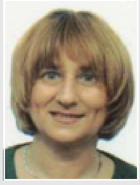
Proceedings of the Institution of Civil Engineers
Municipal Engineer 151
March 2002 Issue 1
Pages 3–12

Paper 12758
Received 31/10/2001
Accepted 03/01/2002

Keywords:
developing countries/environment/social impact/transport management/transport planning



Joyce Dargay
ESRC Transport Studies Unit, University College London

Road vehicles: future growth in developed and developing countries

J. Dargay

This paper examines the trends in the growth of the stock of road vehicles over the past decades and presents projections of its development over the next 25 years for 82 countries at different levels of economic development, from the lowest (China, India and Pakistan) to the highest (the USA, Japan and Europe). The countries included account for 85% of the world population and 93% of the total vehicle stock. The projections employ results from a previous study, which are based on estimates of a dynamic time-series model and an S-shaped function to relate the vehicle stock to income, or gross domestic product (GDP). The estimates are used, in conjunction with assumptions concerning income and population growth, to produce projections of the growth in the vehicle stock on a year-by-year basis to 2025. The projections are made for each country separately and aggregated on a regional level for developed and developing countries. The implications of the forecast growth for traffic, traffic density and CO_2 emissions are illustrated.

1. INTRODUCTION

This paper examines the trends in the growth of the stock of road vehicles in a large sample of countries over the past decades and presents projections of its development over the next 25 years worldwide, and for various groups of countries. The projections are based on a vehicle-forecasting model described in an earlier paper by Dargay and Gately.[1] The study employs an S-shaped function—the Gompertz function—to empirically estimate the relationship between the vehicle stock and income, or gross domestic product (GDP). Pooled time-series and cross-section data are employed to empirically estimate the saturation level and income elasticities for different countries. By employing a dynamic model specification, which takes into account lags in adjustment of the vehicle stock to income changes, the influence of income on the vehicle stock in different time perspectives is examined. In order to allow for differences in saturation related to demographic factors, vehicle saturation is related to population density.

The study includes 82 countries, so that for the year 1996, 85% of the world population and 93% of the total vehicle stock is represented. The comprehensiveness of the data set and particularly the inclusion of a large number of developing countries provide a high degree of variation in both income and the vehicle stock. This allows relatively precise estimates of the relationship between income and the number of vehicles at various stages of economic development.

The estimates are used, in conjunction with forecasts of income and population growth, to make projections of future growth in the vehicle stock over the next 25 years. The projections are made for each country separately and aggregated on a regional level for developed and developing countries. The implications of the forecast growth for traffic, traffic density and CO_2 emissions are illustrated with a few examples.

Section 2 examines the historical development of the vehicle stock, vehicles per inhabitant and the relationship between vehicles and income in the countries included in the study. Section 3 gives a brief description of the forecasting model used and the results obtained. The model is used in conjunction with assumptions of population and income growth to obtain projections of the vehicle stock in individual countries, country groupings and worldwide over the next 25 years. The implications of the findings for the environment and for traffic density are illustrated in section 4. The paper ends with some concluding remarks on policy issues.

2. HISTORICAL PATTERNS IN THE GROWTH OF ROAD VEHICLES

Figure 1 shows the number of vehicles per capita in 25 countries over the past four decades. The vertical axis is in log form, so that the rates of change over time can be compared. This also permits countries with large differences in motorisation rates to be displayed in the same figure. The majority of countries shown in the figure are developed countries, although a small number of less-developed economies are also included. The choice of countries is determined solely by data availability—only for these countries do we have data covering long periods of time. However, because of the high level of motorisation and/or the large populations of these countries, they account for about 80% of world vehicle stocks.

We see that motorisation rates in the various countries vary considerably, although the variation has declined over time. In the 1960s, the number of vehicles per capita ranged from around 4 per 10 000 inhabitants in China to over 4 per 10 inhabitants in the USA. By the mid-1990s, the figures were 9 per 1000 in China and 8 per 10 in the USA. Thus, although the

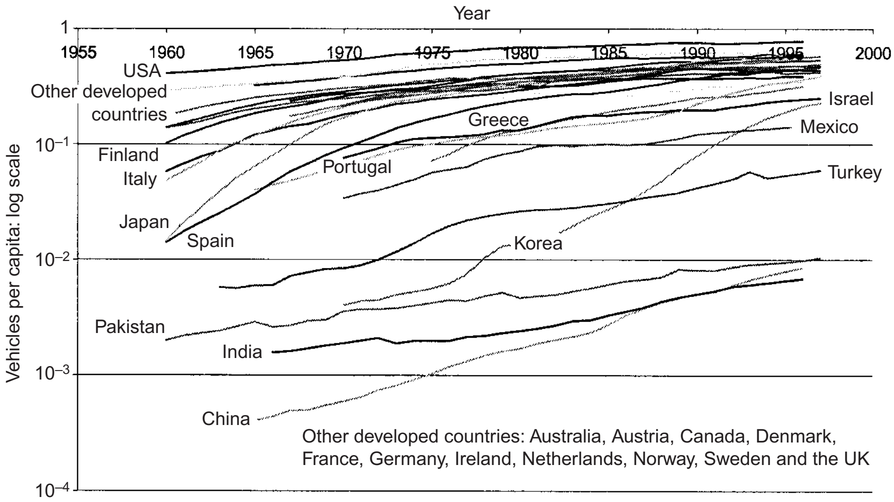


Fig. 1. Vehicles per capita (log scale) 1960–1996/97[2,3]

number of vehicles per capita doubled over the period in the USA, it increased 20fold in China.

The number of vehicles per capita in the majority of the developed countries lies above 0·1 (i.e. 1 vehicle per 10 inhabitants) for the entire period. Others reached this level slightly later, and by 1996/97 vehicles per capita in all developed economies is well over 0·03. The range for the developed counties is between 0·31 in Greece to 0·78 in the USA. The average for the European countries is 0·44. Of the developing economies, only Israel, South Korea and Mexico reach levels in excess of 1 vehicle per 10 inhabitants by the end of the period, while Turkey still has only about 0·06 vehicles per capita. In the poorer countries, namely China, India and Pakistan, there is still less than 1 vehicle per 100 inhabitants.

The rates of growth of vehicles per capita clearly vary among countries as well as over time. In the USA, the growth of 2·6% per annum in the 1960s and 1970s, was reduced to 1% in the 1980s and 0·5% in the 1990s. The declining rate of growth is a sign of saturation—there comes a point where a certain number of vehicles per inhabitant is reached, and there is little, if any, further growth. For the European countries, motorisation came at least a decade later than in the USA. The average annual growth rates for the European countries in the study sample are 11% in the 1960s, 5·3% in the 1970s, 3·4% in the 1980s and 1·8% in the 1990s. Again, declining growth and a trend towards saturation is noted. This is particularly evident in the wealthier countries, where the average growth rate declined from 4% in the 1970s to 0·7% in the 1990s. Comparable figures for the lower-income European countries are 9·8% and 4·5%; clearly, these countries are much further from saturation. Growth has also slowed down in Mexico and Israel, although both of these remain at a relatively low number of vehicles per inhabitant. For the remaining countries in the sample, growth continues at high annual rates over the entire period: South Korea (14%) and China (11%); India (5%) and Pakistan (4·5%).

For the remaining 57 counties in the study, the sample is much smaller, generally from around 1989 or 1990 to 1996. For these countries, the average number of vehicles per capita is about 0·1 in 1996, with an average growth of 3·4% annually. With few exceptions, these countries are lower-income countries.

A summary of the data for all 82 countries by region is shown in Table 1. The first three regions are generally the wealthier countries: (1) North America—that is, USA and Canada; (2) Western Europe; (3) Pacific—that is, Australia, New Zealand and Japan. In the remainder of the paper, these three regions together are denoted as NA-WE-P. The remaining regions (4–8) are classed as less-developed countries (LDCs), although a few countries included have relatively high per capita GDPs (South Korea, Kuwait). On average, the number of vehicles per capita in the LDCs is only one-sixth of that in the NA-WE-P. However, growth is nearly twice as high in the LDCs. Apart from the NA-WE-P countries, the vehicles per capita figure is highest in Eastern Europe followed by the Middle East, and lowest in Africa. Of course, these average figures hide the variation within each group. For example, countries with high vehicle intensity relative to other countries in the same region are South Korea (0·21), Malaysia (0·17), Kuwait (0·44), South Africa (0·14) and Argentina (0·15). Regarding growth rates, these are highest in Asia, and particularly in East Asia, and in Eastern Europe.

The number of vehicles in each region and its growth rate are shown in the corresponding columns of Table 1. It can be seen that nearly 80% of all vehicles are found in the NA-WE-P countries. This could be compared to their 18% of the world population.* For most regions the growth rate for the number of vehicles is much higher than the growth rate of vehicles per capita, because of growing populations. Worldwide, the number of road vehicles is increasing by 5·1% annually—by 2·1% in NA-WE-P and by 6·3% in the rest of the world.

The final two columns concern GDP. The average country in the sample has a per capita GDP of 6·5 thousand 1985 US$, while

*These figures refer only to the countries in the study. For all 165 countries with data given in the World Bank statistics, the NA-WE-P countries account for 73% of vehicles and 15% of population.

Region	Vehicles per capita 1996: mean	Average annual% change 1990–1996: mean	Vehicles, millions 1996: total	Average annual% change 1990–1996: mean	GDP per capita, 1985 US$: mean	Average annual% change 1990–1996: mean
1. North America	0·68	−0·6	222	0·4	18 256	0·6
2. Western Europe	0·45	1·6	185	2·2	13 693	1·2
3. Pacific	0·58	2·2	83	3·1	14 844	1·7
4. Eastern Europe	0·22	6·9	17	6·6	4087	−0·6
5. Asia	0·07	10·2	43	5·6	3827	4·6
East Asia	0·09	12·2	36	14·0	4798	5·5
South Asia	0·01	6·1	8	8·1	1885	2·8
6. Latin America	0·07	2·1	41	4·1	3596	1·8
7. Africa	0·03	2·8	15	5·5	1580	−0·5
8. Middle East	0·14	3·4	11	6·8	6402	1·7
NA-WE-P (1–3)	0·49	1·5	489	2·1	14 111	1·3
LDC (4–8)	0·08	4·1	128	6·3	3304	1·4
World	0·19	3·3	617	5·1	6471	1·4

Table 1. Road vehicles, GDP and mean growth rates by region[2–4]

comparable figures are 14·1 for the NA-WE-P countries and 3·3 for the LDCs. On average, Africa and South Asia are the poorest regions, with average per capita GDPs of less than $2000. Over the period 1990–1996 growth has been, on average, similar for developed and developing countries. Asia, however, has experienced a growth rate considerably higher than average, while real GDP has declined in Africa and Eastern Europe.

The relationship between vehicles per capita and GDP per capita is shown in the scatter diagram in Fig. 2. All available data are plotted for all 82 countries over time. Although the individual countries cannot be distinguished, the general pattern can be gleaned. The number of vehicles rises slowly at the lowest income levels, increases more quickly in the $5000–15 000 range, after which the growth rate begins to decline. In other words, the relationship appears to follow an S-shaped curve. Clearly there is a large variation in the number of vehicles per capita for any given income level. Some of this variation has to do with the fact that the observed vehicle–GDP observations are not in equilibrium. The number of vehicles in a given year is determined not only by current income, but also by past income. Some of the variation, however, is a result of differences in the individual countries—differences in transport policy, prices, or demographic factors.

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

3. PROJECTIONS OF VEHICLE OWNERSHIP TO 2025

As illustrated above, the relationship between vehicle owner-

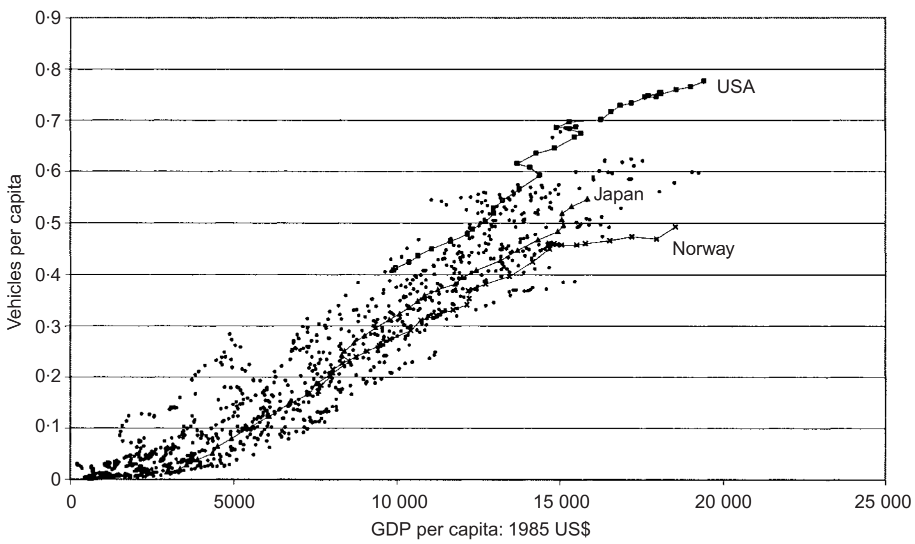


Fig. 2. The relationship between vehicles per capita and GDP per capita

ship and per capita income appears to be represented by an S-shaped curve. This implies that the number of vehicles (per capita) increases slowly at the lowest income levels, and then more rapidly as income rises, finally to slow down as saturation is approached. The data described here were used to estimate a model with these characteristics,† and the results are presented in a paper by Dargay and Gately[1] which itself was an extension of a previous study.[6] The model relates the vehicle/population ratio to GDP per capita.

Region	Real GDP	Population	GDP per capita
North America	2·1	0·7	1·38
Western Europe	2·1	0·2	1·88
Pacific	1·7	0·1	1·59
Eastern Europe	3·2	0·7	2·45
China	5·2	0·7	4·37
Rest of East Asia	4·2	1·1	3·02
India	4·9	1·2	3·59
Rest of South Asia	4·7	1·4	3·20
Brazil	2·5	1·1	1·38
Rest of Latin America	3·2	1·3	1·86
Africa	2·9	2·1	0·78
Middle East	3·2	2·6	0·58

Table 2. Assumptions concerning growth rates for the period 1997–2025

In order to account for lags in the adjustment of vehicle ownership to per-capita income, a simple partial adjustment mechanism is used. Such lags reflect the slow adjustment of vehicle ownership to increased income: the necessary build-up of savings to afford ownership; the gradual changes in housing patterns and land use that are associated with increased ownership; and the slow demographic changes as young adults learn to drive, replacing their elders who have never driven.

In order to allow for differences in vehicle saturation among countries, the saturation level is specified to be a function of population density (inhabitants per square kilometre).‡ Since the population density of each country changes over time as population changes, the saturation level is allowed to vary over time as well as across countries. Estimation of the model indicates a negative and statistically significant relationship between the saturation level and this measure of population density, so that there is empirical verification of this specification.

In addition, the model allows for asymmetry in the response to rising and falling income. Since many of the countries have experienced negative as well as positive per capita GDP growth over the period, it is important that such asymmetry is taken into consideration. To do so, the adjustment coefficient relating to periods of falling incomes is allowed to be different from that to rising income. The equilibrium relationship and the long-run elasticities are thus the same for rising and falling income, only the short-run effects and the time required for adjustment will be different.

The empirical results support the notion of asymmetry: when income rises, 12% of the complete adjustment occurs in one year, but when income falls only 7% of the long-term adjustment occurs in one year. The estimated mean saturation level is 80 vehicles per 100 inhabitants, with a range 0·50 to 0·91.

On the basis of the estimated models and assumptions concerning population and GDP growth, projections of car and vehicle ownership for the different countries can be made. The assumptions (Table 2) used are based on projections from the 2000 IEA World Energy Outlook for the years 1997 to 2020.[5] We assume the same growth rates will hold until 2025. Population density is assumed to grow at the same rate as population (this follows from our definition of population density—that is, inhabitants per square kilometre).

For the year 2000, the estimated long-run GDP elasticity ranges from around 0·2 in the USA to 2·2 in a number of middle-income countries, with rapid growth. In the poorest countries, with the lowest vehicle per capita ratios, the elasticity is around 1·5, while for the majority of NA-WE-P countries, the elasticity is less than unity. The relationship between the elasticity and income level is due to the nature of the Gompertz function and the estimated values—from the lowest income levels, the elasticity increases rapidly as income rises, up to a maximum value well above 1, finally to decline at higher income levels as saturation is approached. The maximum GDP elasticity is estimated to be 2·1, and generally occurs for the different countries at income levels between $4700 and $9500 (2000, USA).

The mean saturation level, in terms of vehicles per capita for the year 2025 is estimated to be 0·8 vehicles per capita, with a range for the individual countries from 0·42 in Korea to 0·91 in Australia. Since the saturation level itself is dependent on population density, it is not constant over time but declines as population increases. The estimates imply that, on average, saturation is reached at per capita GDP level of $44 000 (2000, USA). For comparison, GDP per capita in the USA was around $34 000 in 2000. In general, the lower-income countries reach saturation at lower income levels than higher-income countries, although this is not consistently the case.

The projected growth in the per capita vehicle stock in the world regions is shown in Fig. 3. It must be stressed that these

† The particular form used is a Gompertz function. The Gompertz is similar to the logistic function and was chosen because it is somewhat more flexible than the logistic by allowing different curvatures at low- and high-income levels.

‡ A measure of urbanisation would be more relevant to vehicle saturation. Unfortunately, such data are not available for the countries in our sample. The measure used, however, can be thought to capture some of the differences in the need for travel and hence vehicle ownership among countries.

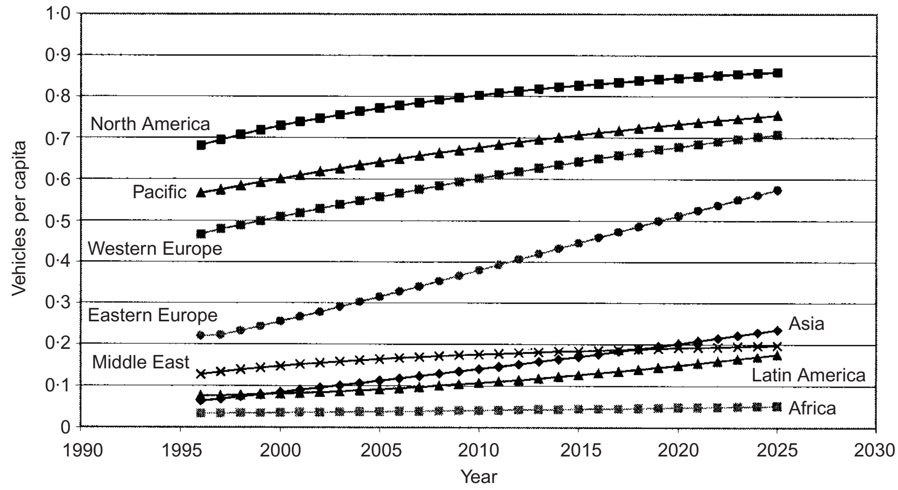


Fig. 3. Projections of vehicles per capita in world regions to 2025

projections, and all those of the following figures, are surrounded by a good deal of uncertainty and are dependent on the many assumptions underlying them.

Given these assumptions, by 2025, vehicles per capita will rise to 0·86 in North America, 0·75 in the Pacific and 0·71 in Western Europe, over 90% of the estimated saturation levels. Of the LDCs, the growth rates are highest in Asia (5% per year) and lowest in Africa (1·2% per year). The number of vehicles per person increases in all areas, but still remains very low in Africa (5 vehicles per 100 inhabitants). The number of vehicles per capita is seen to increase substantially in Eastern Europe, and will reach 2000 levels in Western Europe within 15 years. Within each region, there is significant variation among countries. Most notable is in Asia where vehicles per capita will reach 0·34 in East Asia, compared to only 0·03 in South Asia.

In 1996 there was a difference in vehicle ownership among countries, ranging from less than 0·01 vehicles per capita in many of the poorest countries to 0·78 in the USA. In 2025 the range is even greater—from 0·01 vehicles per capita in some of the lowest African countries to 0·87 vehicles per capita in the USA.

The projections for the total number of vehicles by world region are shown in Fig. 4. These indicate that Asia will overtake both the USA and Canada and Western Europe within the next 25 years. In general, the growth rates of the vehicle stock are far greater for the lower-income countries—due both to faster projected growth in per capita income and to higher income elasticities of vehicle ownership. The countries in the NA-WE-P regions will be approaching saturation, while other regions will continue to experience rapid growth. Of the NA-WE-P regions, the lowest growth is found in the Pacific (0·7% per year) and the highest in Western Europe (1% per year). The countries with the lowest growth rates are Germany, the USA and Japan, the three countries nearest saturation. The growth rate will be highest in Asia (3·9% per year), as a result of the assumed rapid income growth and the high GDP elasticities. The number of vehicles will also increase appreciably in Eastern Europe (2·8% per year), as the economic environment improves as their markets develop. The relatively low projected growth rates in per capita GDP in the remaining regions will result in a rather smaller increase in the vehicle stock: Middle East (2·4% per year), Latin America (2·2% per year) and Africa (2% per year).

These averages conceal substantial differences in vehicle growth rates among countries within each region. In Asia, growth ranges from 5·4% yearly in China to 2·3% in South Korea, which by 2025 will be nearing saturation. The range in Latin America is from about 0·4% per year in Paraguay to 3·5% per year in Chile, and in Africa from 0·9% annually in Zimbabwe to 3·5% in Cote d'Ivoire. Because of the rapid growth in vehicles per capita and its large population, by 2025 China will be second to the USA in total vehicles.

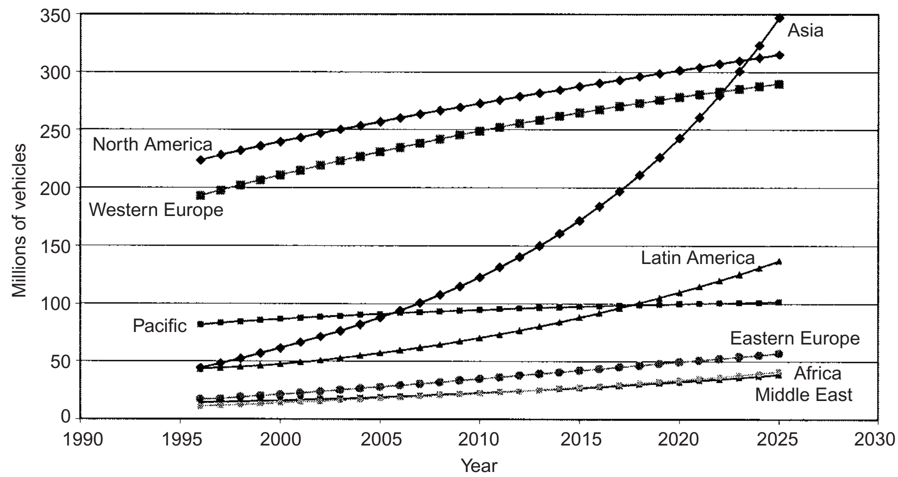


Fig. 4. Projections of road vehicles for world regions to 2025

Figure 5 shows the projections for the total world vehicle stock, and that for the wealthier countries (North America, Western Europe and Pacific) and the rest of the world (the less-developed countries). The projections suggest a doubling of world vehicle stocks over the next 25 years. The average annual growth rate for all countries is about 2% per annum. Over the same period, growth in NA-WE-P will be only 40%

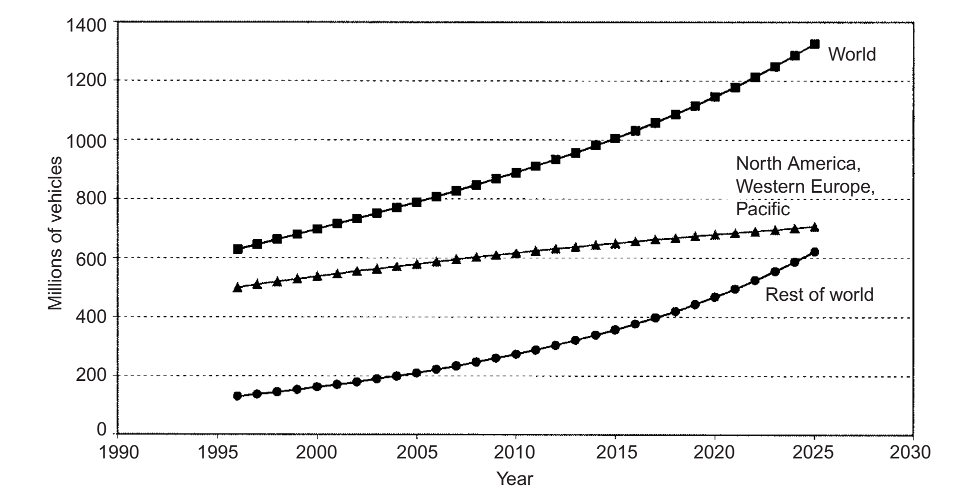


Fig. 5. Projections of road vehicles worldwide and for high- and low-income countries to 2025

(on average 1% per annum) while the number of vehicles in LDCs will more than quadruple (on average, a growth of 2·4% per year). Of the countries in our sample, today, the NA-WE-P countries account for nearly 80% of the vehicles, but with only 18% of the total population. By 2025, the OECD countries' share of vehicles will be reduced to slightly more than half the total of our world sample, while they will account for around 15% of the population.

4. IMPLICATIONS FOR THE ENVIRONMENT AND TRAFFIC DENSITY

The projections of vehicle stocks can be combined with information on average annual vehicle use, vehicle fuel efficiency and fuel mix and possible changes in these, to arrive at forecasts of fuel use and CO_2 emissions. In the example presented here, it is assumed that annual vehicle use, in terms of kilometres per vehicle, remains the same as 2000. Although the number of kilometres driven per vehicle has not been constant historically, the empirical evidence suggests that income has only a small effect on vehicle utilisation, with fuel prices playing a more important role. Since our projections are based on income growth only, with prices remaining at 2000 levels, the assumption of constant vehicle utilisation is justified.

Further, it is assumed that vehicle fuel efficiency improves by 0·5% per annum over the 25-year period—that is, an improvement of average on-road fuel efficiency (km/l) of the vehicle stock of 13%. It is assumed that these efficiency improvements include technical improvements as well as changes in fuel mix. Although far greater reductions in fuel consumption are certainly possible, even with known technologies, it is unlikely that such technologies will be adopted without either price incentives (increased fuel prices or taxation changes) or other policy measures. The efficiency improvements included in our forecasts are only those assumed to occur in the absence of price increases or policy intervention, so that the projections of CO_2 emissions should be seen as a worst-case scenario. Increasing fuel prices or policies aimed at reduction of emissions or car use will result in lower CO_2 growth.

Since we do not have data for all the countries on average vehicle use, fuel mix and efficiency, the projections are shown in terms of an index of growth from today's situation, rather than in absolute levels of emissions.

The projected growth in traffic for the regions is shown in Fig. 6. Since we assume that vehicle use remains constant over time, traffic increases in proportion with the number of vehicles. Traffic is projected to increase more than five-fold in Asia, and by 30% in NA-WE-P. In the remaining countries, the growth is projected to be between 140% (Africa) and 200% (Middle East).

The resulting CO_2 emissions, assuming an annual improvement in fuel efficiency of 0·5%, are shown in Fig. 7. As a result of the enormous growth in road vehicles, CO_2 emissions will grow most rapidly in Asia. According to our projections, emissions in 2025 will be five times those of today. The greatest increases will be in China, the Philippines and Indonesia. The smallest increases, less than 20% on average, are noted for NA-WE-P, as a result of relatively little growth in vehicle stocks which are already nearing saturation. The other regions lie in between, with increases in CO_2 emissions of between 100 and 150%.

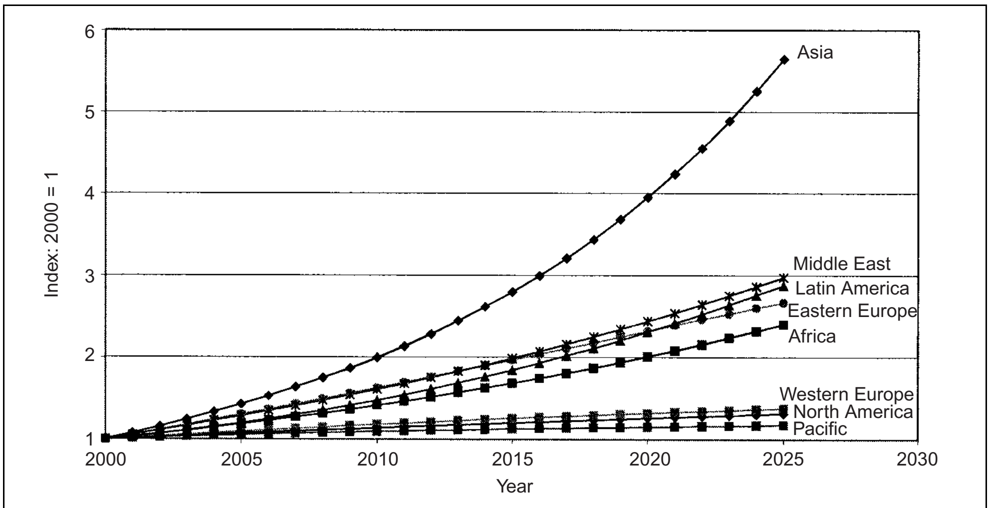


Fig. 6. Projected traffic growth to 2025

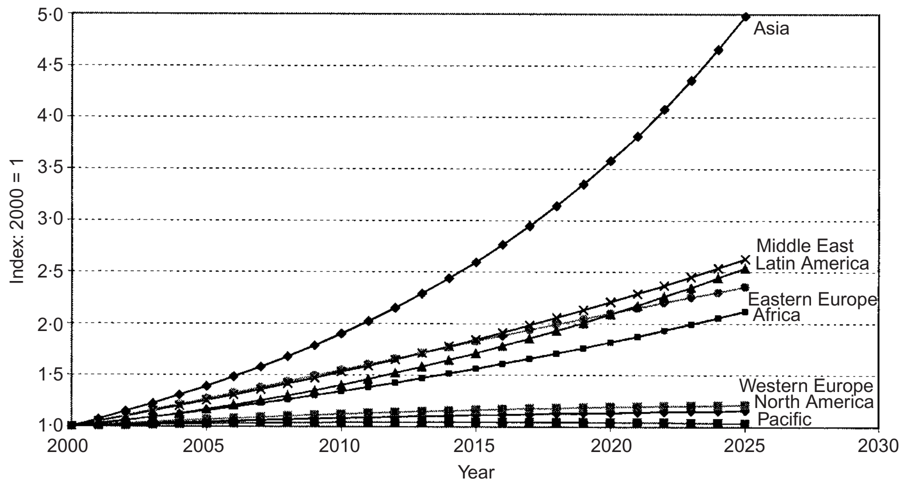


Fig. 7. Projected growth in road-traffic-related CO_2 emissions to 2025

Given our assumptions, world levels of transport-related CO_2 emissions are projected to increase by about 70%, while for LDCs the increase will be nearly 250%. It is to be stressed that these are the probable emissions assuming constant fuel prices and no policy intervention.

Doubling our assumption on vehicle efficiency improvements to 1% per annum (28% over the forecast period)§ results in an increase in emissions of 50% worldwide in 2025. With this rate of efficiency improvement, road transport related CO_2 emissions in NA-WE-P are only marginally higher than they were in 2000. Since such reductions in emissions are within the scope of present technology, it is possible for these countries to meet their commitments under the Kyoto Protocols. However, it is likely that policy intervention will be necessary to encourage the spread of these technologies. In spite of this, emissions will still increase substantially in the LDCs (200%), and particularly in Asia (350%), as a result of the substantial growth in motorisation.

The implications of the difference in growth rates are even more apparent when viewed in terms of incremental demand and emissions on a world level: the LDCs account for over 70% of the projected increase in vehicles, traffic and CO_2 emissions.

The growth in the number and use of road vehicles, particularly in the less-developed regions (largely due to their continued economic development), will not only greatly increase their CO_2 emissions but will also contribute to other more local problems of air quality, noise, traffic accidents, land allocation and congestion.

The growth in road vehicles and related traffic will also give rise to an increase in congestion if road space cannot be expanded to accommodate this growth. There are a number of reasons why this may not be possible, for example, the long time delays involved in road-building projects, the space restrictions in extending the road network in built-up areas, arguments pertaining to protection of the country-side and residential areas. In addition, there is the argument that road building, itself, will induce traffic, so that the reduction of congestion will be much smaller than anticipated.

There is no ideal method to measure congestion, and the concept of a congestion measure on a regional or even national level is itself questionable. Instead, a simplistic measure of traffic density, defined as vehicles per road-kilometre,¶ is used here. An increase in this index may be indicative of increasing congestion, since the number of vehicles, and hence amount of traffic, is increasing faster than road space. However, this need not be the case, since congestion can only be defined in particular road links at particular points in time.

The traffic density index on a regional level for the period 1990–1996** is shown in Fig. 8. The index for each region is calculated as the mean of the indices for the individual countries included in each region, so that it gives an idea of the mean change in traffic density for the countries in the region. According to this measure, traffic density has nearly doubled in the Asian countries in the past six years. This is not surprising given the rapid growth in road vehicles. Although road expansion was relatively high over the period—an average increase of road-km by 20%—this did not keep up with the increase in traffic. The next greatest increase in traffic density is found in African countries. Although the rate of increase in the number of vehicles was only half that of the Asian countries, road expansion was comparatively low, at about 10%. The countries in Latin America, Eastern Europe and the Middle East did somewhat better in containing the increase in traffic density, but it still rose by 20–35%. Only North America has managed to keep traffic density at a constant level,†† while Western Europe and the Pacific have experienced an increase of about 10%.

Also shown in Fig. 8, in parenthesis following the name of the region, is the average number of vehicles per road-km in 1996 for the countries included. According to these data, Africa has the lowest traffic density and Western Europe the highest. The majority of countries have a vehicle : road-km ratio of around 30, with North America and Latin America being slightly lower.

§The 28% reduction in average vehicle CO_2 emissions is only slightly greater than the agreement made in Europe with car manufacturers to reduce by 25% the average CO_2 emissions of vehicles sold by 2008 (which would result in an average fleet reduction of 25% by around 2020.

¶A more realistic measure would be vehicles per lane-kilometre. Such data are unfortunately not available for all the countries included. Vehicles per road-kilometre are taken from World Bank statistics.[2]
**These are the only years for which data are available.
††This is due to a reduction in vehicles per road km in Canada. Traffic density increased by 8% in the US.

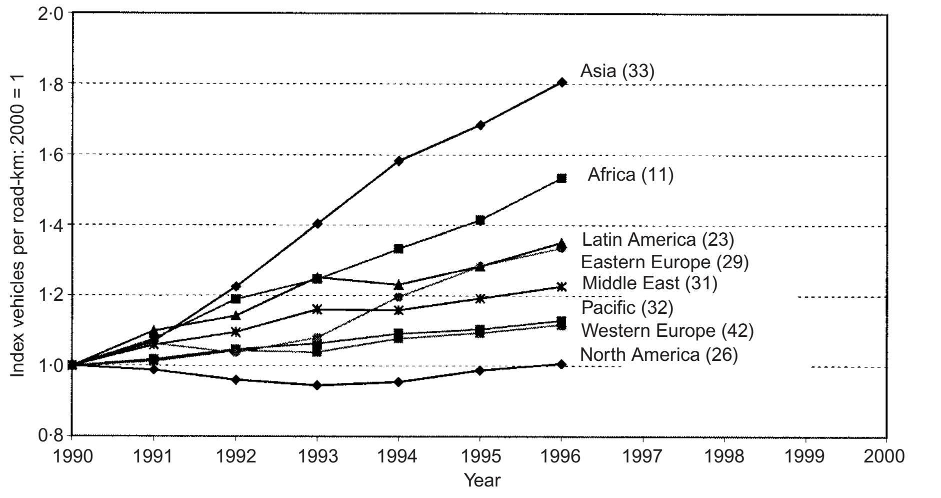


Fig. 8. Traffic density index. Vehicles per road-km, 1990–1996, 2000 = 1. Vehicles per road-km in 1996 in parenthesis

density levels in 2025 which are at least as high as those in Europe in 2000, while traffic density in Asian countries will be twice this.

From these trends it is apparent that very substantial road expansion projects would be necessary to limit the increasing traffic density due to projected rise in road vehicles, particularly in the LDCs. According to our calculations, road-kilometres would need to increase by at least twice the growth rates assumed, if vehicles per road-km are to remain constant. This would require an increase in road-kilometres over the next 25 years of 30% on average in NA-WE-P, 400% in Asia and 200% in the other regions.

Needless to say, these figures must be interpreted with caution, as they are based on measures of road space which do not distinguish been different categories of roads, so that motorways and residential roads are treated the same. In addition, the observations are based on a highly aggregate measure of traffic density so that they mask enormous differences on a local level in each country and region.

The final illustration in this paper uses the projections of vehicles and assumptions concerning road expansion to investigate future traffic density. It is assumed that the growth rate in road-km in the various regions over the next 25 years is similar to that of the first half of the 1990s and which is implicit in the traffic density indices shown in Fig. 8. The rates are 0·5% per annum (13% over 25 years) for NA-WE-P, 2% per annum (64% over 25 years) in Eastern Europe, Latin America, and the Middle East, 1·5% per annum (45% over 25 years) in Africa and 3% per annum (100% in 25 years) in Asia.

The projections, in index form, are shown in Fig. 9. Not surprisingly, the pattern is the same as that noted for traffic and CO_2 emissions: rapid growth in Asia (170%), little growth in the developed countries (4–20%) and moderate growth in the other regions (60–80%). Using the data on vehicles per road-km shown in Fig. 8 as a starting point and the indices in Fig. 9, by 2025, Asian countries will have on average nearly 90 vehicles per road-km; Western European, Eastern European and Middle Eastern countries will have 50; Latin America 40; North America and the Pacific 30; and Africa 17. Thus all regions, with the exception of North America, the Pacific and Africa, will have traffic

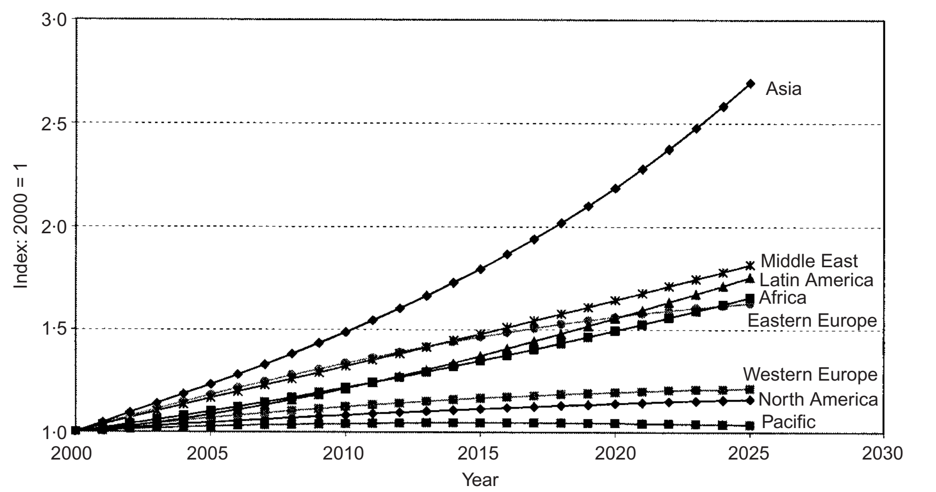


Fig. 9. Projected traffic density to 2025, index 2000 = 1

5. CONCLUSIONS

The projections indicate that the number of road vehicles and amount of road traffic can be expected to increase substantially over the next 25 years. This will inevitably have implications for the environment and for the transport system, as both CO_2 emissions rise and road congestion intensifies. As incomes rise, particularly in developing countries, the dominance of the NA-WE-P countries in terms of road vehicles, road traffic, fuel consumption and CO_2 emissions will decline. The results suggest that the increase in vehicle ownership, traffic and emissions will be greatest in the Asian countries. Over the next 25 years, growth in the number of vehicles in the developed countries will be relatively small (40%) compared to the LDCs (80%), as the former countries approach saturation. Because of this, increases in traffic and CO_2 emissions will be minor relative to those in the developing world. By 2025, Asia will have more road vehicles than Western Europe and North America due to the high vehicle growth rates in the Asian countries (about four times that of the Europe and North America) combined with their large populations. Despite the projected rapid increase in vehicles over the next 25 years, per capita vehicle ownership levels in many of the poorest countries are currently still very low, so the potential for further increases is substantial, as will be the resulting emissions.

Given the current reliance on fossil fuels, the demand for car-based transportation will, in the absence of effective policy measures aimed at traffic restraint and emission reduction through fuel efficiency improvements and alternative power sources, necessarily give rise to a considerable increase in oil-based fuel consumption and inevitably in CO_2 emissions. Although improvements in fuel economy higher than those assumed in our projections are feasible and cost-efficient,[8] it is unlikely that such improvements will be introduced without some external stimulus, for example by more stringent regulation concerning vehicle fuel efficiency or substantial rises in fuel prices and other motoring costs. The negative implications of drastic price increases on the economy, on consumption standards and on personal mobility, however, need to be considered, and taxation policies providing incentives for more environmentally friendly vehicles might be preferable. In the longer term, the development of non-fossil fuel based transportation technologies can provide the only answer to the curtailment of transport-induced emissions if personal mobility is not to be sacrificed, and investment in R&D efforts will be necessary if such technologies are to become economically feasible (e.g. hydrogen fuel-cell powered electric motor vehicles[9]).

Although improvement in vehicle technology can substantially reduce the effects of road transport on air quality and global warming (through a reduction in CO_2 emissions), it cannot address the problems of increasing congestion. Road expansion can offer a partial solution in some areas (and particularly in developing countries with poor road infrastructure), but will be able to contribute very little in most urban areas. Policies aimed at providing and encouraging the use of public transport alternatives, improvements in traffic control, transport telematics, road-use pricing and reducing the need to travel through more travel-efficient land-use planning will be necessary to keep congestion at acceptable levels.

Finally, it must be stressed that as with all forecasts, there is a substantial amount of uncertainty in the projections presented here. This uncertainty has to do with the underlying assumptions.

(*a*) Lower (higher) growth in per capita income would result in lower (higher) rates of growth in the number of vehicles and saturation would be approached later (sooner).
(*b*) Lower (higher) rates of vehicle efficiency improvements would result in higher (lower) rates of increase in CO_2 emissions.
(*c*) Lower (higher) rates of road construction would result in higher (lower) rates of increase in traffic density.
(*d*) There could be significant effects of variables not considered in the model, such as changes in the prices of vehicle purchase and use and changes in government policies regarding transportation.

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

6. ACKNOWLEDGEMENTS

The author gratefully acknowledges the financial support of the Economic and Social Research Council of the UK. Thanks are also due to Dermot Gately of New York University for collaboration on the modelling work on which this paper is based, and the anonymous referees for their valuable comments.

REFERENCES

1. Dargay J. and Gately D. Modelling global vehicle ownership. *Proceedings of the 9th World Conference on Transport Research, Seoul, Korea*, July 22–27 2001.
2. American Automobile Manufacturers Association (previously Motor Vehicles Manufacturers Association. *World Motor Vehicle Data*. Various annual issues. American Automobile Manufacturers Association, Washington, D.C.
3. World Bank. *World Development Indicators 2001*. World Bank, Washington, D.C., 2001.
4. Heston A. and Summers R. *Penn World Tables* 5.6. National Bureau of Economic Research, Cambridge, Mass., 1995.
5. International Energy Agency. World Energy Outlook 2000. International Energy Agency, Paris, 2000.
6. Dargay J. and Gately D. Income's effect on car and vehicle ownership, worldwide: 1960–2015. *Transportation Research A*, 1999, **33**, 101–138.
7. Green D. L. and Duleep K. G. Costs and benefits of automotive fuel economy improvement: a partial analysis. *Transportation Research*, 1993, **27**A, No. 3, May, 217–236.
8. De Luchi M. A. and Ogden J. M. Solar-hydrogen fuel-cell vehicles. *Transportation Research*, 1993, **27**A, No. 3, 255–275.

Please email, fax or post your discussion contributions to the secretary: email: kathleen.hollow@ice.org.uk; fax: +44 (0)20 7799 1325; or post to Kathleen Hollow, Journals Department, Institution of Civil Engineers, 1–7 Great George Street, London SW1P 3AA.