Diesels in Europe: Analysis of Characteristics, Usage Patterns, Energy Savings and $Co_2$ Emission Implications

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# Diesels in Europe

## Analysis of Characteristics, Usage Patterns, Energy Savings and $CO_2$ Emission Implications

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**Abstract**

This paper examines trends in characteristics of light-duty vehicle fleets and new diesel cars in the 1990s in five countries in Europe. Diesels now typically comprise between 8 and 15 per cent of car fleets, and more than a quarter in France. On average, diesels consume 5 to 15 per cent less energy per kilometre than petrol cars. As deployed today, diesel cars are associated with very little savings of energy or reduction of carbon dioxide emissions, since a high proportion of fuel saving is lost to increased travel distance. However, recent trends in new diesel car characteristics, combined with recent increases in diesel taxes in some countries, could lead to much greater energy savings in the future.

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# Purpose and Background

The number of diesel-powered passenger cars increased significantly in the 1990s in several European countries, such as France.[1] From a technology standpoint, diesel engines provide significant potential for fuel saving, which is important for improving energy security and restraining the growth in carbon emissions from transport. But how much of this potential has been realised to date? As this paper will show, the nominal answer is not much. However, it is important to dig deeper into the possible reasons for this answer and what it reveals about policy, and what the future for diesels may hold.

Diesel cars differ from petrol cars in several important respects: types of models available, new car prices, vehicle performance, fuel cost, and other characteristics. The users of these two types of vehicle also differ. In most European countries diesels tend to be used more for commercial purposes (taxis, sales, and so on), and as private vehicles they tend to be bought by wealthier individuals and relatively high-kilometre drivers. Finally, government policies, especially taxation policies, towards the two car types tend to be different, often dramatically so.

All these aspects are potentially important in the analysis of whether and to what extent to which diesel vehicles, as currently deployed, provide energy savings and $CO_2$ reductions. Not only the engine technologies, but also the types of vehicles they are used in, and how these vehicles are used, affect this analysis. Fuel and vehicle taxation policy can affect these choices in several ways. The relative cost of diesel vs. gasoline vehicles, and even the relative cost of fuel, may influence the vehicle choice of car buyers. Reductions in diesel vehicle tax or fuel taxes both act to reduce the overall cost of owning a diesel, and may encourage purchasers to upgrade to more expensive cars by "spending" some of the life-cycle cost savings on a nicer car. Fuel price reductions for diesel may encourage diesel owners to drive farther than they would have otherwise (or than petrol vehicle drivers do), due to lower per-kilometre costs. Such a response has been referred to in the literature as a "rebound" effect, that is, an increase in the level of travel due to a reduction in the marginal cost of travel. (see, for example, Greene *et al.*, 1999). There are two types of rebound effect that are relevant in the context of this study: a vehicle purchase rebound (to larger cars) and a travel rebound. The nature and extent of such rebounds represent strategic unknowns in the debate over how to promote greater fuel economy by selling diesels in IEA countries.

[1] In this paper, cars or autos refer to automobiles. At this stage of the study we have not considered light trucks that are used for personal travel because of lack of data.

Given such potential consumer responses to price signals, one can expect there to be a level of diesel fuel price reduction that will become counter-productive, as it provides a level of monetary savings that provokes an increase in diesel vehicle size and level of travel that begins to erase the fuel savings benefits of diesels.

To analyse and quantify the impact of diesel engines and cars in Europe, we first examine trends and data that characterise fleets of diesel cars in the mid-1990s in five countries in Europe. France is important because it is the leading country in the world for diesel cars, both as a producer and as a market. Germany is important because while the market share of diesels has stagnated in recent years and even fallen back slightly, German car manufacturers have placed considerable hopes on advanced diesels to meet energy-saving targets for reducing carbon emissions from transport. The Netherlands is included because diesels have now eclipsed Liquid Petroleum Gas (LPG) cars in popularity, permitting us to see how a three-fuel competition has fared, and because LPG yields some lessons on its own. Note that LPG cars are included in the analysis for Netherlands and Italy since they have been important rivals to the diesel in those countries during the 1990s.

We encountered several difficulties in this analysis. First, both survey data and aggregated data on car characteristics, ownership, use, and fuel use/km,[2] we still cannot fully separate the effects of the composition of the fleet of cars of one kind or another from the actual differences in cars, and their impact on travel. The same applies to drivers and their driving that leads to a chicken-and-egg problem: to what extent drivers who select diesel drive further as a consequence of their selection?

We also acknowledge that both the policy landscape and the nature of diesel cars are changing. Although data through 1998 support our conclusions, it appears that some countries in the study intend eventually to raise the taxation on diesel fuel closer to that of petrol, which is one major difference in the two fuels to which we attribute much of our findings. Indeed, data submitted to the European Council of Ministers of Transport for new car carbon emissions through 2000 show a clear decline that is more rapid than in previous years, and data on individual country new diesel performance reflect improvements in fuel economy of diesels at an increasing rate. This may in part be driven by the voluntary agreement on fuel economy improvements between the European Union and the European (and Japanese and Korean) manufacturers for cars sold in Europe

[2]The ratio fuel use/km is either called: fuel intensity when we refer to a specific fuel or energy intensity when we refer to no particular fuel but count energy content of any or all fuels.

(IEA 2000). Indeed, the technology of diesel cars is improving so rapidly that, together with the policy changes we refer to here, some of the issues we describe in this study may be less important in the coming years. But there are basic lessons regarding fuel taxes and other policy approaches that will continue to hold, as many countries today are experimenting with new fuels or vehicles that are supported by substantial tax breaks or lower fuel taxation.

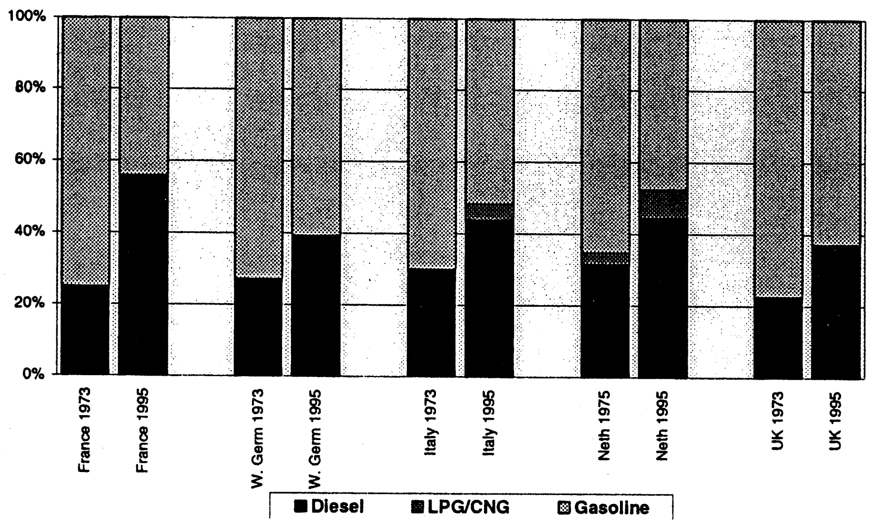
## Overview of the Diesel Penetration in the Private Vehicle Market

### Share of diesel in car fuel use and vehicle fleet

Figure 1 shows the share of petrol, LPG, and diesel fuel used by cars in five European countries.[3] In the 1970s diesel cars were popular in Europe

**Figure 1**

*Road fuel shares, by energy content, 1973 and 1995*




Source: IEA/LBNL

[3] "Cars" include all vehicles normally thought of a cars, following national registration conventions, plus a number of very small vans in the UK used both as personal vehicles and in trades. The splits by fuel and vehicle are explained in Schipper *et al.* (1993) and updated in Schipper and Marie-Lilliu (1999).

among a small segment of car buyers. Beyond professional taxi drivers, diesels were almost always limited to car users with high mileage (travelling salesmen and trades-people, company cars for official use, and so on) and, in some countries, drivers with access to untaxed diesel fuel.

In the 1980s and 1990s this changed, and diesel cars appeared in other segments of the market that were not originally diesel-oriented. The slow turnover of the vehicle stock, as well as the maturing of diesel vehicle technology are two reasons why this reaction was slow to come about. As technology improved, the image of diesel cars changed as well, being perceived less as a heavy, polluting car, lacking in power, that people were reluctant to buy unless the fuel cost savings provided by diesel were substantial. However, as diesels themselves improved, and with a significant fuel price gap persisting throughout the 1990s, diesel cars increased steadily in popularity across all market segments.

**Diesel share of national fleets**

Figure 2 shows the petrol, diesel, and LPG/CNG fleets for five European countries, and, in comparison with Figure 1, reveals that diesel stock share has been consistently lower than diesel fuel share. This is because the average diesel car uses significantly more fuel then the average petrol car.[4] In 1973, diesel cars represented less than 5 per cent of existing cars in Europe. LPG was popular in the Netherlands and Italy. By 1995, diesels made up almost 26 per cent of the French car fleet, 15 per cent in Germany,[5] 12 per cent in Italy and the Netherlands, and had grown rapidly to 11 per cent in U.K. Shares of vehicles using these fuels in the Nordic countries (not shown) are much lower, between 3 and 7 per cent.

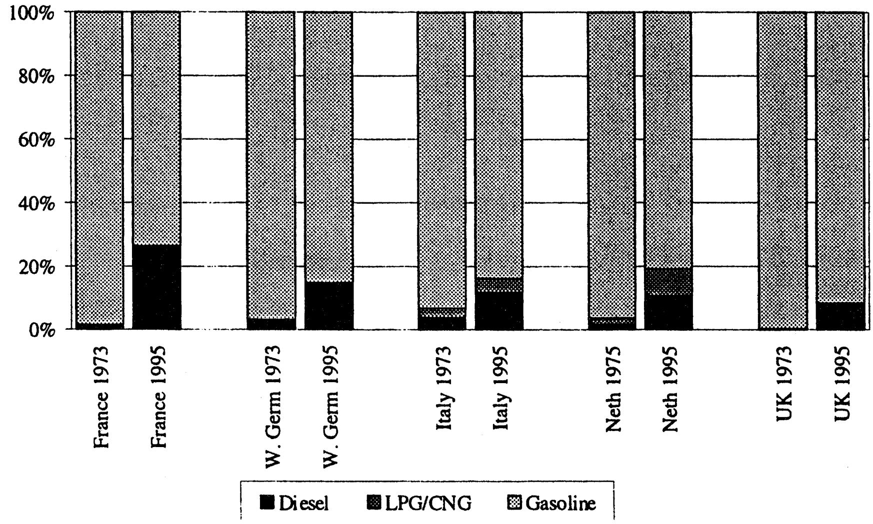
**New cars**

As shown in Figure 3, the shares of diesels in the new car markets in Europe are in most cases significantly higher than their share of the total stock. With diesels no longer solely in the domain of taxis, they have penetrated significantly into other market segments as well. By 1995, the diesel share of new cars exceeded 40 per cent in Belgium, Austria and France. The Western European average has increased steadily in the 1990s and by 1998 was nearly 30 per cent.

At different points in time, major shifts in diesel sales shares have occurred in several countries. While the year-by-year shifts are in some

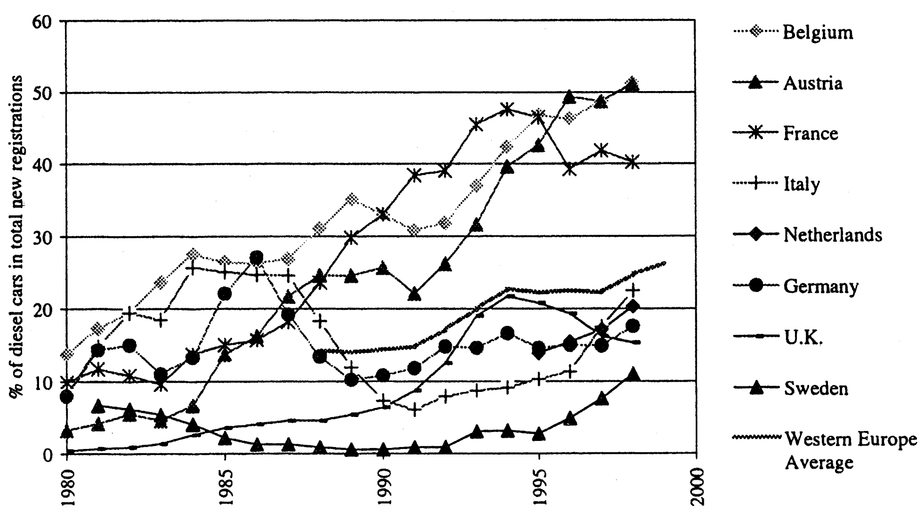
[4] As we shall discuss later, although the fuel economy of diesel cars is better than petrol cars, this does not lead to a net reduction in fuel use, as they are driven much more per year.
[5] For consistency, the former West Germany only is used to allow trend analysis.

**Figure 2**
*Share of on-road car fleet by fuel type, 1973 and 1995*




Source: IEA.LBNL

**Figure 3**
*Diesel penetration of car market, 1980–1999*




Source ACEA, Eurostat/ECMT,AID/Industry Sources. Note: 1999 after 3 months cases dramatic, in many cases this reflects significant changes in vehicle offerings (or engine option offerings) by manufacturers, not just increases or declines in sales of existing models. Thus there have been major changes in direction on both the supply and demand sides of the equation.

In Germany and Italy, large changes in sales closely followed changes in fuel taxation levels (and in the former country, emissions-control requirements). Belgium and Austria (not analysed here in further detail), represent countries with, in recent years, the most attractive combinations of diesel/petrol price differentials and car price differentials. In Sweden, a long-standing tax on the number of kilometres a diesel vehicle was driven was repealed in 1993, and the share of diesels, while small, grew somewhat, particularly among the largest cars. In France, diesel share climbed steadily until 1994. The change in direction in that year could reflect French policies put in place around that time to promote purchases of smaller cars (with most small car models available only with petrol engines), and government announcements of possible plans to increase taxation of diesel cars and fuel in the future to bring these more in line with petrol taxes. The recent decline in diesel market share in the UK roughly coincides with the raising of diesel fuel tax very close to the petrol level. The Western European experience with diesels is rich in changes over time and differences in cross section. Yet overall diesel car sales are continuously growing and now account for over one in four new cars sold.

LPG cars have been important in countries where this fuel is available at low price. LPG cars reached their highest market shares in the Netherlands, mainly sold as conversions. LPG is also common in Italy, where around 700 new LPG cars are registered each year.[6] It has become more popular recently in France with the lowering of LPG tax and because LPG was supplied in a larger number of filling stations. Car manufacturers are proposing many LPG-petrol models for the French market, and the sales are beginning to increase.

## Difference in Diesel and Petrol Car Characteristics[7]

Car characteristics such as weight, power, and engine size are strong determinants of fuel economy. Diesel cars in Europe typically have different characteristics from petrol cars, as presented in Table 1. Some of

[6]Note that LPG remains in use for all taxis in Japan.
[7]LPG analysis is included only where data permit.

**Table 1**
*Differences in diesel and petrol cars (Late 1980s, Early 1990s)*

| *Advantages to diesel car* | *Disadvantages* |
|---|---|
| Longer life | Higher cost (per rated kW) |
| Lower fuel intensity | Larger, heavier (per rated kW) |
| Lower fuel cost | Potential cold weather problems |
| Less component failure | Higher frequency and cost of routine maintenance |
| Lower carbon monoxide and VOC emissions | Higher particulate and $NO_x$ emissions |
| | More noise |

Source: Cars and Climate Change, OECD/IEA, Paris 1993.

these differences have been disappearing in recent years, with the emergence of direct injection technologies. For example, new TDI diesels are generally experiencing fewer cold weather problems and are quieter than older diesels.

**Differences in the characteristics of new petrol and diesel vehicles: matched pairs comparison**

In order to compare the differences in the characteristics of the technologies more clearly, we identified 24 recent "matched pairs" of diesel and petrol vehicles. In all cases the petrol and diesel pairs include the same vehicle model (nameplate) for the 1998 or 1999 model year, with similar specifications but with different engines. Where multiple diesel or petrol engines are available for a vehicle model, the engines were matched so as to provide a similar level of both acceleration and torque. The averages presented in Table 2 provide an estimate of the differences in characteristics between similar diesel and petrol vehicles. In almost all cases, the diesel acceleration is slower (higher in seconds) than the petrol vehicle, but its torque is higher (torque is important in providing instantaneous power for changing speeds). Thus there is clearly a trade-off between acceleration and torque when choosing between diesel and petrol vehicles, and there is probably no such thing as a perfectly matched pair, since different consumers may value acceleration vs. torque differently. As shown in the table, the diesel vehicles have larger engines, on average, which is necessary to match more closely the performance of the petrol engines. This difference in engine type and size also contributes to a different average weight between the vehicles. Thus the "equivalent" diesel car is actually heavier with a larger engine than the corresponding petrol model. This difference offsets some of the potential fuel economy benefit of the diesel, but there are still potentially very large fuel savings from diesel vehicles.

**Table 2**
*Diesel/petrol vehicle matched pairs characteristics for selected models*

| | *Acceleration (0-100 km/hr)* | *Maximum Torque (Nm)* | *Weight (kg)* | *Engine size (cc)* | *Fuel Use l/100 km* |
|---|---|---|---|---|---|
| *Characteristic Basis of comparison* | *Diesel percent slower* | *Diesel percent higher* | *Diesel percent higher* | *Diesel percent higher* | *Diesel percent lower* |
| Average values (24 pairs) | 15.5 | 30.7 | 7.5 | 15.5 | −26.0 |
| Average values, pairs with diesel direct injection (TDI)(11 pairs) | 15.0 | 33.7 | 8.2 | 9.7 | −33.5 |
| Average values, pairs with diesel indirect injection (IDI) (13 pairs) | 15.9 | 28.3 | 6.9 | 20.4 | −19.6 |

Source: Own calculations based on the publication Alles Auto's 98/99, KNAC AutoJaarboek, the Netherlands.

The table includes eleven pairs that have a turbocharged direct injection (TDI) diesel, which has been introduced in many vehicle lines in the past two years. These engines have significantly better fuel economy and performance than conventional indirect injection (IDI) and even turbocharged IDI diesels. Based on the European test cycle, the average diesel vehicle in our database uses about 26 per cent less fuel per kilometre than its comparable petrol partner. However, the difference is much larger for TDI diesels than IDI diesels (including some IDI diesels with turbocharging). For the eleven TDI diesels included in the table, their average fuel consumption per km is about 33 per cent lower than their petrol counterpart; for the IDI diesels, their fuel consumption is about 20 per cent lower than their petrol counterpart.

While there is a substantial difference in fuel economy between matched pairs of diesel and petrol vehicles, this difference is less pronounced when looking across all new gasoline and petrol vehicles sold in the countries studied.

## Differences in averages across all new cars

### *Engine size and weight*

As with the matched pairs differences, in the aggregate the average new diesel car has a larger engine than the average new petrol car. Table 3 gives

**Table 3**
*Average car capacity cylinder comparison based on whole new car fleet, Germany, 1980–1995*

| | *1980*** | | *1985*** | | *1990*** | | *1995*** | |
|---|---|---|---|---|---|---|---|---|
| | *Petrol* | *Dies.* | *Petrol.* | *Dies.* | *Petrol.* | *Dies.* | *Petrol* | *Dies.* |
| New car sales (1000) | 2230 | *196* | 1848 | *776* | 2703 | *338* | 2831 | *484* |
| Engine size distribution by category (%): | | | | | | | | |
| < 1000 cc | 8.0 | - | 9.3 | - | 4.2 | - | 3.5 | - |
| 1000–1499 cc | 40.1 | *27.2* | 32.5 | *0.6* | 27.9 | *0.4* | 33.1 | *0.7* |
| 1500–1999 cc | 38.2 | *36.5* | 43.9 | *82.7* | 55.5 | *65.2* | 52.6 | *62.3* |
| > 2000 cc | 13.7 | 36.3 | 14.3 | 16.7 | 12.4 | 34.4 | 10.8 | 37.0 |
| Total | 100.0 | *100.0* | 100.0 | *100.0* | 100.0 | *100.0* | 100.0 | *100.0* |
| Average engine size (cc)* | 1580 | *1890* | 1610 | *1880* | 1670 | *2000* | 1660 | *2024* |
| Diesel /Petrol difference (%) | | *19.6* | | *16.8* | | *19.8* | | *21.9* |

*Approximation of average cc computed using average cc category weighted by new car market shares.
**1980–1990: Old Länder only, 1995 Germany as a whole.
Source: Deutsches Institüt for Wirtschaftsforschung, 1997.

an overview of the German new car market, broken down by engine size class. Our matched pair diesels have 15 per cent more motor displacement than their petrol counterparts, but the average new diesel car has a cylinder capacity greater by 20 per cent compared to the petrol ones. Similar differences can be observed for the UK, France, and other European Countries.[8] This may reflect greater market shares for IDI diesels (which tend to have relatively bigger engines than the TDI diesels), but probably also reflects differences in the composition of the new diesel and petrol car fleets, with the diesel fleet somewhat more oriented towards the larger vehicle size categories.

Data for the UK show a strong evolution of the diesel market in that country. In 1994, cars built in 1978 or earlier that ran on diesel had 50 per cent greater cylinder volume than those made for petrol, a fact reflecting the dominance of large taxis in the diesel car stock of the 1970s.[9] However, with

[8] Source: confidential data provided by a car manufacturer; UK Dept of Environment, Transport, and the Regions; Verkehr in Zahlen (Germany); Central Bureau of Statistics (Netherlands).

[9] Engine displacement of diesel and petrol cars of this vintage surviving to 1994 were in general significantly larger than those of more recent vintages (20 per cent). We speculate that this is because the largest cars survive the longest.

more recent model years this size difference shrinks steadily, so that diesel cars built between 1985 and 1993 had roughly 20 per cent larger engines than petrol cars of the same vintage. This gap held steady through 1998. The shrinking of this gap may represent the emergence of "mass market" diesel cars (rather than mainly taxis) in the 1990s. The absence of this "shrinking engine size" in Germany probably reflects the fact that in 1980 diesel cars in Germany had a much higher market share than they did in the UK, a share well beyond that representing primarily taxis and a few high-mileage drivers.

Diesel and petrol vehicles are also typically quite different in terms of size and weight, with differences in weight in the aggregate typically larger than differences on a matched pairs basis. For example, in the Netherlands, diesel models and LPG models are typically 10 and 20 per cent heavier, respectively, than the petrol ones. For the diesels, this reflects greater sales in the large size classes relative to the current 7.5 per cent average difference in the weights of the matched pairs. The persistence of higher engine and weight differences in the aggregate than for "matched" pairs may be due in part to the fact that there have, until recently, been more diesels offered in mid-size to large car segments and fewer in the small car segments. However, this appears to be changing with the new offering of diesel options in many small European car models in the past few years.

*Fuel economy*

Measuring on-road fuel economy over the entire fleet of light-duty vehicles (Table 4), in 1995 diesels used less fuel per kilometre by fuel volume than petrol cars (Schipper and Lilliu, 1999).[10] However, although the difference in litres per 100 km was substantial, it was about 20 per cent lower in most countries than for the matched pair data (around 20 vs. 26 per cent for the matched pairs). Furthermore, after accounting for the energy content of the two fuels, the percentage difference in intensity[11] was lower still. Diesels averaged 10–14 per cent lower energy intensity than petrol vehicles in four of the countries; and in Italy they were virtually equivalent. Both fuel economy and fuel intensity measures are shown in Table 4.

Looking at the average *test* fuel economy for *new* vehicles, time-series data available for France and Germany (Table 5) indicate that there has been considerable variation in the relative fuel economy of diesel vs. petrol

[10] Schipper *et al.* (1993) explain how global on-road fuel economy values are derived by national authorities from both vehicle user surveys and statistics on fuel sales and vehicle use. While there are uncertainties associated with these data, the intensities are probably accurate enough to distinguish between the petrol and diesel values, and to discern rising or falling trends over a number of years.

[11] Measured in MJ/km, which accounts for the energy content of one litre of each fuel.

**Table 4**
*On-road fuel economy and energy intensity, 1995*

| *Litre/100 km(equivalent in MJ/km and miles per gallon)* | *France* | *W. Germ** | *Italy* | *Neth.* | *UK* |
|---|---|---|---|---|---|
| Petrol | 8.5 | 9.4 | 7.5 | 8.7 | 9.8 |
| | *2.7* | *3.0* | *2.4* | *2.8* | *3.2* |
| | 27.7 | 25.0 | 31.5 | 27.1 | 24.0 |
| Diesel | 6.7 | 7.8 | 6.8 | 6.8 | 7.8 |
| | *2.4* | *2.8* | *2.4* | *2.4* | *2.8* |
| | 34.9 | 30.2 | 34.7 | 34.5 | 30.3 |
| Percentage difference (based on litre/100 km) | −20.6% | −17.4% | −9.1% | −21.6% | −20.9% |
| Percentage difference (based on energy content of fuels, in MJ/km) | *−12.3%* | *−8.8%* | *0.4%* | *−13.5%* | *−12.6%* |

Sources: France, OEST Transport Statistics; Germany Verkehr in Zahlen and updates made available by the Deutsche Inst. Fuer Wirtschaftsforschung; Automobile Club of Italy and ENEA; Transport Statistics and Car Use Surveys of Central Bureau of Statistics, Voorburg, the Netherlands; UK Digest of Transport Statistics and Dept of Environment, Transport, and Regions data.
*W. Germany, 1994

vehicles over the years in both countries. Note that these figures differ from those in Table 4 in two respects: they reflect test rather than on-road estimates, and they are for new cars, not the entire stock of cars. Therefore the smaller diesel fuel intensity advantage typical in Table 5 may reflect a combination of two factors: (1) a shift towards purchases of large diesel cars in the late 80s and early 90s (especially in Germany) that was not yet fully reflected in the 1995 stock estimates; and (2) an increase in the diesel/petrol differences when using on-road data rather than test data.

In fact, in Germany there was a strong rise and then fall of sales of diesel cars throughout the 1980s (as shown in Figure 3), with much of the fluctuation in sales of small and midsize diesels, while sales in the largest weight classes held more steady. This accounts for much of the fluctuation in fuel economy over this period. In the 1990s German diesel sales grew slowly but steadily with diesel size dropping somewhat, but average diesel size in Germany is still large compared to petrol vehicles.

In France, diesel sales have risen steadily since 1980, without the collapse in sales of small and medium sized diesels that occurred in Germany in the late 1980s. As diesel sales have increased, the average size of diesels has dropped, and the average fuel economy compared to petrol vehicles improved through the 1980s and more or less held firm in the first half of the 1990s.

**Table 5**
*Sales-weighted new car fuel economy averages for Germany and France*

| *l/100 km(Equiv. MJ/km and miles per gallon)* | *1975* | *1978* | *1980* | *1985* | *1990* | *1995* |
|---|---|---|---|---|---|---|
| Germany, Petrol | | 10.7 | 9.1 | 8.2 | 7.8 | 7.7 |
| | | *(3.5)* | *(2.9)* | *(2.7)* | *(2.5)* | *(2.5)* |
| | | (22.0) | (25.8) | (28.7) | (30.2) | (30.5) |
| | | 8.8 | 8.8 | 7.2 | 8.0 | 7.5 |
| Germany, Diesel | | (3.1) | (3.1) | (2.6) | (2.9) | (2.7) |
| | | (26.7) | (26.7) | (32.7) | (29.4) | (31.4) |
| Percentage difference (based on litre/100 km) | | −18% | −3% | −12% | 3% | −3% |
| Percentage difference (based on MJ/km) | | −9% | 7% | −3% | 13% | 8% |
| France, Petrol | 8.5 | 8.3 | 7.8 | 6.8 | 6.8 | 6.8 |
| | (2.7) | (2.7) | (2.5) | (2.2) | (2.2) | (2.2) |
| | (27.7) | (28.3) | (30.2) | (34.6) | (34.6) | (34.6) |
| | 8.6 | 7.9 | 7.6 | 6.0 | 5.9 | 6.1 |
| France, Diesel | (3.1) | (2.8) | (2.7) | (2.1) | (2.1) | (2.2) |
| | (27.4) | (29.8) | (30.9) | (39.2) | (39.9) | (38.2) |
| Percentage difference (based on litre/100 km) | 1% | −5% | −3% | −12% | −13% | −10% |
| Percentage difference (based on MJ/km) | 12% | 5% | 8% | −3% | −4% | −1% |

Sources: France OEST-SES; Germany Verkehr in Zahlen.

In both countries in the last 5 to 10 years two separate trends have been at work: (1) diesels have become more efficient and interesting to a broader range of consumers, as turbo-direct injection (TDI) has begun to be introduced; and (2) increased penetration of diesel has occurred in smaller-car segments of the market. These trends have in turn been driven by a variety of factors. First, the recession of the early 1990s had an effect of the type and size of cars bought. This was reinforced in recent years by the "Baladurettes" or "Juppettes",[12] modest tax subsidies for trading an old car for a new one, which tended to lead to purchase of small second cars. The average new car size in France fell slightly as a result of these Juppettes. Since nearly 50 per cent of new cars sold in the early 1990s were diesels, this meant that by 1995 at least half of all diesels on the road were purchased since 1990, and were both technologically more efficient and smaller than those purchased prior to 1990. We estimate that only one-third to one-half of the improvement in fuel economy of diesels is tech-

[12]"Prime à la casse", scrappage premium. Cars eligible were aged more than 10 years.

nological; the rest is due to this shrinking of average size. (At the same time as the fuel economy of the diesel fleet improved, that of the petrol fleet only improved by 10 per cent, a result of slower turnover and less of a shift towards smaller cars.)

## Driving Distance

Annual driving distances of diesels (and LPG) are significantly higher than those for petrol cars. Table 6 gives figures for France, Germany, Italy, the Netherlands, and the UK and Figure 4 shows the evolution of driving distance over time, as well as the trend of the driving distance weighted by the share of each type of car in the total fleet.

Average travel per vehicle for diesels ranges from about 42 per cent more than petrol vehicles (in Germany) to over 100 per cent more in Italy and the Netherlands. These large differences are indicative of a niche market (such as taxis), but given their large share of the fleet (and new car sales) in France, Germany, and Italy, diesel cars now reach well beyond specialised high-travel market niches. Therefore the high travel per vehicle cannot be due solely to niche market travel behaviour.

This observation is reinforced by the contrast between the index of the average distance all cars are driven and the respective petrol and diesel or LPG distances shown in Figure 4. For most years in each country, the increase in the index is considerably more than the increase in driving of

**Table 6**
*Average annual distance per car, 1995*

| | *France* | *Germany* | *Italy* | *Neth.* | *UK* |
|---|---|---|---|---|---|
| | | | Km (*Miles*) | | |
| Petrol | 11 744 | 12 037 | 10 539 | 13 206 | 13 867 |
| | (*7 340*) | (*7 481*) | (*6 586*) | (*8 253*) | (*8 667*) |
| Diesel | 21 552 | 17 099 | 21 497 | 28 134 | 25 233 |
| | (*13 470*) | (*10 627*) | (*13 435*) | (*17 584*) | (*15 770*) |
| LPG | | | 16 500 | 27 620 | |
| | | | (*10 312*) | (*17 262*) | |
| Percent difference | | | | | |
| Diesels vs. petrol | 83.5% | 42.1% | 104.0% | 113.0% | 81.9% |
| Diesel share of fleet | 26% | 15% | 12% | 12% | 8% |

Sources: France, OEST-SES Transport Statistics; Germany Verkehr in Zahlen and updates made available by the Deutsche Inst. Fuer Wirtschaftsforschung; Automobile Club of Italy and ENEA; Transport Statistics and Car Use Surveys of Central Bureau of Statistics, Voorburg, the Netherlands; UK Digest of Transport either petrol or diesel cars. To make this point clearer, we superimpose the weighted average annual driving distance of all cars on the values for each kind. Indeed, in some countries, notably France and Germany, average annual distance per diesel car has fallen even though the weighted average of all cars in the fleet has increased. This suggests that a significant increase in travel is associated with the switch from petrol to diesel vehicles. Further, as diesels gain market share in each country, the number of naturally high-mileage drivers switching to diesel eventually is exhausted, and the later switchers are more likely to represent persons closer to average in their travel patterns. However, a key question remains: to what extent is the low cost of operating diesels the *cause* of this travel increase, and to what extent is it due to vehicle switching from drivers anticipating travel increases *beforehand*? We return to this question below in reviewing a detailed study of such switching in France (see BOX 1).

**Fuel use comparison**

The differences between petrol and diesel vehicles in terms of on-road fuel economy and driving distance can be used to calculate differences in average annual fuel consumption per vehicle. Doing this for the five study countries, France, Germany, Italy, Netherlands, and the UK, we found that fuel use per car for diesel is substantially greater than for petrol, mainly due to the much higher driving levels for diesel. Since diesel fuel contains more energy per litre, the difference is even greater in energy terms. The results of this combination, expressed as fuel use per car per year in gigajules (GJ), are shown in Table 7.

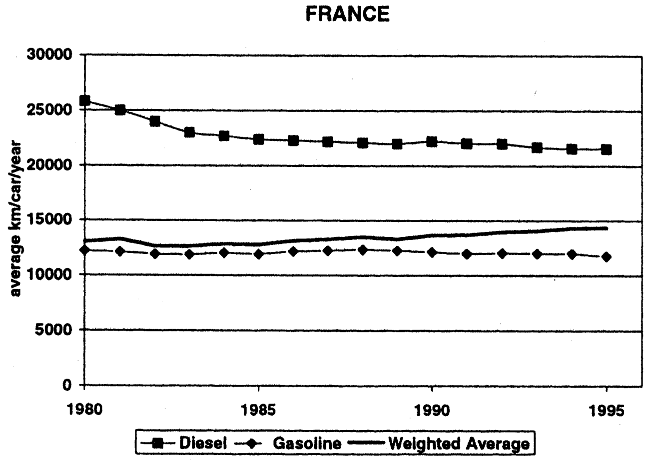
The data for five European countries indicate that at present the fleets of diesel cars in these countries have surprising energy use patterns. Although the average diesel uses 10 to 15 per cent less energy/km than a petrol car in four out of five countries, diesel cars are driven much further

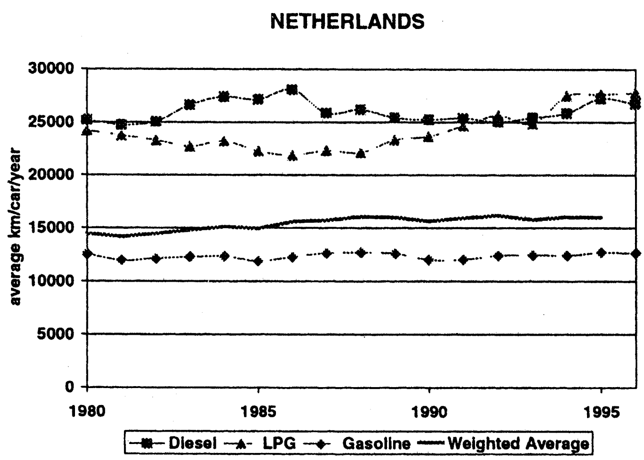
**Table 7**
*Annual fuel use per car, 1995*

| *(GJ)* | *France* | *Germ.** | *Italy* | *Neth.* | *UK* |
|---|---|---|---|---|---|
| Petrol | 32.3 | 41.4 | 25.4 | 37.1 | 44.0 |
| Diesel | 51.9 | 53.2 | 52.0 | 68.6 | 69.9 |
| LPG | NA | NA | 52.2 | 75.8 | NA |

Source: Calculated from average driving distances and average fuel economy. Net calorific values.
*Germany, 1994 data.

**Figure 4**
*Average car distance by fuel type and weighted average, 1980–1996*



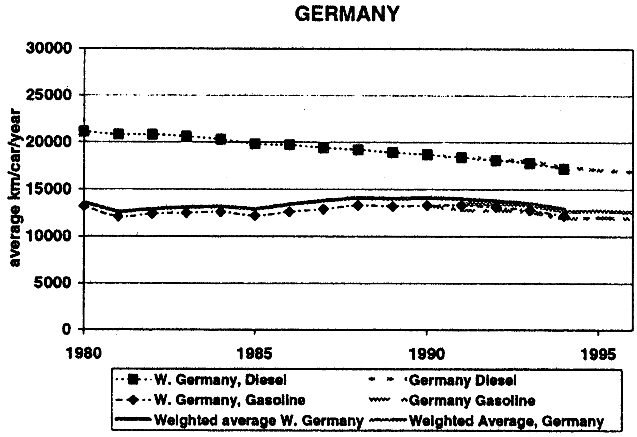




than petrol cars and use up to twice as much fuel per year on average. Since diesels have become so popular, probably only some of this difference in distance can be explained as use by "niche" long-distance and professional drivers. The next section explores one possible reason why this situation has occurred: fuel prices and fuel taxation policy.

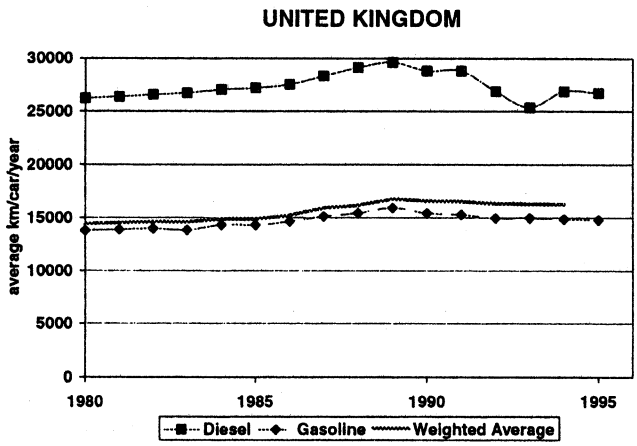
## Differences in fuel prices and taxation

A comparison of pump prices for petrol and diesel fuel in each country through time reveals one possible cause for the lack of a significant fuel-

Figure 4 (cont)




Old Länder, 1980–1994, Germany 1991–1996




Source: France, OEST-SES Transport Statistics; Germany, Verkehr in Zahlen and updates made available by the Deutsche Inst. Fuer Wirtschaftsforschung; Italy, Automobile Club of Italy and ENEA; The Netherlands, Transport Statistics and Car Use Surveys of Central Bureau of Statistics, Voorburg. UK, Digest of Transport Statistics and Dept of Environment, Transport, and Regions data.

saving component arising from the use of diesel. Figures 5 and 6 show the progression of diesel and petrol prices over time, in real 1990 US dollars, with levels for the United States as a reference in both cases. Table 8 shows both the ex-tax price and the taxes on the two fuels in each country in 1995. The taxation of the two fuels significantly favours diesel in all countries except the UK, where the price of petrol (unleaded) and diesel

**Figure 5**
*Price of automobile diesel oil for non-commercial use, 1970–1998*

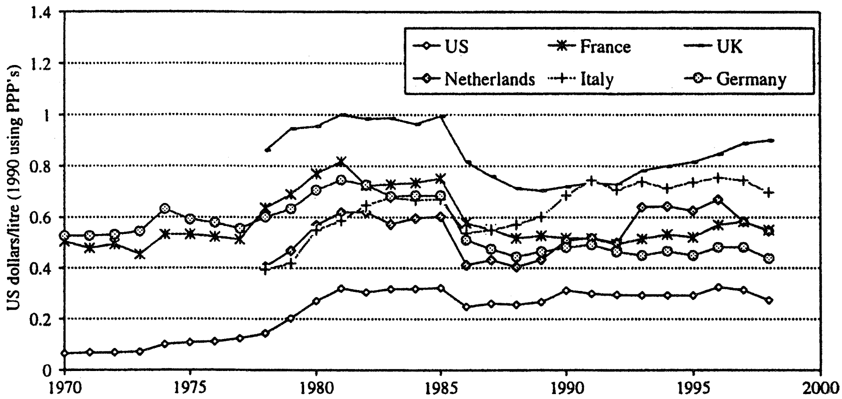
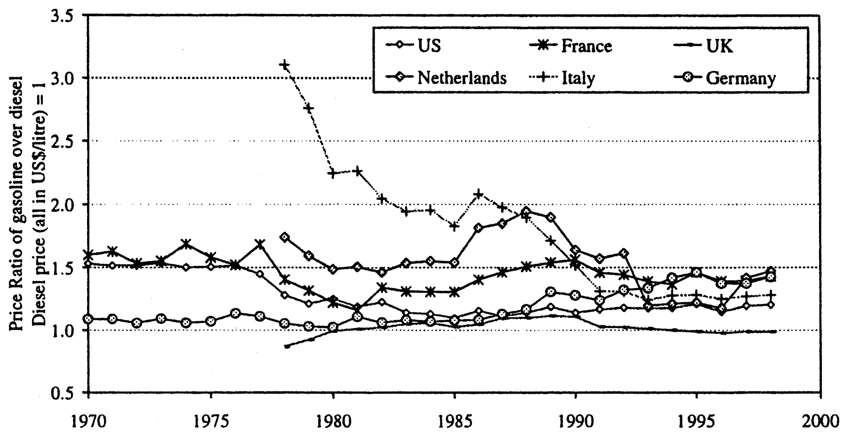



**Figure 6**
*Price ratio of gasoline over diesel, 1970–1998*




are very close. Table 8 shows that the difference in tax levels is the primary determinant of the overall price difference between the two fuels.

By multiplying the fuel price per litre and the average annual consumption per kilometre, the average fuel cost per kilometre can be obtained. Driving a diesel car one kilometre ranges from 54 to 80 per cent as expensive as a petrol car in the five countries. Taking into account the average annual kilometrage of each type of car shows that annual fuel expenditure for diesels is nearly equal to petrol vehicles in France and is significantly higher than petrol vehicles in Italy, Netherlands, and the UK. In these three countries, higher annual travel by diesel vehicles more than offsets the cost savings per kilometre that the diesel efficiency advantage and low diesel fuel prices provide.

The cost of driving a car does not start with the cost of buying fuel — it starts with purchase cost. Diesel vehicle prices can be well over $1,000 above their petrol counterparts. In addition, other expenses, such as taxes on acquisition or ownership, can be different from one type of car to the other and can guide the buyers when choosing a car. Table 9 reviews the taxation scheme of the country studies and highlights differences in taxation of petrol and diesel cars. The table shows a mix of different tax policies in each country, but outside France, taxes are either equal for petrol and diesel or favourable to diesel. In France diesels are still favoured, although recent changes in the "fiscal horsepower"[13] calculation

**Table 8**
*Fuel prices and taxes, 1995*

| | *France* | *Germ.* | *Italy* | *Neth.* | *UK* |
|---|---|---|---|---|---|
| Fuel Prices (USD 1990 PPP per litre) | | | | | |
| Petrol (95 RON) | 0.762 | 0.914 | 0.945 | 0.763 | 0.808 |
| *Ex-Tax Price* | *0.151* | *0.217* | *0.253* | *0.197* | *0.213* |
| *Excise Tax* | *0.486* | *0.578* | *0.541* | *0.452* | *0.475* |
| *VAT* | *0.125* | *0.119* | *0.151* | *0.114* | *0.120* |
| Diesel | 0.521 | 0.660 | 0.737 | 0.625 | 0.816 |
| *Ex-Tax Price* | *0.144* | *0.209* | *0.216* | *0.259* | *0.215* |
| *Excise Tax* | *0.292* | *0.365* | *0.403* | *0.273* | *0.479* |
| *VAT* | *0.085* | *0.088* | *0.117* | *0.093* | *0.121* |
| Fuel price ratio, diesel vs. petrol energy content | 0.62 | 0.65 | 0.70 | 0.74 | 0.91 |
| Ratio of fleet average energy use per km, diesel vs. petrol | 0.87 | 0.91 | 1.00 | 0.86 | 0.87 |
| Ratio of fuel cost per km, diesel vs. petrol* | 0.54 | 0.59 | 0.71 | 0.64 | 0.80 |
| Ratio of yearly fuel expenditure per car, diesel vs. petrol** | 0.99 | 0.84 | 1.45 | 1.36 | 1.46 |

Source: IEA Energy Prices, using national consumer price indices and purchasing power parity for currency conversions to 1990 US Dollars. Purchase power Parities (PPP) are the rate of currency conversion that eliminate the differences in price levels between countries and therefore allow comparison between countries.
*Calculated as (diesel price × diesel fuel economy)/(petrol price × petrol fuel economy).
**Calculated as (ratio of diesel/petrol fuel cost per km) * (ratio of diesel/gasoline km per car).

[13]The French "puissance fiscal" calculation has, since 1 July 1998, been based on a formula that includes both $CO_2$ emissions and kilowatt engine rating.

**Table 9**

*Taxation of passenger cars in France, Germany, the UK, Italy and the Netherlands, 1998 ( + : favouring diesel = : No difference –: disfavouring diesel)*

| | *France* | *Germany* | *UK* | *Italy* | *Netherlands* |
|---|---|---|---|---|---|
| Vehicle purchase tax based on Engine rating | + Based on "Fiscal Horsepower" engine rating: depends on real engine power (KW) and $CO_2$ emissions (g/km) | Engine ratings are not computed | Engine ratings are not computed | Fiscal HP are not computed any more, replaced by KW | Engine ratings are not computed |
| Purchase value-added tax (VAT) | = =20.6% of the selling price | = 16% of selling price | = 17.5% of selling price | = 20% of selling price | = 17.5% of the price exclusive of taxes |
| Vehicle purchase tax charged at time of first registration | = from 2000 on (but used to be + for diesel (Carte Grise): Based on the fiscal horse power (Pa), 'department') | = Fixed price of 50.00 DM | | | = BPM Petrol. car: 0.452 x net list price - 3394 Dfl Dies. car: 0.452 x net list price - 1278 Dfl |
| Annual taxes on vehicle ownership (typically charged during annual registration) | + 'Vignette", annual tax based on the engine rating (Pa) (by category), age and department of registration | – since 1.07.1997: Based on emissions group and fuel, per 100 cc | = VED: Flat-rate charge depending on two categories of engine size (in cc) | – Since 1.01.98, based on real power, (in KW according the EU Standards: Lit. 5000/Kw Diesel Surtax: on the top of ownership tax[a] | – Motor-Rijtuigen Belasting: based on dead weight, province and fuel |

Source: Motor Vehicle Taxation in Europe, ACEA, 1999.

[a]Only for diesel cars that do not respect the emission limits imposed by Directive 91–441.

have reduced the advantage for diesel cars somewhat. In some countries where local environmental concerns are gaining in importance, such as Germany, Italy, and the Netherlands, taxes are geared more towards local pollutant emissions and diesel owners have to pay more for their cars. In the UK, no incentive other than the reducing gap between diesel and petrol fuel prices has been implemented, but the VED (tax on ownership) was expected to change in 2000 to reflect levels of $CO_2$ emissions.

These vehicle price differences may have played a role in driving patterns, as discussed below. The gradual shrinking of the difference in the purchase costs of the two kinds of cars, both before and after taxes, has almost certainly played an important role in the increasing *popularity* of diesels during the 1990s. But other factors have been important as well. Perhaps the most important has been the marked improvement in the performance of diesels, including the reduction in smoke and soot emissions as well as noise. Since 1995, the performance improvements have included the introduction of turbo-direct injection and other advanced technologies that have resulted in improved fuel economy. The increased number of diesel models available have also played an important role.

## Beyond the Figures: Exploring Reasons for the High Fuel Use of Diesel Cars

What is behind the high driving levels and fuel use of diesel cars? There are certainly a number of contributing factors. One potential reason for these high levels is the price differential between diesel and petrol fuels. This differential has diminished in recent years in most of our study countries and has disappeared in the UK. But it persists in most countries and is quite large in some. However, it is certainly not the only possible reason.

In particular, we wish to explore the extent to which this is due to these cars having become attractive to high-kilometre drivers (or drivers planning to become so), vs. an *inducement* of higher travel by the fact that diesels now have substantially lower per-kilometre fuel costs than petrol vehicles. As mentioned above, this first effect can be called a "self-selection" effect and the second effect can be called a "rebound" effect. While this paper does not attempt to separate these effects econometrically, we provide an overview of some of the factors that could be influencing the relative size and travel of diesel cars, apart from changes in behaviour purely attributable to reductions in vehicle and fuel costs. Table 10 lists several possible factors that go beyond self-selection to include other

**Table 10**
*Potential "confounding" factors*

| *Efficiency factors — Whay don't diesels have a bigger efficiency advantage?* | *Travel Factors — Why are diesels driven more?* |
|---|---|
| (1) Basic self-selection: those who need larger cars but are cost conscious (e.g. taxi drivers) more likely to choose diesels since greater fuel cost savings over petrol than for small cars (since more fuel is used). | (1) Basic self-selection: those who were high km travellers already or were planning an increase in travel anyway more likely to choose diesels |
| (2) In many countries diesels may be available more in large car classes than small car classes, making it more difficult for small car buyers to choose diesel and contributing to the self-selection effect. | (2) Newer vs. older cars: newer cars tend to be driven farther than old cars, even if the fuel costs are equal. This is due in part to the greater reliability of new vehicles. On average diesels are newer than petrol vehicles. |
| (3) New diesels may have a bigger efficiency advantage than the existing stock of diesels, especially since 1995 as most new diesels are now TDI. | (3) Reallocation of family car "fleet" to put more km on diesel vehicle and fewer km on other (older or lower efficiency) vehicles that a family owns. (4) If comparing across time, the general time-trend of increased travel due to income and other factors must be accounted for. Petrol and diesel travel both increase through time. |

plausible market factors that could affect the average diesel fuel consumption and travel levels relative to petrol. These factors can be referred to as "confounding" factors, since they confound attempts to assign the purchase and travel behaviour differences between petrol and diesel drivers solely to the low cost of diesel fuel.

From the foregoing a few general points can be drawn:

- Drivers will tend to select diesel (or LPG) when it is clear that the higher first cost and yearly taxation of diesels will be paid back by lower running costs. High mileage drivers will derive the greatest payback and are the most likely to think about life-cycle cost when choosing between petrol and diesel.
- Because of the recent rapid growth in the stock, diesel cars in France, the Netherlands, and the UK are somewhat newer on average than petrol cars. Since newer cars tend to be driven more than older ones, this accounts for some of the differences in yearly driving. This effect will eventually diminish as the shares of diesel cars in new car purchases stabilise, and could reverse since diesel engines have longer lives than petrol engines.
- Diesels may still be used more for commercial purposes than petrol vehicles, and commercial driving generally involves more travel per vehicle than personal driving.

These issues are explored further in Box 1 for the case of France, for which detailed travel survey data are available.

Other important effects can be seen from studying the use of diesels over time (Figure 4, France).

- The average annual driving distance of a diesel was falling over time, because the composition of diesel owners was shifting from taxi and other professional drivers to ordinary drivers with lower kilometres; while the average distance a petrol car was driven was growing very little or even falling, a sign that those petrol drivers with the highest driving distances were switching.
- Those switching from petrol to diesel, which represent 14 per cent of the 1994 fleet, increased their annual kilometre significantly. Hivert's studies show that the average "switcher" drove 16,000 km with his/her petrol car before, and 19,500 km with the diesel car after the switch, a 22 per cent increase consistent with a price elasticity of driving of −0.3 for a reduction in fuel cost/km of approximately 50 per cent. Among the switchers, those having a good reason to do so (changing residence or work place) are the exception, not the rule. Lastly, note that as strange as this can be, the opposite situation exits: people switching from diesel to petrol also reverse their driving habits: 21,000 km before switching and 15,000 km after.

Did the millions of French people who switched to diesels "rebound" by moving farther from work or to rural areas? It seems unlikely: the huge number of diesels purchased since 1989 when their popularity began to soar is far larger than the slow changes in distribution of population. Instead it appears that the dominant change so far involves selection by longer-distance drivers of cars with lower running costs, particularly as the first costs of those cars approached those of petrol cars. But with the enormous popularity of diesel cars, this switching reaches beyond those already driving 20,000 km/year or more, perhaps stimulating those with lower driving distances to switch and enjoy the benefits of lower fuel costs. As Orfeuil points out, however, the diesel itself is creating its own "product": if present trends continue and diesel technology continues to improve and diesel prices remain well below those of petrol, there is no reason not to expect the French driving public to react. After all, diesel offers half the driving costs of petrol today (0.25 F/km against 0.48 F/km). An implication is that the low fuel price of diesel (due in particular to lower taxation, as presented in Table 8), in combination with better fuel economy, makes the cost of driving additional kilometres look quite cheap for those switching from petrol vehicles.

**BOX 1. The Role of Diesel Cars: The French Case.**

The real role of diesel cars in the lives of the French is very complex, as Hivert (1995 and 1996) and Orfeuil (1996) discovered in landmark studies undertaken at INRETS, the French National Institute for Traffic and Safety.

They found that in the aggregate, diesels are driven considerably farther than petrol cars. Although the penetration of diesel cars has reached new markets and new use categories, the differential in kilometres is held constant on the average. In their various reports, Hivert and Orfeuil used the panel "Sofres-Parc Auto". This panel aims at giving a picture of the French Automobile Stock, i.e. the description of the technical characteristics of the vehicles as well as their uses and users; it is based on a sample of 10,000 households, and in 1996, 7,093 households answered, giving information of 8,848 vehicles. The extrapolation to France is made using socio-characteristics of the households.

In their last report, published in 1998, they pointed out that in 1996, the difference in kilometres between the average diesel car and its petrol counterpart was 19,467 km against 11,345, that is about 8,200 km. Note that the gap between petrol and diesel car distance is even wider for small cars ("bas de gamme"). Looking at the category, in general, the bigger the petrol car, the longer the distance, whereas for diesel, the average kilometre is surprisingly constant across vehicle category.

Hivert suggests that diesels are driven more than petrol cars for several reasons:

- The diesel fleet is much newer, and newer cars are always driven more than older ones (65% of diesels less than 5 years old in 1995, vs. 35% for petrol cars); Looking at table 1.1, the difference in driving distance that can be attributed to the ordinary new age effect is 2,000 to 2,500 km per year.

**Table 1.1**

*Kilometre by type of fuel and average prime since ownership*

| | *Diesel* | *Petrol* |
|---|---|---|
| Average time since acquisition (years) | 3.24 | 4.55 |
| Average kilometres, vehicles less than 5 years old | 20,622 | 12,658 |
| Average kilometres, vehicles more than 5 years old | 17,954 | 10,560 |

Source: Le parc automobile des ménages, étude en fin d'année 1996, convention ADEME-INRETS.

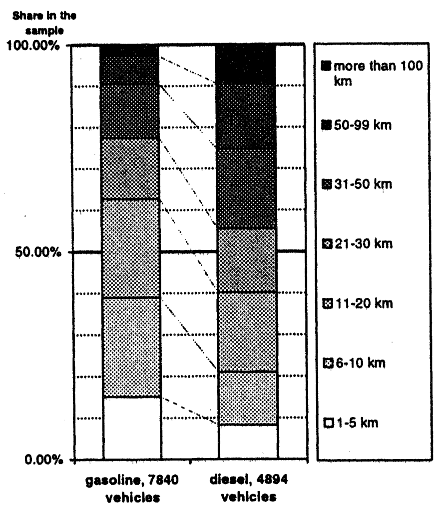
- Diesel owners are marginally more wealthy than petrol car owners, a gap that has diminished as diesel models appear in the market segment of small cars;
- Diesel owners live farther from work, or indeed are more likely to live in rural areas, which in turn is a factor encouraging selection of diesel cars (see figures 1.1 and 1.2 below);
- Diesel fuel costs about 40 per cent less than petrol, and diesel cars use 17 per cent less fuel per km among those surveyed. In all, diesel and petrol owners each spent about 5,000 francs per car in 1994 for fuel, but diesel owners got much farther for their money (Orfeuil, 1996).
- Diesel owners use their cars for work far more than petrol car owners, and they also drive their cars farther on holiday, according to the same survey.

**Table 1.2**
*Percentage of each category of cars effectively used by purpose*

| *Purpose* | *Diesel (per cent)* | *Petrol (per cent)* |
|---|---|---|
| Work (commute) | 65.5 | 49.3 |
| Work related | 32.1 | 18.6 |
| Shopping | 80.6 | 83.9 |
| Leisure | 76.2 | 71.2 |
| Weekend trips | 63.4 | 48.4 |
| Longer vacation trips | 72.0 | 52.5 |
| Trips of more than 100 kilometres | | |
| 1 or 2 times a year | 14.0 | 19.7 |
| 3 to 5 times a year | 14.4 | 17.9 |
| more than 5 times | 65.0 | 41.6 |

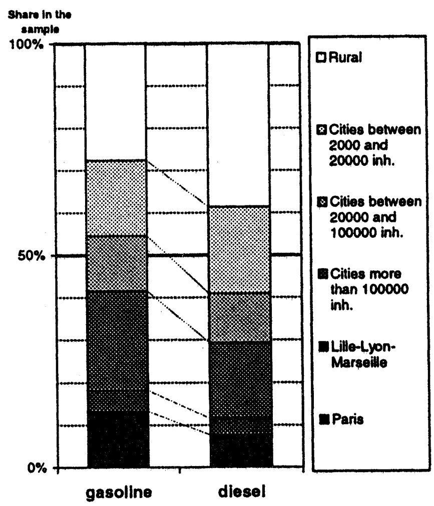
Source: Le parc automobile des ménages, étude en fin d'année 1996, convention ADEME-INRETS.

**Figure 1.1**
*Petrol-diesel home to work distance (and return) distribution by distance classes*




Source: Le parc automobile des ménages, étude en fi d'année 1996, convention ADEME-INRETS.

**Figure 1.2**
*Petrol-diesel vehicle distribution by type of household residence*




Source: Le parc automobile des ménages, étude en d'année 1996, convention ADEME-INRETS.

## Net Impacts: Is the Diesel Fuel Saving?

What are the consequences for road fuel use of dieselisation in Europe? Quite apart from the potential gains in fuel economy that individual diesel vehicles offer over petrol vehicles, the European experience suggests that diesels produced through the late 1990s provided little, if any, overall saving, at least on a fleet average basis. To be sure, there is some savings in fuel use per kilometre when any motorist changes cars and fuels. And, for motorists who make this switch, there is a welfare gain as lifecycle costs fall, and quite arguably an additional welfare gain arising from additional kilometres travelled. But how much of diesel's potential fuel saving is being erased by price-induced rebound effects?

The aggregate trend data, if due solely to price-induced shifting, would suggest an astounding 100 to 300 per cent rebound, or −1.0 to −3.0 elasticity of change in travel with respect to change in fuel cost.[14] These high estimates most certainly reflect a dominant role of self-selection and other confounding factors in accounting for the increased diesel travel, which would have the effect of inflating the apparent rebound elasticity. Hivert's and Orfeuil's analysis, focused on a subset of drivers who have recently switched from petrol to diesel vehicles in France, probably eliminates some of these confounding influences and, not surprisingly, suggests a much lower rebound effect of −0.44. However, this estimate is still relatively high compared to recent literature. A review of the literature by Greene *et al.* (1999) indicates that recent studies of the travel rebound effect have estimated the travel rebound elasticity in the range of −0.1 to −0.5. As they discuss, most studies using aggregate data have shown relatively lower estimates (Haughton and Sarkar, 1996; Jones, 1993; and Greene, 1992 give a combined range of 0.05 to 0.31), while studies using disaggregate data have shown generally higher estimates (Greene *et al.*, 1999; Puller and Greening, 1996, 1997; Goldberg, 1996; Greening *et al.*, 1995 give a combined range of −0.22 to −0.49). However, most of these studies focused on North America. Johansson and Schipper (1997) using pooled, cross-sectional/time series national-level data that include the US, Japan, and nine countries in Europe, found an elasticity of car use with respect to fuel cost of around −0.3.

These studies have focused on the general response of travel to changes in fuel costs (changes that have occurred either through changes in fuel

[14] This ranges from Germany, with average diesel vehicle travel 42 per cent higher than petrol and diesel vehicle fuel cost per kilometre 44 per cent lower, to the Netherlands, with average diesel vehicle travel 113 per cent higher than petrol and diesel vehicle fuel cost 38 per cent lower.

prices or changes in fuel intensity, or both) rather than the travel differences between two types of vehicles with different average fuel costs. Further, and potentially importantly, all but one of these studies used US data. The rebound elasticity in Europe could be different from that in the US, and if so may be higher, given the many more travel options available to the average European than the average American (leading to a greater pool of potential trips switched from public transport and non-motorised modes to car when car travel costs decline). This considerably higher substitutability between car use and other modes of land travel is evidenced by the much higher share of land travel by rail or bus (10 to 15 per cent) compared with the US (3 per cent).

Since we cannot be sure of the role of confounding factors in the observed higher levels of diesel compared to petrol vehicle travel, and we do not have robust estimates of the true rebound elasticity for Europe, we have estimated the fuel savings impacts of diesels for a range of possible elasticities in order to explore the possible relationships between fuel costs and travel, and identify the points at which fuel savings from diesels is lost to increased travel. Table 11 shows the amount by which driving would increase, for a range of fuel cost differentials between diesel and petrol vehicles (a range of 10 to 50 per cent cheaper diesel fuel cost is considered) and for a range of rebound elasticities between 0.1 and 0.4. The resulting increase in travel is simply the product of these two factors.

As shown in the table, if the elasticity of kilometres driven with respect to the fuel cost/km is −0.1, then even with a very high fuel cost differential in the range of 50 per cent (as it is in Italy) the increase in diesel driving *due to the lower fuel cost* is a modest 5 per cent. If diesels provide an average on-road fuel saving per kilometre of 15 per cent, as appears to be the

**Table 11**

*Percentage travel increase (and lost fuel savings) as a function of diesel fuel cost advantage over petrol and assumed rebound elasticity*

| | *Fuel Cost Decrease, percentage* | | | | |
|---|---|---|---|---|---|
| | *10* | *20* | *30* | *40* | *50* |
| Travel Rebound Elasticity | | | | | |
| −0.1 | 1 | 2 | 3 | 4 | 5 |
| −0.2 | 2 | 4 | 6 | 8 | 10 |
| −0.3 | 3 | 6 | 9 | 12 | 15 |
| −0.4 | 4 | 8 | 12 | 16 | 20 |

approximate level in the study countries (except Italy; see Table 4), a travel increase of 5 per cent does not come close to eliminating diesel's per-kilometre fuel savings. However, in the case of a somewhat higher elasticity such as −0.2, then a 50 per cent fuel cost differential yields a travel increase of 10 per cent, which would eliminates more than half of the diesel's per-km fuel savings. At a −0.3 elasticity, a 50 per cent cost differential would eliminate all the fuel savings, and at −0.4 the savings are eliminated with only a 40 per cent, rather than 50 per cent, fuel cost differential.

Tables 12 and 13 apply these relationships to the specific countries in question, using elasticities of −0.2 and −0.4 as examples. Table 12 shows the actual 1995 fuel intensity and fuel cost parameters for each country, expressed as ratios between petrol and diesel. It then shows the implied increase in travel associated with the fuel cost differential for each of the two sample elasticities. Table 13 shows how much the fuel savings per kilometre (resulting from the lower fuel intensities) of diesels is offset by higher driving per vehicle (due to the lower fuel costs), and presents the net fuel savings per vehicle, for each of our two sample elasticities.

In the case of a −0.2 travel rebound elasticity, diesels continue to save some fuel (around 5 to 7 per cent) in France, the Netherlands, and the UK despite their increased driving levels due to lower fuel costs. However, fuel savings in Germany and Italy are eliminated due to longer driving distances in those countries (since diesels have lower efficiency advantages and higher fuel cost advantages in those countries). With a −0.4 elasticity, fuel savings from diesels are eliminated in all five countries.

By comparing the expected results at −0.2 and −0.4 elasticity to actual diesel vs. petrol vehicle travel and fuel use in each country, we see that the estimated "rebound" effect actually explains only a small part of the much higher levels of travel for diesel and its higher fuel consumption per vehicle. This suggests that most of the difference is due to some combination of the various "confounding" factors described in Table 10. Still, with a rebound elasticity of −0.4, increased travel from diesels arising from the lower fuel cost of each km fully offsets the fuel savings per kilometre that diesel provides.

It can also be seen that in each country, the fuel price difference in 1995 had a much greater impact on the ratio of fuel cost per kilometre than did differences in vehicle fuel intensities. Diesel fuel prices were typically 30 to 50 per cent lower than petrol on an energy basis, while diesel fuel intensity was between 0 and 13 per cent better. This suggests that government tax policy has had the main effect in creating such a wide difference in diesel vs petrol fuel cost per kilometre.

## Table 12

*Travel difference in diesel and petrol cars as a function of fuel cost difference and assumed elasticity, by country, 1995*

| | *France* | *Ger.* | *Italy* | *Neth.* | *UK* | *Notes/Sources* |
|---|---|---|---|---|---|---|
| Ratio of average diesel vs. pertol energy intensity (based on relative MJ/km) | 0.88 | 0.91 | 1.0 | 0.87 | 0.87 | *Table 4* |
| Ratio of diesel vs. petrol fuel price (energy basis) | 0.60 | 0.62 | 0.55 | 0.71 | 0.70 | *Table 8* |
| Ratio of diesel vs. petrol fuel cost per km | 0.54 | 0.54 | 0.71 | 0.64 | 0.80 | *Table 8* |
| Estimated ratio of diesel vs. petrol travel per vehicle given fuel cost difference @ −0.2 elasticity | 1.09 | 1.09 | 1.06 | 1.07 | 1.04 | *Calculation: fuel cost difference × elasticity × vkt/year for petrol* |
| Estimated ratio of diesel vs. petrol travel per vehicle given fuel cost difference @ −0.4 elasticity | 1.18 | 1.18 | 1.12 | 1.14 | 1.08 | *Calculation: fuel cost difference × elasticity × vkt/year for petrol* |
| Comparison: actual (observed) travel per vehicle for diesels relative to petrol vehicles | 1.84 | 1.42 | 2.04 | 2.13 | 1.82 | *Based on Table 5* |

Note: In this table, differences in fuel cost count both differences in price and differences in fuel use/km.

## Table 13

*Diesel fuel savings as a function of fuel intensity advantage and additional travel*

| | *France* | *Ger.* | *Italy* | *Neth.* | *UK* | *Notes/Sources* |
|---|---|---|---|---|---|---|
| Estimated ratio of energy use per vehicle, diesel vs. petrol *(and fuel savings, percentage)* after travel rebound effect @ −0.2 elasticity | 0.96 *(4.3%)* | 1.00 *(0.4%)* | 1.06 *(-6.2%)* | 0.93 *(7.3%)* | 0.94 *(9.1%)* | *Calculation: Differences in diesel/petrol energy intensity × difference in diesel/petrol car use (both from Table 12)* |
| Estimated ratio of energy use per vehicle, diesel vs. petrol *(and fuel savings, percentage)* after travel rebound effect @ −0.4 elasticity | 1.04 *(−3.7%)* | 1.08 *(−7.9%)* | 1.12 *(.0%)* | 0.99 *(1.1%)* | 1.01 *(5.6%)* | *Calculation: As in preceding line.* |
| Comparison: ratio of energy use per vehicle calculated from actual (observed) difference in energy intensity × actual (observed) travel difference | 1.61 | 1.29 | 2.05 | 1.84 | 1.59 | *Calculation: energy intensity ratio × travel ratio (from Table 12)* |

## Implications in terms of Carbon Emissions

The results in terms of vehicular carbon emissions per vehicle from diesel vs. petrol are similar to those for energy use. Calculations were made by using IPCC/IEA coefficients of carbon content of each fuel, expressed in grammes per unit of energy (net heating value). Using the heating content of a litre of each fuel, we also express these as grammes per litre of fuel. Using the on-road fuel economy figures from Table 4, we obtain grammes per kilometre of carbon emissions.

As shown in Table 14, the differences in carbon emissions per km between diesel and petrol vehicles are small. As with the fuel analysis, when looking at total emissions per vehicle per year (factoring in annual travel per vehicle), the average diesel car emits far more $CO_2$ than the average petrol-engine car in all five countries.

If emissions/km (which differ by less than 10 per cent in all countries, and are higher for diesels in Italy) are factored into the $-0.2$ and $-0.4$ elasticity scenarios, the net $CO_2$ savings from diesels range from small to significantly negative (that is, diesels provide $CO_2$ increases rather than savings). These results are shown in Table 15.

If we take into account the whole fuel chain, including fuel used during crude oil extraction, transport, refining, and so on (see Box 2), our calculations shown in Table 14 would be revised slightly in favour of diesel. Because lower energy use (and emission of $CO_2$) is associated with the crude oil-to-final fuel process, the carbon emissions from petrol would rise more than those from diesel. However, with increasingly stringent requirements being placed on the sulphur content of diesel fuels, refining energy use for diesel may rise in the future. Therefore, while the full fuel cycle analysis is important for any comparison of carbon emissions from

**Table 14**

*$CO_2$ Emissions by fuel type, 1995*[a]

| | *France* | *Germany* | *Italy* | *Neth.* | *UK* |
|---|---|---|---|---|---|
| Kg $CO_2$ released per 100 km driven | | | | | |
| Petrol | 19.0 | 21.1 | 16.6 | 19.3 | 20.8 |
| Diesel | 18.0 | 20.4 | 17.7 | 18.0 | 19.6 |
| Ton of $CO_2$ emissions per car per year | | | | | |
| Petrol | 2.2 | 2.9 | 1.8 | 2.6 | 3.0 |
| Diesel | 3.8 | 3.9 | 3.8 | 5.1 | 5.2 |
| Ratio of diesel/petrol $CO_2$ emissions per car per year | 1.73 | 1.34 | 2.11 | 1.96 | 1.73 |

[a] $CO_2$ per km are computed from Tables 2 and 5 using IPCC coefficients of carbon contents of a Joule of a given fuel and a weight of 12/44.

**Table 15**
*$CO_2$ savings per car following the developed scenarios*

| *Net CO2 emissions per vehicle ratio, diesel vs. petrol (and $CO_2$ savings, percent) for travel rebound elasticity scenarios* | *France* | *Germany* | *Italy* | *Neth.* | *UK* |
|---|---|---|---|---|---|
| Elasticity = −0.2 | 1.02 *(−2.2%)* | 1.05 *(−5.7%)* | 1.14 *(−13.5%)* | 0.99 *(0.9%)* | 0.97 *(2.8%)* |
| Elasticity = −0.4 | 1.07 *(−6.5%)* | 1.09 *(−9.3%)* | 1.17 *(−16.6%)* | 1.02 *(-2.4%)* | 0.99 *(1.0%)* |

transport fuels, the analysis we present does not have an important impact on our results.

## Conclusions: Why Haven't Diesel Cars Provided Larger Fuel Savings in the Study Countries?

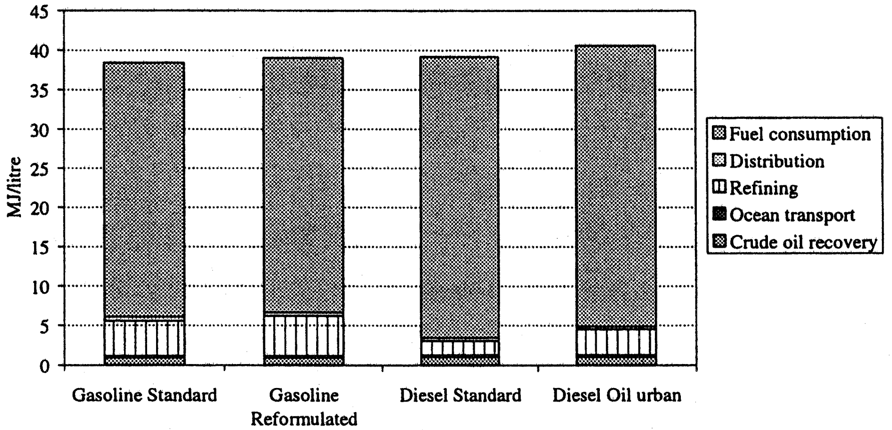
We have shown that as deployed in the late 1990s, diesel cars in five European countries typically provided around 10 per cent less fuel use and nearly equal $CO_2$ emissions per vehicle kilometre compared to petrol vehicles, but were driven up to twice as many kilometres per year. The much higher level of travel of diesels is probably due mainly to selection of diesels by inherently high-kilometre drivers and other "confounding effects". Applying a range of travel rebound elasticities from the literature suggests that diesel's fuel cost advantage over petrol probably results in enough additional driving to offset most or all of diesel's fuel savings from lower energy use per km. Thus as presently deployed, with the current fuel price structure in place in these countries, diesels do not appear to save much, if any fuel, and do not yield net reductions in $CO_2$ emissions compared to the petrol vehicles they replace. The significantly lower price of diesel fuel, relative to petrol, is a principal reason for this situation, the main reason why energy savings are small, accounting for well over half of the travel cost advantage of diesels in all five of the studied countries.

Diesels are typically larger and heavier than petrol cars, both on a "matched pairs" basis and even more so in terms of their size distributions among car fleets. This helps to account for the relatively small on-road fuel economy advantage they hold over petrol vehicles. While many other factors account for some of the difference between the potential energy savings and those realised, it is clear that an analysis of technical potential

## BOX 2. Considering the Whole Fuel Chain in Comparisons

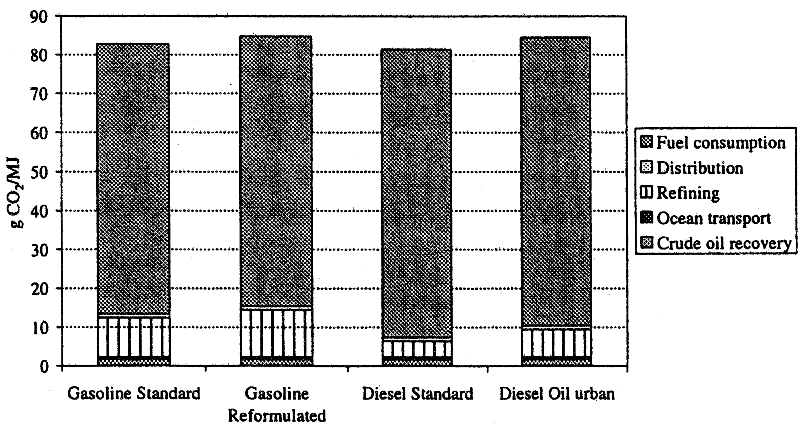
The fuel chain from crude oil via finished motor fuel to the vehicle includes extraction of the crude with some primary treatment, transport to refineries, refining to the required mix of products, transport to distribution terminals and final distribution to gasoline stations. Intermediate storage occurs at every stage.

**Figure 2.1**
*The whole fuel chain cycle, comparing gasoline and diesel*




Source: The Life of Fuels. 1992

**Figure 2.2**
*The whole fuel chain in terms of $CO_2$ emissions*




Source: The Life of Fuels, 1992, and own calculations

Figures 2.1 and 2.2, based on data for Europe extracted from the Life of Fuels (Ekotraffic 1992), compare Gasoline and Diesel when taking into account the whole fuel chain, both in terms of energy and $CO_2$ emissions. While many assumptions could be made about the energy losses in producing each fuel, Life of Fuels presents reasonable calculations that have been widely circulated and adopted. Delucchi (priv comm. 1998) gives similar relationships for the United States.

When taking into account the whole fuel chain, diesel cars have an advantage, as less energy is used in the refining process. This brings the carbon emissions from diesel per unit of energy very close to those of gasoline, reinforcing the overall lower emission/km of the present fleets of diesels in four of the five countries studied. But this advantage is small, especially when comparing Urban (i.e., very low-sulphur) Diesel and gasoline, as the refining process of the former is more energy-intensive than that for regular diesel. The same conclusions apply as far as $CO_2$ emissions are concerned.

alone is insufficient for predicting energy savings in systems whose characteristics are determined both by manufacturers and consumers. Differences in buying patterns and driving patterns are critical components in the comparison, and in this case both serve to reduce the expected fuel savings from diesels.

Reducing running costs was clearly a reason for long-distance drivers to seek diesels over petrol cars. In addition, the popularity of diesel and LPG cars, which have higher purchase costs than gasoline cars but lower running costs, shows that consumers are willing to make an up-front "investment" in order to gain cost reductions over the life of the vehicle.

It should also be noted that increases in driving levels triggered by relatively low prices for diesel provide net benefits to drivers. But whether this individual welfare gain is also an overall gain for society depends on whether the additional kilometres driven, and the diesel fuel used, are priced "correctly" to reflect external costs fully. While it is beyond the scope of this paper to answer that question, with the use of diesels in Europe in the late 1990s, there is no real energy saving and consequently no reduction in carbon emissions from the use of diesels, eliminating that potential external benefit.

## The future looks different

Important changes in policy and technology are under way that could change the impact of diesel cars on fuel use and carbon emissions. First, diesel's air pollutant problems are being addressed through new policies. Forthcoming $NO_x$ and particulate emissions standards pose new technological challenges for diesel engines. Proposed US Tier II standards apply the same strict $NO_x$ standards (less than 0.1 ppm) and particulate standards (0.01 ppm) to both light duty spark ignition and diesel engines. Further complicating the picture is a growing concern over small particulate emissions, which may lead to new requirements on very fine particulate emissions (current rules focus on larger particulates, PM10 and above). There are promising technologies to mitigate diesel emissions and meet these new policy requirements,[15] and proposals for intensified research into solving particulate problems have been put forward (Saricks *et al.*, 2000). In addition, new diesel fuel standards (less than 20–50 ppm sulphur) have recently been adopted in both the US and in Europe. With these developments diesels stand a good chance to meet future air emissions requirements, and may continue to gain market share in Europe and even in North America.

Another reason to believe that diesels' impacts may be different in the future is that many countries are now beginning to close the gap between diesel and petrol fuel prices. A principal conclusion of this paper is that fuel pricing adjustments must be made in some countries in order to bring diesel vehicles into a carbon saving mode. More research is needed to better estimate diesel travel rebound elasticities — the amount of increased travel that can be attributed to lower diesel fuel costs — but our estimates for a range of possible elasticities indicate that prices in some countries are currently set so low that the per-kilometre fuel savings from diesels are wiped out by price-induced travel increases. If diesels continue to provide only a 10 to 15 per cent fuel intensity advantage on-road, then we estimate that diesel fuel prices should be set no lower than 20 per cent below petrol prices in order to be fairly confident that the fuel savings from diesels are not mostly (more than half) lost to increases in driving.

Notable among trends in diesel vs. petrol pricing, the UK raised the tax on diesel fuel so that its retail price is nearly equal to that of petrol, a result of policy changes that started in 1995. Not surprisingly, the share of new diesel cars in the UK has fallen off somewhat from its peak earlier in the 1990s. In France, the government has announced long-term changes in the pricing of diesel and of the taxation of diesel cars[16] that will slow or reverse the growth in diesel car sales and diesel fuel consumed.[17] The

[15] PSA announced a filter to appear on its 2000 models (*Automotive Environment Analyst*, May 1999, or the Psa web site: http://www.psa.fr).

[16] It has been decided to align in seven years the taxation (Taxe Intérieure sur les Produits Pétroliers, TIPP) gap between unleaded petrol and diesel with the European average.

[17] In France, the new yearly fee methodology is now less favourable to diesel cars, and will apply to all new cars bought after 1 January 1999.

Dutch government has also begun to swing both variable and fixed fees on fuel and vehicles to favour LPG over diesel.

Apart from fuel pricing issues, diesels continue to emerge as a potential source of significant energy and carbon savings, and their potential for reducing real fuel use/km appears to be larger than ever with the introduction of turbo direct injection (TDI) diesels. New TDI diesels can provide more than 30 per cent fuel savings per kilometre compared to their "performance equivalent" (non-direct injection) petrol vehicles, a difference that is not likely to be wiped out by higher driving levels even in countries with very inexpensive diesel fuel (see Table 2). But of course the lower the price of diesel fuel, the larger is the offset from increased driving levels. Maximising the carbon savings from diesels will not occur unless countries "get the prices right".

The Association of European Automobile Manufacturers (ACEA) has agreed with the European Union to reduce the sales-weighted $CO_2$ emissions per kilometre of new cars sold by 25 per cent by 2008 (EC, 1999). Diesels can assist ACEA to meet this target both through increasing market share and through reduced $CO_2$ emissions from new diesels relative to those they replace, without changes in diesel market share. The closing of the fuel taxation gap will encourage manufacturers to offer even more fuel-efficient cars, and restrain the travel rebound effect. Sharpened fuel quality requirements (also for petrol) will add a small amount to the cost of fuels. Thus there are a number of forces that serve to reinforce the prospects for diesel to play a major role in every country's strategy to reduce carbon emissions from cars. We note however, that the closing of the fuel taxation gap may make increased use of diesel vehicles to meet the ACEA/EU agreement more difficult. If the fuel taxation gap is not closed, and diesels are an important element in meeting the ACEA/EU agreement, the data in this paper suggest that the greenhouse gas goals underlying the agreement could be significantly undermined, not withstanding the achievement of improved vehicle efficiency.

## References

AID (1999): "Diesel Era Dawns". Ternworth, England: Automotive Industry Data Ltd.

Association des Constructeurs Européens d'Automobiles (ACEA) (1999): "Motor Vehicle Taxation in Europe", Bruxelles, Belgium.

Automotive Environment Analyst, May (1999): "Lower Emission Peugeot". *Financial Times Business*, London. Issue 52, 12–13.

Akira, Y. (1998): Nissan Motor Co,. Japan, private communication.

Delucchi, M. (1998): University of California, Davis US, private communication.

European Commission (1998): Proposal for a Council Decision, "Establishing a scheme to monitor the average specific emissions of carbon dioxide from new passenger cars", COM(1998)348final, Brussels 12.06.1998.

European Commission (1999): *Voluntary Agreement to Reduce $CO_2$ Emissions from new Automobiles*. 99/125/EC. Brussels: Commission of the European Community

European Council of Ministers of Transport (ECMT) (1998): "Efficient Transport for Europe". Policies for Internalisation of External Costs. Paris: OECD.

EKOTRAFFIC AB. (1992): "The life of fuels: motor fuels from source to end use". Stockholm.

Girault, M. (1998): "Quels instruments pour limiter les nuisances de la circulation?". *Notes de synthèses du SES*.

Goodwin, P. B. (1992): "A Review of New Demand Elasticities with Special Reference to Short and Long Run Effects of Price Changes". *Journal of Transport Economics and Policy* 26, 155–70.

Greene, D., J. Kahn, and R. Gibson, (1999): "An Econometric Analysis of the Elasticity of Vehicle Travel with Respect to Fuel Cost per Mile Using RTEC Survey Data". Oak Ridge National Laboratory.

Hivert, L. (1995): "Les nouveaux Diésélistes, rapport de 1ère Phase: Estimation des évolutions de kilométrages. Rapport de Convention Institut National de Recherche sur les Transport et leur Sécurité (INRETS)/Mission Interministérielle de l'Effet de Serre.

Hivert, L. (1996): "Le Parc Automobile des Ménages, Etude en fin d'année 1995". Rapport de Convention Agence de l'Environnement et de la Maîtrise de l'energie (ADEME)/INRETS.

Hivert, L. (1999): "Diesel in France and the "New Dieselists" Behaviour: Recent Developments in the French Car Fleet". Presentation at the 1999 European Energy Conference, Paris, October 1999.

IEA (1993): *Cars and Climate Change*. OECD-IEA.

IEA (1994): *Refining and Environmental Implications of Increased Use of Diesel-engined Passenger Cars*. OECD-IEA, Paris.

IEA (2000): *The Road from Kyoto*. Paris, International Energy Agency.

Johannsson, O. and L. Schipper (1997): "Measuring Long-Run Automobile Fuel Demand: Separate Estimations of Vehicle Stock, Mean Fuel Intensity, and Measured Annual Driving Distances". *Transport Economics and Policy*, 31.

Koninglijke Nederlnadsche Automobile Club (KNAC) (1999): "Alle Auto's 98", Alkmaar, Netherlands.

Orfeuil, J. P. (1996): *Rapport sur l'utilisation du gazole transmis par le Gouvernement au Parlement (art. 20 de la loi de finances pour 1996), Contribution à l'Expertise Collective: Diesel et Santé. Pilotée par le CNRS.*Arcueil, France: INRETS, September.

Santini, D. (1995): "Performance equivalent Fuel Economy of diesel vs. Gasoline Passenger Cars". Argonne National Laboratory, 1995. Unpublished manuscript.

Saricks, C., D. Rote, G. Stodolsky, and J. Eberhardt (2000): *Alternatives to Diesel Fuel in California. Fuel Cycle Energy and Emission Effects of Possible Replacements due to the TAC Diesel Particulate Decision.*

Schipper, L., R. Steiner, M. Figueroa, and L. Price (1993): "Mind the Gap". *Energy Policy*

Schipper, L. and C. Lilliu (1999): "Carbon Dioxide Emissions from Transport in IEA Countries: Recent Lessons and Long-term Challenges". Kommunikations Forsknings Beredning, Stockholm.

White, D. (1999): International Energy Agency, Oil Industry and Markets, private communication.