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## **Automobile Fuel; Economy and CO2 Emissions in Industrialized Countries: Troubling Trends through 2005/6**

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### **ABSTRACT**

A review of recently available data on both on-road fuel economy and new car test fuel economy shows that while US on-road fuel economy has been flat for almost 15 years, major European countries and Japan have shown modest improvements in response to “voluntary” agreements on fuel economy, steadily rising fuel prices (since 2002), and to some extent shifts to smaller cars and 2<sup>nd</sup> family cars.

At the same time the sales weighted average of new vehicles sold in the European Union, expressed in terms of their implied CO2 emissions, have fallen short of 2008 goals. That a significant part of the improvements in Japan are related to the growing share of mini-cars (displacement under 600 CC) suggest that technology is not the only factor that can or will yield significant and rapid energy savings and CO2 restraint in new cars.

Fuel economy technology, while important, isn't the only factor that explains differences in tested or on-road fuel economy when comparing vehicle efficiency and transport emissions in different countries. Fuels, technology, and driver behavior also play significant roles in how much fuel is used. As long as the upward spiral of car weight and power offsets much of the impact of more efficient technology on fuel efficiency, fuel economy will not improve much in the future. And as long as the numbers of cars and the distances cars are driven keep creeping up, technology alone will have a difficult time offsetting all of these trends to lower fuel use and CO2 emissions from this important sector.

## 1. AUTOMOBILES, FUEL AND CO<sub>2</sub> IN A LONGER TERM PERSPECTIVE

Energy use and travel for personal transport in wealthy countries is dominated by automobiles. While fuel economy improvements and some slowing of the rise in ownership and use of automobiles has lowered the growth in fuel use, these vehicles still account for roughly 9% of total energy use (and 20% of oil use) in OECD countries, with higher shares in the United States (1.) Their share in total energy use in developing countries is smaller, but rising rapidly (2). Since most all fuel is from oil products or natural gas, automobiles also account for a significant amount of global release of carbon dioxide, the main greenhouse gas associated with climate change. Hence the automobile and its energy use is a central focus of energy and environmental authorities in almost every country.

This paper focuses on a automobile fuel economy, defined as fuel use per traveled of automobiles and household light trucks. By paying some attention to car ownership and use, as well as new vehicle characteristics like weight, power, and fuel, policy makers gain of understanding of what is causing total fuel use to rise, and what components of that rise might be changing towards restraint of fuel use.

This work updates a series of papers by Schipper and co-workers. Schipper et al. (3,4) set out some of the difficulties facing development of data and subsequent analysis of the components of automobile fuel use, particularly in countries like the United States, where actual fuel use is not surveyed and vehicle usage only inferred from infrequent travel surveys. Schipper and Tax (5) reviewed the fundamental problem of understanding the gap between tested new vehicle fuel use and that obtained in real traffic. (6) presented an historical analysis of automobile usage and fuel consumption in a dozen countries of the International Energy Agency, work which led to usage and fuel economy published in the ORNL data book (7). Ref. (8) carried out the first international cross-section, time-series econometric analysis of automobile *fuel* consumption, i.e., quantities of gasoline, diesel, and even LPG consumed by automobiles. Ref. (9) expanded this analysis to all modes of both travel and freight through 1995, based on earlier analyses of freight activity and fuel use in IEA countries (10). These figures were updated in (1) and (11). Finally, (12) analyzed diesel cars in five countries in Europe with significant use of diesels and in two cases LPG cars as well.

The IEA (1) monitored on-road fuel intensity of cars through 1998 with some data extending to 2000, but there has been little published information since that time other than from individual countries. A focused effort evaluating real fuel economy and comparing with simulations as well as the test/actual gap has been undertaken by Zacharides, Samaras and colleagues in Europe (13-16), particularly with the development of the Voluntary Agreement Limiting CO<sub>2</sub> Emissions from new cars promulgated by the EU (17). Overall, however, little has been done internationally to estimate on-road fuel economy across countries.

This update is important for several reasons. First, concern for oil consumption has been enhanced, if not supplanted, by concerns about the CO<sub>2</sub> emissions associated with fuels use for automobiles. Indeed, the European Union entered into a Voluntary Agreement with EU country vehicle manufacturers by which the latter would strive to lower the CO<sub>2</sub> emissions per kilometer of new cars by some 20% between 1998 and 2008. Enough time has passed to allow at least a cursory evaluation of the changes in those specific emissions relative to the 2008 target. A similar program called "Top Runners" was kicked off in Japan in 1998 as well (11). And starting in 2002, world oil prices have climbed, sending road fuel prices in the US up by almost 100% by 2007 and by roughly 40% in Europe and Japan. Indeed, both climate and higher oil prices in the US led to much political debate. Thus we expect to see changes in all three regions given both price changes and policy changes.

At this writing, US authorities seem headed for a serious revision of the present standards. A revision of standards affecting light trucks and SUV's promulgated by the US Dept. of Transportation called for a reduction in sales-weighted fuel use in new vehicles of this type of some 7% starting in 2008. The share of new light trucks/SUVs in 2005 and 2006 dropped slightly from its slow 40 year rising trend (18). And car

and light truck use is off relative to its long-term trends against economic activity (in GDP) (19, Table VM-1 and Fig. 10 below). Judging the impact of past changes is crucial for understanding what could happen in the future, and how much influence changes in policies or changes in fuel prices might have.

## 2. ON ROAD FUEL ECONOMY - APPROACH

We have updated the figures for on-road fuel economy from previous work. While the national data sources are similar those used previously (see Appendix), those from France, UK, and Japan have more details and expanded coverage than previously. As we shall argue, understanding on-road fuel economy (and consequent CO<sub>2</sub> emissions) is critical for both interpreting how changing fuel prices and other conditions have changed vehicle use and vehicle purchases, and for estimating the impacts of future policies and technologies. Whatever the tested or hoped-for fuel economy and emissions were, the atmosphere sees the real emissions.

National authorities have three approaches to estimating fuel economy and vehicle usage. The most accurate fields surveys of thousands of drivers to record annual fuel use and annual vehicles utilization (Australia, Canada, France, Netherlands until 1998, the US in the early 1980s). Some countries survey parts of this couplet, Sweden for vehicle use for example. As a variant, it is possible to derive annual vehicle use from national travel surveys if these represent all seasons and days of the week. It is also possible to estimate fuel use from household budget surveys if respondents also supply average prices of fuel they paid. These approaches are bottom-up.

Less accurate approaches use infrequent travel survey data and other estimates of vehicle utilization, together with model-based estimates of fuel economy or limited survey data to pin down total vehicle use. Often gasoline use is estimated by subtracting from total sales estimated quantities for two wheelers, gasoline mini buses and light trucks, and other miscellaneous uses of gasoline. Diesel is more complicated in Europe, because it is distributed among trucks and cars, unlike in the US, where almost all is used for trucks (and a small amount for buses and specialty vehicles like fire engines.) With the rising popularity of diesel cars in Europe, more careful surveys are needed measure independently fuel intensity and distance/vehicle. This is also true for gasoline in countries with high use of diesel for cars, since the number of gasoline-using vehicles maybe shrinking, and average distance/year for gasoline and diesel cars differs widely. Without surveys, analysis collides with a circularity, i.e., estimating distance per car as total fuel divided by fuel economy while estimating fuel economy as total fuel divided by distance per car and numbers of cars (3). While the U.S. uses the most top down approach (total km estimated from state data, total fuel use from gasoline sales parsed into cars and light trucks), the low use of diesel and other fuels (including biofuels) makes this acceptable for identifying large changes. Unfortunately, when distances traveled are changing slowly and fuel economy hardly at all, the US approach is not very accurate for separating changes in fuel economy from changes in vehicle use. These two components have become the object of policy debates, such as whether higher fuel prices have affected car use or fuel economy. Adding ethanol to gasoline makes the estimating of yearly changes even more difficult. Thus in the US almost nothing can be said today about year on year changes in overall fuel use as measured by sales alone.

Why is accuracy important? First, stakeholders need to know the parameters determining automobile use if they want to agree on policies to change fuel use. Second, the same stakeholders will hold authorities accountable for what did occur if a policy is instituted. One contentious element of this debate is the so-called rebound effect, by which lower fuel intensity, particularly if imposed by standards, is associated with a small degree of increased driving (20). Without good measures of fuel use, vehicle use, and fuel economy, it is virtually impossible to untangle impacts of higher fuel prices on fuel economy and car use over time to compare what is observed with what would have been expected with no improvement in fuel economy. The problem in part is that even a blunt, top down instrument, raising fuel prices, is contested today – what is the elasticity of vehicle use and fuel use in the short and long term? How much do higher fuel prices affect which car a multi-car household drives? And how much do higher prices influence new car fuel economy, as

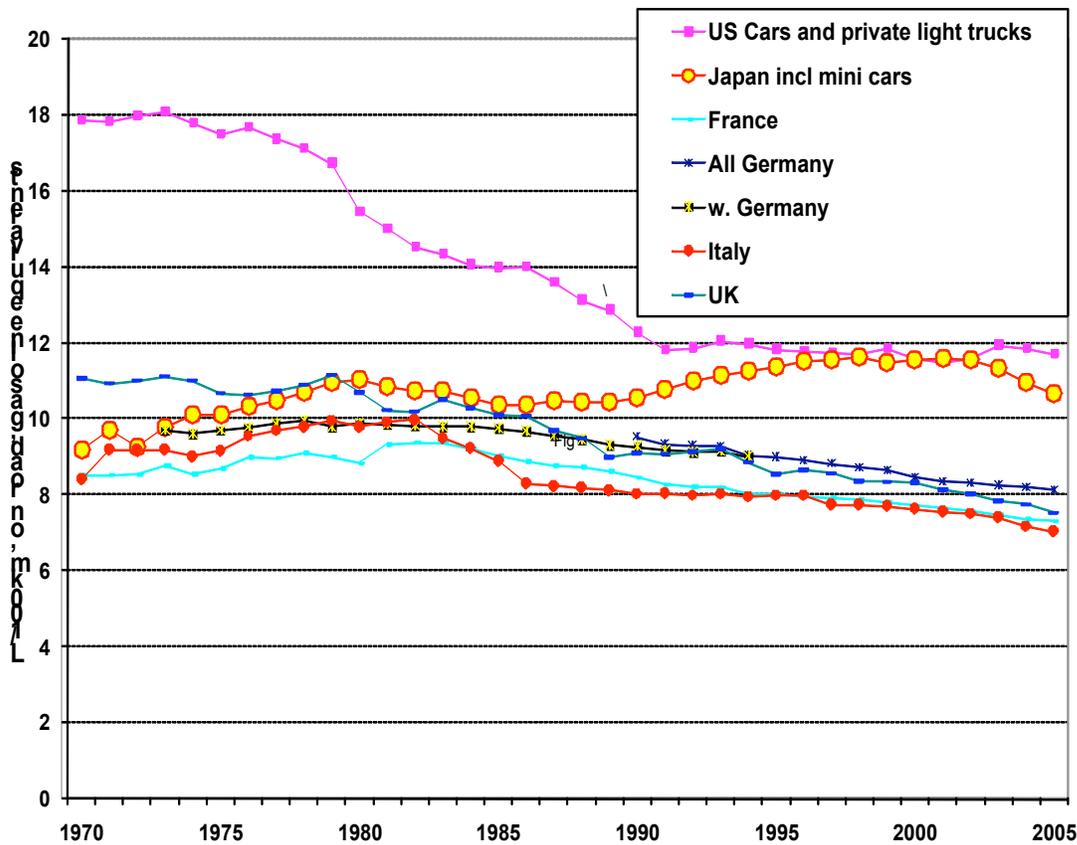
measured not by tests but by on-road surveys. Finally, how do higher prices, fuel economy standards, and other forces affect car uses in different geographical locations or from different income strata? Only regular surveys could answer these questions. In the US, by contrast, there has been no wide surveying of vehicle use and fuel economy since 1985, which leads to much speculation and debate as to the impacts of past policies and potential for prospective initiatives. Good policies require good information before and after.

The approach taken by the past teams (and that used by the national authorities cited herein) has to follow certain rules. First, the vehicles must be defined. For example, in the US, the Vehicle Inventory and Utilization Survey taken every five years for all trucks (until its recent demise), allowed the main US data compilation [7] to discern the share of light trucks, their utilization and fuel use (about 80% in 2002) truly linked to households, rather than to businesses or government. Fortunately in other countries in the present paper, light trucks/SUVs contribute a small portion to the automobile stock as “automobiles” or are counted in that stock (7). Second, for many European countries, authorities must estimate the small but not insignificant share of foreign vehicles using their roads and fuel, and somehow eliminating use of cars garaged in each country but driven elsewhere for vacation or business. This leads to the purchase of fuel in one country by residents of another country. Indeed, this problem plagues many US states and multi-state areas like Chicago, the NY City region, or Washington DC. For Europe, the most notorious example is Luxembourg, whose low fuel prices attract drivers from Belgium, Netherlands, Germany and France to give that country very high gasoline use as measured by sales. In short, there are many effects that while small in most cases, can cover up slowly changing trends.

Equally important is accounting for all fuels. While CNG is insignificant, liquid petroleum gas (LPG, mostly propane) has been important in some countries (Netherlands, Italy, and to a lesser extent in France). Diesel use has been rising. Unfortunately, some countries report fuel economy of the entire stock in volumetric terms without taking into account energy content of different fuels. In our work when a volumetric figure is cited for fuel economy, i.e., l/100 km, diesel and LPG are converted to gasoline at their energy equivalents, i.e., a liter of diesel counts as approximately 1.12 liters of gasoline, while a liter of ethanol would be counted at roughly 66% of the value of gasoline. Some countries (US, Japan Canada, for example) report energy equivalents of volumetric quantities higher heating value, i.e., roughly 34.2 MJ/liter of gasoline, while others report the heating value net of energy used to evaporate water in the fuel, e.g. roughly 31.4 MJ/l of gasoline. Consistent accounting makes comparisons in either energy or volumetric units possible, and conversion to CO<sub>2</sub> using standard IPCC practices straightforward.

### **3. RESULTS FOR ON ROAD FUEL ECONOMY**

Figure 1 shows on-road fuel economy for six countries: US, Japan, UK, France, Germany, and Italy, with Germany representing “western” Germany before 1995 and all Germany from 1991, leaving four overlapping years. Diesel and LPG are included at gasoline equivalents defined above.



**FIGURE 1 On road fuel economy for US, Japan and European Countries gasoline equivalent L/100 km. Data sources see Appendix.**

The rapid improvement in fuel economy in the US in the 1970s and 1980s was, much larger than uncertainties in data at that time. This behavior contrasts with the slower and less dramatic improvements in European countries or Japan, which actually saw a turn around in the late 1980s and 1990s as worsening traffic and larger cars together more than offset technological improvements in fuel economy. While Japan, w. Germany and France engaged manufacturers in voluntary agreements to improve fuel economy, these did not have the same political force that those of the late 1990s did. However, the four European nations shown exhibit a slow but continuing decline in fuel intensity while Japan’s finally turns around in the early 2000s and that of the US shows a small improvement that is not reflected in new car averages (see below), but may arise when families who can use their smaller car more and their larger car less.

Vehicle ownership and use has continued to grow in all these countries, but the resulting total v-km has been lagging behind GDP growth since the late 1990s, in contrast to earlier years (1; 9). Saturation of ownership occurs as more and more families in Europe and Japan acquire a 2<sup>nd</sup> car not driven as much the first car. A booming low-cost air travel market and fast international trains in Europe could be taking some long-distance travel that would have occurred on cars, too. Finally, worsening traffic, while having a deleterious effect on fuel economy, does tend to retard vehicle use as more and more time is required to move about. In short, car use is growing more slowly, but growth in use still pushes fuel use up more than increased fuel economy retards fuel use growth.

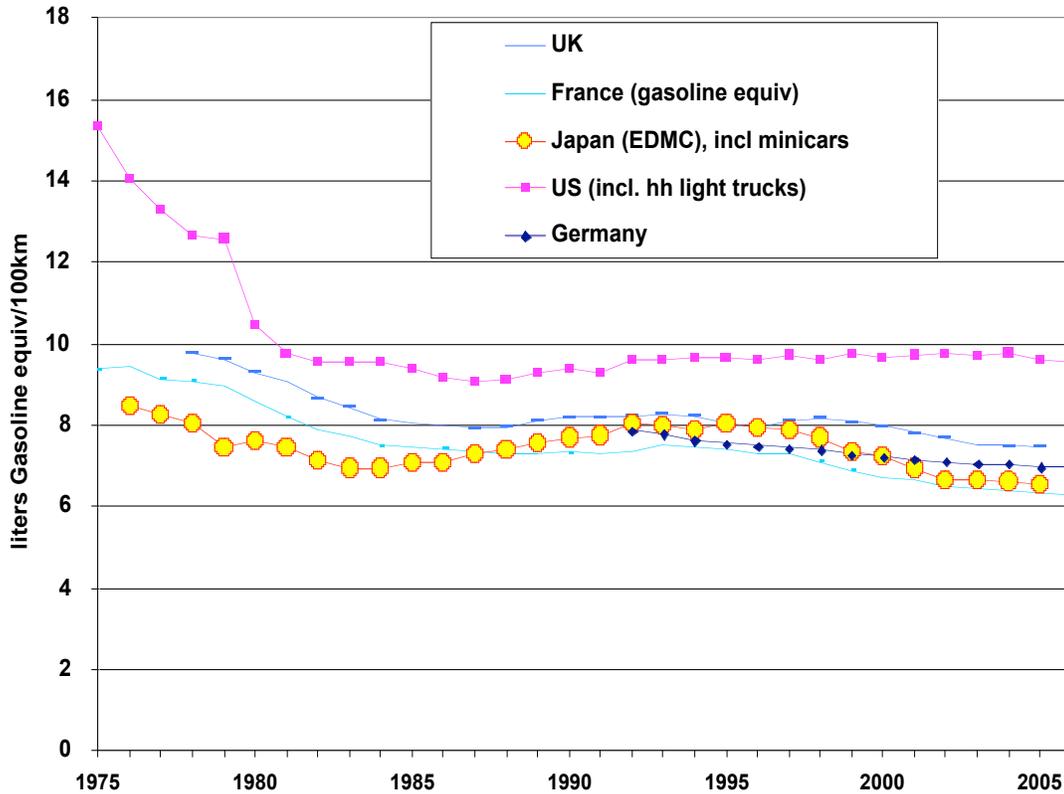
**4. NEW CAR FUEL ECONOMY**

New car fuel economy, as measured by tests and weighted by sales, is an important indicator of how on-road fuel economy will behave as the fleet is renewed. But a cautionary note is important. Ref. (5) and references therein have emphasized the enormous uncertainties in interpreting sales-weighted test values of new vehicles. While such indicators are extremely important in determining the overall impact of technology and consumer choice, they are very difficult to translate into on-road values that can be matched to what is derived from bottom-up surveys or top-down analysis applied to the entire stock. Ref. (18) and other US EPA sources make some estimates of the approximate translation of CAFÉ test values of each model year into on-road that are remarkably realistic. For the 1996-2005 period, for example, (18) estimated on road MPG of the combined new car and light truck sales at 21.3±0.2 MPG, remarkably close to the on-road estimate that as not fluctuated very much. Were the “real values” for these cars that would be measured by surveys much different, the on road estimates would not have been so flat.

Unfortunately, in a debate over the impact of small changes observed in fuel use, or in the impact of modest changes in new vehicle fuel economy, better accuracy is needed. Since the “gap” between test and real world is likely changing with increased speeds, congestion, accessory use (particularly air conditioning in the US, Japan, and now even Europe), continual revision of revision of tests and chaining of results is necessary to obtain long-term time series that are realistic measures of how well vehicles will do in real traffic. Such revisions have occurred in Japan and Europe, and are about to be imposed in the US. Few believe the gap can be eliminated, however. Only a wide, regular survey of vehicles by vintage permits comparison of fuel economy from a given year with what was indicated for that cohort from new vehicles sales.

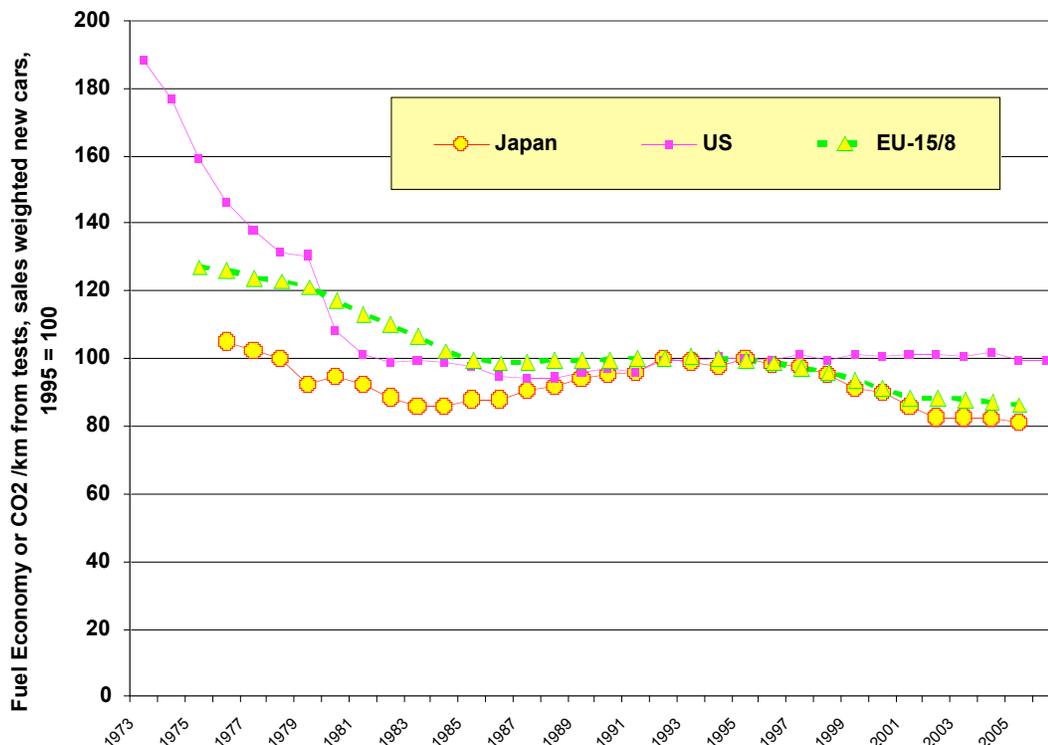
This gap has important ramifications for discussions of policies aimed at boosting fuel economy. The widespread misunderstanding of the gap means politicians may expect larger changes in fuel economy because “new” as proposed may be much larger than “on road”: At this writing, for example, the US congress is debating a 35 MPG, sales-weighted standard that would average in both SUVs and cars. “On road” fleet average today is closer to 21 MPG. If the 35MPG figure is deflated by approximately 20% (5, 18) to be comparable to today’s “on road”, then the difference between the two is 28/21 or 33%, which means 25% less fuel/km new vs. fleet, instead of 35/21 or 40% less fuel/ km. That difference, 15%, is equivalent to nearly 1 mn barrels per day of gasoline at 2006 rates of use.

This new/actual/fleet gap is even larger in Japan, as can be seen by comparing the so called 15-mode test values of cars sold in the last dozen years with official on road calculations for either regular cars or mini-cars (21). The 15-mode test (the basis for figure 2 below) gave 8.1 l/100 km in 1995, from which new vehicle on road averages fell to just over 6.5 l/100 km in 2005. But the on-road figures fall from 11.3 l/100 km to only 10.6 l/100 km in the same period. This implies that the roughly half the stock that was bought between 1995 and 2005 could not have achieved anywhere near the fuel economy implied by tests. Similarly, while the EU target for gasoline cars implies about 6.8 l/100km (35 MPG), the EU on-road average by 2005 appears close to 28 MPG, implying a 20% gap between new and on road. Thus expectations (or hopes) that Japanese or Europeans have already attained a high fleet fuel economy must be moderated. Moreover, it must be remember that a complete turnover of the fleet in any country takes between 10 and 20 years, so one as a way to go before seeing the ultimate impact on the fleet of standards or any spontaneous improvement in new vehicle fuel economy.



**FIGURE 2 New vehicle sales-weighted fuel economy gasoline equivalents for each year shown, using each country/region’s testing procedures, from each country’s official publications.**

With this in mind, Figure 2 shows US, Japan, and a number of European Country averages for new vehicle fuel economy. For the US, the EPA light truck average is counted with cars, using 80% of the light truck sales as indicative of how many should be averaged with cars sold to give a combined value. Japanese values are chained from the 15-mode (and earlier 10mode) tests reported by (21). European values are given as weighted averages provided by EU (22) and before then the European Automakers Association (ACEA) as tabulated by the European Council of Ministers of Transport (S. Perkins, ECMT/OECD, priv., comm.). Figure 3 then shows these values indexed to their 1995 values, the year from which EU authorities have tabulated figures to gauge the progress of their voluntary agreement on lower CO2 emissions/fuel economy. Indexing eliminates misleading comparisons of countries with different test procedures. As noted above, diesel is counted at its energy equivalent, which gives somewhat different values for France, Italy, or Germany when those countries report new vehicle fuel economy.



**FIGURE 3 Long term trends in new car sales-weighted fuel economy indexed to 1995. Source: Official national sources, EU.**

Either portrayal suggests three period. The 1970s and early 1980s saw a dramatic decline in new vehicle fuel intensity in the US and more modest but still substantial declines in Japan and EU. In the mid 1980s to mid 1990s, EU new vehicle fuel intensities were stagnant while those in Japan and the US rose as SUVs in the US and larger cars in Japan became increasingly more important. Finally, after 1995, values in Japan and EU headed down again, presumably as voluntary agreements came under discussion, while the US average fluctuated. While the EU values through 2005, approximately 165 gm/km of CO2 in absolute terms, fall short of a path to the ultimate goal (140 gm/km) the improvements are still in stark contrast to developments in the US, where, ironically, the relative changes in fuel prices from higher crude prices have been much larger because so little of the price is taxation.

**5. IMPACT OF DIESELS – AMBIGUOUS**

Shifting from gasoline to diesel should save fuel and reduce CO2 emissions as well, goes the mantra in Brussels. In theory diesels are much more efficient, as matched pair analysis in Schipper et al 2002 showed. But the same analysis questioned the ultimate role of shifting to diesel if the goal is less fuel use or carbon emissions than otherwise.

The analysis of data in the 2002 study was reviewed briefly and the same important surprises still hold. Recall that when account is taken of the greater energy density of diesel and the greater CO2 released per unit of energy in diesel fuel, diesel fuel economy values have to be increased by 12% in energy terms or 18% in CO2 terms before they can be compared with gasoline. This step cuts the apparent advantage of diesels significantly. The lower energy use and CO2 emissions associated with producing diesel only make up for a small part of this difference.

**TABLE 1 Parameters of Diesels in France and Germany, 1995 and 2005 Source Ref. 12, Ademe (2006), Verkehr in Zahlen (2007) and DIW (2007)**

		France		Germany	
		1995	2005	1995	2005
<b>New Diesels</b>					
Share of Sales	%	46.5%	69.1%	14.6%	42.6%
Test Fuel Economy	L/100 km	6.60	5.60	6.5	6.5
Fuel Economy Relative to gasoline	%	88.0%	83.6%	85.5%	86.4%
CO2/km Rel. to gasoline,	%	104%	99%	101%	102%
<b>Stock of Diesels</b>					
Share of Stock	%	26.5%	46.6%	13.7%	20.0%
Yearly distance	KM/ car	20627	16736	17980	19470
Distance, Rel. to Gasoline	%	178%	164%	144%	180%
<b>On Road Fuel Economy</b>					
Fuel Economy	l/100 km	6.67	6.43	7.47	6.82
Relative to gasoline	%	78.6%	83.9%	81.7%	81.7%
Rel. to gasoline, CO2/km	%	92.7%	99.0%	96.4%	96.4%

Note in this table CO2 derived from IUPCC values for direct combustion of each respective fuel.

Table 1 shows diesel and gasoline new car fuel economy in 2005 in two important European markets. Also shown are the “on road” values for those countries as well as the average distances gasoline and diesel vehicles are driven. Why is energy use/km of diesels so close to that of gasoline cars? First, in a matched pair/model analysis in the original paper, diesel cars were heavier than gasoline cars, and their engines were larger (in CC) than those of gasoline cars, in part to provide more torque. And when the figures for energy use are translated into CO2, the results show only a small advantage of diesel cars, which for Germany is negative because SUVs are mostly diesel. Values obtained for the Netherlands (K. Geurs, RIVM priv. comm.) show the same behavior. In France there is no CO2 advantage of purchased diesels over purchased gasoline cars, and in Germany diesels bought in 2006 emitted more CO2/km than gasoline cars because of the popularity of diesel SUVs. Over all EU countries, however, Zacharides (2007 priv. comm.) finds that the 2004 emissions/km average is about 6% less than it would have been if the diesel/gasoline new car market shares had been constant at their 1995 values. He also notes that diesel car fuel economy improved faster than that of gasoline cars. So overall we must conclude there is a small extra reduction in CO2 emissions per km due to a higher share of diesel cars.

A different and potentially critical effect is also shown in the table. Diesel cars in Europe are driven 40-80% more than gasoline cars. Part of this effect is the fact that diesel cars are on average newer, as their numbers (in new car sales) have risen faster than new gasoline cars. Being larger than gasoline cars, they may be used more as first family cars or for touring. The small number of taxis and other professional vehicles that are diesels, with yearly driving in excess of 60 000 km/year is another effect. These cars were chosen for durability and to some extent for fuel economy. There is also a self selection process – since diesels given equivalent performance cost more than gasoline cars, drivers who pick them must figure how many more miles they drive before a diesel becomes less costly overall to own and drive. This up-tick in driving was

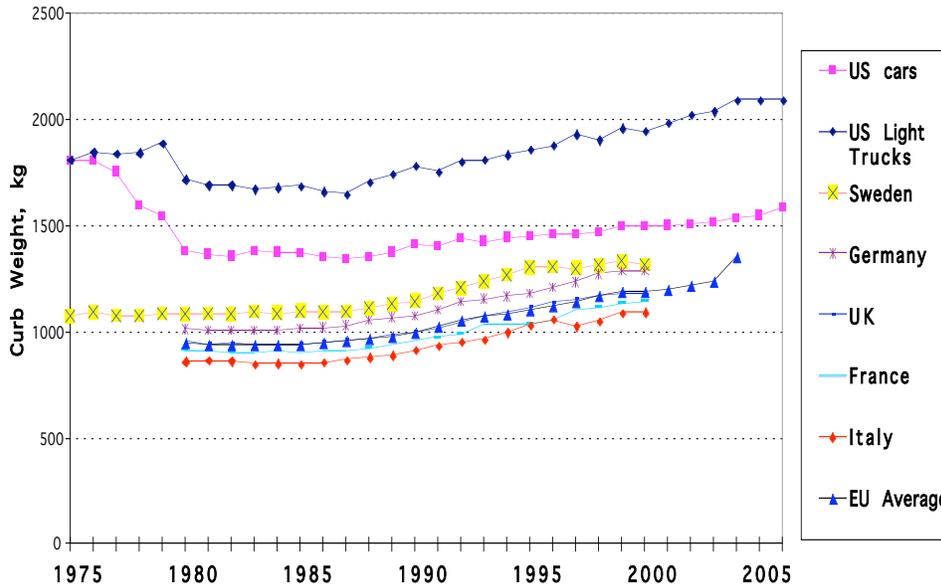
confirmed by a direct survey of French drivers who switched to diesel carried out in the mid 1990s (23). The various increases or differences in average driving distance are hard to account for by any of these effects along or in combination. Instead, the low price of diesel (as much as 30% lower in some European countries, i.e., greater than the differences in fuel economy) must contribute as well to greater driving. As (12) noted, even a rebound effect of -0.2 can boost driving of lower fuel-cost diesel enough to offset any advantage of fuel economy in overall CO<sub>2</sub> emissions.

The results of these diverse impacts of dieselization on usage also has another interesting effect. While diesel yearly mileage is significantly higher than that of gasoline, the average for the stock of each fuel type is slowly falling in some countries. It appears that “new” diesel drivers use their diesels more than they would have driven gasoline cars, but less than existing diesel drivers used their cars. As the higher mileage drivers leave the gasoline fleet for diesels, the average distance driven by gasoline cars fall slightly. But the weighted average of gasoline and diesel car distance is falling less rapidly, and not falling on a per capita basis. Indeed, in Germany diesel mileage is rising, perhaps because 1995 was still feeling the impacts of the reunification, for which eastern Germany was still catching up in motorization to w. Germany. It appears for these countries (as well as UK, Italy, and Netherland, not shown here) that the switch to diesels is in part responsible for an increase in driving compared to what would have obtained if market shares of gasoline were constant.

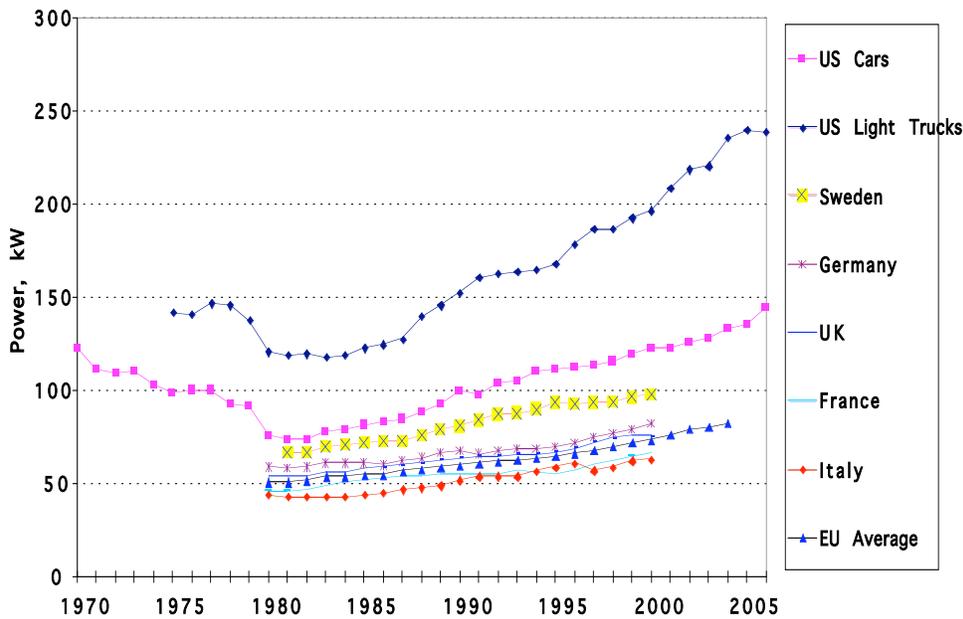
In other words, the broad findings of (12) remain with 10 more years’ of data – increased dieselization per se has only contributed to a small decline in energy use/km or CO<sub>2</sub> emissions/km. If only a small part of the higher yearly use of diesels is attributed to the combined effects of the lower cost per km of using diesel fuel – mostly the lower price and to some extent the lower specific use – then it is still hard to say that dieselization leads to significant energy saving or lower CO<sub>2</sub> emissions. Whatever the cause of greater diesel use, the net savings in fuel and CO<sub>2</sub> emissions are small. Given concerns over the emissions of particulate matter and NO<sub>x</sub> from diesels (24), it remains questionable whether the popularity of diesel cars is as beneficial as hoped for on environmental grounds.

## **6. THE RACE FOR WEIGHT, POWER, AND SPEED**

Throughout this report we have avoided using the term “efficiency” for the indicators we have presented. The reason is clear – real fuel efficiency, if expressed as energy required to move a given mass a given distance, or the energy required to provide a given level of power to an engine, or to extract a given amount of power from a given volume has risen markedly in the US and Europe. In simple terms, these efficiency improvements have more or less countered increased weight and power (as well as extras) in the US, overwhelmed them in one period in Japan, but only taken back part of the improvements in true efficiency in Europe.

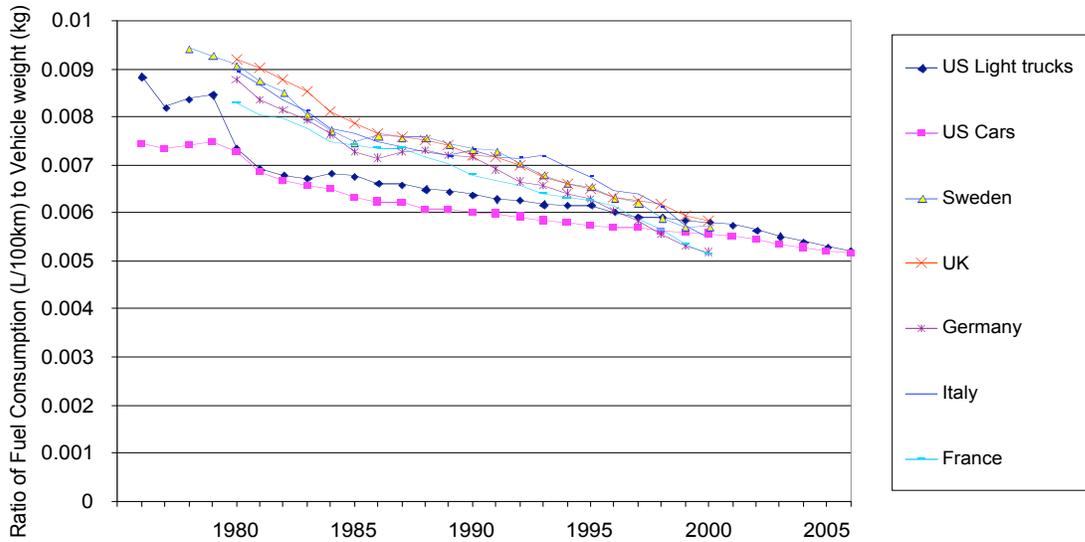


**FIGURE 4 New car curb weight.**

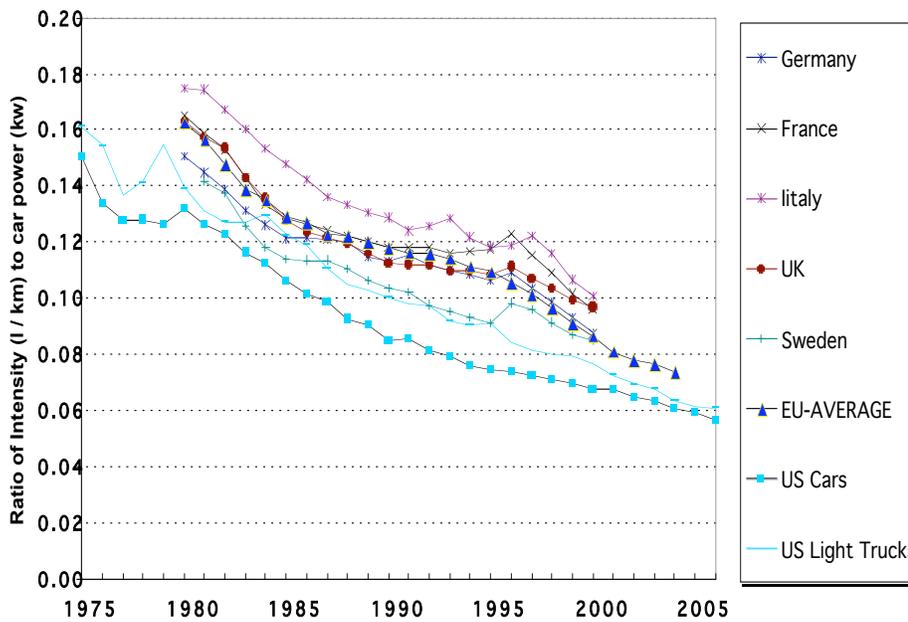


**FIGURE 5 New car engine power (diesel and gasoline averaged).**

Figure 4 shows new vehicle weight, Figure 5 power in the US and selected European countries over time (7,17). The European countries bracket the averages for years where all countries' data are available. Swedes buy the largest cars, Italians the smallest in Europe. These figures have been creeping up in both the US and Europe. In Japan, however, an indicator of a possible trend break is the percentage of mini-cars in overall new car purchases, up from the teens in the 1980s, the 20s in the 1990s, and the 30s after 2000 (21). This represents a break in trends, motivated as much by the lack of space for parking and narrow streets as well as the desire to save fuel.



**FIGURE 6 Fuel consumption to weight ratio for new cars.**



**FIGURE 7 Fuel consumption to power ratio for new cars.**

When we divide fuel economy by weight or by power, we obtain indicators of “efficiency” in the narrow sense (Figs 6 and 7). The first reveals a big drop in fuel use required to move a vehicle. Since power to weight ratios increases in the US and Europe, this means acceleration and top speed have both increased. That is, the lower fuel-use to weight ratio signals greater efficiency, not declining performance, because power/weight is up in all countries. The lower fuel use to power ratio says the engine itself is more efficient, providing potentially more power for a given average fuel consumption. In short efficiency has fed power and weight.

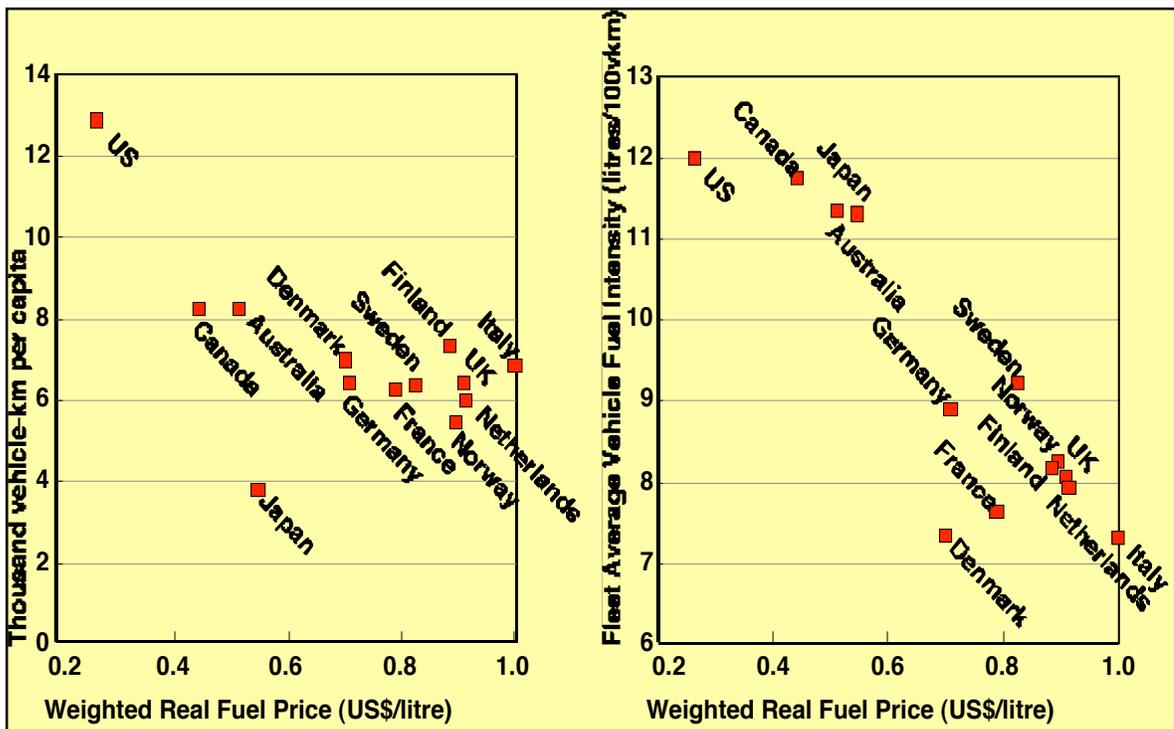
The analysis suggests that without a slowing or even reversing of the seemingly endless upward spiral of vehicle weight and power, “technology” per se will not be deployed solely to reduce fuel intensity, but also and possibly preferentially to provide more vehicle performance. Indeed, during the years since oil prices started to rise in 2002, average new car or light truck engine displacement, weight, and power kept rising. The fuel to weight or power ratio continued to fall, but this was only enough to balance increases in HP or weight (18). In short, it is not clear how much (or how rapidly) technology can reduce fuel as long as much or all of the technology goes to boost power or weight.

K. Blumberg (2007 priv. comm.) showed that a dramatic halt to this power and weight spiral occurred in Japan after 1997. To some extent this may reflect an economic slowdown. But her presentation shows essentially no in the average weight of new cars while test fuel economy rises dramatically. Although the weight and power of new cars in Europe grew after 1998, fuel was still saved, perhaps in response to the Voluntary agreement there (EU). Thus it appears such agreements do have an impact.

**7. DRIVING FORCES**

The foregoing suggests that short of a low-carbon fuel that can be produce at a level of 20 million barrels per day for IEA countries, serious oil saving or reduction in GHG emissions – say bringing automobiles back to their 1990 levels of emissions or fuel use --- cannot occur without both reductions in vehicle use and an end to the upward spiral of weight and power. What could drive this change?

Ref. (9) showed an inverse cross sectional relationship between fuel prices (weighted by actual use of automobile fuels) and average per capita distances cars were driven. The inverse relationship between fuel prices and fuel economy must be linked at least in part to fuel prices, vehicle size/power, and technology choices. Similarly there is a clear inverse relationship between fuel prices and on-road fuel economy. Updated by the International Energy Agency to reflect 1998, these are shown in Figure. Figs 8 and 9. While population density and urbanization certainly affects total vehicle use, the relationship shown in Figure 8 is borne out by more recent data and in formal calculations [8].



**FIGURES 8 AND 9 Car use (in km/year/capita) and car fuel economy vs real fuel prices weighted by diesel and gasoline shares, converted to US dollars at 1995 purchasing power parity.**

That study found a substantial price elasticity for fuel economy (-0.5-0.7, i.e., a 10% rise in fuel prices leads to a 5 to 7% decline in fleet fuel intensity over time). These same authors found a small elasticity of vehicle use (-0.2-0.3) and an even smaller elasticity of vehicle ownership (-0.050) in this cross sectional time series study. Over the short term, (26) and (20) find a small short term elasticity of use for the US, -0.1 or less, which also means the “rebound effect” is small. From the data in Figs 4 and 5, we surmise that a large part of the US-Europe difference is caused by differences in car weight and power, while the improvement in fleet fuel economy in Japan is at least related to the popularity of min-cars, which now account for 1/3 of new sales and around 15% of the vehicle stock.

Applied to the US, a near doubling of the real price of fuel since 2002 should mean that over the long run, driving will fall (from what it would have been) by a modest amount, but fuel economy will improve significantly.

## **8. CHANGING THE TRENDS?**

Johansson and Schipper’s (8) findings suggest economic forces – fuel prices – are an important determinant of fuel use for cars. In the US, at least, the reaction to higher prices has been small (26,20). Yet comparing both new vehicle fuel economy and changes in the stock among the US, EU and Japan since 2000 show that improvements in the later two but not in the first. This occurred even though the relative price changes in the US were larger since the price of crude and refining represents a much larger share to consumers than in Japan and Europe, where taxes are 2-3 times higher. From this comparison it is difficult not to conclude that the Voluntary agreements in both regions affected new vehicle fuel economy.

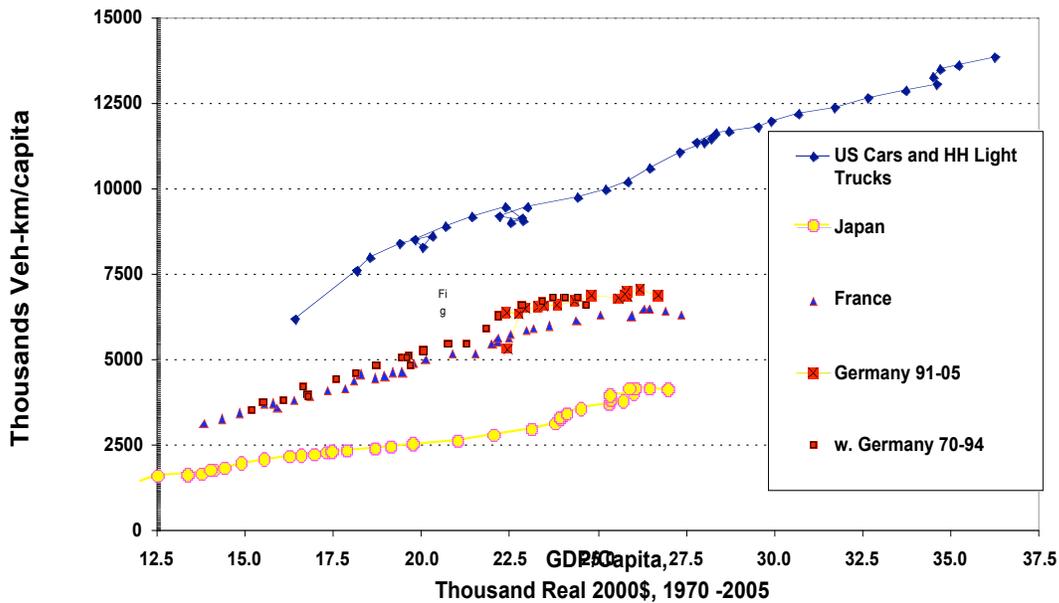
Voluntary or mandatory programs remain contentious in the US. Even if the CAFÉ standards themselves and the assignment of “cause” of the large increase in fuel economy in the US is contentious (15, 27) it is difficult not to attribute a significant part of the big changes in fuel economy in the US from the mid 1970s until the early 1990s to CAFÉ. By contrast, the near doubling of the real price of gasoline between 2002 and 2007, in the absence of any significant tightening of CAFÉ standards was accompanied by very little change in real fuel economy on the road or among new cars (Fig 1 or 2). While the share of gasoline in household budget in the US, or alternatively the real cost of fuel for 1 km was still below its peak of 1981 in mid 2006, it is still striking how little new car buyers seem to care about fuel economy, at least through model year 2006. One could argue that present fuel prices in the US (>\$3/gallon at this writing) are consistent with purchases of cars and light trucks that obtain roughly the 21.5 on-road MPG average they do, while the prices in the 1990s through 2001 were too low, i.e., CAFÉ, not fuel prices, was the determining factor. Clearly the cross sectional evidence (8) suggests that fuel prices do explain a considerable amount of the US/Europe difference, i.e., lead to purchase of smaller, less powerful cars in Europe than in the US as well as somewhat more fuel saving technology in a car of a given size (28).

The issue remains: what will change the car buying preferences of Americans? In 2005 and 2006 the share of SUVs in the total number of light duty vehicles sold fell slightly, but average weight, engine size, and horsepower of the combined fleet still increased and the stalemate of technology and car power remained. In the EU, by contrast, efficiency factors improved more than car power or weight (EU 2006), leading to a real improvement in both new vehicle and fleet, on-road fuel intensity. In Japan the arrest of increased car power and size and technology together led to fuel economy improvements.

## **9. VEHICLE USE – THE OTHER PART OF THE EQUATION**

Many are surprised that on road fuel economy in Japan was so close to that of the US in spite of much higher fuel prices. But per capita car use in densely populated Japan is but a third of what it is in the US, and per

capita use in Europe lies between 35% and 45% (Figure 8). In short, Japan has high fuel intensities but low yearly car utilization, leading to low per capita fuel use compared with the US. While it is no simple matter to rearrange land uses in the US quickly to reduce vehicle use, it is hard to believe that present day driving patterns (roughly 4 car trips per capita per day, vs 2-3 in Europe) cannot be modified through more effective scheduling or trip chaining to reduce vkt/capita in response to higher fuel prices. Indeed, (7) shows a clear increase in the share and use of urban mass transit in the US, admittedly from very low values, since the rise in fuel prices that started in 2002. Whether authorities or the public like it, some of this shift must be attributed to higher fuel prices. But in the longer term, continued higher prices could influence decisions on both home buying and home building, more transit-oriented development and a slightly more compact landscape in the US. While this result cannot approach the higher densities of Japanese or even European cities, it could enable a continued drop in US vkt/capita.



**FIGURE 10 Vkt/capita vs GDP per capita in 2000 US Dollars, converted at purchasing power parity**

Will car use grow continually with higher incomes? The horizontal axis is per capita GDP, converted to real 2000 US dollars from real 2000 local currency at purchasing power parity. The vertical axis shows vkt/capita for cars. Data for each country range from 1970 to 2004 (Japan) or 2005 (Europe and the U.S.), but are plotted using the GDP/capita data for each year. When GDP/capita falls, a knot in the curve appears as the x-axis values fall temporarily.

With this portrayal we see a slight tendency that increments of per capita GDP do not bring the same increments of vkt growth, i.e., the GDP elasticity of car use is less than 1. Note too that the graph shows how much higher vkt were in the US than in Europe or Japan for comparable levels of GDP/capita - this means that GDP/capita does not explain more than part of the Europe/US/Japan differences in vehicle use. Indeed, combining Figures 8 and 9 (or the vkt data in Figure 10 with on-road fuel economy of Figure 1) suggests that even in 2005, most of the US/Europe or US/Japan differences in per capita fuel use (and consequent CO2 emissions) arise from differences in car use per capita, with only about 1/3 explained by the differences in fuel use/km. Since Figures 4-7 imply that a considerable amount of the differences in fuel economy arise because of differences in vehicle weight and power, this means that technology per se is only a small component of the overall difference in automobile fuel consumption between Japan, Europe, and the U.S.

Finally, note that Figure 10 conflates car ownership per capita and car km/car/year. Car ownership levels in Europe are converging on 500-600 vehicles/1000 people vs. over 700 in the US. In European countries with fewer cars per capita, like Finland or Denmark, vkt/car is higher than in other EU countries and vkt/capita is comparable. Thus vkt/capita is a good indicator of automobility and more directly related to fuel use or emissions than car ownership alone.

## 10. CONCLUSIONS

On-road fuel economy is improving in Japan and Europe, but hardly at all in the US, at least through 2006. Fuel economy (miles/gallon) is higher in Europe and to some extent Japan than in the U.S. In 2005, on-road fuel economy in the U.S. was slightly above 11 l/100 km (about 21 mpg). Japan's average was 10.5 km/100 km (22 mpg), while Germany, the U.K. and France were 8 (29), 7.7 (31) and 7.5 (32) respectively. These "real world" on-road figures include diesel and other fuels. For the US, the figure includes the portion of light trucks that are household vehicles, such as SUVs, all of which are far less significant in the other countries.

New vehicle fuel economy has also improved in the first two regions, even if the improvements in Europe have fallen short of the target expressed in CO<sub>2</sub> emissions of 140 gm/km (about 6.7 l/100 km of gasoline). The shift to diesel cars was expected to spark significant fuel economy improvements in Europe to meet this target. But for a variety of reasons, new diesel cars show only slightly lower energy- or CO<sub>2</sub> intensities than new gasoline cars. The same is true when comparing on road fuel economy. Test fuel economy of both new diesel and gasoline cars, as well as their respective on-road values have improved in Europe. But when the higher yearly usage of diesel is folded in, the real energy or CO<sub>2</sub> savings are disappointing.

Technology has reduced the fuel required for a given car horsepower and weight markedly, but in the US (and to some extent Europe) this has been offset by greater new car power and weight. Further improvements in fuel economy depend both on technology to reduce fuel use per unit of weight or power, and a slowing, halting, or even reversal (i.e., downsizing or down-weighting) of new vehicle power and/or weight beyond weight reductions in a given car class, i.e., downsizing.

The European Union proposes to strengthen their "Voluntary Agreement" to become a mandatory target with the goal of 120 gm/km CO<sub>2</sub> emissions from new cars, which corresponds to roughly to 5.5 l/100 km or 42 MPG gasoline equivalent. Calls for higher fuel economy in the US start at 35 MPG (6.7 l/100 km) and echo even more stringent values. Discounting roughly 20% to get on road values, this would mean that fleet fuel economy in the range of 6.6 l/100 km in Europe and perhaps 7-8 l/100 km in the US (compared with 11.5 today). Getting such changes into law and through the planning cycles of manufacturers and then into the stocks would take 20 years, given the delays and turnover times at each stage. While the literature leaves little doubt that these levels could be reached, such an achievement would be made increasingly harder by continued increases in car weight, power and features. Finding a mechanism for this transformation to occur faster than the present rates may indeed be a key goal of all stakeholders in the near future.

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### **Appendix: Main Data Sources**

US – Oak Ridge transport Energy Data Book (TEDB), US EPA, FHWA Table VM1, Bureau of Transport statistics. The share of light trucks, their annual distances driven and fuel use is taken from various editions of ORNL and interpolated between the years in which surveys ere taken by the Truck (Vehicle) Inventory and Utilization Survey.

Japan. Energy Data Modelling Center Energy in Japan Handbook for 2006/7 and yearly tables published by the Ministry of Land Transport and Infrastructure.

France. ADEME, the French Agency for Environment, publishing year books on Energy Efficiency Trends and yearly updates on motor vehicles.

Germany- *Verkehr in Zahlen*, published yearly by Deutsches Institut fuer Wirtschaft (DIW) in Berlin for the Federal Ministry of Transport, DIW also provided the new vehicles fuel economy and CO2 emissions data.

Italy. The Unione Petrolifera has assumed responsibility for motor vehicle trends and published them in their latest forecast, *Previsioni di Domanda Energetica e Petrolifera Italiana 2007- Italiana 2007-2020*.

UK. Department for Transport. *Transport Statistics of Great Britain*. and Dept. for Trade and Industry *Digest of UK Energy Statistics*, as well as spreadsheets available online from DfT.

European Council of Ministers of Transport. European Transport Data Base and material submitted to ECMT from ACEA.