Disappointed by diesel? The impact of the shift to diesels in Europe through 2006

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Abstract

A previous review of trends in light-duty diesel vehicle sales and usage in Europe through the mid 1990s questioned whether the shift toward diesels would yield large energy savings (Schipper, Fulton and Marie 2002, SFM). This study expands the sample of countries in the previous work and adds about ten years more data from both new vehicle test fuel economy and on-road performance, including usage.

The updated findings renew the concerns first expressed in SFM. Although there is still evidence that diesels of a certain size have a substantial (volumetric) fuel economy advantage over gasoline vehicles of a similar size (perhaps 30% on average), average new diesel cars[1] and the stock of diesels on the road maintain a smaller efficiency advantage over gasoline, on the order of 15% in most countries as of 2005. When the higher energy content of diesel is considered, the new vehicle and on-road figures shrink to less than a 5% and 7% fuel intensity advantage for new diesel vehicles and stock, respectively. The net CO_2/km emissions advantage for diesels is even less; for new cars, below 5% in all but one country and 0% on average across the 8 sampled countries in 2005. For total stock, diesel has a 2% average CO_2 advantage.

Even normalizing for the larger average size of diesels, their CO_2 advantage appears to be no more than 15-18% for vehicles of a similar size class. Diesels are typically larger and are driven 60-100% more per year than gasoline cars. While much of these differences could be ascribed to self selection and related effects, some are likely due to a rebound effect created by diesel's better fuel economy and (in many countries) the lower price of diesel fuel. Using typical elasticity estimates to measure the driving rebound effect, the average result is about a 5% increase in annual driving and up to a 12% increase depending on the country and assumed elasticity. This is small compared to the observed driving difference between gasoline and diesel vehicles (and therefore raises questions for further research), but it is enough to offset the remaining fuel savings and CO_2 benefit of diesels in the sampled countries.

The findings indicate that after taking all factors into account, diesels in Europe may provide significant fuel savings to individual drivers, but probably do not provide significant national energy or CO_2 savings on average across the 8 countries studied. Almost certainly, taxing diesel fuel lightly relative to gasoline is counterproductive from an energy savings and CO_2 point of view since it contributes to a higher rebound effect (by lowering the cost per km of driving diesels). The good news is that diesel fuel price subsidies relative to gasoline have declined in most EU countries in the past 10-15 years, and the price-induced rebound effect is probably much lower in many countries than it once was.

1. In this paper, we use the word "car" in a broad sense, interchangeably with "LDV". This includes SUVs, personal vans and personal light trucks.

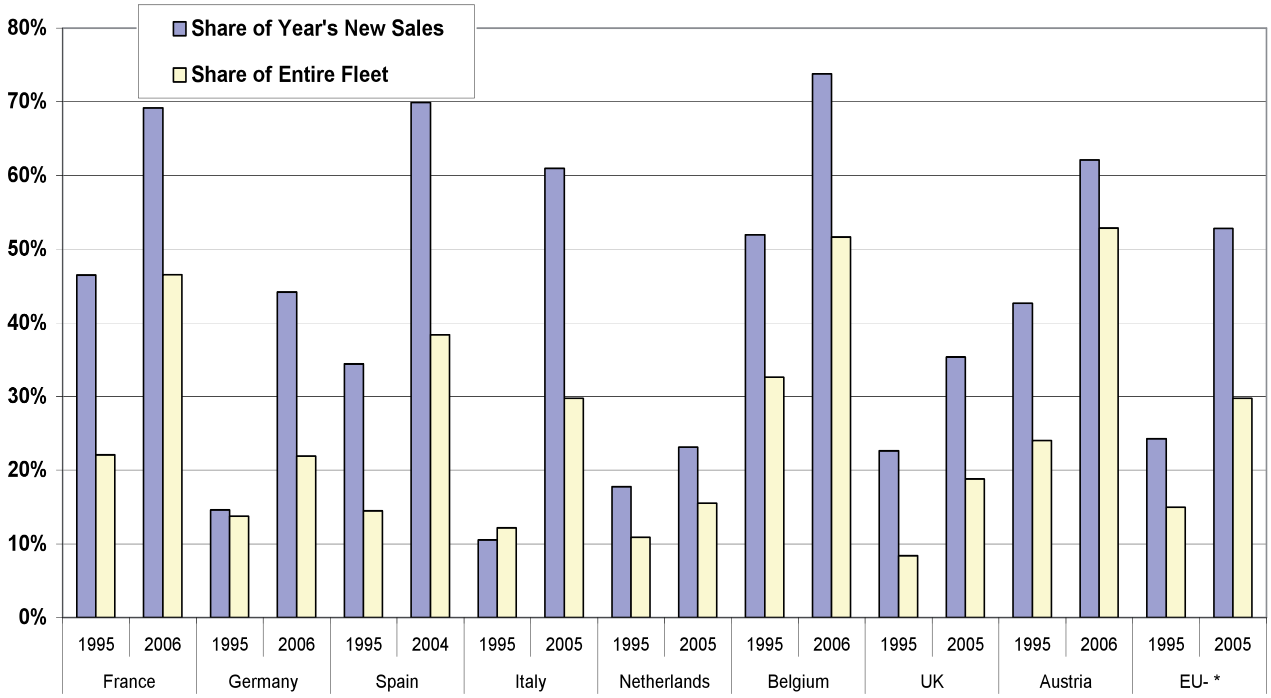

Figure 1. Share of diesel cars/SUVs in each country's new sales and entire on road fleets, 1995 and 2005/6. Source: EU 2004 and ECMT 2006 (priv. comm. of EU data).

Automobiles, fuel and CO_2 in a longer term perspective

Energy use and travel for personal transport in wealthy countries is dominated by automobiles. While fuel economy improvements in Europe and Japan since 1995 and some slowing in the rise in ownership and use of automobiles around the OECD has reduced the growth rate 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 (IEA, 2004). Their share in total energy use in developing countries is smaller, but rising rapidly (WBCSD, 2003). 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.

A major component of the European strategy for reducing fuel use and CO_2 emissions from the light duty vehicle sector has been a shift to diesel technology (IEA 2000; Clerides S., Zachariadis T, 2006; Fontara and Zamaras 2007). Diesel sales shares have steadily increased in most countries and by 2006 more than half of all cars and SUVs sold in EU were diesel, with diesel particularly dominant in France and Belgium. Even in the Nordic countries with relatively few diesels on the road, the share of new diesel cars is booming.

Shifting from gasoline to diesel vehicles should save fuel and reduce CO_2 emissions as well, since diesel vehicles are more efficient in principle (per km), as the matched pair analysis in SFM showed differences ranging up to 35%, with an average around 25% (in volumetric terms). But the same analysis found much lower fuel savings and CO_2 reduction for average gasoline and diesel vehicles purchased or in use, due to a range of factors.

This study updates the earlier one, using data through 2005/6. In addition, Spain, Austria and Belgium have been added to the original countries studied (France, Germany, Italy, Netherlands, and the UK).

When account is taken of the greater energy density of diesel and the greater CO_2 released per unit of energy in diesel fuel, diesel fuel economy values have to be increased by 11-12% in energy terms or 17-18% in CO_2 terms before they can be compared with gasoline. The higher use and CO_2 emissions associated with producing diesel in Europe worsen this comparison (Concawe 2007). This means that diesels need to be at least 20% less fuel intensive (in l/100 km) than gasoline vehicles, in use, just to break even. The evidence to-date from new vehicles and on-road performance shows this threshold has not been crossed in most countries, on a sales-weighted average basis.

New car fuel economy and the role of diesels

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 in order. Schipper and Tax (1994) and references therein have emphasized the uncertainties in interpreting sales-weighted test values of new vehicles. While such indicators are important in determining the overall impact of technology and consumer choice, they are very difficult to compare across test cycle or to translate into on-road values that can be matched.

Figure 1 gives the share of diesel cars in the new automobile markets of key European countries in 1995 and 2005/6 as well as the shares of diesel in each country's respective stocks for the same two years. In general the yearly data show a continuous

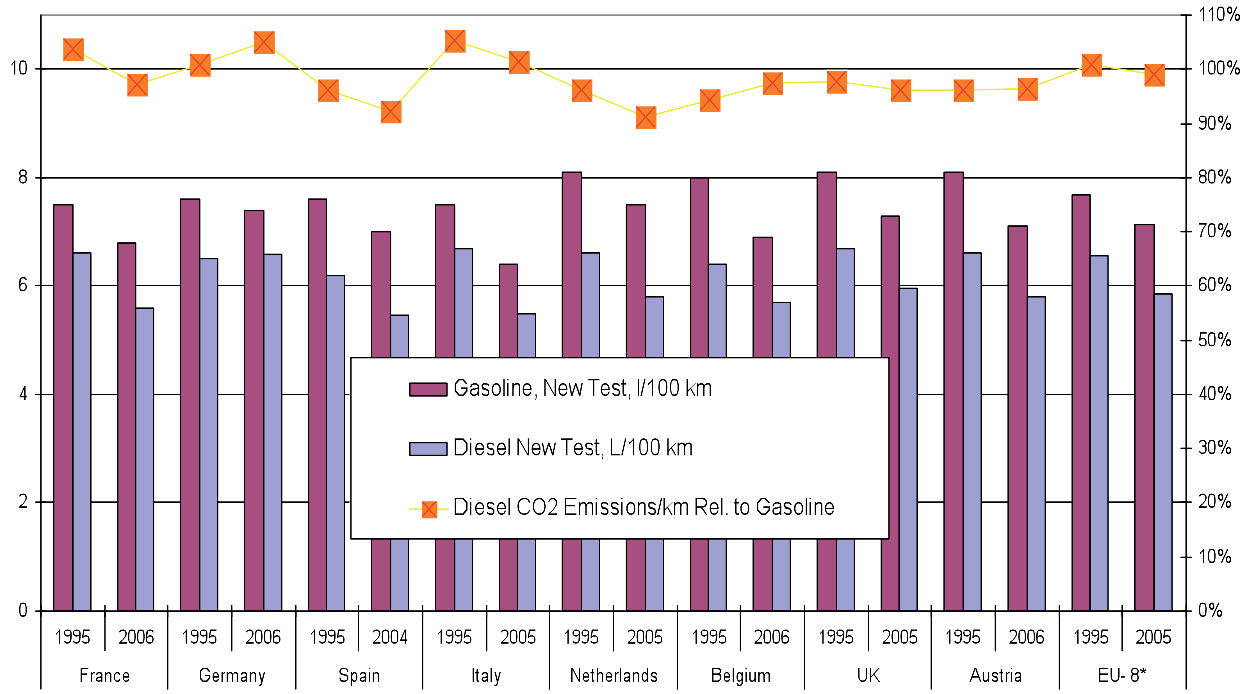

Figure 2. Fuel Sales weighted fuel economy of new gasoline and new diesel cars, l/100 km. The square dots above the bars give the diesel/gasoline CO_2 emission/km ratio.

rise in the diesel share (EU 2004). The results are dramatic – in these eight countries, diesels accounted for over half of the new cars in 2006 and nearly a third of the stock by that time.

Figure 2 gives the 1995 and 2005 comparison of new gasoline and diesel vehicle test fuel economy. The first pair of figures are the volumetric differences (l/100 km) in 1995 and 2005/6. The square dots give the CO_2 emissions/km for the new cars using lower heating values and the IPCC conversions of fuel to CO_2. Figure 2 also gives the diesel/gasoline "advantage" in CO_2/km for new cars for both those years shown as square dots, referring to the RH Axis. For points less than 100%, new diesels sold emitted less CO_2/km than new gasoline cars sold.

The new vehicle test data give a clear message. New diesel cars test with lower fuel consumption in l/100 km than new gasoline cars. In some countries that difference has lessened over time (UK, Germany, Belgium or Austria for example) while in others it increased (France). Expressed in CO_2 emissions per km, only Spanish and Dutch bought cars in 2005/6 that tested at 95% or less CO_2/km than gasoline, and Germans, Italians, and Austrians bought diesel cars that showed greater CO_2 emissions/km than gasoline cars bought there.

On road fuel economy – Global Results for Europe and the US

We have updated the figures for on-road fuel economy from previous work (Schipper 2008; Schipper 2009 in press and references therein). Austria, Belgium and Spain – countries with high diesel shares – have been added to the previous analysis of SFM. A variety of approaches from bottom up fuel and vehicle use surveys to modeling of on-road consumption are employed in each country, as reviewed in Schipper 2008, Schipper et al 1993a and 1993b and Schipper et al 1994. Understanding average on-road fuel economy and consequent CO_2 emissions is critical both for interpreting how changes in fuel prices and other conditions have changed vehicle purchase and use patterns, and for estimating the impacts of future policies and technologies.

Figure 3 shows average on-road fuel economy for five of the study countries, including gasoline, diesel and LPG vehicles (all at gasoline equivalents defined above). The data reflect a break in the trends in European countries from other OECD countries in the late 1980s, with a steady improvement through 2005/6. The US value is also included for comparison. The apparent drop in the US value starting in 2004 may be due to imposition of new standards on SUVs, which show a drop in new vehicle sales weighted tests starting in 2004 (Heavenrich 2007). Schipper 2008 demonstrates that most of the US-Europe difference in intensity arises from differences in vehicle power, weight and engine size.

The same data expressed in gm/km of tail-pipe emissions give the same downward sloping curve for European countries. But the higher CO_2 content of energy in diesel means the emissions/km have fallen slightly less than the fuel intensity as displayed. While these figures are estimated and uncertain, it is clear there has been fuel savings among both gasoline and diesel cars and in the aggregate. In the next section we shall see that most of the fuel economy improvement was due to the reduction in fuel intensity of new diesel and gasoline cars separately, not the increased share of diesels on the road.

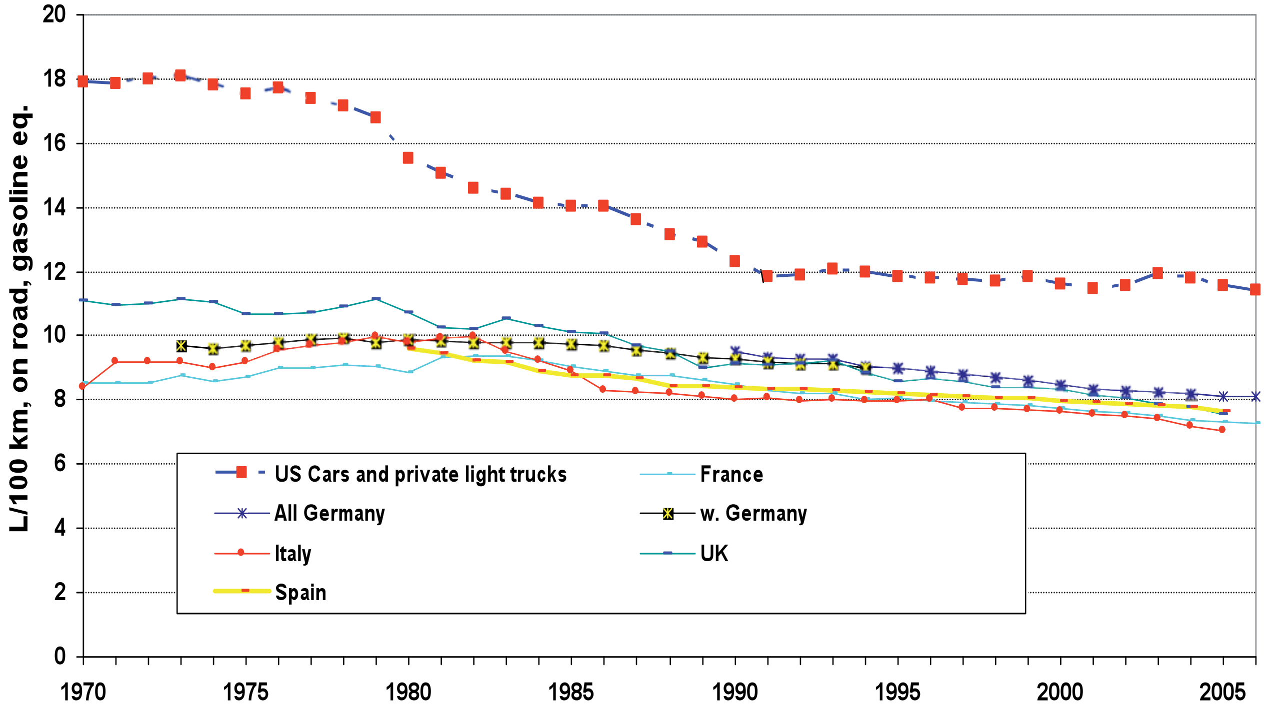

Figure 3. On-road fuel economy for US, European countries. Note: data in gasoline equivalent L/100 km. Data sources in Schipper 2008 and the Appendix. Note: Data for Germany represent West Germany before 1995 and all Germany from 1991, leaving four overlapping years.

Impact of diesels compared to gasoline cars – disappointing?

The data used to compare vehicle shares, average new car test fuel economy and on-road fuel economy for diesel and gasoline are given in Table 1 (at end of text). Also included are annual driving distances as measured or estimated from surveys. These will be discussed later. They are important here since they affect the weight of diesel cars in the average stock on-road fuel economy.

For comparison, the table gives the volumetric ratios of diesel to gasoline fuel intensity (l/100 km) as well as the ratios of CO_2 emissions in gm/km. The result is that while average 2005/6 on-road fuel economy of diesel in these eight countries (weighted by numbers of cars and distances driven) is 17% better than that of the gasoline cars on the road, this difference expressed as CO_2/km was almost nil, down from 5% in 1995. The diesel/gasoline yearly driving ratio rose from 170% to almost 180% over the same period. New car test values, weighted by sales, show almost no difference from gasoline in CO_2/km. Thus for both new vehicles and the total stock, gasoline and diesel cars and SUVs are now showing near CO_2 equivalence.

There are some important trends underlying these findings. The diesel advantage of lower emissions/km over gasoline for new vehicles has been shrunk as vans and SUVs have migrated to diesel from gasoline. This is illustrated by the small new vehicle differences in the UK and the clear disadvantage for all the cars sold in Germany. Over all EU countries, Zacharidis (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 new diesel car fuel economy improved faster than that of gasoline cars, consistent with our findings. We note that for the eight countries studied here, the rising shares of diesels alone contributed about 2% to the improvement in fuel economy, while the improvement in newly sold diesels alone was about 10%. The overall stock of diesel cars improved only 6%, but that is because the stock always improves more slowly than new vehicles improve. That the diesel-gasoline new car advantage in CO_2 was virtually zero led to the diesel-gasoline advantage on the road narrowing slightly, in part because new gasoline cars improved relative to new diesel cars.

One question that emerges from this comparison is why the efficiency (energy use per km) advantage of diesels compared to gasoline vehicles is not greater. In the 2002 paper, a comparison of diesel/gasoline "matched pairs" (same vehicle model/configuration with similar engine power/torque in gasoline v. diesel versions) diesel cars typically heavier than gasoline cars, and their engines were larger (in CC) than those of gasoline cars, in part to provide comparable horsepower. But the diesel models used 20-40% fewer liters/km than gasoline equivalents.

In this paper we do not attempt a new matched pairs analysis, but a vehicle size class comparison from Germany provides some clues to the relative fuel economy of similar size gasoline and diesel vehicles for the 2006 model year. The results are shown in Table 2[2]. The table shows sales-weighted CO_2/km for all gasoline v. diesel vehicles in the database, and the result is that average CO_2/km is virtually the same for gasoline and

2. Data are from German Environment Agency, UBA. These results are preliminary, as the data base available covers only about half of all German car sales and the reasons for this are being investigated.

Table 2

	Gasoline		Diesel		CO_2 difference %
	Sales	CO_2/km	Sales	CO_2/km	
All LDVs in sample	921917	174.6	718112	174.7	0%
Top 20 selling LDVs	187447	155.4	145691	161.9	-4%
Average by vehicle size (footprint, m^2)					
<6 m^2	37,071	139.0	1,414	146.5	-5%
6-7 m^2	354,668	150.9	47,381	133.1	12%
7-8 m^2	346,719	182.4	254,571	155.6	15%
8-9 m^2	161,728	204.1	304,351	175.9	14%
>9 m^2	21,731	280.8	110,395	233.6	17%

Notes: data from Umwelt Bundes Amt Berlin; these do not account for all vehicle sales in Germany (which were around 3 million) so should be considered a full sample.

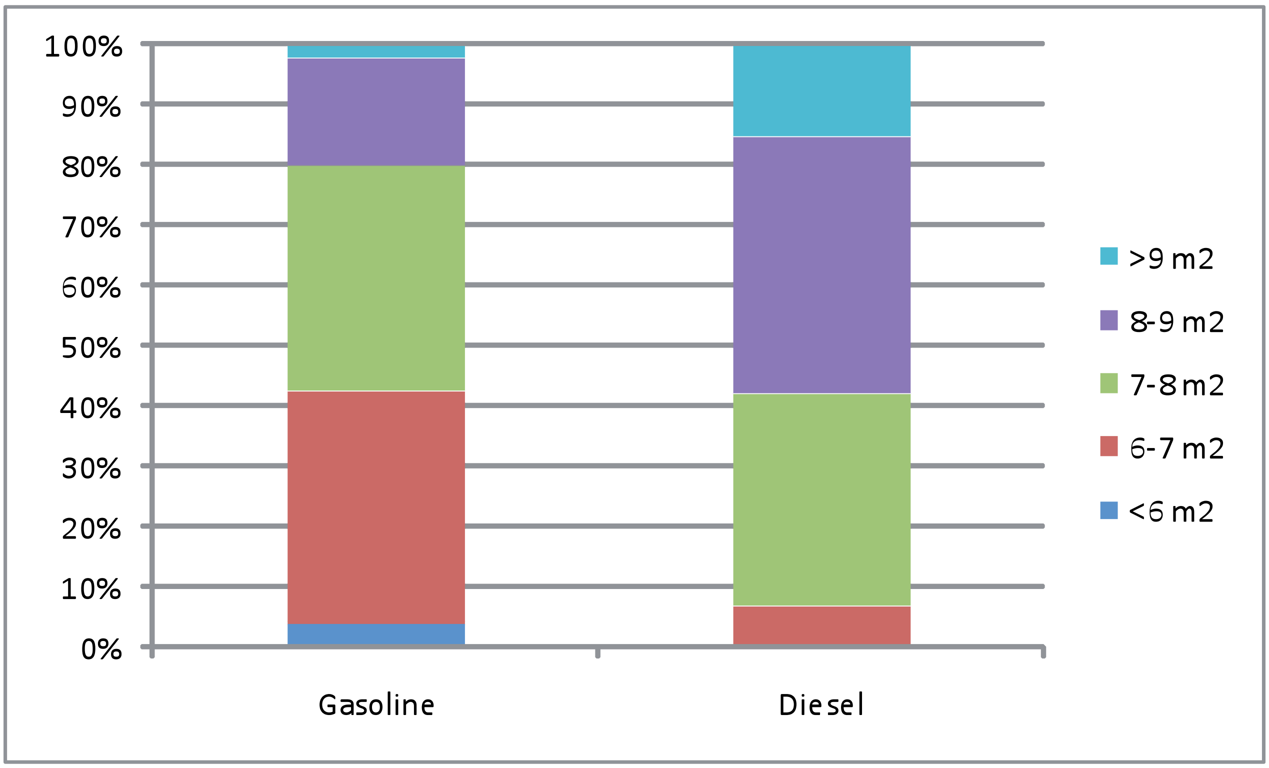

Figure 4. Percentage of gasoline and diesel vehicle sales by size class (based on vehicle footprint) in Germany, 2006.

diesel vehicles. Results including only the top 20 selling models are also shown, actually showing gasoline vehicles with a slight CO_2 advantage over diesel.

However, if one breaks out sales and CO_2 by size class (based on vehicle footprint, measured in m^2), diesel vehicles are around 15% lower than gasoline in CO_2/km, with increasing advantage toward the larger size classes. (The diesel number for < 6 m^2 vehicles is a small sample and needs further investigation to understand why it is an outlier). Figure 4 shows the share of gasoline and diesel vehicle sales by size class, indicating a large difference in the shares of small v. large gasoline and diesel cars.

These findings suggest that diesel cars and light trucks sold in Germany in 2006 had a technical advantage on the order of 15% less CO_2/km than gasoline (supporting the aggregate data in Table 1), but that purchases of larger diesel vehicles offset virtually all of this advantage. This raises a basic question – do diesels (and their "matched pairs" efficiency advantage) encourage people to buy larger cars, or do people who already planned to buy larger cars tend to choose diesels? Most likely there's an element of both, but the relative importance of these two explanations is critical for estimating the "true" energy savings of diesels. Unfortunately the detailed French survey of switchers (Hivert 1994) does not contain much detail about the "before" gasoline car that was given up for the diesel car.

Perhaps the only way to separate the effects is to use stated preference (e.g. ask those who bought diesels what they would have done if there were no diesels available). Analysis of detailed household and business travel surveys could also shed some light, by accounting for as many variables as possible and isolating the effect of gasoline/diesel fuel economy and availability on size class choice. This could benefit from multi country data, where the availability of diesels varies by country. But few recent travel surveys are available, and only in a few countries are these carried out yearly or as panels. Another test could be econometric – estimate the share of diesel cars bought as a function of the price differentials for comparable cars, for cars actually bought (based on the income of buyers), fuel prices and taxes. The latter explains some of the increase in diesel sales in the UK in recent years despite the higher price of that fuel – the vehicle excise duty refund scheme (Mazzi and Dowladabati 2007).

An additional factor related to stock turnover is important. Since their popularity has risen dramatically in recent years, diesel cars on the road are somewhat younger than gasoline cars. Since the new cars of both cohorts have become less fuel intensive over time, the younger age of the on-road diesel fleet should boost their advantage over the gasoline-fueled fleet, yet this does not appear to be the case; in fact the reverse occurred in all but two countries. This is consistent with diesels being purchased in larger size classes, perhaps increasingly so.

Comparison of the curb mass of new gasoline and diesel cars sold in the 15 Countries of the EU shows that diesels weigh more. In 1995 the average new diesel weighed 1204 kg, about 12% more than the average gasoline driven car. By 2001 that weight difference grew to almost 17%, where it remained through 2004 (ECMT priv. comm. of ACEA data). Interestingly, however, the power of new diesel cars was only 92% that of gasoline cars, but surpassed it at 101% by 2000. That growth increased the power-to-weight ratio of diesel cars by nearly 10%, helping acceleration and adding torque. While the tested fuel consumption of the same set of cars in 15EU countries fell, the increase in mass and power kept that figure from falling further. Interestingly the power-to-weight ratio of new gasoline cars only rose 6%. Were diesels playing catch up?

Use of Diesel Cars. The Other Surprise

Table 1 also shows travel per vehicle, in km/year. This indicates that diesel cars in Europe are driven 40-100% more per year than gasoline cars. Additionally, the diesel/gasoline driving gap increased on average in the time span shown in Table 1. Average diesel and gasoline car driving distances have risen very little or even fallen in most countries over the roughly 10 year period, which itself is striking., but except for France, the U.K. and Italy, diesel driving has dropped less (or risen more) than gasoline vehicle driving.

Part of this effect is 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, diesels may be used more as first family cars or for touring. Another factor is the use of diesel cars for businesses including taxis, which are driven almost twice as much as private cars according to Dutch data. These cars were chosen for durability and fuel economy. However, these business users only make up only a small minority of diesel owners, and their shares are decreasing. Similar indications arise from UK data for 2003 (DfT 2004) and France (Cerri and Hivert 2003). And the high shares of new vehicles sold as diesels, now about 50% in EU, means that by far most new buyers are private users.

Finally, diesel fuel prices have risen more than gasoline prices in most countries, which should lead to a greater response (reduction in travel) from diesels than from gasoline. In most countries is not the case. For example, in Germany and Austria, the diesel fuel price advantage (difference between diesel and gasoline prices) fell by nearly half, but the diesel/gasoline driving ratios increased (in Germany, by a large amount).

There is also a self selection process – since diesels of equivalent size and performance cost significantly more than gasoline cars, drivers who pick them must figure how many more miles they drive before a diesel becomes less costly overall. New dieselists, those switching from a gasoline to diesel car, use their diesel cars more than their former gasoline cars, confirmed by a direct survey of French drivers who switched to diesel carried out in the mid 1990s (Hivert, 1994), and updated to the 1995-2001 period in 2003 (Cerri and Hivert, 2003). Cerri and Hivert even find this increase among those switching from gasoline to a used diesel car. Though it is likely that gasoline-to-diesel switchers are dominated by people who knew they were going to have an increase in driving, and therefore switched to diesel, this self-selection seems unlikely to explain all of the consistently significant increase in driving by switchers. Clearly the issue of selection cannot be resolved easily without of model of what cars consumers would have bought, and how they would have driven them, in the absence of diesel cars. An exploration of the role of fuel prices in providing some explanation follows.

Driving forces – Diesel and Gasoline prices

A key force driving the popularity of diesel fuel in many European countries has been its lower price relative to gasoline. However this price difference has been narrowing in recent years in most countries, due both to higher taxes and market forces (e.g. higher demand for diesel leading to higher retail prices). Figure 5 shows the prices of gasoline and diesel in 1995 and 2005 for selected European countries. Each country's currency is expressed in real, 2000 units and then converted to US dollars at the 2000 purchasing power parity levels used by the OECD ($1 (2000 PPP) = 0.90 Euro). While diesel fuel is now more expensive than gasoline in the UK (and US), prices still favor diesel in other countries in our sample. Prices for both fuels are up over the period displayed.

Both lower fuel price and efficiency gave diesel lower cost/km than gasoline. In 1995 the fuel price difference between diesel and gasoline, in percentage terms, was typically greater than the difference in on-road volumetric fuel intensity (true for France, Germany, Spain and Italy, and nearly true for Austria). In other words, fuel price contributed more than efficiency in the lower fuel costs/km for diesels at that time. However in the 2004-06 data, this had changed for every country but Italy.

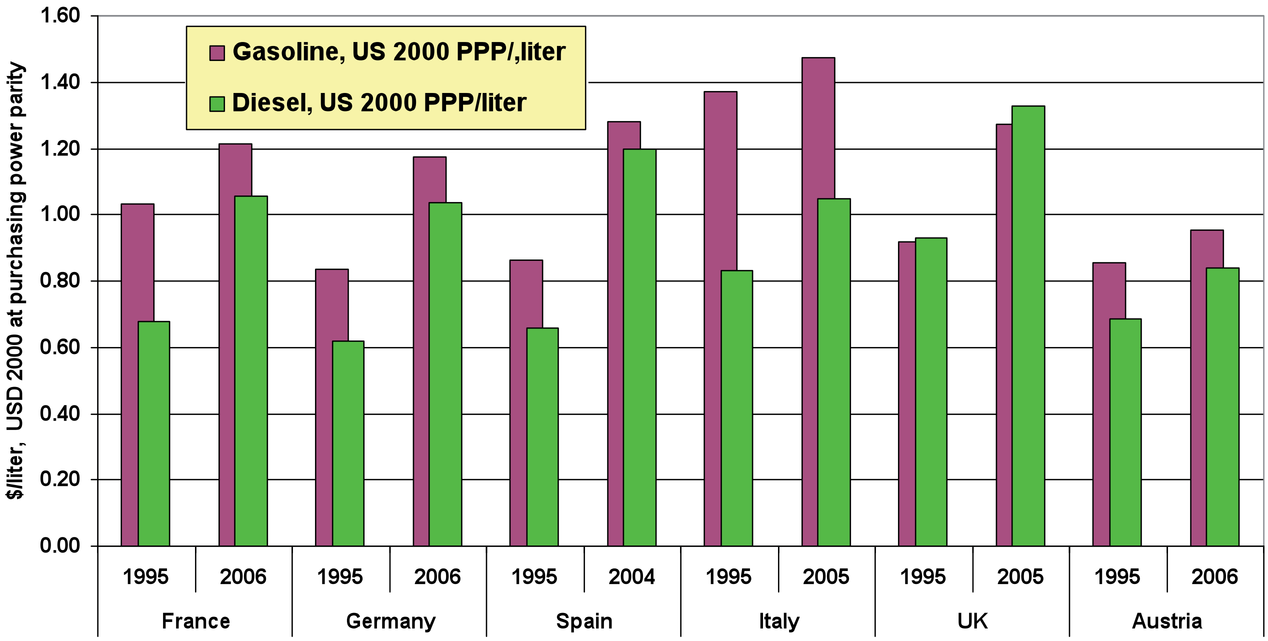

Figure 5. Diesel and Gasoline Prices in European Countries 1995 and 2005. All values converted to 2000 US Dollars using real local currency and purchasing power parity.

Price converged on gasoline, while efficiency improved slightly relative to gasoline.

Both the fuel price advantage and the efficiency advantage of diesels contribute to the lower cost of driving, and therefore to the "rebound effect"of higher driving - but only the efficiency advantage contributes to fuel savings. Short term elasticities of travel (and fuel use) are low, probably less than -0.2 in Europe and -0.1 in the US (Small and Vandender 2007; Hughes, Knittle, and Sperling 2008, Basso and Oum 2007, Johansson and Schipper 1997)). Longer term travel elasticities may be higher, as people have more time to adjust their lifestyles, job/work location, etc. A shift from gasoline to diesel vehicles could result in long-term types of fuel cost responses since this shift may coincide with, and may effectively enable, lifestyle shifts, like moving farther from one's job. With a -0.2 travel elasticity, this means the typical diesel vehicle efficiency advantage in the range of 15-20% results in 3-4% more travel. However, coupled with the 1995 price advantage of up to 30% in some countries, this would have resulted in an additional 4-6% increase in travel, for an overall rebound-driven travel increase of up to 10%, wiping out most of the efficiency benefit and probably resulting in higher CO_2 emissions from diesel. If a larger long-term elasticity were more applicable, say -0.3, then the affect would reach 15%, still far below the 60-100% higher annual driving observed by diesels in the EU.

Given the recent narrowing of fuel price differences, most of the countries would have a much smaller fuel price-related rebound effect now, perhaps on the order of 1-3% from a price advantage of around 5-15%. Exceptions are the UK, where diesel has no price advantage, and Italy, where it still enjoys more than a 20% price advantage. Even as the price advantage in France is narrowing diesels still dominate new vehicle sales. Overall, it appears that European countries have moved toward an average of about a 10% diesel fuel price advantage and, combined with a 15% volumetric efficiency advantage, therefore a 25% overall fuel cost advantage (combined from both the price and efficiency effect). With a -0.2 elasticity, this would mean a 5% overall (fuel-cost related) rebound effect, or 7.5% using a -0.3 elasticity (and up to 12% in Italy with this higher elasticity). Given the narrow advantage diesel has in energy/km and especially CO_2/km, this driving rebound effect erases most or all of the diesel advantage.

Discussion and conclusions

The share of diesel cars in the stock of household vehicles in Europe has risen steadily over time and is now over 30% in the countries covered in this study, and is now over 50% of sales. In theory more efficient diesels should reduce average fuel intensity or carbon emissions/km significantly, but our observations show this is probably not the case. First, much of the difference in fuel intensity of new or on-road vehicles disappears when the higher energy content of diesel and the greater carbon content of diesel is considered. Only a small part of this loss is offset by diesel fuel's lower upstream energy requirements and CO_2 emissions.

When the direct combustion factors are considered, on road diesels in the eight sampled European countries in 2004-2006 used on average 19% less fuel (in liters/100 km), 8% less energy/km than gasoline and emited 2% less carbon/km on-road, than the gasoline cars in these countries. Figures for new diesels are similar in relation to gasoline. The shift to diesels alone, e.g., the higher share of diesel in the new car mix has led to at most a 4% reduction in combined energy intensity of new cars in Europe, while reductions in the new vehicle test fuel intensity of gasoline and diesel themselves have been around 10% and 11% respectively between 1995 and 2005/6. In other words, diesel has contributed to fuel savings in Europe more from increased efficiency than from its higher share in overall new vehicles.

From the German example, it would appear that diesels still do achieve on the order of a 15-20% reduction in CO_2/km for similar sized vehicles, but that most of this is lost due to the larger sizes of diesel vehicles. Thus there is an open question regarding the extent to which the lower cost of operating diesels contributes to its much larger average car size.

Thus diesels in Europe in 2006 appear to save relatively little CO_2 per km compared to gasoline vehicles. If one then factors in the much higher average travel per vehicle, it may well be the case that diesel use leads to a net increase in CO_2. As with the larger vehicle size, it is difficult to account for the relative importance of self-selection vs. cost-driven rebound effects. But assuming a -0.2 rebound elasticity results in about a 5% travel increase with diesels on average, which further erodes its CO_2 benefits.

Given these findings, it is difficult to assign significant energy savings or reductions in CO_2 emissions to the increasing share of diesel vehicles in European fleets. What savings have occurred arose from reductions in fuel use/km for both diesel and gasoline cars.

In other words, the broad findings of Schipper, Marie-Lilliu and Fulton, (2002) remain applicable with 11 more years' of additional data and addition of two more countries – increased dieselization per se has only contributed to a small decline in energy use/km and perhaps an increase in CO_2 emissions/km. However, the narrowing of diesel's fuel price advantage in most countries is an important step in the right direction. If this advantage were fully elimated, as it is in Britain, the rebound effects would be reduced to those caused by efficiency alone – and therefore probably no worse than for any fuel economy technology.

These findings have important implications for strategies aimed at reducing oil use or CO_2 emissions from cars and household light trucks or SUVs. Put simply, a cheaper fuel will be used more. Creating "incentives" for drivers to use clean or more efficient fuels could backfire if those fuels are too inexpensive. In the case of diesel fuel, three types of rebound effect could occur: drivers of gasoline vehicles could switch to the cheaper diesel fuel, and drive more; drivers already using diesel could drive more if diesel becomes cheaper, and vehicle purchasers might be encouraged to switch to larger vehicles since running costs have been reduced. We emphasize that it is not diesel technology that is the problem, it is the lighter taxation of diesel fuels. A similar set of problems could occur with cutting taxes on other alternative fuels, such as "green" fuels like ethanol will likely result in a travel rebound effect that will offset some of the CO2 or other benefits of the fuel.

This concern extends to various other types of fuel or vehicle tax incentives that cut the cost of or encourage more driving. For example, the Vehicle Excise Duty Scheme in the UK, permitting hybrids or other "green vehicles" into high occupancy vehicle lanes or past toll gates or congestion pricing zones without charge) may be counterproductive, if the rebound effects are significant. In short, "earmarking" and subsidizing a fuel or a kind of vehicle risks behavioral rebounds that undermine the goals of saving oil or reducing CO_2 emissions. More analysis on a case-by-case basis would be useful to better understand how much various rebound effects are undermining policy objectives. We also concede an important point raised by reviewers, namely that the degree to which we are observing a real rebound effect on driving vs self selection of higher mileage drivers, as well as self selection whereby buyers of larger cars prefer diesel versions to lower operation costs is uncertain. But these effects should not be so large as to leave no obvious savings in energy or CO_2 when either new vehicle or on –road fuel economy is compared or when the total fuel use (and CO_2 emissions), i.e. both energy or CO_2/km and km/year are considered together. If no savings are apparent, then the EU strategy of dieselization can hardly be called a success.

In fact these findings for diesel raise some questions for fuel economy improvement in general. Though with diesels there are some special issues, such as refining energy/CO_2 differences with gasoline and fuel price variations, otherwise diesel is basically a fuel economy technology. If the rebound effects of lower fuel costs in terms of shifts to larger vehicles and increased driving for diesel are substantial, they would likely also be substantial for other fuel economy technologies as well. The data show that until recently, the diesel price advantage over gasoline was much greater than the diesel efficiency advantage. For pure fuel economy improvement, there is no fuel price effect, so overall rebound effects would tend to be far lower than for diesel where the fuel is cheaper than gasoline. As the diesel price gap has narrowed in most of Europe, we expect diesel technology to improve more rapidly than before. In any case, as fuel economy programs advance, there is a strong need to include in these (or combine these with) measures that help prevent such rebounds (e.g. higher fuel taxes and measures that discourage shifts to larger vehicles). In the end it may not be diesel technology that has disappointed us, rather the way that policies and prices have failed to produce a clear sign of significant oil savings through dieselization of the European car fleet.

References

Basso, L.J. and Oum, T.H. (2007) "Automobile Fuel Demand: a critical assessment of empirical methodologies". Transport Reviews, 27(4), 449-484.

Clerides S., Zachariadis T., Are standards effective in improving automobile fuel economy? Discussion Paper 2006-06, Department of Economics, University of Cyprus, July 2006.

CONCAWE 2007. Well-to-wheels Analysis of Future Automobile Fuels and Power Trains ion the European Context (Version 2c). Ispra: Joint Research Centre.

European Commission, 2006. Monitoring of ACEA's Commitment on CO_2 Emission Reductions from Passenger Cars. Report SEC (2006)1078, Brussels: CEC.

Cerri., V., Hivert, L., 2003, De nouveaux « Nouveaux Diésélistes? », Paris/Arcueil- INRETS.

Fontaras G., Samaras Z., A quantitative analysis of the European Automakers' voluntary commitment to reduce CO_2 emissions from new passenger cars based on independent experimental data. Energy Policy 35 (2007) 2239–2248.

Fulton, L., 2001. Saving Oil in Transport: Options and Strategies. Paris, International Energy Agency.

Heavenrich, R., 2007. Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2006. Advanced Technology Division Office of Transportation and Air

Quality. Washington, DC: U.S. Environmental Protection Agency. Issued again in 2007.

Hivert, L, 1994. Les Nouveaux Dieselistes. Paris-Arcueil: INRETS

Hughes, J., Knittle, C., and Sperling D., 2008. Evidence of Shift in the Short-Run Price Elasticity of Gasoline Demand. The Energy Journal. Preprint.

IEA 2000. The Road from Kyoto. Paris: International Energy Agency

IEA, 2004. After 30 Years. Oil and Energy in IEA Countries. Paris, International Energy Agency.

Johansson, O. and Schipper, L., 1997. Measuring the Long-Run Fuel Demand of Cars. Journal of Transport Economics and Policy, September 1997.

Mazzi, E. & Dowlatabadi, H. (2007). Air Quality Impacts of ClimateMitigation: UK Policy and Passenger Vehicle Choice. Environmental Science & Technology, v. 41, pp. 387-392.

Major, Mark, 2007. DG-Environment Presentation at the 13th Conference of the Parties (COP). Bali, Indonesia.

Schipper, L., 2008. Automobile Fuel; Economy and CO_2 Emissions in Industrialized Countries: Troubling Trends through 2005/6. Proc. 2008 Transportation Research Board, January. Washington DC. TRB.

Schipper, L.J. M.J. Figueroa, L. Price, and M. Espey, 1993a, Mind the Gap: The Vicious Circle of Measuring Automobile Fuel Use, Energy Policy 21. (12)1173-1190.

Schipper, L., Marie-Lilliu, C., and Fulton, L., 2002. Diesels in Europe: Analysis of Characteristics, Usage Patterns, Energy Savings and CO_2 Emissions Implications. J. of Transport Economics and Policy 36 (2), pp. 305-340.

Schipper, L., Steiner, R., Figueroa, M., Dolan, K., 1993b, Fuel Prices and Economy: Factors Effecting Land Travel, Transport Policy 1 (1) 6-20. LBL-32699

Schipper, L.J. and W. Tax. 1994. New Car Test and Actual Fuel Economy: Yet Another Gap? Transport Policy 1. (2)1-9.

Small, K. and van Dender, K., 2007. Fuel Efficiency and Motor Vehicle Travel. The Declining Rebound Effect. The Energy Journal, 28 (1), 25-51.

WBCSD 2003. Sustainable Mobility 2030. Report of the Sustainable Mobilty Project. Geneva- World Business Council for Sustainable Development

Zachariadis T., On the baseline evolution of automobile fuel economy in Europe. Energy Policy 34 (2006) 1773-1785.

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Appendix: Main Data Sources

Belgium. Data provided by Inge Mayares from sources Flemish Institute of Technology and Flemish Planning Bureau.

France. ADEME, the French Agency for Environment, publishing year books on Energy Efficiency Trends and yearly updates on motor vehicles. Ministère de l'Equipement (et INSEE, Nation Institue of Statistics), yearly data "Bilan de la Circulation" for "Rapport de la Commission des Comptes Transport de la Nation".

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 CO_2 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.

Netherlands. Data from the Bureau of Statistics communicated by Dr. Karst Geurs, Ministry of Planning, based on CBS and Verkeer en Vervoer data.

Spain. Data come from IDAE, the Spanish energy conservation agency, and the Ministry of Transport.

Sweden. SCB (Central Bureau of Statistics) and SIKA (Statens Institut foer Kommunikations Analyser).

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.

US. Oak Ridge Transportation 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 Use Survey.

International Energy Agency, Paris France (www.iea.org): All fuel price data

European Council of Ministers of Transport (Now the International Transport Forum http://www.international-transportforum.org/). European Transport Data Base and material submitted to ECMT from ACEA, the European Association of Automobile Manufacturers.

Table 1. Summary Parameters of Diesels in eight countries 1995 and 2005/6. Sources given in the appendix. Note in this table CO_2 derived from IPCC values for direct combustion of each respective fuel.

	France		Germany		Spain		Italy		Netherlands		Belgium		UK		Austria		EU- 8*	
	1995	2006	1995	2006	1995	2004	1995	2005	1995	2005	1995	2006	1995	2005	1995	2006	1995	2005
New Diesels																		
New Diesel, 1000s	898	1393	484	1506	267	858	171	1141	59	106	152	305	373	706	119	192	2522	6209
Share of Sales, %	47%	69%	15%	44%	34%	70%	11%	61%	18%	23%	52%	74%	23%	35%	42.6%	62.1%	25%	54%
New diesel, l/100 km	6.60	5.60	6.50	6.59	6.20	5.47	6.70	5.50	6.60	5.80	6.40	5.70	6.70	6.24	6.60	5.80	6.55	5.89
L/100 km rel. to gasoline	88%	82%	86%	89%	82%	78%	89%	86%	81%	77%	80%	83%	83%	85%	81%	82%	85%	84%
CO_2km rel. to gasoline	104%	97%	101%	105%	96%	92%	105%	101%	96%	91%	94%	97%	98%	101%	96%	96%	101%	100%
New Gasoline, l/100km	7.50	6.80	7.60	7.41	7.60	7.00	7.50	6.40	8.10	7.50	8.00	6.90	8.10	7.30	8.10	7.10	7.69	7.14
On Road Diesel Stock																		
Diesels stock, '000	6622	13969	5545	10091	1559	5685	3137	7529	614	1093	1393	2571	1722	4834	807	2220	21401	47991
Share of Stock, %	22%	47%	14%	22%	14%	38%	12%	30%	11%	16%	33%	52%	8%	19%	24%	53%	15%	29%
Km/car/year, thousands	20.6	16.7	18.0	20.0	15.7	16.6	21.5	18.9	25.3	25.7	22.7	20.1	26.7	21.1	17.7	17.1	19.7	17.8
km/year, Rel. to gas.	178%	164%	144%	191%	130%	155%	204%	193%	212%	236%	184%	200%	180%	151%	138%	145%	171%	176%
Diesel Stock l/100 km	6.67	6.43	7.47	6.90	6.90	6.75	6.68	6.06	6.90	6.77	7.33	6.54	7.49	7.12	7.07	6.41	7.02	6.62
l/100 km Rel. to gasoline	79%	84%	82%	83%	83%	83%	84%	85%	83%	83%	75%	79%	81%	81%	79%	79%	81%	83%
CO_2/km Rel. to gasoline	93%	99%	96%	98%	98%	98%	99%	101%	98%	98%	89%	93%	96%	96%	93%	93%	95%	98%
Gasoline l/100 km	8.49	7.67	9.14	8.28	8.32	8.11	7.93	7.10	8.33	8.16	9.76	8.30	9.25	8.79	8.97	8.11	8.70	7.94
COMBINED, l/100 km	8.05	7.33	9.00	8.09	8.19	7.79	7.99	7.17	8.12	7.90	9.00	7.59	8.56	7.55	8.66	7.59	8.4559	7.641