

ARE WE REACHING PEAK TRAVEL?
TRENDS IN PASSENGER TRANSPORT IN EIGHT INDUSTRIALIZED COUNTRIES

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ABSTRACT

Projections of energy use and greenhouse gas emissions for industrialized countries typically show continued growth in vehicle ownership, vehicle use and overall travel demand. This represents a continuation of trends from the 1970s through the early 2000s. This paper presents a descriptive analysis of cross-national passenger transport trends in eight industrialized countries, providing evidence to suggest that these trends may have halted. Through decomposing passenger transport energy use into activity, modal structure and modal energy intensity, we show that increases in total activity (passenger travel) have been the driving force behind increased energy use, offset somewhat by declining energy intensity. We show that total activity growth has halted relative to GDP in recent years in the eight countries examined. If these trends continue, it is possible that accelerated decline in the energy intensity of car travel; stagnation in total travel per capita; some shifts back to rail and bus modes; and at least somewhat less carbon per unit of energy could leave the absolute levels of emissions in 2020 or 2030 lower than today.

INTRODUCTION

The transport sector's trends of more people; owning more cars; owning larger and more powerful cars; and driving more have sometimes seemed inexorable. With the exception of the 1970s oil price shock and the recent fuel price hike, most industrialized countries have continued on a steady path of motorization. Developing countries, meanwhile, seem poised to follow these trends (Dargay et al. 2007). The International Energy Agency (2009b) projects an average annual increase in global transport energy demand of 1.6% between 2007 and 2030, although this does represent a slowing from 2.3% annual growth over the 1980-2006 period.

Efforts to reduce the carbon intensity of fuels have so far been largely unsuccessful, even if plug-in hybrids and second-generation biofuels have long-term promise. Past improvements in vehicle efficiency, meanwhile, have often been negated by increases in power and weight, leaving fuel economy constant. Future increases in fuel economy – for example through more stringent regulation – may be counteracted by increased vehicle travel. In the U.S., projected annual increases in vehicle miles travelled (VMT) will leave carbon emissions roughly constant over the next 25 years, despite increases in fleet fuel economy (Ewing et al. 2008). As of April 2010, the U.S. Energy Information Administration (2010) was still projecting annual VMT growth of 1.7% from 2008 through 2035.

In short, any pathway to reducing oil consumption and carbon emissions in the transport sector is strewn with rocky obstacles. To give a sense of the scale of the challenge, for transport to contribute a proportionate share of emission reductions in the U.S. to achieve an atmospheric stabilization goal of 450 ppm CO₂, light-duty vehicle fuel economy would have to rise to 136mpg, cellulosic ethanol would have to gain an 83% fuel market share, or vehicle travel would have to fall by 53% by 2050 (Grimes-Casey et al. 2009).

Recent events, however, have suggested that the path to passenger transport emission reductions may be slightly less challenging than would have appeared several years ago. Increases in fuel prices from 2003 as oil reached around \$150 per barrel led to a noticeable reduction in vehicle travel and energy use, as well as marked increases in the use of alternative modes. Even in the U.S., public transport systems posted ridership gains – an increase of 2.1% from 2007 to 2008 – and consumer preferences appeared to shift modestly to urban, walkable environments associated with less vehicle travel (Leinberger 2007).

Basic travel demand theory would suggest that there exists some saturation point for vehicle ownership and travel. Unless travel speeds increase, the fixed number of hours in a day and the consistent average of 1.1 hours per day that people devote to travel (Schafer and Victor 2000) preclude ever-rising travel activity. But even if travel speeds do increase, declining marginal utility to new destinations implies that there exists some saturation point for travel demand. While in the past, higher speeds from infrastructure improvements have been used to access more distant destinations rather than reduce aggregate travel times, this relationship may no longer hold (Metz 2010).

Policy and investment choices also influence total travel, as reduced expenditure on transportation infrastructure expansion appears to constrain travel growth (Duranton and Turner 2009). Aging of the population may also lead to changes in travel patterns. And there is some limited evidence that income elasticities for fuel demand tend to decline as income and car ownership increase (Johansson and Schipper 1997; Espey 1998), which would be a direct consequence of fixed travel time budgets

and mean that rising GDP has less impact on VMT than in the past. Johansson and Schipper (1997), for example, found income elasticities of car use lower in countries with higher car ownership. This stands to reason, as the number of available cars has exceeded the number of licensed drivers in the U.S. already (Davis et al. 2008). That there exists some level of saturation has long been accepted by modellers of vehicle ownership (Tanner 1978); it is equally plausible that demand for travel may also saturate. In short, with talk of “peak oil”, why not the possibility of “peak travel” when a clear plateau has been reached?

This paper provides some qualitative evidence to support these ideas of saturation. It finds that since 2003, motorized travel demand by all modes has levelled out or even declined in most of the countries studied, and that travel in private vehicles has declined. Car ownership has continued to rise in most instances, but at a slower rate and these cars are being driven less. If the trends toward reduced energy intensity of passenger travel, primarily from more efficient vehicles, can hold or be reinforced, the road to transport emission reductions may be slightly less challenging than originally thought.

The evidence presented here is suggestive rather than conclusive. In particular, while we speculate as to possible explanations, we do not attempt to identify the precise reasons for the observed plateau in passenger travel. (The same applies to the other trends and cross-national differences identified in this paper.) While we draw on explanations anchored in the literature and suggest where our cross-national evidence provides further support for the previous conclusions of others, our work is not a formal test of competing hypotheses.

Instead, the results can be seen as a challenge to travel demand and energy models that project continued rises in VMT and passenger travel. Travel demand models are ill-equipped to deal with any saturation; at least in the U.S., they are rarely “based on a coherent theory of travel behavior” (Meyer & Miller 2001, cited in Transportation Research Board 2007). While activity-based models are beginning to be used in some metropolitan regions, they are not suitable for aggregate forecasting.

A similar picture can be observed with energy models. The U.S. Energy Information Administration, for example, projects per-driver VMT based on changes in fuel prices, disposable income and demographic adjustments for changing proportions of female and elderly drivers (Energy Information Administration 2001). However, neither limited road infrastructure nor travel time budgets are assumed to impose any constraint, nor do the projections take into account any shift in growth towards less auto-oriented development patterns. Similarly, global integrated assessment models often project transportation demand as a function of population, travel costs and income (for example, Kim et al. 2006), without reference to demographic shifts, infrastructure investment or other constraints.

This paper is based on a cross-national analysis of trends in passenger transport in eight industrialized countries – the United States, Canada, Sweden, France, Germany, the United Kingdom, Japan and Australia. These countries span a wide range of land-use patterns and transport systems, from the auto-oriented suburban landscape that dominates the U.S., to the transit-focused, high-density Japan. Figure 1 shows that this sample covers high-income OECD countries across the

full range of CO₂ emissions from “transport”¹. However, it covers neither lower-income OECD countries in Latin America, Eastern Europe or the European periphery, nor large developing countries such as Brazil, China or India. Unfortunately, there are no reliable national time series data on travel or fuel use by mode for these countries. Recent work by the International Energy Agency (2009a) based on the Sustainable Mobility Project (WBCSD 2004) points to lower car ownership use and fuel consumption in developing countries, although there also exists a wide spread in the actual levels at a given per capita GDP.

The next section provides an overview of the analysis methods and data sources. The paper then presents a qualitative discussion of trends in activity, modal structure and modal energy intensity across the eight countries. The subsequent section provides a more formal decomposition of the components of energy demand changes using Laspeyres indices. We conclude with some observations on the implications for emissions projections and the potential for CO₂ reductions.

METHODS AND DATA

Data Sources

A wide variety of national-level data sources were compiled for this analysis, as detailed in the Appendix. The paper uses a similar dataset to earlier analyses from 1993 and 1999 (Schipper et al. 1993b; Schipper and Marie-Lilliu 1999), allowing us to capture recent trends.

A typical problem is that activity and energy data are published by different agencies, and do not necessarily agree. Another is that the scope and procedure for data collection often change over time. In general, bottom-up calculations using activity and on-road fuel economy data are presented here, calibrated to top-down fuel consumption data. Interpolations are sometimes used for missing years. Importantly, the analysis includes all transport fuels, not just gasoline. The inclusion of diesel for cars as well as public transport makes a significant difference to the results in several countries.

The data cover passenger travel by car and household light truck; bus; rail; and domestic air. Household light trucks are significant in Australia, Canada, and the U.S. and identified by surveys. SUVs in Japan, Sweden, France, Germany and the U.K. that are household vehicles are counted as such as well. The rail category includes local metro and streetcar systems, except in Canada where official statistics aggregate these modes with bus. Motorcycles are excluded as their share of travel is minimal. Water transport is excluded for consistency reasons and is small even in Japan. Our analysis does not include non-motorized travel, largely because of the poor quality or non-existence of the data in several countries.

With the exception of electricity, we measure final energy at the point of combustion using net calorific values. The limited amounts of electricity used were converted to primary energy, i.e. accounting for generation and transmission losses, using data from the International Energy Agency.

¹ The IEA make no further disaggregation of fuel use or emissions in transport beyond four categories: road transport, rail transport, domestic maritime transport, and domestic air transport. No further breakdown of road transport energy use is available from any international authority, hence the use of national authoritative data sources for this study. For views of energy use for freight across countries, see Schipper, Scholl and Price (1997) or Kamakate and Schipper (2009). Apfelbaum (2009) provides an exemplary description of how basic data are obtained and analyzed in this case for Australia.

We have taken into account the important differences in the energy content of gasoline, LPG and diesel, the main fuels used in the study countries.

Unless otherwise stated, prices and GDP are deflated to real 2000 currency and then converted to U.S. dollars at each country's purchasing power parity (PPP) exchange rate as published by the OECD. This measure of GDP converted to constant U.S. dollars provides a more consistent indicator of the cost in each country of a basket of goods or services than do exchange rates, which are influenced by trade more than differences in what local consumers buy or can afford. Our series generally runs through 2007, although some figures for Sweden, the United Kingdom and Japan include data through 2008. For most countries the series begins in 1970, except for Australia (1971), Canada (1984) and Germany (1990, after unification). In Germany and France, our data only cover activity; vehicle ownership and use; and energy for private cars. We do not have energy data for non-car modes.

Analysis Approach

Some of the time series in this paper are plotted with GDP per capita on the x-axis, rather than the conventional approach of plotting against time. This effectively controls for the impact of income on vehicle ownership and travel and for different rates of economic growth over time, and thus highlights structural differences between countries. However, the path over time can still be discerned in the charts. To facilitate comparisons over time, some data are also presented as time series. The Appendix shows GDP per capita over time for each country, allowing the reader to convert the plots against GDP per capita to plots against time.

A useful framework to understand the driving forces behind changes in passenger transport fuel consumption and emissions is the ASIF decomposition (Schipper and Marie-Lilliu 1999; Schipper et al. 2000). This expresses total greenhouse gas emissions from passenger transport as a function of passenger travel demand or activity; modal structure; modal energy intensities; and fuel carbon content.

$$G = \sum_{i,j} A \cdot S_i \cdot I_i \cdot F_{i,j}$$

Where A is total activity measured in passenger kilometres; S is a vector of modal shares for each mode i ; I is the energy intensity of each mode i ; and F is a vector of the carbon content of each fuel j used for each mode i . Energy intensity can be further decomposed into three factors: technical efficiency; vehicle characteristics such as power and weight; and load factors. The focus of this analysis is on energy use, not greenhouse gas emissions, and so we consider only the first three terms and ignore fuel carbon content (which tends to be stable across time, with the exceptions of electricity and the small differences in the CO_2 content of a unit of energy from diesel vs. gasoline fuel).

TRAVEL TRENDS

Activity

The last three decades have shown rapid increases in total travel activity, or the number of passenger kilometres travelled in motorized modes. Figure 2 shows how per capita travel by country has changed along with per capita GDP. As noted by many others, GDP growth has been the main

driver of increased travel, partly as greater prosperity translates into rising car ownership (Webster and Bly 1981). This increase in travel simply reflects the positive income elasticity for vehicle travel observed in many studies (Goodwin et al. 2004).

There are clear differences in the total amount of travel between the U.S.; a second grouping of Canada and Australia; a third grouping of European countries; and Japan with the lowest amount of travel. Income is behind some of these cross-national differences, as is evident from the plot of travel against GDP in Figure 2. The patterns may also to some extent be a simple reflection of geography, with per capita travel tending to be lower in smaller and more crowded countries due to higher densities and shorter potential travel distances. However, they appear to reflect more structural differences between North America, Europe and Japan. We do not attempt to isolate the relative importance of different factors, but gasoline taxation (Sterner et al. 1992; Parry and Small 2005), and development patterns and transportation infrastructure (van de Coevering and Schwanen 2006) have all been identified by others as explaining some cross-national differences. Even more research identifies the importance of these factors at the national level (e.g. Stead 2001; Ewing et al. 2008), and so it is not surprising that they also explain differences between countries.

As well as the largest amount of passenger travel, the U.S. also shows the highest rate of growth through the 1980s and 1990s, both in terms of growth per year and per unit of GDP. This difference in growth rates is more difficult to explain, as most cross-national studies have focused on travel in a single year rather than exploring variations over time. We can speculate that congestion constraints and land-use planning policy may be important explanations (and see Cameron et al. 2004), but there is little good data that tracks potential explanatory variables across countries over time.

There are signs of a levelling out or saturation of total passenger travel since the early years of the 21st century. This levelling out has occurred at a level of GDP between \$25,000 and \$30,000 in most countries, and in the U.S. at a slightly higher income of about \$37,000. To some extent, this saturation is related to higher fuel prices, whose rise began in 2002, but this levelling out predated the rapid rises in oil price from 2007. In a study of vehicle travel in the U.S., Puentes and Tomer (2008: 3) also note that the drop in VMT “began prior to the rapid rise in oil prices,” although (in common with this paper) they are unable to isolate the cause of the decline. In the U.K., Metz (2010) identifies a similar drop in VMT that predates the oil price rise, and suggests that this represents that saturation of travel demand. Importantly, the flattening of total per capita travel over so many countries has never been experienced. If it is a truly permanent change, then future projections of CO₂ emissions and fuel demand should be scaled back.

Figure 3 shows total car and household light truck use, expressed in vehicle rather than passenger kilometres. It shows a similar picture to Figure 2, which is unsurprising as cars and light trucks account for the majority of travel. However, some countries actually posted declines in passenger car use in the past few years, notably Australia and some European countries. Perhaps surprisingly,

Sweden continues a slow increase in passenger car use, although the reliability of the recent data here are questionable.²

The trends in car and light truck use shown in Figure 3 are qualitatively similar to those (not illustrated) for car and light truck travel, the former being measured in vehicle kilometres and the latter in passenger kilometres. However, in all countries except Canada vehicle kilometres have increased at a faster rate than passenger kilometres as vehicle occupancy rates have declined. The most marked reductions in vehicle occupancy for car travel have occurred in the United Kingdom (down 15% 1970-2008, from 1.99 to 1.69 persons per vehicle), Sweden and the U.S. (both down about 25% 1970-2008, from 2.16 to 1.58 in the U.S. and from 2.01 to 1.52 in Sweden). In the U.S., the decline in carpooling for commute trips has been attributed to rising vehicle availability, falling fuel prices and demographic shifts (Ferguson 1997). While commuting accounts for less than one-third of passenger travel in cars, these same factors may also be partly responsible for lower rates of carpooling for non-work trips.

As with total travel activity, the recent decline in car and light truck use is difficult to attribute solely to higher fuel prices, as it is far in excess of what recent estimates of fuel price elasticities would suggest. For example, Hughes et al. (2006) estimate the short-run fuel price elasticity in the U.S. to range from -0.034 to -0.077, which corresponds to a reduction in fuel consumption by just over 1% in response to the 15% increase in gasoline prices between 2007 and 2008. In reality, per capita energy use for light-duty vehicles fell by 4.3% over this period.

Signs of saturation are also evident in data on vehicle ownership (Figure 4). Again, there is a split between Australia and the U.S. with higher rates of growth and ownership levels of about 600 to 750 vehicles per 1,000 people, and most European countries and Japan which have converged and levelled out at between about 450 and 500 vehicles per 1,000 people.³ Growth in car ownership has slowed in every country and has even declined in the U.S. since 2007, with exceptions being a recent spurt in Australia and Canada, and one starting in Japan in 1990, after new car taxes were revised (Hayashi et al. 2001). Interestingly, about one-third of the new car registrations today in Japan are mini-cars under 660cc engine displacement (EDMC 2009). Japan's ownership has caught up to levels in Europe, but because of the constraints on space, the gap has in part been filled by mini-cars as evident from the new vehicle data in EDMC (2009).

Factors such as parking constraints, taxes on vehicle ownership, an aging population and saturation of car ownership among those not living in the centres of thriving cities likely explain both these trends and the cross-national differences. In Japan, for example, parking constraints and taxes have

² For passenger car travel and energy use in Sweden, we use data on vehicle kilometres disaggregated by fuel type and published by SIKa, which show an increase from 2007 to 2008 (Statens Institute for Kommunikations Analyser). However, alternate figures published by the Swedish National Roads Administration show a drop in vehicle kilometres by passenger cars between 2007 and 2008, and data on person-kilometres and top-down energy use figures also show a decline. Different methodologies appear to lie behind the discrepancy, but communications with Swedish experts were unable to pinpoint the precise cause. Unfortunately, the National Road Administration was unable to provide the details of their own model and data.

³ Germany exhibits a curious trend until it is recalled that from 1991 "Germany" includes the less motorized eastern part as well as the highly motorized western part. By 1995 the two parts were nearly even. However in 2006 German authorities recognized that they had been counting more than 4 million cars that were no longer in use and dropped the total stock from over 45 million to closer to 41 Million (DIW 2009).

historically been important (McShane et al. 1984), together with industrial and land-use policies that discouraged motorization, at least until the 1980s (Hook and Replogle 1996). Parking constraints have also had an impact in the U.K. and dense U.S. cities such as New York (Stead and Marshall 2001; Weinberger et al. 2009). Ryan et al. (2009) meanwhile, demonstrate the importance of vehicle circulation and fuel taxes on vehicle ownership and new vehicle sales across different European countries.

Interestingly, the observed plateau in Figure 4 is much lower than the saturation levels estimated econometrically by Dargay et al. (2007), even accounting for their inclusion of all vehicles rather than just (as in this paper) passenger cars and light trucks. The Dargay et al. saturation level estimates reach 852 vehicles per 1,000 people in the U.S. and are only slightly less in Canada and Sweden, Great Britain, Japan and Australia range from 707 to 785. Their model explicitly allows for saturation levels to vary across countries, which they find decline with increased population density and urbanization.

Figure 5 shows passenger travel by domestic air services. The volatility of travel demand is striking. The most recent downturn in demand corresponds to the aftermath of the terrorist attacks of September 2001. (The analysis does not extend to the recent declines in air travel due to high fuel prices, the economic downturn and Icelandic volcanic ash.) There are also twists in individual countries, for example corresponding to industry restructuring in Canada and a long strike in Australia in 1990.

There is also a clear divide between large countries with little inter-city passenger rail infrastructure, which have high rates and rapid growth in domestic air travel; and those that are more compact and have invested in high-speed rail as well as reliable regional service. The U.S., and Australia, and to a lesser extent Canada, belong to the first group; European countries and Japan to the second.

These groupings are unsurprising, given evidence that rail improvements in Europe and Asia have taken market share from air travel as well as bus and car modes (Campos and Gagnepain 2009). However, to some extent, national boundaries make this an unfair comparison, as low-cost intra-European international flights are not included in the figures for data availability reasons (and their emissions are not allocated to individual countries under the UN Framework Convention on Climate Change). To some extent, international flights may substitute for domestic travel, and airline deregulation and “open skies” agreements also reduced the relative cost of international travel during the period analyzed in this paper.⁴ Including international flights would close the gap somewhat, but not completely.

Modal Structure

The growth in passenger travel by private vehicle and air has not, in general, been at the expense of bus and rail. Figure 6 shows travel per capita by mode for three years – 1973, 1990 and 2007. Rather than a major shift away from public transport, increased energy use and emissions have been caused by growth in total activity based on the car and domestic air. The mode share of bus and rail has remained relatively constant or declined only slightly in seven of the eight countries (Figure 7).

⁴ We are grateful to one of the anonymous reviewers for suggesting this point.

Moreover, since 2002 the share of these modes in Sweden, the UK and France has held steady or even risen slightly, and even in the United States has moved up from a much lower level.

The exception is Japan, where the share of public transport declined precipitously until the year 2000. However, compared to the other five countries, Japan still has the largest mode share and per capita level of travel by bus and rail, at least partly due to high land prices, compact development patterns and historically high spending on rail infrastructure (Hook and Replogle 1996).

To some extent, growth in car travel has eaten away at bus load factors even if mode shares have remained steady. Average bus passenger loads fell by between 9% and 40% between 1970 and 2007 in all countries for which this data is available. Conversely, switching back to these modes from cars, if the shift is absorbed by existing runs, will add little energy or emissions while saving the energy that would have been used for cars.

Intensity

The energy intensity of cars and light trucks has declined since 1980 in all countries analyzed, including Germany when West German data is used prior to unification (DIW 2009) (Figure 8). The most noticeable decline was in the U.S. from the late 1970s – a change which analysts such as Greene (1998) attribute largely to the introduction of Corporate Average Fuel Economy (CAFE) standards. But after 1990, Japan's intensities increased and those in the U.S. were stagnant, while intensities in the U.K. and other EU countries fell slowly from 1995 until the present. Japan's intensity started falling again by 2000 as the mini-cars began to have an impact on the fleet. Those in the U.S. started to fall after 2003; possible explanations include consumers demanding vehicles with improved fuel economy (over the standard) as a result of higher oil prices; and slightly tighter standards on new light trucks.

Lower vehicle occupancy, however, have meant that the change in energy intensity of car travel and aggregate passenger travel has been less pronounced, particularly in Europe. Even though individual modes, particularly cars, have become less energy intensive per vehicle kilometre, the energy intensity of travel itself has shown less of a drop. This is partly because the growth has occurred in car and air travel, the most energy intensive modes, and partly because of the declining bus load factors noted above. In the U.S., the shift away from carpooling has also been important as noted earlier. In Japan, the energy intensity of aggregate travel increased through the mid-1990s, as these factors together with a shift to larger and heavier cars outweighed the improvements in technical efficiency (Kiang and Schipper 1996).

Even after the initial CAFE standards promulgated in the late 1970s had affected the entire U.S. car and light truck fleet (i.e. by the mid 1990s), the U.S. has the most energy intensive vehicles, followed by Australia, Canada and Japan. The inverse relationships between fuel price and fuel intensities (International Energy Agency 2004) still hold across countries. Indeed, in Europe taxation rates on vehicles and fuel appear to have a larger effect on emissions intensity than voluntary fuel economy agreements with auto manufacturers (Ryan et al. 2009).

Note that differences in energy intensity across countries are not the same as one might predict from test values of new cars, even if adjusted to a common test cycle (as in An et al. 2007). Japan has more energy intensive vehicles in real traffic, i.e. "on road," than Sweden or the U.K.; Japanese data sources imply that new car fuel economy test values in Japan must be multiplied by 1.33 to reflect

approximate on-road values, indicating bad congestion (EDMC 2009). A recent European study uses an adjustment of 1.195 (Smokers et al. 2006). US EPA (2010) recently adjusted upward its correction from test to on-road fuel intensity. Older sources for Sweden find a smaller adjustment for cars there (Schipper et al. 1993b), possibly because a smaller share of driving occurs in its three large cities than in corresponding urban areas in other countries.

With long stage lengths, air travel in North America or Australia is much less energy intensive than in Europe, where even in France and Sweden “domestic flights” are mostly less than 500 km.⁵ (Energy intensity tends to decline with stage length until about 2000 km (Babikian et al. 2002)). In fact, the energy intensity of air travel in the U.S., with close to 80% of seats filled, is currently below that of car travel, with an average of 1.6 passengers per vehicle or roughly 30% of seats filled.

DECOMPOSING TRANSPORT ENERGY USE

Laspeyres indices provide a simple way to understand the driving forces behind trends in passenger transport energy use, through decomposing changes into a number of underlying factors (Schipper et al. 1992). Laspeyres and similar indices are widely used, not just in transport but in energy policy more generally, to understand the drivers of change and facilitate cross-country comparisons (Ang 2004). The indices are defined mathematically below, but intuitively they show the impact of each factor (in this case: activity, modal structure and modal energy intensity) on energy use by allowing only that factor to change. All other factors are held at their respective base year values.

In other words, the indices show the hypothetical change in passenger transport energy use if *only* overall activity, modal structure or modal energy intensity had changed, holding the other two elements constant. The approach can be extended to include fuel mix, but even major shifts to diesel cars have had minimal impact on the CO₂ content of fuel, because diesel has only slightly greater emissions per unit of energy than gasoline. More sophisticated indices can give slightly more accurate results but are much more cumbersome to calculate (Ang 2004).

Table 1 shows the annual average changes over the 1973-2007 period and three subperiods for the six countries for which full data are available. The “Actual” row refers to the change in total (not per capita) passenger energy use, which increased in all countries and time periods with the notable exception of Japan and the U.K. from 2000-2007. In the U.S., for example, passenger transportation energy use increased by 1.0% per year between 1973 and 2007.

The “Activity” row indicates a hypothetical case in which modal structure and modal energy intensities remain constant over the period, but total travel does change. In other words, it assumes that growth in activity is distributed across modes according to their initial modal shares, and that the energy intensities of each mode do not change. Formally, energy use under the “Activity” case E^A is calculated as a percentage of total energy use in the base year (1990) as follows:

$$E_{it}^A = \frac{A_{it}}{A_{i0}}$$

⁵ Recall that a coast-to-coast flight in Australia, Canada or the U.S. (4000-5000 km) implies a stage between London and Tehran or Vienna and Mumbai!

Where: A_{it} is total activity (passenger kilometres) in country i in year t and A_{i0} is total activity in the base year, 1990. Annual average change δ^A in country i in the period between years a and b (as shown in Table 1) is then calculated as follows:

$$\delta_{a,b}^A = \exp \left[\frac{\log E_{ib}^A - \log E_{ia}^A}{b - a} \right] - 1$$

Table 1 shows that increased activity has been the largest contributor to rising passenger transport energy demand over the period of analysis, and that activity increases alone have increased energy demand by between 1.3% and 2.6% a year over the study period. The 1970s and 1980s were a particular period of rising activity.

The “Structure” row indicates a hypothetical case in which activity and modal energy intensities remain constant, but in which the share of cars, bus, rail and air travel change. Formally, energy use under the “Structure” case E^S is calculated as a percentage of total energy use in the base year (1990) as follows:

$$E_{it}^S = A_{i0} \frac{\sum_m S_{mit} I_{mi0}}{E_{i0}}$$

Where: A_{i0} is as above, S_{mit} is the share of passenger kilometres for each mode m in country i in year t ; I_{mi0} is the energy intensity of each mode (MJ per passenger kilometre) in country i in the base year; and E_{i0} is total energy use in country i in the base year. Annual average changes are then calculated in the same way as for the Activity case.

In five of the six countries, changes in mode shares have been minimal over all periods of analysis, indicating that neither a shift away from public transport nor a shift to domestic air travel explain much of the change in energy use. The exception is Japan, which witnessed a major decline in public transport use through the 1970s, 1980s and 1990s, although in recent years the mode share of bus and rail has begun to rise again.

The “Intensity” row indicates a hypothetical case in which activity and modal shares remain constant, but in which the energy intensities of different modes change. Formally, energy use under the “Intensity” case E^I is calculated as a percentage of total energy use in the base year (1990) as follows:

$$E_{it}^I = \frac{\sum_m I_{mit} A_{mi0}}{E_{i0}}$$

Where: I_{mit} is the energy intensity (MJ per passenger kilometre) of each mode m in country i in year t ; A_{mi0} is total passenger kilometres by each mode m in country i in the base year; and E_{i0} is as above. Annual average changes are calculated in the same way as for the Activity case.

With a few exceptions – notably Japan and Sweden since the 1990s – the energy intensity of travel has fallen over time, meaning that were it not for the growth in total activity and a change in modal shares, total passenger transportation energy use would have fallen. However, energy intensity has not fallen enough to offset increases in total activity. Particular reductions in vehicle energy intensity have been achieved in the U.S., most likely through the imposition of CAFE standards for cars and light-duty vehicles. The reasons for increased energy intensity of car use in some countries are more difficult to discern. In Japan, rising congestion may be a factor as well as the boom in the sale of large cars following tax reforms of 1990 (noted above). By a few years into the new millennium, however, light duty vehicle energy intensities on the road were heading downward in all of the eight countries, with the possible exception of Sweden.

CONCLUSIONS

Several conclusions emerge from this international comparison of travel trends. First, activity, i.e. total passenger kilometres in motorized modes, has slowed its growth relative to GDP and even declined in per capita terms in some countries. This represents a marked change after robust increases in the 1970s and earlier. Most of the growth that has occurred was led by cars and domestic air travel. Second, mode shift towards travel in cars has not been an important explanation for rising energy use, except in Japan until the turn of the century. Third, the energy intensity of car travel, the dominant factor in travel-related energy use and CO₂ emissions, has fallen in every country except Japan since 1990, and started falling in Japan after 2000. In the U.S., the large drop in the intensity of car use ended in the 1990s, just as various policies kicked off a new round of declines in Europe and Japan. However, at least until the middle of the first decade of the 21st century, the impact of reduced energy intensity was outweighed by greater activity, meaning that energy use overall continued to increase. Thus, the major factor behind increasing energy use and CO₂ emissions since the 1970s – activity – has ceased its rise, at least for the time being. Should this plateau continue, it is possible that accelerated decline in the energy intensity of car travel, some shifts back to rail and bus modes, and at least somewhat less carbon per unit of energy might leave absolute levels of emissions in 2020 or 2030 lower than today. Whether more ambitious targets can be met depends on how much less carbon per passenger kilometre will be emitted. But it also depends on the total level of activity.

Our cross-national results also reveal major differences in the levels of travel and automobile fuel economy between OECD countries. We did not analyze fully the reasons for these differences. However, fuel prices certainly play a role in the differences in light duty vehicle intensities and to some extent mode shares of ground travel. The demographic transition to a more elderly population, one consequence of very slow population growth in Japan and Europe, may also contribute. Given the wide range of travel at a given GDP, fuel prices, geography, urban structure and transport infrastructure must also play some role. Thus, our results suggest that the relationships between urban form and travel behaviour found by many researchers at the national level also hold in a cross-national setting.

Despite the substantial cross-national differences, one striking commonality emerges: travel activity has reached a plateau in all eight countries in this analysis. The plateau is even more pronounced when considering only private vehicle use, which has declined in recent years in most of the eight countries. While we did not identify the causal mechanism that led to this plateau, it is consistent with behavioural theories of travel time budgets, and evidence that income elasticities decline at high incomes. The reduced rate of infrastructure expansion in the countries studied would also help

account for the plateau. Importantly, the start of the plateau preceded the recent escalation in oil prices, and so a dampening of demand from high fuel prices can only provide a partial explanation.

Our work does leave several important questions unanswered, and further work using each country's most recent travel surveys would help address many of these issues, as it did over twenty years ago (for an example, see Salomon et al. 1993). In particular, we do not make any predictions about future trends. One possibility is that the plateau will be a temporary hiatus, with growth in activity most likely to resume through domestic air travel or high-speed rail, or if road infrastructure reverts to its previous rate of expansion. Another possibility is that the plateau will continue – an outcome that is plausible if travel speeds remain relatively stable, and travel time budget constraints continue to bite. The third possibility is that we will see a decline in activity in the coming years, and that we will have reached “peak travel.” This would be likely with some combination of high oil prices, stagnating economic growth, a continuation of demographic trends towards a more elderly population, and a renaissance in walking and cycling. The latter might reduce passenger travel as the slower speeds of non-motorized modes mean that less distance can be covered within a semi-fixed travel time budget.

Each of these three scenarios – temporary hiatus, continued plateau or peak travel – brings its own set of policy implications for energy supply, transport infrastructure provision, and the costs of achieving a given target for greenhouse gas emission reductions. The most fundamental point, however, is that continued, steady growth in travel demand cannot be relied upon. Most aggregate energy forecasts and many regional travel demand models are based on the core assumption that travel demand will continue to rise in line with income. As we have shown in the paper, this assumption is one that planners and policy makers should treat with extreme caution.

ACKNOWLEDGEMENTS

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REFERENCES

An, F., D. Gordon, H. He, D. Kodjak and D. Rutherford (2007). Passenger Vehicle Greenhouse Gas and Fuel Economy Standards: A Global Update. Washington, DC, International Council on Clean Transportation.

- Ang, B. W. (2004). "Decomposition analysis for policymaking in energy: which is the preferred method?" Energy Policy **32**: 1131-1139.
- Apelbaum, J. (2009). "A case study in data audit and modelling methodology--Australia." Energy Policy **37**(10): 3714-3732.
- Babikian, R., S. P. Lukachko and I. A. Waitz (2002). "The historical fuel efficiency characteristics of regional aircraft from technological, operational, and cost perspectives." Journal of Air Transport Management **8**(6): 389-400.
- Cameron, I., T. J. Lyons and J. R. Kenworthy (2004). "Trends in vehicle kilometres of travel in world cities, 1960-1990: underlying drivers and policy responses." Transport Policy **11**(3): 287-298.
- Campos, J. and P. Gagnepain (2009). Measuring the Intermodal Effects of High Speed Rail. Economic Analysis of High Speed Rail in Europe. G. s. d. Rus. Bilbao, Fundacio n BBVA: 71-88.
- Dargay, J., D. Gately and M. Sommer (2007). "Vehicle Ownership and Income Growth, Worldwide: 1960-2030." Energy Journal **28**(4): 163-190.
- Davis, S. C., S. W. Diegel and R. G. Boundy (2008). Transportation Energy Data Book: Edition 27. Oak Ridge, TN, Oak Ridge National Laboratory.
- Deutsches Institute für Wirtschaftsforschung (DIW) (2009). Verkehr in Zahlen. Berlin, DIW and Verkehrsministerium.
- Duranton, G. and M. Turner (2009). The Fundamental Law of Road Congestion: Evidence from US cities, NBER.
- EDMC (2009). Handbook of Energy and Economic Statistics in Japan. 2009 Edition. Tokyo, The Energy Conservation Center.
- Energy Information Administration (2001). The Transportation Sector Model of the National Energy Modeling System. Model Documentation Report Washington, DC, Office of Integrated Analysis and Forecasting, Energy Information Administration.
- Energy Information Administration (2010). Annual Energy Outlook. Washington, D.C., U.S. Energy Information Administration.
- Espey, M. (1998). "Gasoline Demand Revisited: An International Meta-analysis of Elasticities." Energy Economics **20**(3): 273-295.
- Ewing, R., K. Bartholomew, S. Winkelman, J. Walters and D. Chen (2008). Growing Cooler: The Evidence on Urban Development and Climate Change. Urban Land Institute, Urban Land Institute.
- Ferguson, E. (1997). "The rise and fall of the American carpool: 1970–1990." Transportation **24**(4): 349-376.

- Goodwin, P., J. Dargay and M. Hanly (2004). "Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review." Transport Reviews **24**: 275-292.
- Greene, D. L. (1998). "Why CAFE worked." Energy Policy **26**(8): 595-613.
- Grimes-Casey, H., G. Keoleian and B. Willcox (2009). "Carbon Emission Targets for Driving Sustainable Mobility with US Light-Duty Vehicles." Environmental Science & Technology **43**: 585-590.
- Hayashi, Y., H. Kato and R. V. R. Teodoro (2001). "A model system for the assessment of the effects of car and fuel green taxes on CO2 emission." Transportation Research Part D **6**(2): 123-139.
- Hook, W. and M. Replogle (1996). "Motorization and non-motorized transport in Asia : Transport system evolution in China, Japan and Indonesia." Land Use Policy **13**(1): 69-84.
- Hughes, J. E., C. R. Knittel and D. Sperling (2006). Evidence of a Shift in the Short-Run Price Elasticity of Gasoline Demand, National Bureau of Economic Research, Inc, NBER Working Papers: 12530.
- International Energy Agency (2004). After 30 Years. Oil and Energy in IEA Countries. Paris, International Energy Agency.
- International Energy Agency (2009a). Transport, Energy and CO2. Moving Toward Sustainability. Paris, OECD/IEA.
- International Energy Agency (2009b). World Energy Outlook. Paris, OECD/IEA.
- Johansson, O. and L. Schipper (1997). "Measuring the Long-Run Fuel Demand of Cars: Separate Estimations of Vehicle Stock, Mean Fuel Intensity, and Mean Annual Driving Distance." Journal of Transport Economics and Policy **31**(3): 277-292.
- Kamakaté, F. and L. Schipper (2009). "Trends in truck freight energy use and carbon emissions in selected OECD countries from 1973 to 2005." Energy Policy.
- Kiang, N. and L. Schipper (1996). "Energy trends in the Japanese transportation sector." Transport Policy **3**(1-2): 21-35.
- Kim, S. H., J. A. Edmonds, J. Lurz, S. J. Smith and M. A. Wise (2006). "The ObJECTS: Framework for Integrated Assessment: Hybrid Modeling of Transportation." The Energy Journal.
- Leinberger, C. (2007). The Option of Urbanism: Investing in a New American Dream., Island Press.
- McShane, M. P., M. Koshi and O. Lundin (1984). "Public policy toward the automobile: A comparative look at Japan and Sweden." Transportation Research Part A **18**(2): 97-109.
- Metz, D. (2010). "Saturation of Demand for Daily Travel." Transport Reviews. DOI [10.1080/01441640903556361](https://doi.org/10.1080/01441640903556361)

Parry, I. W. H. and K. A. Small (2005). "Does Britain or the United States Have the Right Gasoline Tax?" American Economic Review **95**(4): 1276-1276.

Puentes, R. and A. Tomer (2008). *The Road...Less Traveled: An Analysis of Vehicle Miles Traveled Trends in the U.S.* . Washington, DC, Brookings Institution.

Ryan, L., S. Ferreira and F. Convery (2009). "The impact of fiscal and other measures on new passenger car sales and CO2 emissions intensity: Evidence from Europe." Energy Economics **31**(3): 365-374.

Salomon, I., P. Bovy and J.-P. Orfeuil, Eds. (1993). A Billion trips a day: Tradition and transition in European travel patterns. Dordrecht, Netherlands, Kluwer.

Schafer, A. and D. G. Victor (2000). "The future mobility of the world population." Transportation Research Part A-Policy and Practice **34**(3): 171-205.

Schipper, L. and eight others (2000). *Energy Use in Australia in an International Perspective* Canberra, Department of Industry, Science and Resources.

Schipper, L., F. Johnson, R. with Howarth, B. Andersson, B. Andersson and L. Price (1993a). *Energy Use in Sweden: An International Perspective*. Berkeley, Lawrence Berkeley National Laboratory.

Schipper, L. and C. Marie-Lilliu (1999). *Carbon-Dioxide Emissions from Transport in IEA Countries: Recent Lessons and Long-Term Challenges*, International Energy Agency.

Schipper, L., C. Marie-Lilliu and R. Gorham (2000). *Flexing the Link Between Transport and Greenhouse Gas Emissions*. Paris, International Energy Agency.

Schipper, L. and L. Price (1994). "Efficient Energy Use and Well Being: The Swedish Example After 20 Years." Natural Resources Forum **18**(2): 125-142.

Schipper, L., L. Scholl and L. Price (1997). "Energy use and carbon emissions from freight in 10 industrialized countries: An analysis of trends from 1973 to 1992." Transportation Research Part D **2**(1): 57-76.

Schipper, L., R. Steiner, P. Duerr, F. An and S. Strom (1992). "Energy use in passenger transport in OECD countries: changes since 1970." Transportation **19**(1): 25-42.

Schipper, L., R. Steiner, M. J. Figueroa and K. Dolan (1993b). "Fuel prices and economy. Factors affecting land travel." Transport Policy **1**(1): 6-20.

Smokers, R., R. Vermeulen, R. v. Mieghem, R. Gense, I. Skinner, M. Fergusson, E. MacKay, P. t. Brink, G. Fontaras and Z. Samaras (2006). *Review and analysis of the reduction potential and costs of technological and other measures to reduce CO2-emissions from passenger cars*. Delft, TNO Science and Industry.

Stead, D. (2001). "Relationships between land use, socioeconomic factors, and travel patterns in Britain." Environment & Planning B: Planning & Design **28**(4): 499-513.

Stead, D. and S. Marshall (2001). "The Relationships between Urban Form and Travel Patterns. An International Review and Evaluation." European Journal of Transportation and Infrastructure Research **1**(2): 113-141.

Stern, T., C. Dahl and M. Franzen (1992). "Gasoline Tax Policy, Carbon Emissions and the Global Environment." Journal of Transport Economics and Policy **26**(2): 109-119.

Tanner, J. C. (1978). "Long-Term Forecasting of Vehicle Ownership and Road Traffic." Journal of the Royal Statistical Society. Series A **141**(1): 14-63.

Transportation Research Board (2007). Metropolitan Travel Forecasting. Current Practice and Future Direction. Washington, DC, Transportation Research Board.

US EPA (2010). Light-Duty Automotive Technology, Carbon Dioxide Emissions, And Fuel Economy Trends: 1975 Through 2009. . . . Washington, DC, US Environmental Protection Agency.

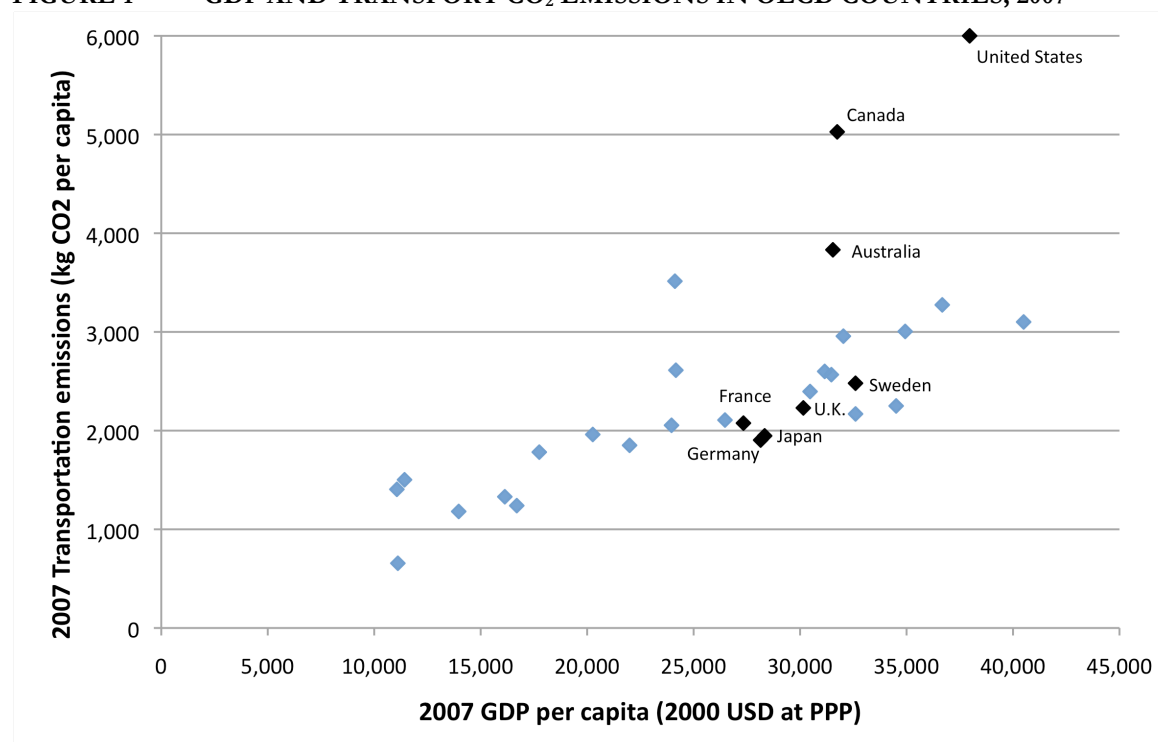
van de Coevering, P. and T. Schwanen (2006). "Re-evaluating the impact of urban form on travel patterns in Europe and North America." Transport Policy **13**(3): 229-239.

WBCSD (2004). Mobility 2030: Meeting the Challenges to Sustainability. Geneva, World Business Council for Sustainable Development.

Webster, F. V. and P. H. Bly (1981). "The demand for public transport." Transport Reviews **1**(4): 323-351.

Weinberger, R., M. Seaman and C. Johnson (2009). "Residential Off-Street Parking Impacts on Car Ownership, Vehicle Miles Traveled, and Related Carbon Emissions." Transportation Research Record **2118**: 24-30.

FIGURE 1 GDP AND TRANSPORT CO₂ EMISSIONS IN OECD COUNTRIES, 2007



Note: Excludes Luxembourg. The eight countries in this paper's sample are labeled and marked with black symbols.

FIGURE 2 TOTAL MOTORIZED TRAVEL ACTIVITY 1970-2007/08

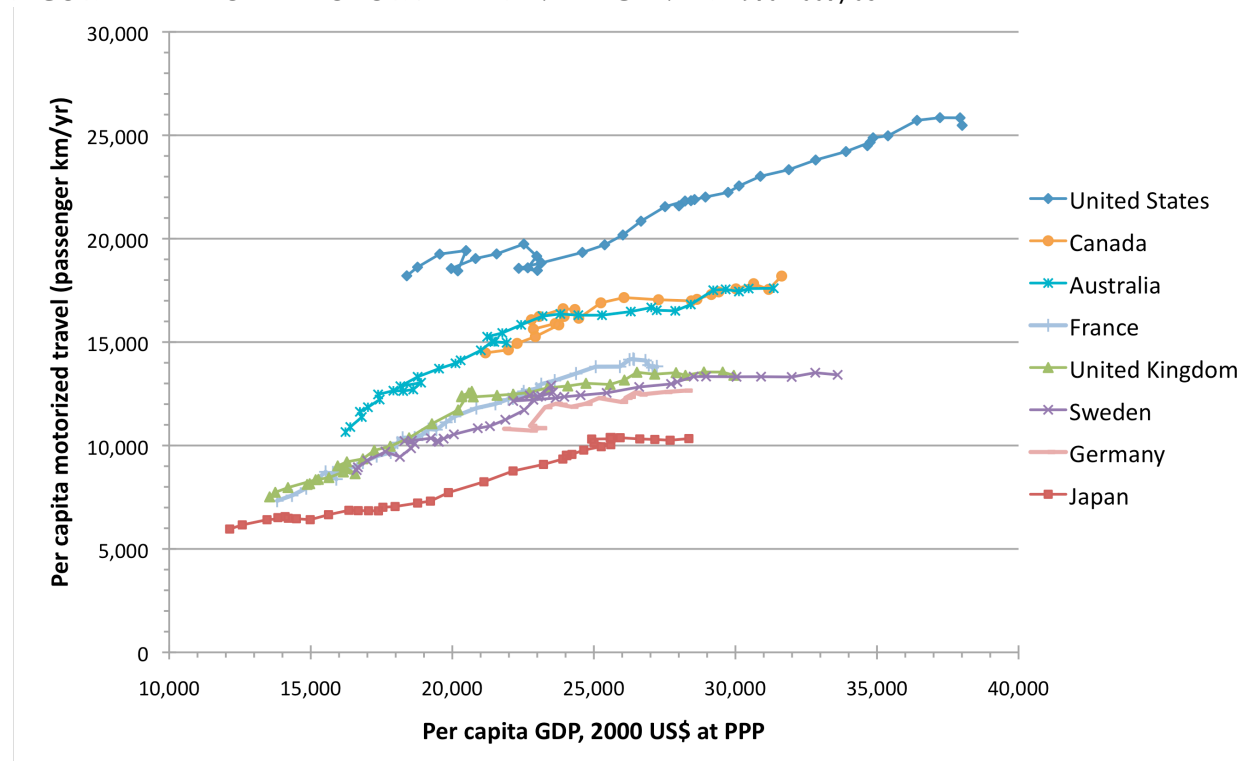


FIGURE 3 DISTANCE DRIVEN IN CARS AND LIGHT TRUCKS 1970-2007/08

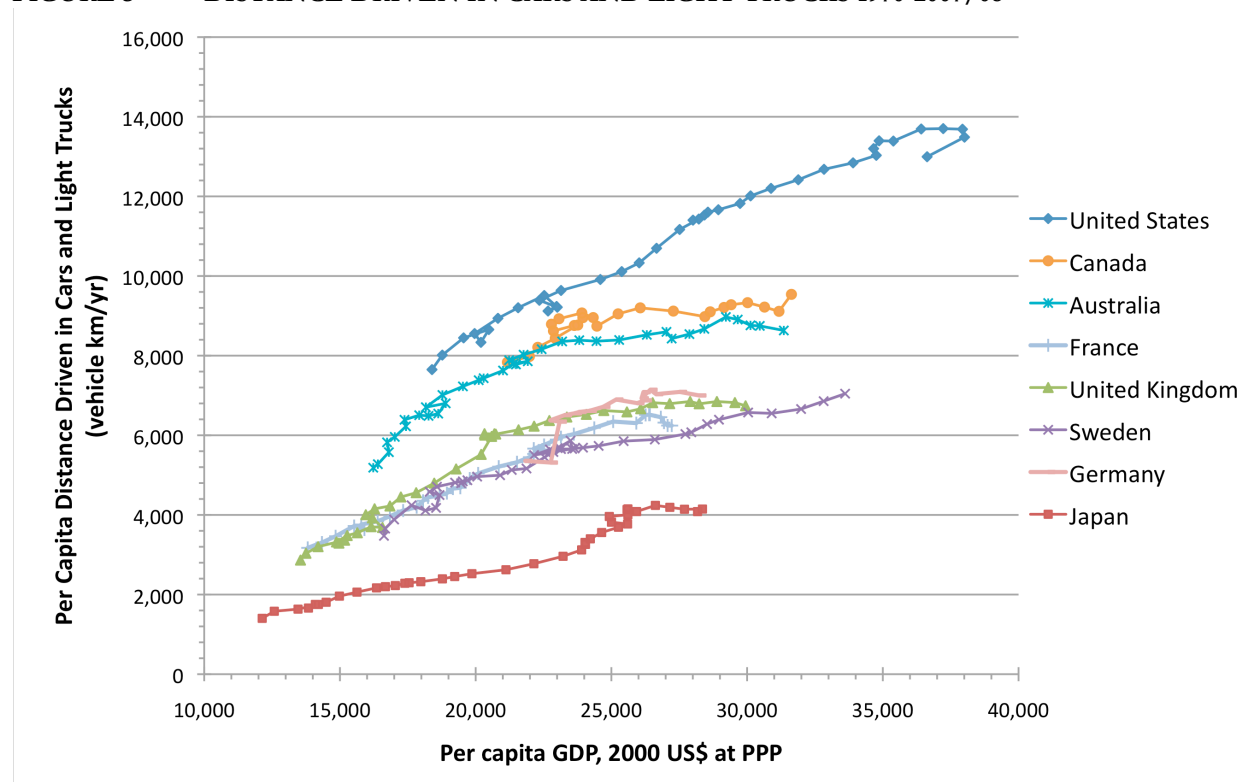


FIGURE 4 VEHICLE OWNERSHIP 1970-2007/08

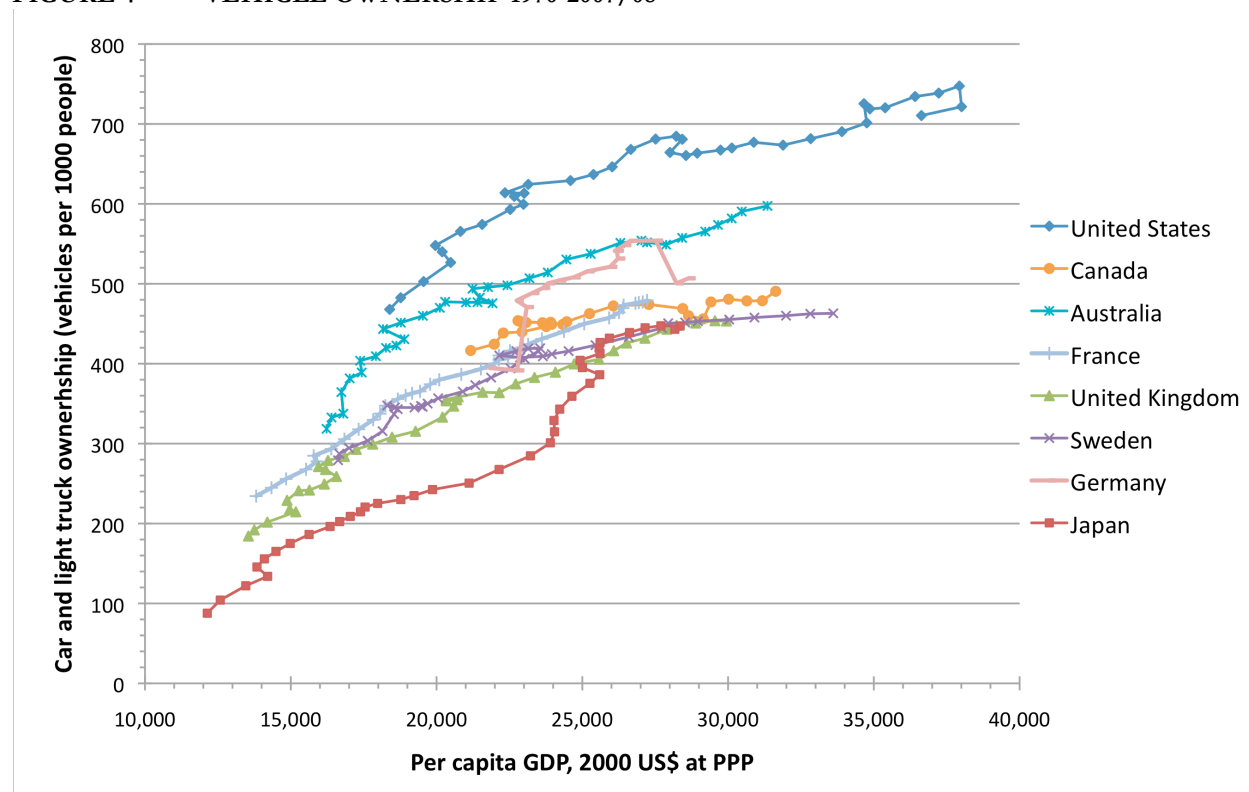


FIGURE 5 PASSENGER TRAVEL ON DOMESTIC AIR SERVICES 1970-2007/08

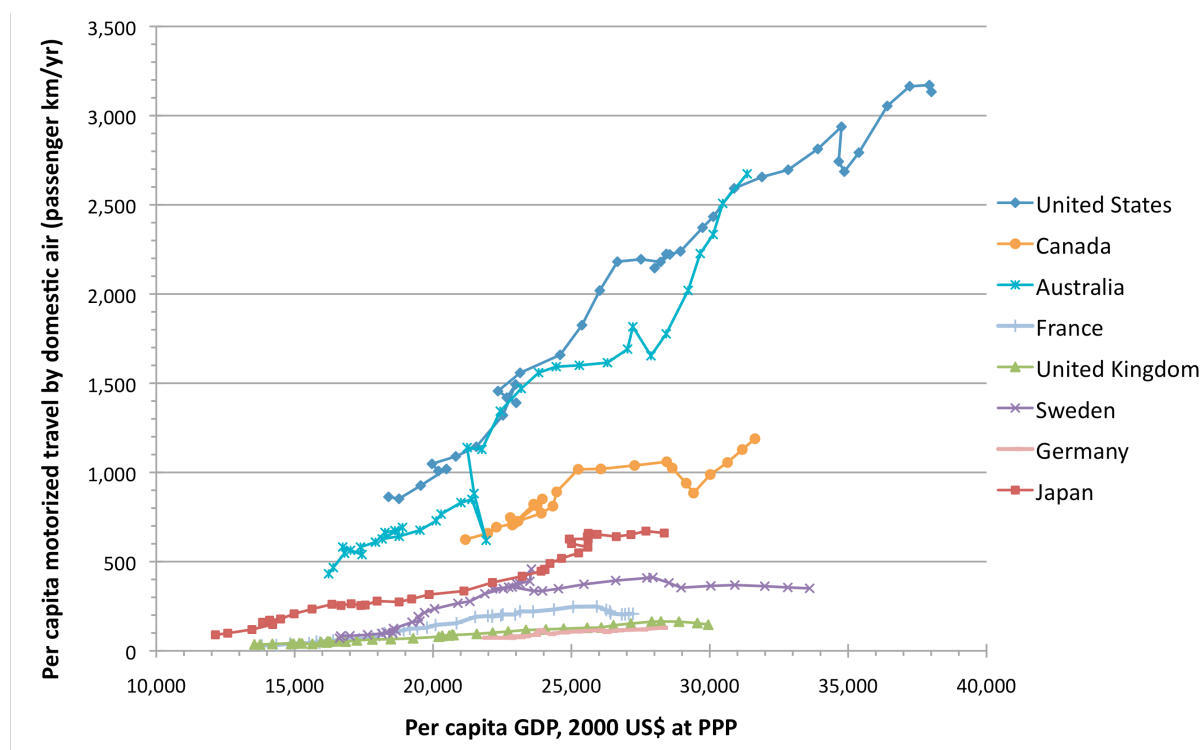
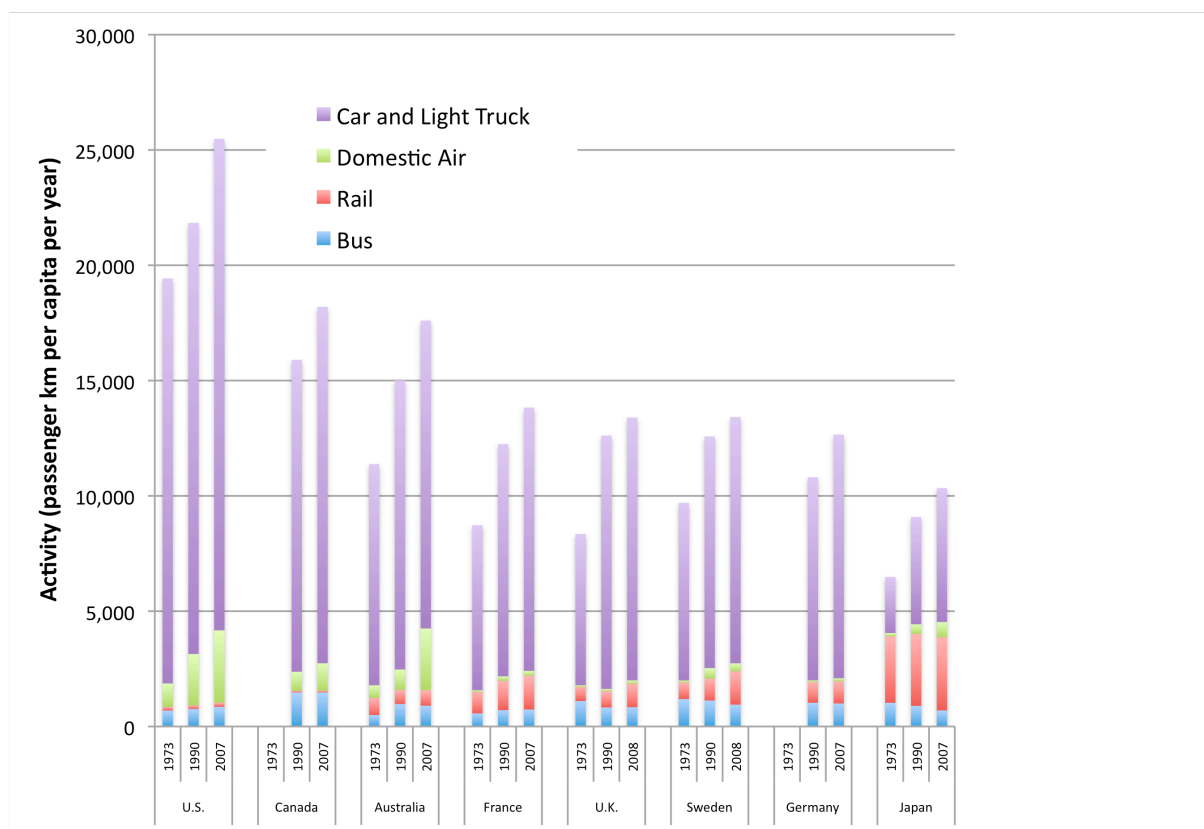


FIGURE 6 PASSENGER TRAVEL PER CAPITA BY MODE

Note: For Canada, metro and other local rail services are included in the "bus" category.

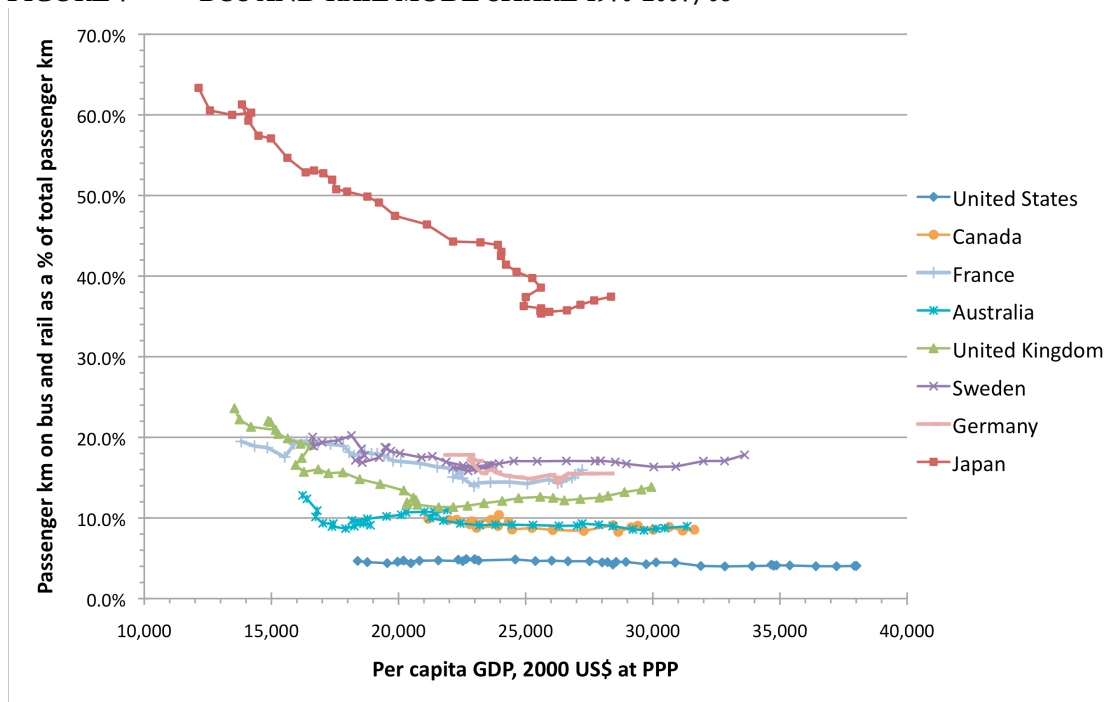
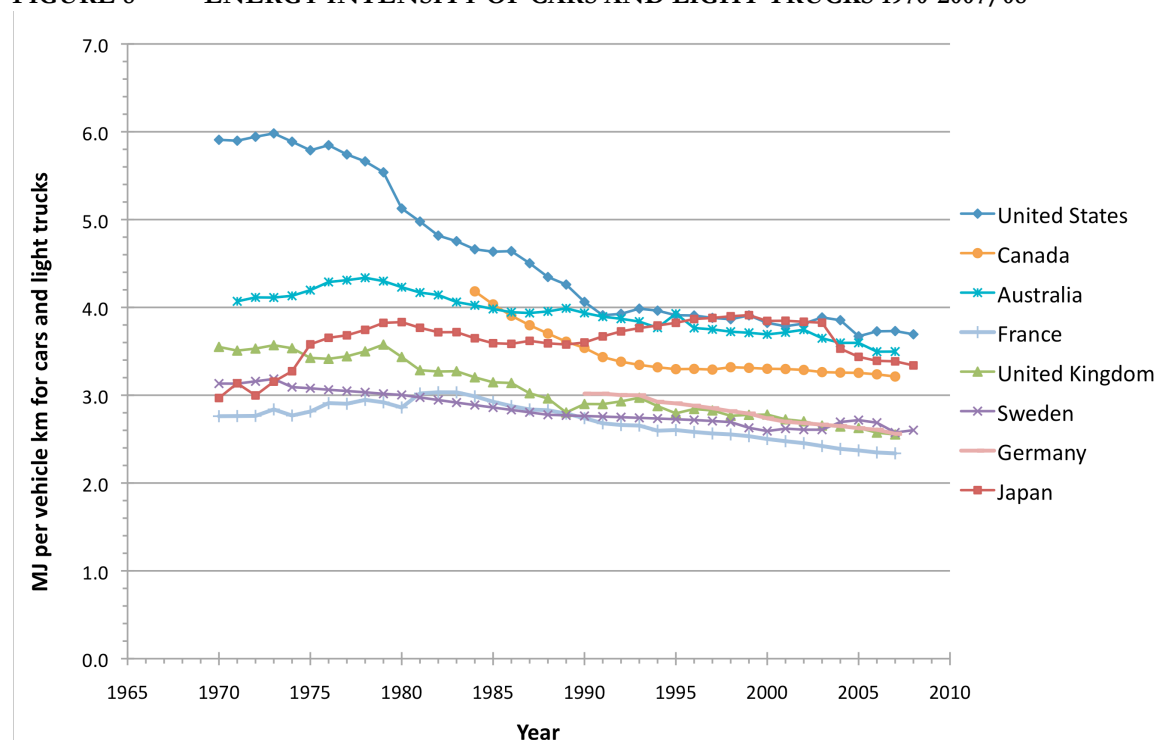
FIGURE 7 BUS AND RAIL MODE SHARE 1970-2007/08

FIGURE 8 ENERGY INTENSITY OF CARS AND LIGHT TRUCKS 1970-2007/08**TABLE 1 LASPEYRES DECOMPOSITION OF PASSENGER TRANSPORT ENERGY USE**

		Australia	Canada	Japan	Sweden	U.K.	U.S.
1973-2007	Actual	2.2%		3.1%	1.3%	1.4%	1.0%
	Activity	2.6%		1.8%	1.3%	1.7%	1.9%
	Structure	0.1%		0.8%	0.1%	0.1%	0.0%
	Intensity	-0.4%		0.3%	-0.2%	-0.5%	-0.9%
1973-1990	Actual	2.8%		4.3%	1.4%	2.3%	0.6%
	Activity	3.0%		2.7%	1.8%	2.6%	1.7%
	Structure	0.1%		1.2%	0.2%	0.2%	0.0%
	Intensity	-0.3%		0.1%	-0.8%	-0.6%	-1.2%
1990-2000	Actual	1.8%	0.5%	3.6%	0.8%	0.8%	1.8%
	Activity	2.1%	1.7%	1.5%	0.7%	0.5%	2.5%
	Structure	0.2%	0.0%	0.9%	0.0%	0.0%	0.0%
	Intensity	-0.5%	-1.2%	0.6%	0.1%	0.2%	-0.6%
2000-2007	Actual	1.5%	1.4%	-0.8%	2.0%	-0.1%	1.0%
	Activity	2.2%	2.0%	0.1%	1.0%	1.2%	1.8%
	Structure	0.2%	0.0%	-0.3%	0.0%	0.0%	0.0%
	Intensity	-0.6%	-0.6%	0.2%	1.0%	-1.2%	-0.7%

Note: 1990 is base year.

Actual: annual average percentage change in energy use.

Activity: hypothetical annual average percentage change in energy use were only activity (passenger kilometres) to vary, with modal structure and modal energy intensities held at 1990 levels.

Structure: hypothetical annual average percentage change in energy use were only modal structure to vary, with activity and modal energy intensities held at 1990 levels.

Intensity: hypothetical annual average percentage change in energy use were only modal energy intensities (MJ per passenger kilometre for each mode) to vary, with activity and modal structure held at 1990 levels.

APPENDIX DATA SOURCES

For each country, data are obtained from either a set of official and semi-official data sources or from a noted national authority. The key data include numbers of vehicles by fuel, average annual vehicle distance driven by fuel, fuel economy by fuel, and thereby total fuel use by fuel. In many instances, the authors' judgment and personal communications with national experts are used to reconcile differences between alternative sources and to interpolate for missing years. Other sources not listed were used in many instances to verify results.

Population and GDP data are from OECD National Accounts using real 2000 local currency converted to U.S. Dollars at the OECD 2000 purchasing power parity (PPP) conversion. Conversions from final to primary energy for electricity were made using IEA data for each country.

Australia

Apelbaum Consulting Group (2009). *Australian Transport Facts 2009*. Also previous editions. These data are based on regular surveys of road vehicle use and fuel consumption and other official sources. See also Apelbaum (2009). Passenger kilometer data by mode from Bureau of Infrastructure, Transport and Regional Economics (2009), *Australian Transport Statistics Yearbook 2009*, BITRE, Canberra ACT. Also previous editions.

Data for years prior to 1984 were compiled by Schipper et al. (2000) as well as by Apelbaum (2009) and references therein.

Canada

The Office of Energy Efficiency of Natural Resources Canada publishes exhaustive tables on all aspects of vehicles, vehicle activity, and fuel use for each branch of transport in Canada back to 1990 and in some cases back to the 1970s. Data are linked to surveys and other information collected by Transports Canada. See <http://oee.nrcan.gc.ca>.

The split between domestic and international air travel was calculated based on Statistics Canada, *Canadian Civil Aviation*, various years.

France

ADEME, the French Agency for Environment, publishes yearbooks on Energy Efficiency Trends and yearly updates on motor vehicles' characteristics and fuel consumption. The Ministère des Equipements issues yearly data called "Bilan de la Circulation" that give data on vehicle use and fuel consumption by mode. See www.statistiques.developpement-durable.gouv.fr/rubrique.php?id_rubrique=47

Germany

Verkehr in Zahlen, published yearly by Deutsches Institut für Wirtschaftsforschung (DIW) in Berlin for the Federal Ministry of Transport, provides key data on vehicle fuel economy and use as well as travel by mode. Various DIW "Wochenbericht" provide more detailed data on the fuel use and distances driven of cars. See <http://www.diw.de/deutsch>.

Japan

Energy Data Modelling Center Energy in Japan, Handbook for 2008/9 and yearly tables published by the Ministry of Land Transport and Infrastructure accessible for the most recent years. Other key data are from Unyu Kankei Enerugi Yoran Showa, published by the Ministry of Land, Infrastructure and Transport. See http://www.mlit.go.jp/k-toukei/transportation_statistics.html

Sweden

Data for historical years were tabulated by Schipper et al. (1993a) and Schipper and Price (1994) from an exhaustive survey of historical Swedish sources. More recent data are taken from the Central Bureau of Statistics (SCB) for numbers of vehicles and driving distance, Statens Institute for Kommunikations Analyser (now Trafikanalys), and Vägverket (the Swedish Road Authority), which publishes an annual vehicle use and fuel consumption overview. Recent top-down data on energy consumption come from Statens Energimyndighet's reports, *Transportsektorns energianvändning*.

United Kingdom

Department for Transport (2009). *Transport Statistics Great Britain 2009 Edition*, London: Department for Transport. Also previous editions.

Energy consumption data from Department of Energy and Climate Change (2009). *Energy Consumption in the UK*. Also previous editions. Energy data also from Department of Trade and Industry *Digest of UK Energy Statistics*, as well as spreadsheets available online from DfT.

Vehicle stock data prior to 1995 from Vehicle Database Report from the Driver and Vehicle Licensing Centre.

In some cases, data are scaled up from Great Britain to the United Kingdom based on population estimates from Office of National Statistics (2009), *Population Trends*.

United States

Davis, S. C., S. W. Diegel and R. G. Boundy (2009). *Transportation Energy Data Book: Edition 28*. Oak Ridge, TN, Oak Ridge National Laboratory. Also previous editions.

Federal Highway Administration's Table VM1, Bureau of Transport Statistics publishes the "authoritative" table of vehicle registrations annual usage and fuel consumption.

The share of light trucks, their annual distances driven and fuel use is taken from various editions of *Transportation Energy Data Book* and interpolated between the years in which surveys are taken by the Truck (Vehicle) Inventory and Utilization Survey by the U.S. Department of Commerce, published every five years until its demise in 2002.

APPENDIX GDP PER CAPITA (2000 US\$ PPP) TO YEAR CONVERSION

Year	Australia	Canada	France	Japan	Sweden	United Kingdom	United States
1970	\$16,270	\$15,638	\$13,330	\$12,136	\$16,622	\$13,547	\$18,391
1971	\$16,227	\$15,808	\$13,895	\$12,581	\$16,665	\$13,748	\$18,771
1972	\$16,397	\$16,477	\$14,412	\$13,456	\$16,996	\$14,195	\$19,555
1973	\$16,803	\$17,410	\$15,235	\$14,205	\$17,638	\$15,173	\$20,485
1974	\$16,736	\$17,803	\$15,813	\$13,840	\$18,149	\$14,963	\$20,194
1975	\$17,020	\$17,865	\$15,587	\$14,094	\$18,541	\$14,872	\$19,961
1976	\$17,433	\$18,548	\$16,210	\$14,491	\$18,669	\$15,268	\$20,821
1977	\$17,378	\$18,966	\$16,710	\$14,980	\$18,307	\$15,641	\$21,565
1978	\$17,919	\$19,520	\$17,296	\$15,627	\$18,573	\$16,151	\$22,526
1979	\$18,264	\$20,063	\$17,830	\$16,348	\$19,242	\$16,567	\$22,982
1980	\$18,621	\$20,235	\$18,038	\$16,676	\$19,526	\$16,195	\$22,666
1981	\$18,897	\$20,687	\$18,102	\$17,041	\$19,465	\$15,952	\$23,006
1982	\$18,165	\$19,858	\$18,432	\$17,391	\$19,695	\$16,276	\$22,346
1983	\$18,775	\$20,197	\$18,553	\$17,548	\$20,055	\$16,842	\$23,146
1984	\$19,531	\$21,170	\$18,738	\$17,979	\$20,900	\$17,245	\$24,593
1985	\$20,112	\$21,980	\$18,964	\$18,775	\$21,330	\$17,809	\$25,381
1986	\$20,294	\$22,289	\$19,331	\$19,227	\$21,872	\$18,474	\$26,025
1987	\$21,008	\$22,932	\$19,706	\$19,861	\$22,540	\$19,280	\$26,664
1988	\$21,404	\$23,761	\$20,494	\$21,117	\$23,023	\$20,204	\$27,514
1989	\$21,920	\$23,949	\$21,222	\$22,145	\$23,496	\$20,588	\$28,220
1990	\$21,483	\$23,635	\$21,666	\$23,220	\$23,555	\$20,689	\$28,430
1991	\$21,233	\$22,865	\$21,779	\$23,904	\$23,144	\$20,334	\$28,007
1992	\$21,766	\$22,792	\$21,969	\$24,047	\$22,736	\$20,326	\$28,556
1993	\$22,431	\$23,069	\$21,676	\$24,028	\$22,152	\$20,740	\$28,941
1994	\$23,187	\$23,913	\$22,076	\$24,225	\$22,863	\$21,580	\$29,741
1995	\$23,817	\$24,330	\$22,464	\$24,642	\$23,648	\$22,153	\$30,128
1996	\$24,451	\$24,466	\$22,635	\$25,261	\$23,955	\$22,715	\$30,881
1997	\$25,287	\$25,248	\$23,062	\$25,597	\$24,531	\$23,360	\$31,886
1998	\$26,305	\$26,064	\$23,784	\$25,004	\$25,452	\$24,077	\$32,833
1999	\$27,029	\$27,283	\$24,446	\$24,923	\$26,600	\$24,721	\$33,904
2000	\$27,220	\$28,444	\$25,233	\$25,593	\$27,727	\$25,573	\$34,759
2001	\$27,874	\$28,641	\$25,520	\$25,578	\$27,944	\$26,079	\$34,660
2002	\$28,425	\$29,149	\$25,601	\$25,586	\$28,525	\$26,520	\$34,863
2003	\$29,217	\$29,413	\$25,701	\$25,892	\$28,964	\$27,149	\$35,388
2004	\$29,655	\$30,019	\$26,166	\$26,594	\$30,038	\$27,902	\$36,415
2005	\$30,124	\$30,642	\$26,456	\$27,126	\$30,905	\$28,234	\$37,225
2006	\$30,467	\$31,175	\$26,821	\$27,695	\$31,988	\$28,887	\$37,934
2007	\$31,352	\$31,633	\$27,983	\$28,213	\$32,820	\$29,550	\$38,009