences) multiplied by 100, 100 \( \ln(y/x) \), logarithmic percentages and to note them \( L\% \). Literally, 100 \( \ln(y/x) = 100(y-x)/L(x,y) \) indicates the absolute variation \( y-x \) as a percentage of the logarithmic mean \( L(x,y) \).

**Remark.** If need be, one can get back to the habitual measure of relative difference. A variation equal to a proportion \( p \) of \( x \) is equivalent to a variation \( \delta \) of \( \ln x \). If \( p = (y-x)/x \), one has \( y/x = 1 + p \) and so \( \delta = \ln(y/x) = \ln(1 + p) \) and \( p = e^\delta - 1 \).

APPENDIX

Logarithmic differences to measure relative variations

Törnqvist et al.\(^{35} \) advocate the use of the logarithmic difference as an indicator of relative difference or change. Thanks to its symmetry and additivity properties, this measure permits avoiding several practical difficulties. For example, the usual relative difference \((y-x)/x\) is not symmetric: its value depends on the term chosen as the basis of comparison. Moreover, successive relative changes are not additive. Finally, the identical equation between the relative variation of a product (for instance, a value as the product of a price and a quantity) and the sum of the respective relative variations of the two terms of the product does not hold. The approximation consisting in adding the relative changes in the two terms to obtain the relative change in the product is valid only for small variations.

The logarithmic difference between two positive numbers \( x \) and \( y \) is
\[
\ln(y/x) = \ln y - \ln x.
\]
Like most of the indicators of relative difference listed by the authors, the logarithmic difference is a difference with respect to a mean. Indeed, it can also be written as
\[
\ln(y/x) = (y-x)/L(x,y),
\]
where \( L(x,y) \) is the logarithmic mean of \( x \) and \( y \), defined by
\[
L(x,y) = \begin{cases} 
(y-x)/\ln(y/x) & \text{if } x \neq y \\
x & \text{if } x = y.
\end{cases}
\]
Every indicator of relative difference between \( x \) and \( y \) is a function of the ratio \( y/x \) alone. An indicator \( H(y|x) \) is symmetric if and only if
\[
H(y/x) = -H(y/x).
\]
Only the sign of the relative difference changes when \( x \) and \( y \) are permuted.

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38 • IATSS RESEARCH Vol.33 No.2, 2009