FINAL REPORT

DELIVERABLE B8.4:

Taxation and pricing strategies to discourage the use of diesel vehicles in Central and Northern Europe

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AIRUSE

Testing and development of air quality mitigation measures in Southern Europe

Contents

1 INTRODUCTION

More diesel cars are sold in Europe than in any other part of the world. Since the late 1990s increasing the market share of diesel cars has been encouraged by EU policies to reduce road transport carbon dioxide (CO_2) emissions, national fiscal policies and industrial interests. However there are a number of negative impacts. Diesel cars emit more nitrogen oxides (NOx) and particulate matter (PM) than gasoline cars, and there is controversy over whether dieselisation of the car fleet has led to a real reduction in road transport CO_2 emissions. At best, it is though the CO_2 benefits have been marginal.

The aim of this report is to review the effect of taxation and pricing of new cars and automotive fuels on the diesel share of the car market. It focuses on taxation and subsidies as these are the areas controlled by public policy, whereas pre-tax prices are influenced by a myriad of commercial decisions. It also briefly discusses the evidence on the CO_2 benefit and the urban air quality disbenefits of diesel car emissions, before discussing the evidence, albeit rather limited, of the effect of tax and subsidies on the sales of diesel cars.

Another AIRUSE report discusses the use of fiscal, and other, incentives to promote the purchase and use of electric, hybrid and gas vehicles[1]. This report covers similar issues but from the perspective of what influences the diesel car sales.

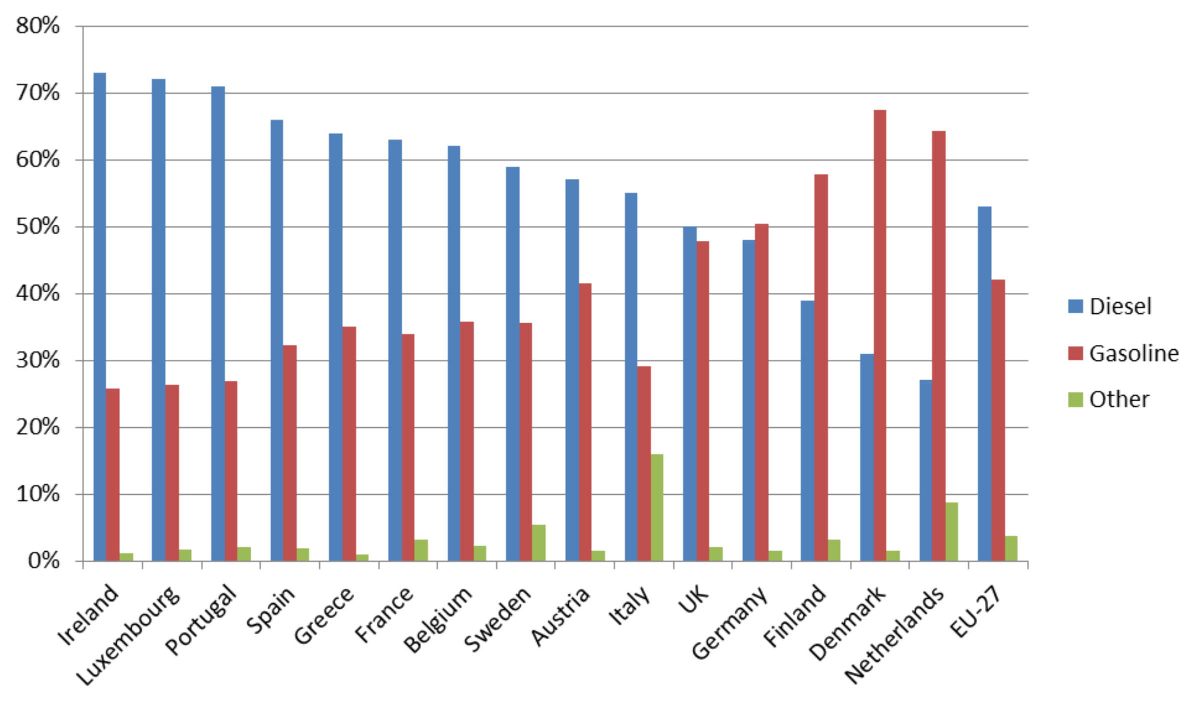
2 DIESEL MARKET SHARE

In 1990 approximately 10% of the new cars sold in Europe were diesel cars. At that time these vehicles did not match the performance of gasoline cars. However improvements over time have led to quieter and more refined diesel engines and the performance gap has narrowed. Some motorists now prefer diesel over gasoline cars due their high torque performance at low vehicle speeds (i.e. pulling power) (Cames & Helmers, 2013). Over the last decade approximately half of the new cars sold in the European Union (EU) have been diesel. Virtually all the rest have been gasoline with other technologies contributing approximately 4% in 2014. There is a significant difference between Member States as shown in Figure 1. In Portugal and Luxembourg (over 70% of new cars where diesel; in Belgium, France, Greece and Spain over 60% in 2014; while in the Netherlands it was less than 30% (International Council on Clean Technology, 2015). However new cars are only a small proportion of the overall vehicle fleet, and in 2014 41% of the EU passenger car fleet was diesel (ACEA, 2015). This is likely to increase in future years.

Diesel tends to be the preferred choice for larger cars while gasoline is still preferred for small and sports cars (approximately 70%) and mini cars (about 95%) (International Council on Clean Transportation, 2013a).

[1] AIRUSE Report, 2014, Strategies to encourage the use of electric, hybrid and gas vehicles in northern and central Europe. Available from www.airuse.eu

Figure 1: EU-15 Member States New Car Market Share by Fuel, 2014 (International Council on Clean Transportation, 2015)



The advantage of diesel cars is that they are more fuel efficient than equivalent gasoline models and the fuel is cheaper in most EU countries. The purchase price of new and second-hand diesel cars is often higher, although the gap is closing. For high mileage drivers there can be a significant economic benefit of using diesel vehicles. However several researchers have argued that the increase is diesel cars is mainly the consequence of technological improvements, reinforced by favourable diesel taxation, and more lax emissions standards. They argue that fiscal instruments are not especially effective in reducing diesel consumption or discouraging diesel car purchase (e.g. Burguillo-Cuesta et al, 2011). This view is not universal and, as discussed later in this report, many researchers and policy makers believe that fiscal incentives can be influential.

It has been argued that as the demand for fuel oil declined due to the increasing use of gas to heat homes and generate electricity, the European oil companies were faced with a surplus. Diesel and fuel oil are similar middle distillate products of refineries and an increase in demand for diesel was an obvious solution to the declining sales of fuel oil. The influential oil industry therefore promoted the dieselisation of the car fleet. Over the same period the European automotive industry heavily invested in the development of diesel engine technology, and persuaded the European Union to adopted less stringent emission limits for diesel cars, enabling these vehicles to continue to be sold. In the United States, on the other hand, federal emission limits are strictly technology neutral, and the market share of diesel cars is low.

The tax on diesel fuel in most EU member states is lower than on gasoline, as historically diesel was used predominantly for commercial freight transport. National governments are under pressure not to increase road freight costs, and it is difficult to apply separate tax regimes for diesel used in private and commercial vehicles. This is translated into higher gasoline prices at the pump in all EU countries except Bulgaria, Cyprus, Czech Republic Estonia, and the UK, where it was less than 1% to 4% more expensive in December 2014. On the other hand diesel is about 20% cheaper than gasoline in the Netherlands, Belgium, Denmark, France, Germany, Greece, Luxembourg and Portugal (European Union, 2015). Ironically the two countries, with the highest price differential, have some of the lowest diesel car fleets.

Diesel car fuel consumption has improved significantly over the last two decades with the introduction of direct injection, higher fuel pressure and turbocharging. These improvements have also reduced the mass and size of the PM emitted, but at the same time increased the NOx emissions. Cames & Helmers (2013) argue that over much of this period there was less innovation to improve the fuel economy of gasoline cars, and that the CO_2 emissions from gasoline cars would have been similar as those from diesel cars if the same effort had been devoted to improving their fuel consumption.

This report focuses on passenger cars as these vehicles dominate the vehicle fleet. However much of the comments are relevant to light duty commercial vehicles (vans), specially the smaller ones which are derived from car models.

The following sections describe the emissions of CO_2, NOx and PM from diesel cars, and then the evidence on the factors that influence the purchase and use of diesel cars are discussed.

3 CARBON DIOXIDE (CO_2) EMISSIONS

Road transport is an important source of CO_2 emissions, contributing 19% of EU emissions in 2013 (European Environment Agency, 2015). Diesel vehicles are more fuel efficient than the equivalent gasoline vehicles. As heavy duty vehicles (HDVs) are already virtually all fuelled by diesel, with few alternatives[2], a technology shift from gasoline to diesel cars was identified in Europe as the main measure for reducing the greenhouse gas emissions from the road transport sector. As diesel has more carbon per litre than gasoline the CO_2 benefit is less than indicated simply by the fuel consumption. In other parts of the world, e.g. Japan and the United States hybrid gasoline cars are the favoured option.

Diesel cars have a fuel economy advantage over gasoline vehicles of similar characteristics (i.e. power), but because diesel buyers tend to choose larger, heavier and more powerful cars than the gasoline equivalent, on average switching to a diesel car from gasoline will have a relatively small fuel economy advantage (e.g. Zachariadis, 2013). According to Cames & Helmers (2013), since 2006 the CO_2 emissions of new diesel cars in Germany have increased compared to gasoline vehicles, due, at least in part, to the increase in engine power. Between 2001 and 2011 the average power of new gasoline cars increased by 7.5%, while over the same period the power of diesel cars increased by 22%.

When average CO_2 emissions per kilometre are considered the benefit of diesel cars was found to be typically less than 5% in 2005 (Schipper & Fulton, 2008). However diesel cars are typically driven 40-100% further than gasoline cars (Schipper & Fulton, 2013). While much of the difference may be due to self-selection, that is higher mileage drivers opt for diesel because the running costs are cheaper, and diesel cars are on average newer than

[2] See the AIRUSE Report on Strategies to encourage the use of electric, hybrid and gas vehicles in central and northern Europe.

gasoline cars, and newer cars tend to be driven further, some of the difference is likely to be due to the reduced costs encouraging higher mileage. This is known as the rebound effect. When this effect is taken into account, diesel cars probably do not provide significant national CO_2 savings. Taxing diesel fuel lightly relative to gasoline is counterproductive as it contributes to a higher rebound effect by lowering the cost per kilometre (Schipper & Fulton, 2008). Cames & Helmers (2013) and Hivert (2013) also report that the CO_2 benefit of diesel cars is marginal.

Carslaw et al (2013) found that the average maximum power of diesel cars manufactured since the mid-1990s in the UK has increased by almost 50% while the maximum power of gasoline cars remain similar over the same period. On average diesel cars were about one third more powerful than gasoline cars in 2010. The average weight of new gasoline cars has increased by 10% from 2001 to 2011 while new diesel cars are more than 25% heavier, on average, than gasoline cars (International Council on Clean Transportation, 2015a).

European Commission Regulations 443/2009 and 333/2014 sets standards for average CO_2 emissions from new passenger cars registered in the EU. These are fleet averages of 130 g CO_2 km^{-1} by 2015 and 95 g CO_2 km^{-1} from 2020. Under these regulations each manufacturer has a CO_2 emission target depending on the average weight of their vehicles. That is manufacturers of heavy vehicles get a less stringent target to meet.

Emissions per kilometre vary widely among Member States. The Netherlands have the lowest emissions (108 g km^{-1}) and the highest proportion of plug-in hybrid vehicles (PHEVs). Average new car CO_2 emissions are high in Germany (132 g km^{-1}) but much lower in France (115 g km^{-1}). This is likely to be due, at least in part, to new passenger cars in Germany being, on average, 12% heavier and 18% more powerful, both factors associated with higher CO_2 emissions (International Council on Clean Transportation, 2015a).

The difference in average CO_2 emissions of new diesel and gasoline cars sold in the EU has reduced from 17 g km^{-1} in 2000 to just 3 g km^{-1} in 2014 according to provisional figures from the European Environment Agency. In 2014 they were 126 and 123 g km^{-1} for gasoline and diesel respectively, giving an average for all new cars of 123 g km^{-1} taking account of the credits for very low emitting vehicles. The target of 130 g km^{-1} by 2015 was achieved in 2013, i.e. 2 years early (International Council on Clean Transportation, 2015a).

Ajanovic (2011) has estimated that most of the reduction in CO_2 emissions between 1980 and 2007 was brought about by efficiency improvements of both gasoline and diesel cars. The overall fuel savings was about 9%, of which 1% was due to the switch to diesel. Given this moderate result the author concluded that the diesel tax incentives provided in most European counties were not justified. Schipper & Fulton (2013) also argue that the reduction in vehicle CO_2 emissions is almost exclusively due to technology improvements, rather than a shift to diesel cars. If only the shift to diesel cars had occurred, with no technology improvements, the average new car emissions in 2009 would have been 184.5 g km^{-1} instead of 145.6 g km^{-1}, an improvement of just 1% from the 1995 average emissions. Schipper & Fulton conclude that the lack of reduction in CO_2 emissions associated with the shift from gasoline to diesel cars is not the fault of the technology, but rather the result of the joint actions of both buyers and manufacturers, who have used technology improvements in part to improve performance. This has attracted buyers of more luxurious cars away from gasoline to diesel. To reduce total car CO_2 emissions requires detailed understanding of the choices consumers make in purchasing and using cars. These are complex.

Car CO_2 emissions are measured as part of the type approval process using a chassis dynamometer over a pre-defined driving cycle, known as the New European Driving Cycle (NEDC). The results are used for consumer information and CO_2 based taxation systems as well as compliance with the European type approval regulations. According to research undertaken by the International Council for Clean Transportation (2015b) the difference between the laboratory tests and on-road CO_2 emissions in 2001 was less than 10%, but by 2014 this difference had increase to around 40%. Some of the difference between the driving cycle and the real world emissions is that the NEDC is not totally representative of on-road conditions. However there are other reasons that explain the increasing gap:

- Increasing use of 'flexibilities' in the type approval procedure, for example when tolerances are allowed in the laboratory testing or the procedures are open to interpretation. A study for the European Commission concluded that the use of flexibilities has increased in recent years and their use may have resulted in around 11% reduction in official CO_2 emissions from new passenger cars between 2002 and 2010 (Kadijk et al, 2012). More recently the International Council on Clean Transportation (2015b) estimated that these flexibilities explain more than half the difference.
- Road load test results, undertaken on test tracks to characterize the aerodynamic drag and rolling resistance that a car needs to overcome, are used to define the chassis dynmometer settings. These flexibilties include tyre selection and preparation, test track surface, ambient conditions, and pre-conditioning of the vehicle, among others. These are though the to account for about one-quarter of the overall gap observed in 2014.
- The increasing use of technologies that show a higher benefit in the type approval test than under real-world driving conditions. These include stop-start technology, hybrids, advanced automatic transmissions, and downsized turbocharged engines. The type approval data over-estimates real world CO_2 emissions from hybrid cars by about 50%.
- Changing consumer preferences such as the increased use of air conditioning, energy intensive entertainment and comfort systems (e.g. heated seats) and automatic transmission. Air conditioning, entertainment systems and heating are not turned on during the test.

There was an especially pronounced gap between the official data and real word experience after 2007-2008 when a number of EU member states switched to CO_2 based vehicle taxation systems and the mandatory CO_2 targets for new cars was introduced. The effect is that car CO_2 emissions have not decreased by as much as the Regulations intended.

The type approval figures show a significant CO_2 emissions reduction, from 170 g km $^{-1}$ in 2001 to 123 g km^{-1} in 2014 27% reduction). On the other hand, German real word data provided by Spritmonitor.de, an on-line database of motorist fuel consumption by car model, shows a much smaller reduction from 184 g km^{-1} in 2001 to 168 g km^{-1} in 2014 (8 % reduction) (International Council for Clean Transportation, 2015b).

The official data appears to under-estimated average CO_2 emission from diesel cars more than from gasoline cars. In 2014 the gap with real world driving data was 37% and 42% respectively. The official figures from 2012 only indicated a 1.5 g km^{-1} average benefit of diesel cars. It therefore seems possible that there is in fact no overall CO_2 emissions benefit of dieselisation of the car fleet (International Council for Clean Transportation, 2013).

To partially address the issue of the difference between the type approval test results and real-world data the United Nations have recently developed a new test procedure known as the Worldwide Harmonized Light Vehicles Test Procedure (WLTP), as well as a separate test procedure for air conditioning systems, but these have not yet been adopted into EU regulations. It has been suggested that this should reduce some of the official/real-world driving divergences (International Council for Clean Transportation, 2015b). However, it is very difficult to design an effective laboratory test to simulate real world driving conditions, due to the wide range of vehicle performance, driving styles and driving conditions and the new test procedure may have currently unknown flexibilities.

In summary, it appears that the switch from gasoline to diesel has only, at best, resulted in a marginal reduction in CO_2 emissions from road transport, and may have resulted in an increase due to the rebound effect.

In Japan and the US gasoline hybrid vehicles have been encouraged to reduce road transport CO_2 emissions not diesel vehicles. The type approval test procedure and driving cycles are different in these countries. The first International Council on Clean Transportation (2013b) study on the comparison of real world and official emissions included an analysis of US data which suggested that the US Federal test underestimates hybrid vehicle emissions more than gasoline or diesel. This is supported by more recent European data ((International Council for Clean Transportation, 2015b). Therefore the approach taken in these countries to reduce transport CO_2 emissions may not be any better than promoting diesel cars.

4 NITROGEN OXIDES (NOX) EMISSIONS

In recent years there have been a number of studies which have shown that the real world NOx emissions from diesel cars have not declined in line with the emission limits. Carslaw et al. (2011), using remote sensing data, show that while the EU emissions standards have been effective in reducing NOx emissions from gasoline cars the requirements have not reduced emissions from diesel vehicles to the same degree. There has been little improvement in diesel car emissions over a twenty year period, and the introduction of Euro 4[3] and Euro 5a[4] emission standards have not decreased emissions compared to older generations of car. The authors concluded that the type approval test is a poor indicator of emissions under real driving conditions. Weiss et al. (2012) also found, using portable emissions measurement systems (PEMS), that real-world NOx emissions from Euro 4 and 5 diesel cars were significantly higher on-road than during laboratory tests including the type approval test.

[3] all new cars were required to meet this standard from January 2006

[4] Euro 5a standards applied from September 2009 (new types) and January 2011 (all new vehicles) for all pollutants except particle number. The Euro 5b limits on particle number were introduced from September 2011 (new types) and January 2013 (all new cars) for diesel cars.

A study from Zurich, in which annual remote sensing measurements were made at the same site between 2000 and 2012, concluded that NOx emissions from diesel cars have increased over this period, despite the tightening of emissions standards. The NOx emissions from pre-Euro 1 diesel cars were slightly lower than those from Euro 5 cars, with the highest real-world NOx emissions from Euro 2 and 3 cars (Chen & Borken-Kleefeld, 2014).

More recent remote sensing measurements from Carslaw (2014) shows that Euro 6 diesels[5] cars emit approximately 40% less NOx than Euro 5 cars. This is less than the 56% difference between the respective limit values, and is significantly higher than the in-service NOx emissions from gasoline cars. The data also shows that Euro 6 diesel cars have lower primary NO_2 emissions, and that gasoline hybrid cars have NOx and NO_2 emissions similar to gasoline cars.

Ligterink et al. (2013) measured the real world emissions from nine early Euro 6 diesel cars, and found that the NOx emissions are dependent on the abatement technology used. During the type approval tests control strategies are active and effective, but during real world driving the systems can be partly switched off. All the cars met the type approval limit of 80 mg km^{-1}, but on-road emissions were, on average, 550-800 mg km^{-1}, i.e. very significantly higher than the emission limit. Only one vehicle, fitted with exhaust gas recirculation and a lean NOx trap, emitted less than 80 mg km^{-1} in real world driving conditions. The carbon monoxide, total hydrocarbon and PM emissions were all under the type approval limits. The authors concluded that the real world NOx emissions of Euro 3, 4, 5 and early 6 vehicles do not really differ. There is concern that this issue will not be resolved until there is a requirement to comply with the limit values under real driving conditions, which is unlikely to be implemented before 2017, at the earliest.

5 PARTICULATE MATTER (PM) EMISSIONS

One of the main disadvantages of diesel cars is that they emit significant amounts of PM, unless fitted with a diesel particle filter (DPF), and are an important source of $PM_{2.5}$ and PM_{10} in urban atmospheres, which have been associated with a wide range of health effects (World Health Organization, 2013, International Agency for Research in Cancer, 2012).

PM emissions from recent port fuel injection gasoline cars, tested under laboratory conditions, are in the range less than 1 to 6 mg/km; while a modern diesel car without after-treatment may emit between 30 and 60 mg/km. With a DPF the diesel emission reduces to less than 1 mg/km. Emissions in real world driving conditions may be higher (Minjares et al., 2013).

The PM in diesel exhaust contains a high proportion of black carbon, a strongly light absorbing but short-lived climate forcing pollutant. Diesel vehicles are thought to be responsible for about a quarter of global black carbon emissions. These emissions, however, are not accounted for in the estimate of diesel car greenhouse gas emissions. Minjares et al. (2013) have estimated, using 2007 German type approval data, that when these emissions are taken into account there may be no benefit of diesel cars over the short term using the 20 year global warming potential (GWP). A small diesel advantage remains when using the 100 year GWP. Using real-world CO_2 emissions is likely to favour gasoline cars even over the longer GWP.

[5] All new cars are required to meet this standard from September 2015

The Euro 5b[6] and 6 emission standards include a particle number limit, which is only achievable using a DPF, and therefore future diesel exhaust PM emissions are likely to decline. But as new vehicles represent only a small proportion of the total vehicle fleet it will take some years before the majority of diesel vehicles in use on Europe's roads are fitted with these devices.

Over the last decade there has been a sharp increase in the market share of passenger cars with gasoline direct injection (GDI) engines. The estimated market share in 2014 was around 35% of the gasoline vehicles; i.e. about 16% of the overall passenger car market (International Council for Clean Transportation, 2015a). These vehicles have emissions more similar to those of diesel engines, with lower CO_2, but PM emissions possibly double those from conventional port injection gasoline cars (Minjares et al., 2013). As a consequence the Euro 6 GDI cars are also subject to the same particle number emission limit as diesel cars, and may also be fitted with particle filters. However, the particle number standards for GDI cars will not apply until 3 years after the introduction of the Euro 6 standard (from September 2018 for all new cars).

6 FACTORS THAT INFLUENCE NEW DIESEL CAR SALES

The European automotive industry believes that tax measures are an important tool in shaping consumer demand toward fuel efficient cars and help create a market for new technologies (ACEA, 2013). There is evidence from a number of studies that motorists switch to diesel cars to reduce the running cost of their vehicles and that purchase price (including tax) is less important than fuel prices and annual vehicle taxes (e.g. Hivert, 2013, Ryan et al., 2009). However, there is also contrary evidence that purchase/registration tax regimes which provide a strong incentive for motorists to buy a particular type of vehicle can be successful (Brand et al., 2013; Mayeres & Proost, 2013; Hivert, 2013; Klier et al., 2012).

The cost of vehicles and their fuel is essentially made up of two components: (1) production, distribution and marketing, and (2) taxation. Governments have little control over the former, but can and do vary the taxes. In theory taxes should correct market prices for external costs (e.g. accidents, air pollution and congestion) and raise government revenue in an equitable and efficient way.

There are a number of taxes associated with private car use. These include fuel tax (also known as fuel duty, but may include energy and consumption taxes); and vehicle taxes (purchase or registration tax, typically a one-off payment by the first owner of the vehicle, and an annual vehicle tax, typically levied on vehicles that use public roads). New vehicles and fuel are also subject to VAT in EU countries. Increasingly, since the 2000s, vehicle taxes have been based on a car's CO_2 emissions, as measured in the type approval test. About 70% of EU countries now have a CO_2 based vehicle taxation system.

In some countries the vehicle purchase/registration tax is combined with a rebate or subsidy to reward purchasers of less polluting cars and penalise the purchasers of above average polluting cars. These are known as feebate systems, and are often designed to be revenue neutral. However, as consumer behaviour is difficult to predict, setting the feebate at the correct level to ensure neutrality has in reality proved to be difficult (e.g. Brand et al., 2013).

[6] All new cars were required to meet this standard from January 2013

Few studies have explicitly looked at the role of fuel and vehicle taxation on the market share of diesel cars, although there is an extensive literature on the effect of changing fuel prices on the fuel economy of the vehicle fleet, going back to the fuel price rises of the 1970s.

6.1 Fuel taxation

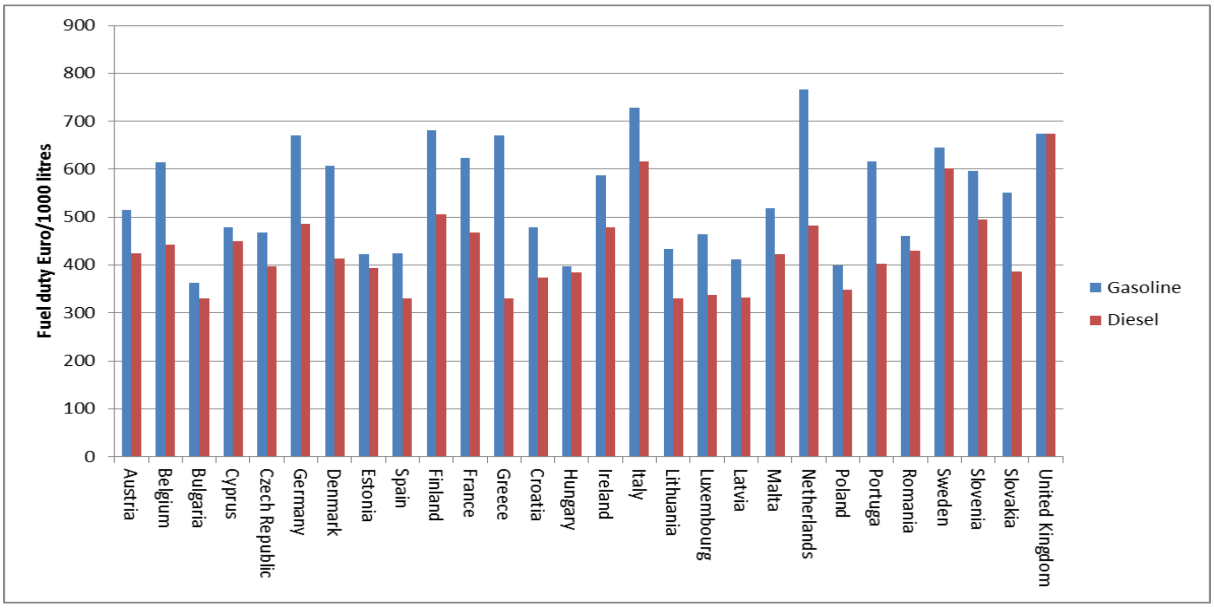
Burke & Nishiutateno (2013) analysed data from 136 countries for the period 1995 to 2008 to estimate the long-term price elasticity of gasoline to be between -0.2 and -0.5. That is a 10% increase in fuel prices results in a 2% to 5% reduction in fuel consumption. Using a subsample of 43 countries the authors also found that a 10% increase in gasoline prices induce consumers to buy 2% more fuel efficient vehicles. They concluded that if the United States had the same fuel prices as the UK, over time the fuel economy of new vehicles would improve by one sixth. However, increasing fuel prices is politically challenging in all countries but particularly the United States.

The EU stipulates minimum tax rates for gasoline (0.359 € per litre) and diesel (0.330 € per litre). Whilst Member States may not tax automotive fuel below these rates, they can use their discretion over how high the tax should be above these minimum levels.

Figure 2 shows the fuel tax applied to gasoline and diesel in each EU Member State. The tax on gasoline is greater than that on diesel in all countries except the UK, where it is the same. The pump price of automotive fuel is dependent not only on the level of tax but also on the cost of producing and distributing the fuel, and in five EU countries, including the UK, diesel is more expensive than petrol (EU, 2015).

In December 2015 in diesel was more than 10-20 % cheaper than gasoline in 9 EU countries, and more than 20% cheaper in 2 countries (Greece and Netherlands) (European Union, 2015), but in the past the difference has been greater. Minjares et al. (2013) report that the average difference between diesel and gasoline prices (per megajoule) in the EU-15 and EFTA countries was in the range 32% to 24% over the period 1998 to 2004, when the new diesel car market share rose rapidly from 25% to 48%. From 2004 to 2008 the diesel market share rose more slowly, up to 53% when the average fuel price difference reduced down to 11%.

Figure 2: Fuel Duty in EU Member states (ACEA, 2015)



There is a significant difference in the new diesel car market in individual European countries, and there is no simple relationship in western European countries with either pump price or fuel taxation. For example, the country with the lowest market share of diesel cars is the Netherlands (28%). However, it has the highest tax on gasoline in the EU and diesel is 22% cheaper than gasoline at the pump. This suggests that there are other factors that influence fuel choice. The Netherlands is a densely populated country and its inhabitants are relatively receptive to environmental issues, and this may have influenced motorists' fuel choice. According to Cames & Helmers (2013) of greater importance is the indigenous oil industry. Dutch refineries produce more light than middle distillates, favouring the production of gasoline over diesel. As a result Dutch policy has, over many years, penalised diesel cars. As far back as 1998 the National Environmental Policy included a target to reduce the share of diesel vehicles from 11% in 1998 to 5% in 2010 (in reality it was 20% in 2010). The car taxation system changed in 2008 to become primarily CO_2 based, but with a penalty for diesel cars. The Dutch market share of new diesel cars has remained in the range 20% to 28% from 2001 to 2014 (International Council on Clean Transportation, 2015a).

Greece had a low very diesel car market despite having a high tax on gasoline and diesel tax being set at the EU minimum rate. At the pump diesel is approximately 20% cheaper than gasoline (European Union, 2015). Greece differs from many other European Countries in that it has no automobile industry, and imposes a substantial tax on the purchase and use of new cars, which rises sharply with engine size (Adamou et al., 2012). However a ban on diesel vehicles in Athens and Thessaloniki from 1991 until 2011 was the main cause of the low number of diesel cars in the country. The ban was imposed to improve air quality in Athens and to limit the damage to local antiquities. It was replaced by the low emission zone in Athens in 2012. Since the ban was lifted there has been a rapid increase in diesel car sales. In the year before the ban was lifted diesels were 4% of new car sales. In 2011 it increased to 10% and by 2014 had increased to 64% (International Council for Clean Transportation, 2015a). A study modelling the effect of car attributes on demand in Greece found that a car's engine capacity, power, torque, and climate control are important, but CO_2 emissions were not (Adamou et al, 2012).

Dynamic modelling that takes account of delays in consumer adaptation to changes in taxation, undertaken by Ryan et al. (2009), suggests that there are country specific factors that influence the share of diesel cars sold. Whilst the total new car sales are influenced by fuel prices, annual circulation taxes and gross national income per capita, registration taxes were found to be not important overall. The main factors influencing the share of diesel vehicles sold were population density and vehicle price (diesel price was not included as a variable). An explanation could be that in areas of high population density if people buy a vehicle at all then it is for longer trips outside the city and therefore motorists prefer to buy a diesel vehicle. It should be noted that Ryan et al. investigated the diesel market share over the period from 1995 to 2004 before the mandatory CO_2 targets were agreed in 2009.

Bonilla (2009) investigated UK consumer demand for new car fuel economy over the period 1978 to 2004. He found no effect of fuel prices on short term demand for fuel efficient cars, however over the long term, fuel efficiency was found to be dependent on income and diesel price.

In 2007 the European Commission proposed raising the minimum tax on diesel by nearly 20% bringing it firstly in line with gasoline and then increasing it above the gasoline rate. This proposal was rejected by Member States, as there was no political appetite to increase diesel fuel prices. This remains the case today. For example, increasing fuel taxation in the

UK during a period of rising oil prices led to public complaints from both commercial and private motorists and a campaign to boycott fuel stations and blockade oil refineries, which led to panic buying and fuel shortages (House of Commons, 2104).

Tscharaktschiew (2014) argues that even gasoline is undertaxed. He estimated that the economically optimal tax in Germany is possibly as much as 50% higher than the current level, despite the country already having a one of the highest gasoline taxes in the EU. The optimal diesel tax is even higher due to the additional air quality impacts of diesel car emissions. The model excluded the consumption of diesel in commercial vehicles and Tscharaktschiew acknowledges that the inclusion of these vehicles is likely to change significantly his estimate of the optimum diesel tax.

Mayeres & Proost (2013) argue that in the absence of a better instrument to internalise the external costs of congestion and traffic accidents, gasoline and diesel cars should attract the same tax per mile. To compensate for diesel cars emitting more air pollution and due to their better fuel economy paying less per mile, diesel used in passenger cars should be taxed at a higher rate than gasoline. The authors acknowledge the difficulties governments face in taxing diesel used in cars and commercial vehicles differently, and therefore they argue that an additional fixed charge per year its require to discourage diesel cars.

Several studies have shown that, on average, diesel cars are driven further than gasoline cars e.g. in France (Hivert, 2013), the UK (Bonilla, 2009), Germany (Schipper, 2008), and Ireland (Hennessy & Tol, 2010). This rebound effect is thought to be the net result of cheaper fuel (in most EU countries) and more fuel efficient vehicles. However, over time the average annual mileage of diesel cars has fallen as lower mileage gasoline car drivers convert to diesel. It appears that motorists that switched later tended to be more satisfied with lower costs rather than exploiting the lower costs to drive further (e.g. Hivert, 2013). This is not surprising as those that benefit most from lower fuel costs would switch before those who benefit less. Kågeson (2013) argues that in Sweden there are other reasons for diesel cars being driven further than gasoline cars. The diesel car fleet is relatively ‘young’, a result of the rapid growth in the number of diesel cars, and are mainly owned by companies. He also suggests that there is no evidence of a rebound effect, but it may show up more clearly as the fleet gets older as second owners are more fuel price sensitive than first owners. Brand et al. (2013) modelled the effects of a range of fiscal policies on transport demand and also found that the rebound effect is not hugely significant in the UK, Sweden and the UK have the smallest tax differential between gasoline and diesel (see Figure 2).

6.2 Vehicle Taxation

This section discusses the influence of purchase or registration and annual vehicle (also known as a circulation tax) taxes on the diesel car market share. Although these taxes have different effects, and one may be more effective than the other in determining the diesel market share, many studies have considered the effects of both together, and therefore it is often difficult to identify the effects of individual fiscal instruments. Therefore they have been considered together in this section.

The effectiveness of vehicle taxes obviously depends upon how steeply they are graduated. Whilst there have been studies on individual taxation regimes, no studies has been identified that explicitly determines the relationship between tax and market share of different types of vehicles. This is considered to be because there are a wide range of non-price determinants of consumer behaviour, such as the potential for different emotional and possibly cultural responses. There may be a threshold or tipping point which leads to disproportionate consumer reactions (Brand et al., 2013).

Diesel cars are more expensive than equivalent gasoline cars, but the difference has diminished over time. As diesel technology has improved and become relatively cheaper, it has become not only a replacement for large and medium sized gasoline cars, but increasingly also for small cars. This has resulted in diesel cars becoming more attractive for lower mileage motorists (Hivert, 2013), especially in countries with a significant price difference between gasoline and diesel.

Several EU countries have subsidised the purchase of low CO_2 emitting cars, although the effect has not always been positive for the exchequer. When the Belgium Government introduced a subsidy in 2008 it led to increasing sales of diesel cars and use of diesel fuel. This resulted in a small reduction of CO_2 emissions, but at a large social cost as the substitution of gasoline by diesel halved the tax revenue per kilometre. It has been estimated that the cost of CO_2 abatement was €500-1,000 per ton, compared to the cost of reducing carbon in the industrial sector of €10-30 per ton (Mayeres & Proost, 2013), and therefore may not have been a cost-effective option.

Also in 2008 the Irish government changed its car registration and annual vehicle taxes from an engine size regime to a steeply graduated system based on CO_2 emissions. The impact of this reform has been the subject of several studies. Giblin & McNabola (2009) used a car choice model to predict the impact on the diesel market share, CO_2 emissions and Government revenue. They predicted that the introduction of the new taxes would result in a 6% shift to diesel cars, a 3% reduction in private transport CO_2 emissions, and a reduction in annual government revenue of €191 million. The model also predicted that the average size of new car engines would fall. Purchasers' car choice was found to be more influenced by the annual vehicle tax than the purchase tax, possibly because the purchase tax is included in the price of a new vehicle and hence is 'hidden' from the purchaser. The model did not take account of any rebound effect.

A second study also investigated the effect of the tax reforms on the diesel car market using a car stock and car purchase model (Hennessy & Tol, 2010). The model predicted a much larger shift to diesel cars, increasing from 28% to 58% as a direct result of the tax reform. The costs of a tonne of CO_2 avoided was estimated to be €3,800 in 2011 assuming no rebound effect; with a rebound effect this increased to €17,000. These values are significantly higher than those estimated for Belgium by Mayeres & Proost, but are likely to be due to the substantial reduction in tax revenue predicted with the new system.

An analysis of the effects of the tax reform in the first full year after their introduction show that there was not a shift towards cars with smaller engines but there was a significant shift towards diesel cars as predicted by Hennessy & Tol. During the first half of 2008 the diesel share was 28% which increased to 54% in the second half of the year. In 2009 56% of new cars purchased were diesel and in 2010 it increased further to 64% (and to 73% in 2014). The policy was estimated to have reduced Ireland's average new car CO_2 emissions from 165 to 145 g km^{-1} between 2007 and 2009, based on type approval data (Rogan et al., 2011). A carbon fuel tax was also introduced in November 2009, which was estimated to only recover about one sixth of the reduced vehicle tax revenue (Hennessy & Tol, 2010).

Other countries have also found that vehicle taxation policies aimed at reducing CO_2 emissions have reduced tax revenue substantially. Prior to 2008, France imposed vehicle purchase tax largely on the basis of vehicle power, but at the beginning of 2008 the government changed the system and began to impose vehicle purchase tax based on CO_2 emissions, with subsidies for the least polluting vehicles. The aim of the system was to be revenue neutral. The tax increased in discrete steps from a subsidy of €5,000 for vehicles with emissions below 60 g km^{-1} up to a tax of €2,600 for vehicles with emissions above 250 g km^{-1}. In the first year the programme incurred a debt of €225 million, which was widely attributed to an unexpectedly large consumer response. The Government responded by modifying the subsidies and taxes in 2010 (Klier et al., 2012).

Brand et al. (2013) modelled a number of theoretical future scenarios using the UK transport carbon model. The analysis investigated several fiscal policies including purchase taxes/feebates and annual vehicle taxes. As UK fuel taxes were already high compared to other countries it was felt that further increases would be politically unacceptable. Each policy was subject to different policy ambitions, from 'low' (more likely; politically feasible) to 'high' (less likely; politically infeasible in current climate). The study concluded that a car purchase feebate system is the most effective in accelerating low CO_2 car technology and reducing life cycle CO_2 emissions. The authors concluded that governments should design incentive schemes with strong up-front price signals that reward 'low carbon' and penalise 'high carbon'. Potential policy instruments should be scrutinised for impacts on government revenues, and other measures such as high graduated annual vehicle taxes can be successful in reducing CO_2 emissions if used to boost revenues and maintain the marginal cost of driving. However they may face opposition by motorists and car lobby groups for increasing private motoring costs.

The Danish government adopted a different approach in 2007 by basing its car registration tax on fuel efficiency. Gasoline cars capable of more than 16 km l^{-1} became 19% cheaper while diesel cars capable of less than 18 km l^{-1} became 4% more expensive. The average new car fuel efficiency increased from 15.9 km $^{-1}$ in the four months before the change to 17.4 km l^{-1} in the following eight months. The diesel market share increased from 24% to 40% during the same period, but both the average new gasoline and diesel car fuel consumption decreased suggesting that there had been a technology improvement as well. Modelling the average fuel efficiency and diesel market share for the period 2005 to 2008 showed that the tax reforms and the increase in fuel price that occurred over the same period only accounted for a minor change in fuel efficiency and diesel market share, and that the effect of technological development was much larger (Mabit, 2014).

The UK was one of the first EU countries to introduce a graduated CO_2 based car taxation regime in 2001. There is no car purchase or registration tax in the UK, so the annual road tax was adapted to be based on CO_2 emissions. According the Brand et al. (2013) studies on its effectiveness has had mixed results. One study found that annual costs would have to increase by about £1,200 (€1,500) before motorists would switch to a more fuel efficient car, while another study found that the most important factors influencing consumers purchase decisions were overall price, fuel efficiency, size, reliability and comfort. Only 3% of respondents stated that tax would influence their car purchase decision (Lehman et al., 2003). On the other hand the Brand et al. study found that a highly differentiated annual vehicle tax could be effective.

In Sweden the diesel car market share grew from 10% to more than 60% in six years between 2005 and 2011, despite the difference in the pump price of diesel and gasoline narrowing. In 2005 the government introduced an annual vehicle tax based on CO_2 emissions. At the beginning of 2011 it was changed again to comprise two components: (1) a fixed rate and (2) a levy based on the g km^{-1} for vehicles with emissions greater than 120 g km^{-1}. Cars that run on ethanol or biogas pay a reduced rate, and diesel cars attract an additional fee to account for their greater emissions of urban air pollutants compared to gasoline cars. According to Kågeson (2013) the increase in new diesel car sales was, at least in part, due to the growing number of diesel models available with CO_2 emissions less than 120 g km $^{-1}$. The sales of alternatively fuelled vehicles did not increase.

In 2005 the European Commission proposed that car registration taxes be replaced by restructured annual circulation taxes, based on CO_2 emissions. The aims were to reduce double taxation that can occur when motorist move with their car from one Member State to another and to reduce CO_2 emissions. However, as there was not the required unanimous support amongst Member States the proposal was rejected.

6.3 Other Factors Influencing New Diesel Car Purchase

Cames & Helmers (2013) suggest that there are a number of other factors that influence the diesel market share. For example, there is a relationship with employment in the automotive industry. Excluding Sweden and Germany, there is a high correlation (R^2= 0.728) between these two parameters. In Sweden and Germany a high proportion of the cars are exported suggesting that automotive industry employment is less dependent on the national diesel car market. In addition, society in these two countries have a high interest in environmental protection (the authors call this ‘environmental modernisation’) which exerts an influence on motorists’ fuel choice. This is also likely to be important in Finland and Denmark.

Another factor that influences the market share of diesel cars is the relationship between the industry and Government. In some countries industry has an undue influence over political decisions, such as the automotive industry in France and the oil industry in the Netherlands. The French automotive industry was an early promoter of diesel cars, and the country has one of the largest new diesel car markets in Europe. Conversely in Greece there is no automotive industry, therefore the industry has little influence over Government policy, and it had for many years the lowest diesel market share.

Some small states, such as Luxembourg and Belgium, with a high level of transit traffic tend to tax diesel at lower levels than their neighbours to increase sales and overall tax revenue (known as ‘fuel tourism’). In these countries it is unlikely that there will be a relationship between fuel taxation and diesel car sales.

7 CONCLUSIONS

Most European Governments have promoted policies that indirectly support the increase in the market share of diesel cars, by providing fiscal incentives for cars with lower CO_2 emissions. These have replaced previous tax systems based on weight or power. There is evidence that these policies reduce real world CO_2 but probably only marginally, but at the same time exacerbate poor urban air quality. The EU ambient limit values for NO_2, and PM_{10} remain difficult to achieve in many cities, and the policies to increase the number of diesel cars has indirectly made achievement of these limits more difficult.

There have been few studies explicitly investigating the reasons for the increased number of diesel cars sold in different European countries. Those that exist generally pre-date the introduction of the mandatory new car CO_2 targets which might have influenced consumer choice since 2008. Some economic models suggest that fuel price and annual car tax may be the most important determinants of diesel car purchase, while other studies show that steeply graduated purchase / registration tax, possibly part of a feebate system, is more important.

Each country uses a different combination of taxes for both private and company motorists, and these tax regimes are often changed, making identifying the influence of one tax difficult. Many of the studies have relied on economic models to identify the effect of changes in taxes, but these do not take account of the wide range of non-economic influences on car purchases.

Diesel is cheaper than gasoline in most EU countries, and with the better fuel economy provides an incentive for consumers to purchase diesel cars. However, there is not a simple relationship between the diesel-gasoline price differential and the market share of diesel cars. It appears that there are other economic and political influences that affect Member States differently.

The only measure that appears to have had a clear negative impact on diesel car sales is the ban on diesel cars in the two main cities in Greece. However banning diesel cars is politically difficult as illustrated in London recently. The Mayor of London was going to propose banning all pre-Euro 6 diesel cars, i.e. essentially those manufactured before 2015, from the London ultra-low emission zone in 2020. Following media objections he revised the policy within days.

There are encouraging signs that Euro 6 diesel cars have lower NOx and PM emissions than vehicles meeting earlier emission standards, and the introduction of in-service portable emissions measurement systems, proposed from 2017, should ensure that real-world emissions are better controlled. In the long term, as the fleet turns over, this should be reflected in improvements to urban air quality. As the average car in the EU is 8.3 years old and two thirds of the cars on the EU roads are more than 10 years old (ACEA, 2013), it is likely to be some years before these improvements to urban air quality are measureable.

8 REFERENCES

ACEA, 2015, The automotive industry pocket guide 2015-2016, http://www.acea.be/uploads/publications/POCKET_GUIDE_2015-2016.pdf. Accessed 10 December 2015..

Ajanovic A., 2011, The effects of dieselization of the European passenger car fleet on energy consumption and CO2 emissions, 34th IAEE International Conference , Stockholm ww.hhs.se/IAEE2011/Program/ConcurrentSessions/Documents/1%20online%20proce dings/2149734%20Ajanovic_Paper%20IAEE%202011_15.04.2011.pdf.

Bonilla D, 2009, Fuel demand on UK roads and dieselisation of fuel economy, Energy Policy, 37, 3769-3778.

Brand C., J. Anable, and M. Tran. Accelerating the transformation to a low carbon passenger transport system: The role of car purchase taxes, feebates, road taxes and scrappage incentives in the UK, Transportation Research Part A, 49, 132-148.

Burguillo-Cuesta M., M. J. García-Inés and D. Romero-Jordan, 2011, Does Dieselization favour a cleaner transport? Evidence from EU-15, Transport Review, 31, No. 5, 571-589.

Burke P.J. and S. Nishitateno, 2013, Gasoline prices, gasoline consumption, and new vehicle fuel economy: Evidence for a large sample of countries, Energy Economics, 36, 363-370.

Cames M. and E. Helmers, 2013, Critical evaluation of the European diesel car boom - global comparisons, environmental effects and various national strategies, Environmental Sciences Europe, 25 (15), 1-22.

Carslaw D., 2014, Recent findings from comprehensive vehicle emission remote sensing measurements, Frontiers in Air Quality Science, 23-24 June 2014, Centre for Environment & Health. Kings College London.

Carslaw D.C., M.L. Williams, J.E. Tate and S.D. Beevers, 2013, The importance of high vehicle power for passenger car emissions, Atmospheric Environment, 68, 8-10.

Carslaw D.C, S.D. Beevers, J.E. Tate and M.L Williams, 2011, Recent evidence concerning higher NO2 emissions from passenger cars and light duty vehicles, Atmospheric Environment, 45, 7053-7063.

Chen Y. and J. Borken-Kleefeld, 2014, real-driving emissions from cars and light commercial vehicles – results from 12 years remote sensing at Zurich/CH, Atmospheric Environment, 88, 157-161.

European Environment Agency, http://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer. Accessed 21 December 2015.

European Environment Agency, 2014b, Monitoring CO2 emissions from new passenger cars in the EU: Summary of data for 2013, Copenhagen.

European Union, EU Oil Bulletin, 7 December 2015, Brussels.

Giblin S and A. McNabola, 2009, Modelling the impact of a carbon emission-differentiated vehicle tax systems on CO2 emissions intensity from new vehicle purchases in Ireland, Energy Policy, 37, 1404-1411.

Hennessy H. and R.S.J. Tol, 2010, The impact of tax reform in new car purchases in Ireland, ESRI working paper, No. 349, The Economic and Social Research Institute (ESRI), Dublin.

Hivert L., 2013, Short-term beak in the French love for diesel? Energy Policy, 54, 11-22.

House of Commons, 2014, Taxation of Road Fuels, Standard Note SN824, 2014, London.

International Agency for Research on Cancer, 2012, IARC: Diesel Engine Exhaust Carcinogenic, Press Release No 213, Lyon.

International Council on Clean Transportation, 2015a, European Vehicle Market Statistics, Pocketbook 2015/2016, Berlin.

International Council for Clean Transportation, 2015b, From laboratory to road: a comparison of official and 'real-world' fuel consumption and CO2 values for cars in Europe and the United States, Berlin.

International Council for Clean Transportation, 2013, From laboratory to road: a comparison of official and 'real-world' fuel consumption and CO2 values for cars in Europe and the United States, Washington DC.

Kadijk G., M. Verbeek. R. Smokers, J. Spreen, A. Patuleia, M. van Ras, J. Norris, A. Johnson, S. O'Brien, S. Wigley, J. Pagnac, M. Seban and D. Buttigieg, 2012, Supporting analysis regarding test procedure flexibilities and technology deployment for review of the light duty vehicle CO2 regulations, prepared for the European Commission, Framework Contract on vehicle emissions,TNO, Delft.

Kågeson P., 2013, Dieselization in Sweden, Energy Policy 54, 42-46

Klier T. and J. Lin, 2012, Using vehicle taxes to reduced carbon dioxide emissions rates of passenger vehicles: Evidence from France, Germany and Sweden, Resources for the Future, Washington DC.

Lehman C., K. McLoughlin, and M. Dewhurst, 2003, Assessing the impact of graduated vehicle excise duty: Qualitative report, Report for the UK Department of Transport.

Ligterink N.E., G Kadjik, P. van Mensch, S. Hausbereger and M. Rexeis, 2013, Investigations and real world emission performance of Euro 6 light-duty vehicles, TNO, Delft.

Mabit S., 2014, Vehicle type choice under the influence of a tax reform and rising fuel prices, Transportation Research Part A, 64, 32-42.

Mayeres I. and S. Proost, 2013, The taxation of diesel cars in Belgium – revisited, Energy Policy, 54, 33-41.

Minjares R., K. Blumberg, F.P. Sanchez, 2013, Alignment of policies to maximise the climate benefits of diesel vehicles through control of particulate matter and black carbon emissions, Energy Policy 54, 54-61.

Rogan F., E. Dennehy, H. Daly, M. Howley, and B.P. Ó Gallachóir, 2011, Impacts of an emission based private car taxation policy – First year ex-post analysis, Transportation Research Part A, 45, 583-597

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

Schipper L., 2008, Automobile fuel: Economy and CO2 emissions in industrialized countries: Troubling trends through 2005/6, University of California, Transportation Centre, Berkeley.

Schipper L. and L.Fulton, 2013, Dazzled by diesel? The impact on carbon dioxide emissions of the shift to diesels in Europe through 2009, Energy Policy, 54, 3-10.

Schipper L. and L. Fulton, 2008, Disappointed by Diesel? The impact of the shift to diesels in Europe through 2006, Institute of Urban, and Regional Development, University of California, Berkeley, http://metrostudies.berkeley.edu/pubs/reports/004_trb_diesel.pdf.

Tscharaktschiew S., 2014, Shedding light on the appropriateness of the (high) gasoline tax level in Germany, Economics of Transportation, in press, DOI: 10.1016/j.ecotra.2014.06.001.

Zachariadis T., 2013, Gasoline, diesel and climate policy implications – Insights from the recent evolution of new car sales in Germany, Energy Policy, 54, 23-32.

World Health Organization, 2013, Review of evidence on health aspects of air pollution – REVIHAAP Project, Technical Report, Copenhagen.

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Testing and development of air quality mitigation measures in Southern Europe

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