ARE WE REACHING ”PEAK TRAVEL”?

TRENDS IN PASSENGER TRANSPORT IN 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 transport trends in six industrialized countries (Japan, US, Canada, Australia, Sweden and the UK) providing evidence to suggest that these trends may have halted. Through decomposing passenger transport energy use into activity, mode structure and 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 six 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, and some shifts back to rail and bus modes, and at least somewhat less carbon per unit of energy could might leave the absolute levels of emissions in 2020 or 2030 lower than today.

Keywords: mobility, mode shares, fuel, CO2, sustainability

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 (2009) projects average annual growth 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 traveled (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 2009, the Energy Information Administration (2009) was still projecting annual VMT growth of 1.5% through 2030.

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 CO_2, 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 notable 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. Reduced expenditure on transportation infrastructure expansion may 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 increases past (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. That there exists some level of saturation has long been accepted by modelers 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 "peak travel?"

This paper provides some qualitative evidence to support these ideas of saturation. It finds that since 2003, motorized travel demand by all modes has leveled 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, or the other trends and cross-national differences that we identify. While we draw on explanations anchored in the literature, 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 – particularly those that are, as is the norm in the U.S. at least, not "based on a coherent theory of travel behavior" (Meyer & Miller 2001, cited in Transportation Research Board 2007). 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.

The paper is based on a cross-national analysis of trends in passenger transport in six industrialized countries – the United States, Canada, Sweden, the United Kingdom, Japan and Australia. Where data permits, we supplement this sample with France and Germany. 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. U.S. cities tend to have the highest passenger transport energy consumption, followed by Australia and Canada, Europe, and finally Asia (Newman and Kenworthy 1999). Unfortunately, there are no reliable time series data on travel or fuel use by mode from large developing countries such as Mexico, Brazil, China or India.

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 six countries. The subsequent section provides a formal decomposition of the components of energy demand changes using Laspeyres indices. We conclude with observations on the implications for emissions projections and potential CO_2 reductions.

METHODS AND DATA

A wide variety of national-level data sources were compiled for this analysis, as detailed in the Data Appendix. The paper uses a similar dataset to earlier analyses from 1993 and 1999 (Schipper et al. 1993; 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 changes 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, 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 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. 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. We have taken into account the important differences in the energy and CO_2 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. For Sweden, Australia, the United States and Japan, our series runs through 2007. For the United Kingdom and Canada, it runs through 2006. For most countries the series begins in 1970, except for Australia (1971) and Canada (1984).

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.

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 kilometers; *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, with the exception of electricity, tend to be stable across time and across countries).

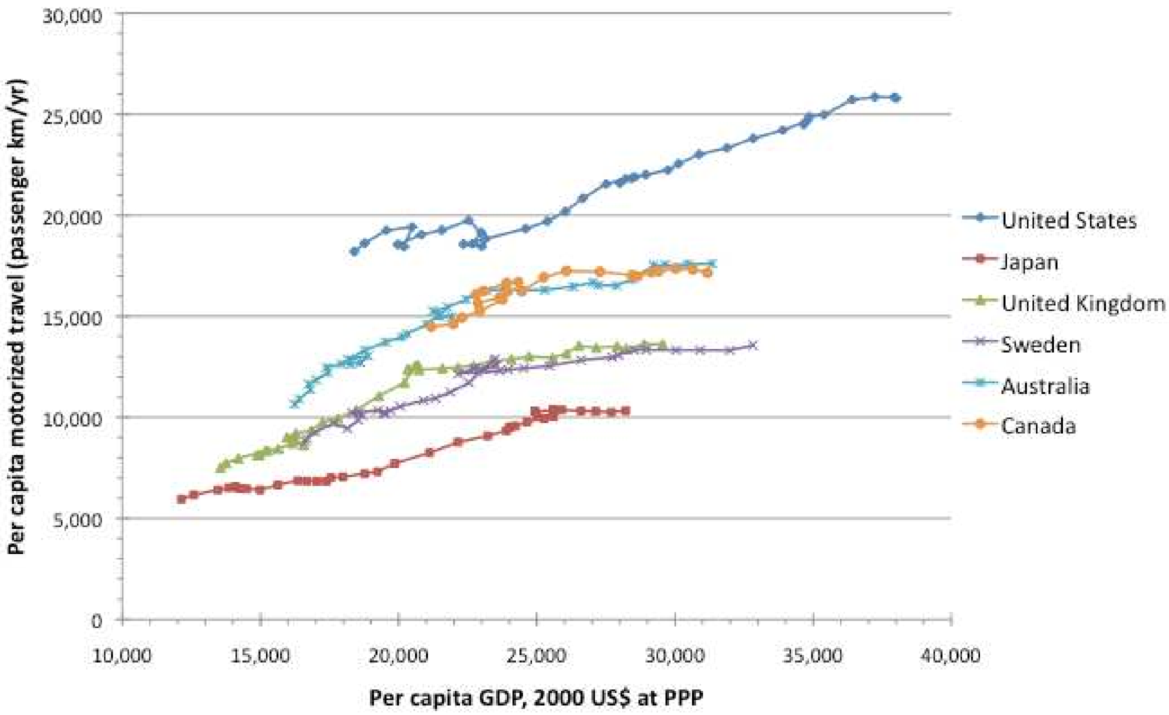
TRAVEL TRENDS

Activity

The last three decades have shown rapid increases in total travel activity, or the number of passenger kilometers traveled in motorized modes. Figure 1 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 Sweden and the U.K.; 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 1. 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 & Small 2005), development patterns and transportation infrastructure (Newman & Kenworthy 1999; van de Coevering & 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.

Figure 1 – TOTAL MOTORIZED TRAVEL ACTIVITY 1970-2006/07



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 explanatory variables across countries over time.

There are signs of a leveling out or saturation of total passenger travel since the early years of the 21st century. This leveling 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 leveling out predated the rapid rises in oil price from 2007. In a study of vehicle travel in the U.S. alone, 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. 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 2 plots total passenger travel in cars and household light trucks against GDP. It shows a similar picture to Figure 1, which is unsurprising as cars and light trucks account for the majority of travel. However, some countries actually posted declines in passenger car travel in the past few years, notably Canada, Australia and Japan. Similar trends (not shown in the chart) can be observed in France and Germany, with both countries lying close to the U.K. values (Schipper under review). Perhaps surprisingly, Sweden continues a slow increase in passenger car travel, although the reliability of the data here are questionable.

Figure 2 – TRAVEL ACTIVITY IN CARS AND LIGHT TRUCKS 1970-2006/07

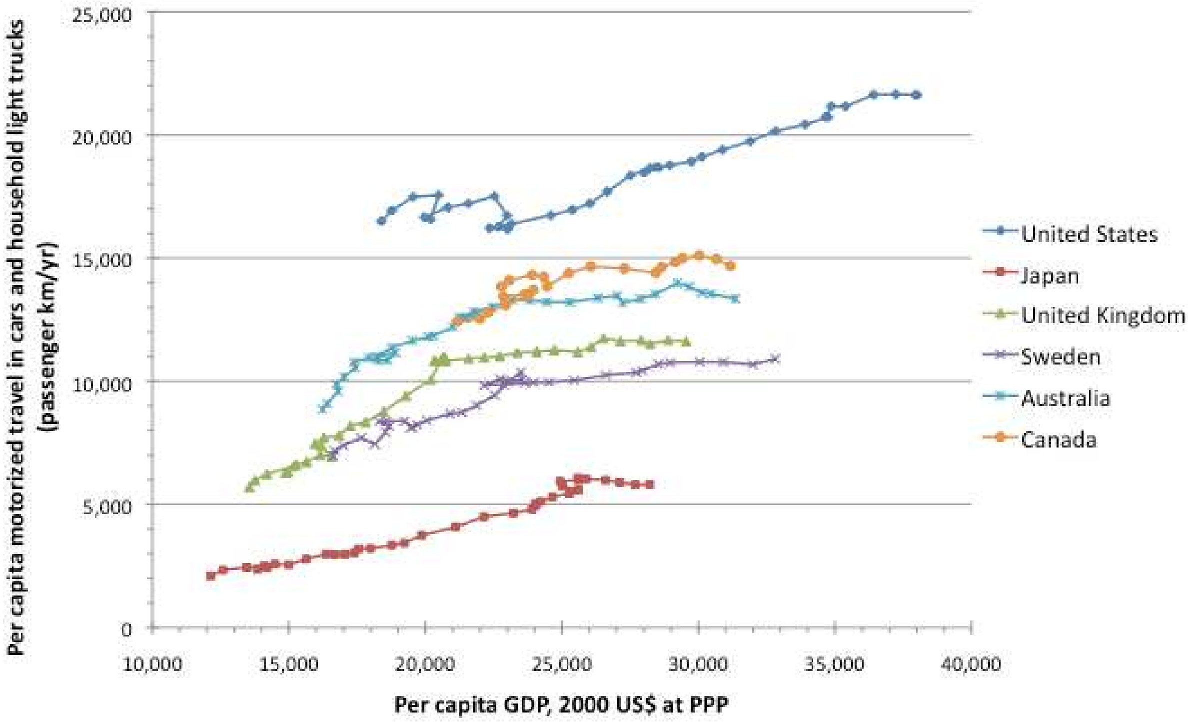
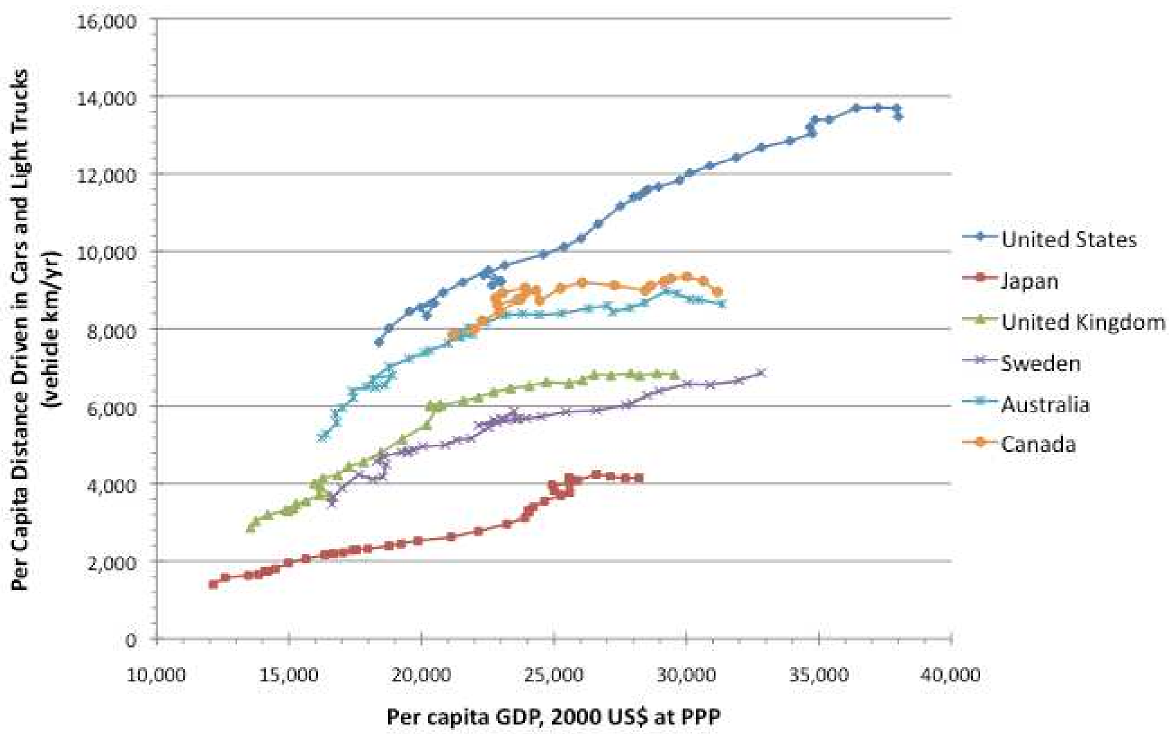


Figure 3 shows total car and household light truck use, expressed in vehicle rather than passenger kilometers. The trends are similar to those in Figure 2, indicating no major changes in vehicle occupancy rates. The exception is the U.S., where vehicle use has increased at a faster rate than passenger travel as carpooling has declined, due to rising vehicle availability, falling fuel prices and demographic shifts (Ferguson 1997).

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 6.8% over this period.

Figure 3 – DISTANCE DRIVEN IN CARS AND LIGHT TRUCKS 1970-2006/07



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 Europe, Canada and Japan which have converged and leveled out at between about 450 and 500 vehicles per 1,000 people. Even the U.S. experienced an apparent decline in ownership rates in 2007 and 2008 according to DOT's Highway Statistics. Growth in car ownership has slowed in every country, with exceptions being a recent spurt in Australia 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 2008). 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.

Factors such as parking constraints, taxes on vehicle ownership, an aging population and saturation of car ownership among those not living in the centers of thriving cities likely explain both these trends and the cross-national differences. For example, parking constraints and taxes have historically been important in Japan (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 passenger cars and light trucks. The Dargay et al. 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 4 - VEHICLE OWNERSHIP 1970-2006/07

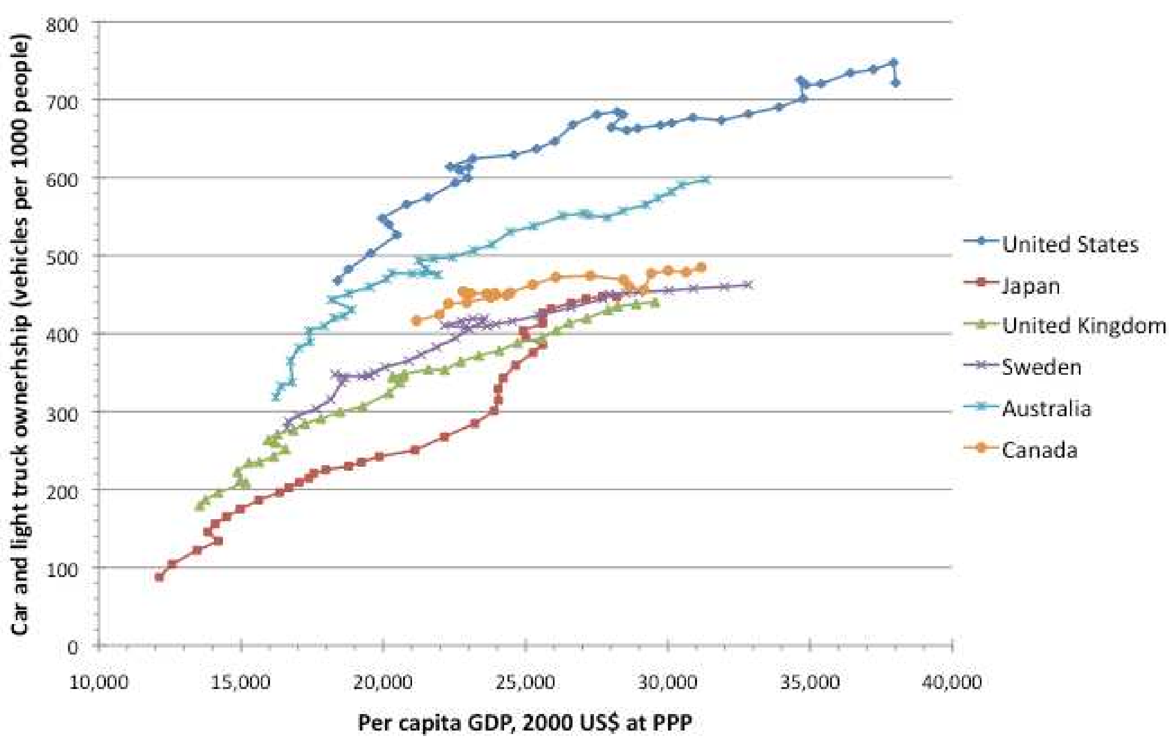
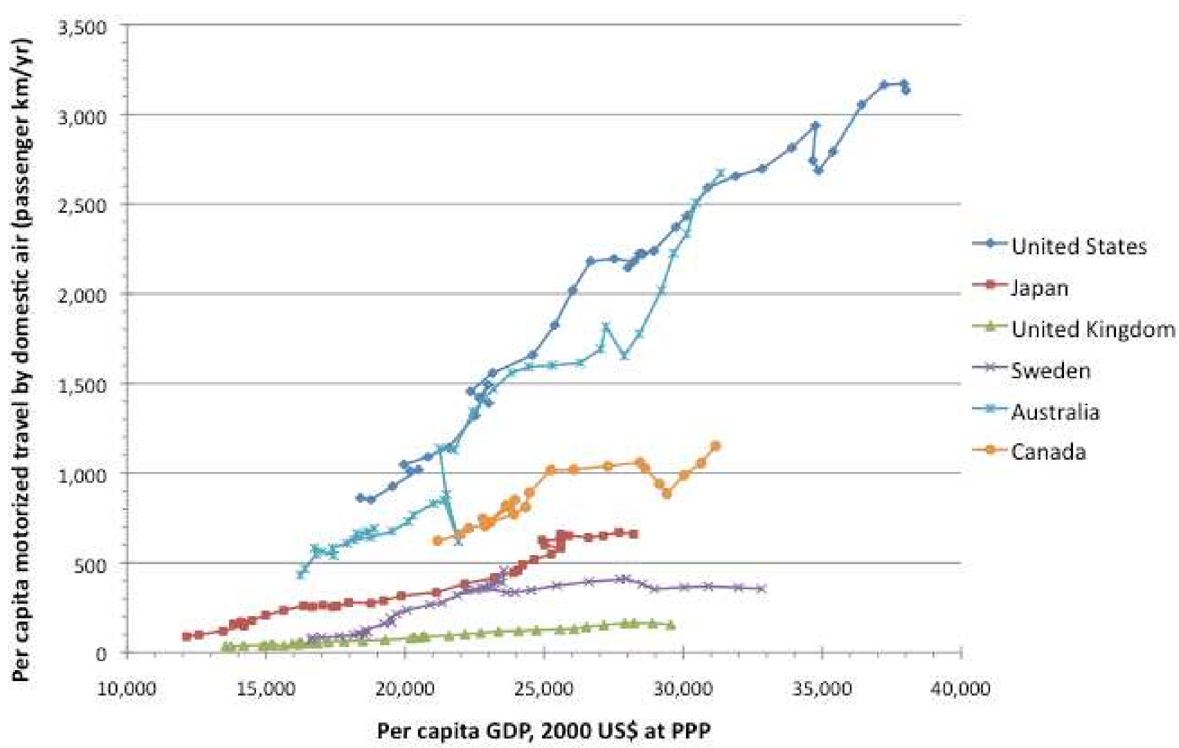


Figure 5 shows passenger travel by domestic air services. The volatility of travel demand is striking. The most recent downturn in demand corresponds to the aftermath of the terrorist attacks of September 2001. (The analysis does not extend to the recent declines in air travel due to high fuel prices, 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; the U.K., Sweden 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 (and their emissions are not allocated to individual countries under the UN Framework Convention on Climate Change). Including these flights would close the gap somewhat, but not completely.

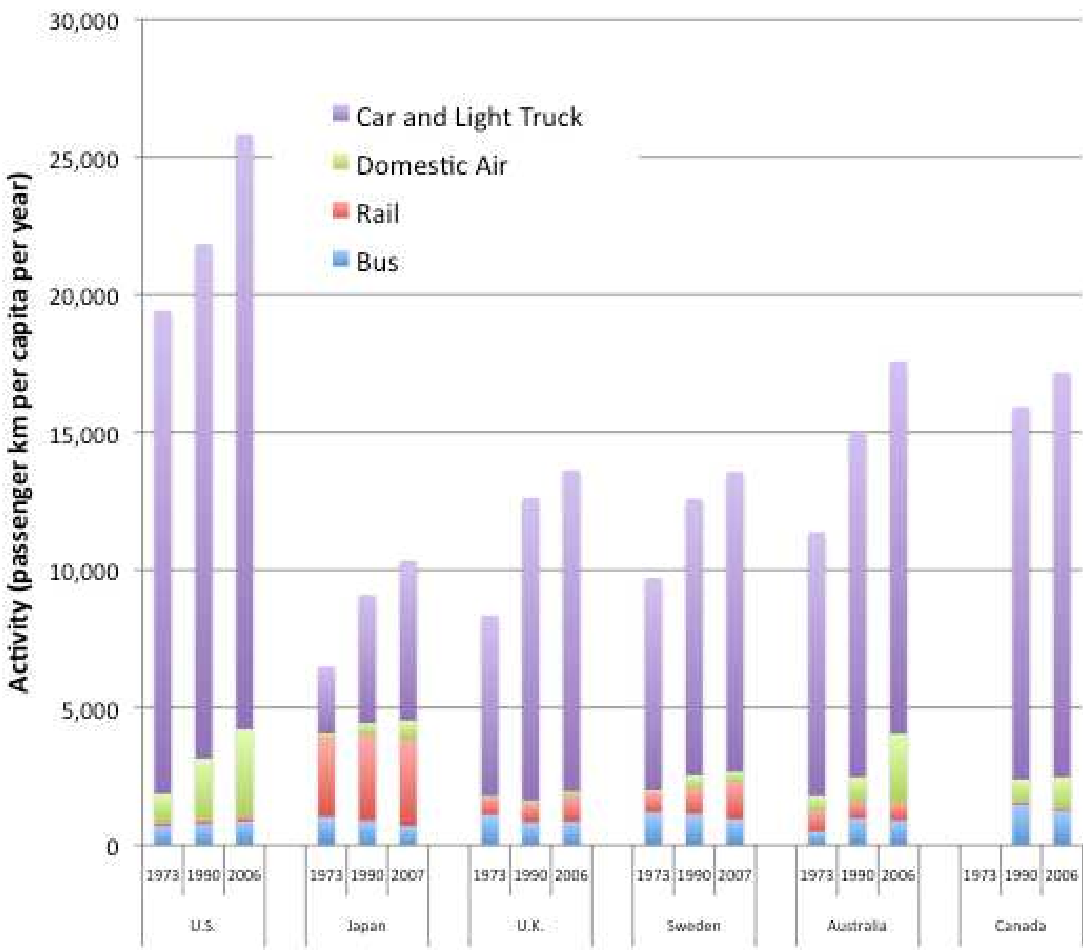
FIGURE 5 – PASSENGER TRAVEL ON DOMESTIC AIR SERVICES 1970-2006/07



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 five of the six countries (Figure 7). However, since 2002 the share of these modes in Sweden and the UK, as well as France (not shown) has held steady or even risen slightly, and even moved up from a much lower level in the United States. 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).

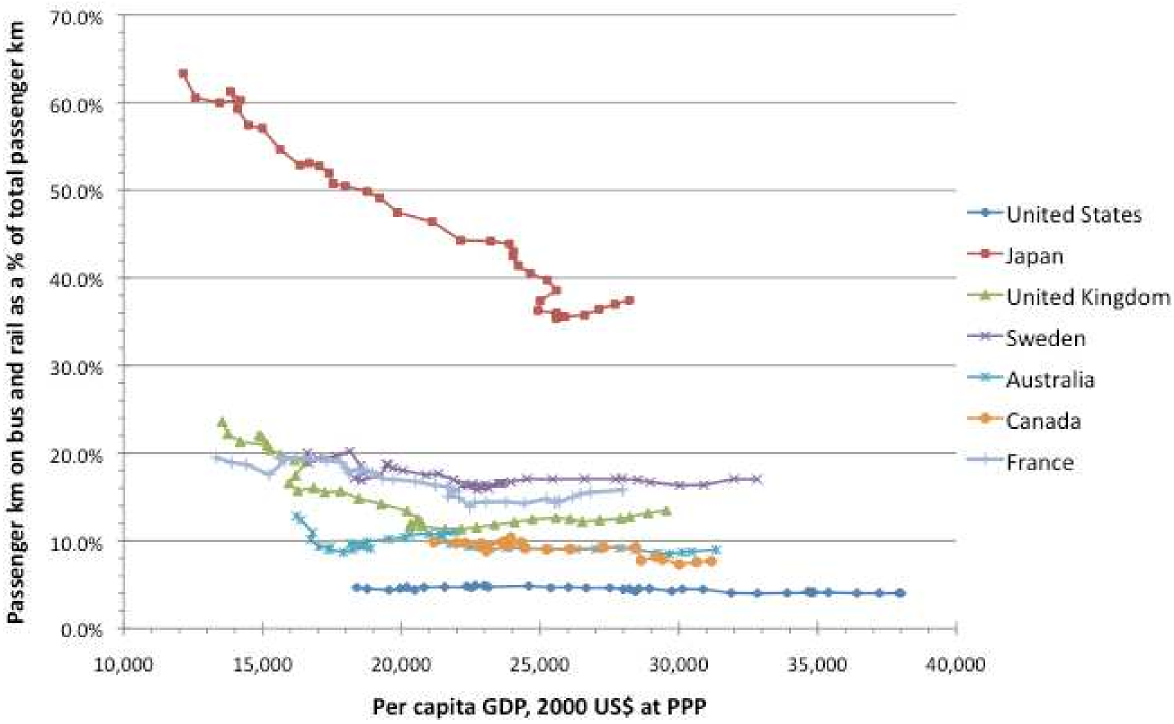
Figure 6 – PASSENGER TRAVEL PER CAPITA BY MODE



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

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 five of the six countries (full data are not available for Canada). 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.

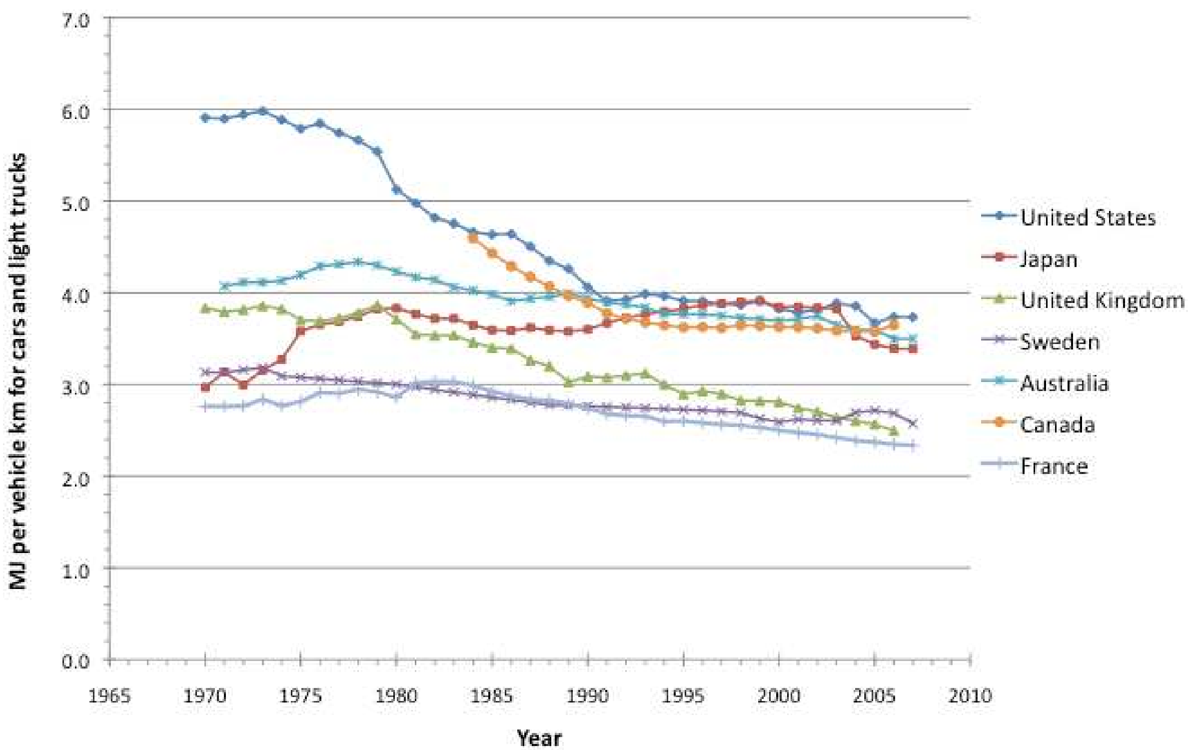
Figure 7 – BUS AND RAIL MODE SHARE 1970-2006/07



Intensity

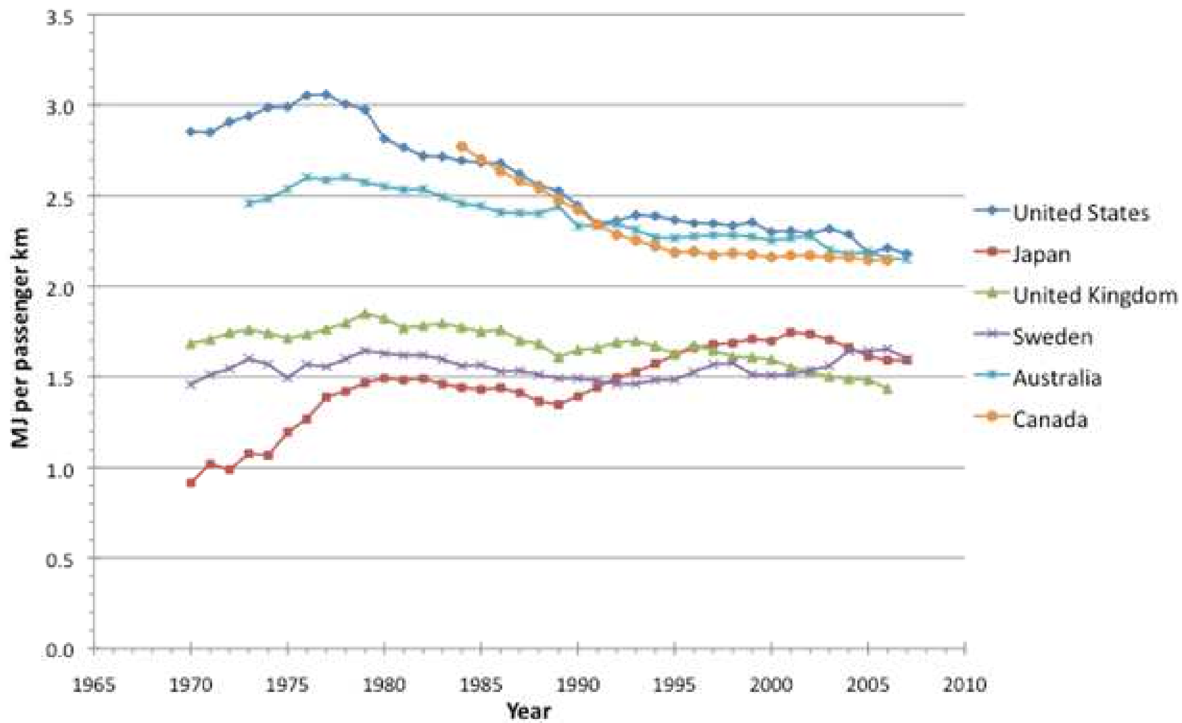
The energy intensity of cars and light trucks has declined in all six countries, as well as France, since 1980 (Figure 8). The most noticeable decline was in the U.S. from the late 1970s – a change which analysts such as Greene (1998) attribute largely to the introduction of Corporate Average Fuel Economy (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, and those in the U.S. started to fall after 2003, when higher oil prices seemed to have led to improved fuel economy of new cars (over the standard) and slightly tighter standards on new light trucks had an impact as well (Davis et al. 2009).

Figure 8 – ENERGY INTENSITY OF CARS AND LIGHT TRUCKS 1970-2006/07



Lower load factors, however, have meant that the change in energy intensity of car travel and aggregate passenger travel has been less pronounced, particularly in Europe (Figure 9). Even though individual modes, particularly cars, have become less energy intensive per vehicle kilometer, 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).

Figure 9 – ENERGY INTENSITY OF PASSENGER TRAVEL 1970-2006/07



In spite of the impact of CAFE standards, 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 (An et al. 2007). Japan has more energy intensive vehicles than Sweden or the U.K.; Schipper (under review) notes that 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, while for Europe the adjustment is closer to 1.12. Older sources for Sweden find an even smaller adjustment for cars there (Schipper et al. 1993), probably because a smaller share of driving occurs in the 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. (Energy intensity tends to decline until stage lengths reach 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 (data not shown).

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 activity, modal structure and modal energy intensity (Schipper et al. 1992). They 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 1973-2006 period and three subperiods. 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 2000-2006. In the U.S., for example, passenger transportation energy use increased by 1.1% per year between 1973 and 2006.

Table 1 LASPEYRES DECOMPOSITION OF PASSENGER TRANSPORT ENERGY USE

		Australia	Canada	Japan	Sweden	U.K.	U.S.
1973-2006	Actual	2.2%		3.1%	1.4%	1.1%	1.1%
	Activity	2.6%		1.9%	1.3%	1.7%	1.9%
	Structure	0.1%		0.9%	0.1%	0.1%	0.0%
	Intensity	-0.4%		0.2%	-0.1%	-0.8%	-0.9%
1973-1990	Actual	2.7%		4.3%	1.4%	2.2%	0.6%
	Activity	3.0%		2.7%	1.8%	2.6%	1.7%
	Structure	0.0%		1.2%	0.2%	0.2%	0.0%
	Intensity	-0.3%		0.0%	-0.8%	-0.7%	-1.2%
1990-2000	Actual	3.6%	1.1%	7.4%	1.6%	0.5%	3.7%
	Activity	4.3%	3.5%	3.1%	1.4%	1.1%	5.0%
	Structure	0.5%	0.1%	1.9%	-0.1%	0.0%	0.0%
	Intensity	-0.9%	-2.3%	1.2%	0.1%	-0.6%	-1.2%
2000-2006	Actual	1.5%	1.0%	-1.1%	2.4%	-0.5%	1.1%
	Activity	2.3%	1.1%	0.0%	0.8%	1.3%	1.8%
	Structure	0.2%	0.1%	-0.3%	0.0%	0.0%	0.0%
	Intensity	-0.7%	-0.2%	0.2%	1.6%	-1.7%	-0.6%

Note: 1990 is base year.

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:

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

Where: A_{it} is total activity (passenger kilometers) 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:

$$\partial^A_{a,b} = \exp\left[\frac{\log E^A_{ib} - \log E^A_{ia}}{b-a}\right] - 1$$

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 1.1% and 3.1% a year over the study period. The 1990s were a particular period of rising activity, but the rate of growth has slowed since the turn of the century in all countries except the U.K.

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:

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

Where: A_{i0} is as above, S_{mit} is the share of passenger kilometers for each mode *m* in country *i* in year *t*; I_{mi0} is the energy intensity of each mode (MJ per passenger kilometer) 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 case in which activity and modal shares remain constant, but the energy intensities of different modes change. Energy use under the "Intensity" case E^I is calculated as a percentage of total energy use in the base year as follows:

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

Where: I_{mit} is the energy intensity (MJ per passenger kilometer) of each mode *m* in country *i* in year *t*; A_{mi0} is total passenger kilometers 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 Activity.

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 improved enough to offset increases in total activity. Particular gains in 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 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).

CONCLUSIONS

Several conclusions emerge from this international comparison of travel trends. First, total domestic travel 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 away from travel in cars has not been an important explanation for rising energy use, except in Japan where they were a major factor until the turn of the century. Thus major factors pushing up fuel and CO_2 emissions appear less important, at least during the present decade, than before.

The energy intensity of car travel, the dominant factor in travel-related energy use and CO_2 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. It is possible that accelerated decline in the energy intensity of car travel, stagnation in total travel per capita, and some shifts back to rail and bus modes, and at least somewhat less carbon per unit of energy could might leave the absolute levels of emissions in 2020 or 2030 lower than today. Whether more ambitious targets can be met depends both on how much less carbon per passenger kilometer will be emitted. But it also depends on the total level of activity.

We did not analyze fully the reasons why the levels of travel and automobile fuel economy differ so widely among the study countries. However, fuel prices certainly play a role in the differences in intensities and to some extent mode shares of ground travel. Given the wide range of travel at a given GDP, fuel prices, geography, urban structure and transport infrastructure must play some role. The demographic transition to a more elderly population, one consequence of very slow population growth in Japan and Europe, may also contribute. The fact that car use has slowed or declined in all the countries (as well as several not shown) suggests that, whatever the causes of differences in travel among industrialized countries, some kind of peak or plateau in per capita travel has been reached. How broad that peak is, and whether we will soon see a decline on the other side, is a question that cannot be answered yet. Further work using each country's most recent travel surveys would help answer many questions. However, the assumption of continued, steady growth in travel demand, which is inherent in many transport models and energy use projections, is one that planners and policy makers should treat with extreme caution.

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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, Fundación 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 (2009). *Transportation Energy Data Book: Edition 28.* Oak Ridge, TN, Oak Ridge National Laboratory.

Duranton, G. and M. Turner (2009). *The Fundamental Law of Road Congestion: Evidence from US cities*, NBER Working Paper.

EDMC (2008). *Handbook of Energy and Economic Statistics in Japan.* 2008 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 (2009). *An Updated Annual Energy Outlook 2009 Reference Case Reflecting Provisions of the American Recovery and Reinvestment Act and Recent Changes in the Economic Outlook.* Washington, DC, 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 (2009). *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.

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." Tr*ansportation Research Part A* 18(2): 97-109.

Newman, P. and J. R. Kenworthy (1999). *Sustainability and cities: overcoming automobile dependence.* Washington, D.C., Island Press.

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.

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. (under review). "Automobile Fuel; Economy and CO2 Emissions in Industrialized Countries: Trends through 2008." *Transport Policy.*

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., 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 (1993). "Fuel prices and economy. Factors affecting land travel." *Transport Policy* 1(1): 6-20.

Stead, D. (2001). "Relationships between land use, socioeconomic factors, and travel patterns in Britain." *Environment & Planning B: Planning & Design* 28(4): 4993.

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.

Sterner, T., C. Dahl and M. Franzén (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.

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.

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.

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. 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 are 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 complied by Schipper et al (1998) as well as by Apelbaum for that 1998 study.

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.

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.

Sweden

Data for historical years were tabulated by Schipper et al (1994, 1995 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 the Swedish Road Authority, which publishes an annual vehicle use and fuel consumption overview. Various publications from Banverket, Vägverket, Statens Insitut för Kommunikationsanalys, Statistiska Centralbyrån and Statens Energimyndighet are also used.

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.

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.

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.

Other sources include the Federal Highway Administration’s Table VM1, Bureau of Transport Statistics, and new vehicle fuel economy from US EPA.