WHAT IS KNOWN ABOUT THE INFLUENCE OF CO2 DIFFERENTIATED VEHICLE TAXES ON CAR SALES IN THE EU?

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What is known about the influence of CO_2 differentiated vehicle taxes on car sales in the EU?

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Abstract

The transport sector causes a big impact on the environment, and more than 50% of the emission in this sector is caused by passenger cars. The amount of passenger cars has been increasing the last decades, so governments have tried to find ways to decrease average emissions. In the European Union, as well as worldwide, goals have been set to reach a maximum average emission per car (e.g. 120g CO_2/km by 2012). However these goals would be difficult to reach without big interference in the market. Governments adapted tax systems in order to stimulate lower average emission cars by making the systems CO_2-based. This paper investigates what is known about the effect of the differentiation towards CO_2-based systems on the car market in the European Union. Current literature on the subject is mainly country based; this paper aims to fill a gap by providing an overview of all the literature on the effects in Europe. The results should help reviewing the results in Europe, and present a clear overview of knowledge to work further with. The main tax tools and incentives are VRT, AMT, fuel tax, CCT, and vehicle scrappage incentives. With these governments have tools to affect the car market, however high costs are involved for small reductions in average emission. The trend towards bigger, faster and heavier cars is reversed with the introduction of CO_2 based taxes and the average CO_2 emission decreased. Furthermore CO_2 based tax systems can cause fuel swapping, lowering the emission of CO_2 but increasing other pollutants with high health related risks. Scrappage schemes do not work for emission reduction, however are good tools to stimulate the car industry. In and export of vehicles cause subsidies to flow away so governments might have to adapt tax systems also for the second-hand market. Lastly the current literature shows no short term reaction of manufacturers to certain thresholds set by governments.

Key words:

Transport in Europe, environment, CO_2 based tax systems, average passenger car emissions, CO_2 abatement, VRT, AMT, fuel tax, CCT, and vehicle scrappage incentives

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1. Introduction: What is the influence of CO2 differentiated vehicle taxes on car sales in the EU?

Reducing passenger car emissions (mainly CO_2) has been on the agenda of national and European policy makers for decades. Emission from transport is one of the growing sectors in energy consumption, while e.g. energy used for residential purposes is decreasing. $C0_2$ emission of passenger cars makes up a large amount (more than 50%) of the greenhouse gas (GHG) caused by transport (Kok, 2011). Cars with less CO_2-emission are promoted by making purchase and use cheaper, while dirty cars are made unfavourable with high ownership and user costs. This way governments are trying to manage pollution as agreed upon by European Union as well as worldwide politics, in the so called Kyoto Protocol (United Nation, n.d.). The EU goal is an 8% reduction of GHG emissions (compared to 1990 levels) by the period of 2008-2012 (Gallachóir et al., 2009). The strategy towards that goal was to reduce average CO_2 emission of newly sold vehicles to 120g/km by 2012 (EC, 2009). In the European countries there are different, complex and dynamic systems of taxation on the purchase and use of vehicles. These rules change regularly due to the influence of politics, with environmental related inspirations, however this does make it complicated to evaluate.

CO_2 emission in the passenger car industry can be regulated in two ways; set regulation for car manufacturers for the carbon emission standards, or stimulate demand by creating tax benefits for consumers. One example of supply side stimulation are voluntary agreements made with the European automobile sector which committed manufacturers to reduce CO_2 intensity from passenger cars with 25% in the period of 1995 till 2008 (Ryan et al., 2009). This resulted in an average target of 140g/km of CO2 emission per newly sold car by 2008. The Japanese and Korean car manufacturers associations (KAMA and JAMA respectively) also committed to the same target, but with target year 2009 (Gallachóir et al., 2009). Furthermore the EU set on improving consumer information on fuel-economy, making car owners more aware of their vehicle specifications, and to make emission one of the important sale points of a vehicle. An example of this is the energy label as will be explained later in chapter 3. Moreover in 2005 the European Commission proposed to restructure member states car taxation systems, and although this proposal was never really adopted, several member states introduced tax systems based on CO_2 emission (Kok, 2011; Ryan et al., 2009). These modifications in the tax systems are the subject of this study.

Technology, as designed by the manufacturers, has progressed during the years, however a distortion of this effect is caused by a change in customer preferences. Consumers in many countries in Europe, as well as the USA, have been buying bigger, heavier and more powerful cars offsetting the efficiency gains by technology (Knittel, 2011; O Gallachoir et al., 2009; Sprei et al., 2008). From 2007 onwards many countries have adapted their vehicle related tax systems in order to lower CO_2 emission values of the new car fleet. These modifications resulted in a decline of the above mentioned car specifications, and a decline in average CO_2 per vehicle sold (Kok, 2015). This means that governments have tools to modify customer behaviour in form of the tax system. However the results differ between countries, and different tools have separate effects.

From the moment new tax rules are introduced an impact can be expected on car sales because potential customers take taxes into account when buying a new car. These changes in taxation are heavily used by car brands to promote to customers that they can still profit from old rules until the end of the year, to have lower car ownership costs. In media, newspapers, radio and television, as well as in the showroom of dealerships a lot of advertisements focus mainly on the tax class, or how good the cars specifications are within its tax segment. In some situations customers can profit from the tax reforms for 5 years, which is a considerable part of the lifespan for a new car. According to the ANWB auto survey (2011) a car in the Netherlands is owned on average for three and a half years (both for new and second-hand). So these tax rules can have a high impact on car sales, or at least on the timing of those sales. This probably means that the effects of tax rules should be represented in sales figures of cars. In order to get insight in the effects of car related tax rules other potential effects need to be looked at. Other potentials effects could be fuel changing (from diesel to petrol or vice versa), up or downsizing of car or engine size, change in power characteristics or even a change in the use of cars (mileage). Reducing travelled km's can be realised through carpooling, use of public transport, living closer to work etc. But changes in the taxation could also result in a change of annual mileage.

Fontaras et al. (2010) made an estimation of the road towards lower CO_2 emission as shown in figure 1. This study will focus on the reduction part before hybridization and bio fuels.

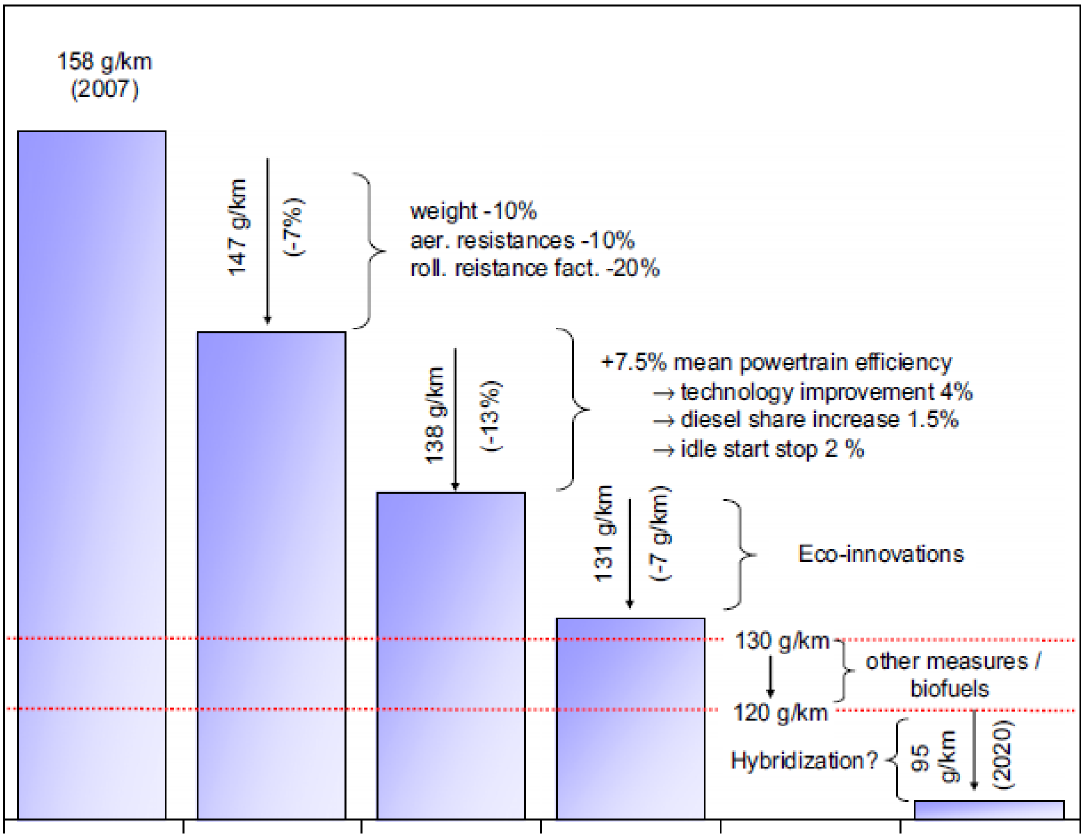

Figure 1. Route to 130g CO_2/km and beyond (Fontaras, 2010)

1.1.Research question

This results in the following research question:

'What is the influence of CO_2-differentiated vehicle taxes on car sales in the European Union?''

To answer the research question five sub questions are created. The first three questions aim to map the current vehicle related tax systems, and the effect they have on the car fleet. The fourth sub question addresses the issues with the main measure of emission and how this affects current literature. The fifth sub question regards to if and how manufacturers deal with changes in tax systems because these adaptations might be unfavourable for sales.

1.1.1. Sub Questions

1. *What are the car related taxes, and how did they change?*
2. *Can evidence of effects of tax rules be found in car sale figures and characteristics?*
3. *How are rules differentiated across the European Union?*
4. *How is $C0_2$ emission measured? And is this a correct test for tax purposes?*
5. *How do brands cope with tax rule changes?*

The aim of this study is to create an overview of the current findings of research on the effects of tax incentives on the car industry. Until now such an overview does not exist, and the related studies differ in such a way that comparing European results is difficult. Future research on this topic might benefit from this overview, because the focus and scope is clearer, and studies can be designed in such a way that results are comparable.

1.2.Relevance

Knowing and understanding the effect of tax differentiation is important for both the government as well as manufacturers and importers of cars. Firstly the government adapts tax rules periodically, influenced by European politics and environmental lobbyists. Tax rules are changed with a certain goal in mind, for instance 10% reduction of $C0_2$ emission in a certain period, while maintaining the needed tax revenues of the country's financial planning. The dilemma between the environmental goal and tax revenues can cause problems. If manufactures of cars can slightly modify the cars specifications in order to lower CO_2 emissions just enough to fall in a lower tax category, a small reduction of $C0_2$ is realised whilst tax revenues have been reduced significantly more. According to Kok (2011) this was the case in the Netherlands in 2009 and 2010. Average CO_2 emission was reduced with 6 g/km, with an estimated Vehicle Registration Tax (VRT) revenue reduction of around €0.5 billion in 2010 (Kok, 2011). The problem gets more outstanding when manufacturers willingly commit fraud with pollution tests, like seen in the VW scandal case. Untrue emission figures are used to put a car in an emission class, resulting in an unfairly VRT revenue loss.

Also innovation on the technology of car engines is continually improving the efficiency and emission of cars, making it difficult to set the tax rates or the borders of the tax classes (also called bands or thresholds). Some countries use linear systems, where a certain price per CO_2 g/km of tax needs to be paid. Others use tax classes or bands which are certain ranges of CO_2 emission that fall into the same tax category. Kok (2011) states that until 2015 emission classes in the Netherlands were planned to stay the same, resulting in, due to innovation, almost all new cars to fall into the VRT free class. This way the VRT free incentive loses value because the decision of a newly bought car is not based on emission anymore. Kok (2011) analysed that about 62% of all new cars would fall in the VRT-free class by 2015, and so tax revenues would drop significantly. However the government acknowledged this issue and gradually lowered the CO_2 classes, in such a way that around 12% would fall into the VRT-free class (<82g/km in 2015) and the rest of the car owners need to pay taxes.

There are a lot of different studies in the field of vehicle taxation. There are studies aimed at: researching the distributional effect of taxes (e.g. Blow & Crawford, 1997;Bureau, 2011; Potoglou & Kanaroglou, 2007), climate change and how to measure it (Meyer et al., 2007; Kok et al., 2011), different policies and its effects (Brant et al., 2013; d'Haultfoeuille et al., 2014), characteristics of future cars (Mueller & de Haan, 2009; Klier & Linn, 2012b; Fontaras & Samaras, 2010), demand for alternative-fuel vehicles (Haan et al., 2007; Mabit & Fosgerau, 2011; Sherpherd et al., 2012), critique on EU regulations (Bampatsou & Zervas, 2011), technology vs. consumer behaviour (Mehlin et al., 2004; Sprei et al., 2008; Knittel, 2011; Kok, 2013) and ex -post experience and the effect tax has on the car market and the average emission of the car fleet (Giblin & McNabola, 2009; Ryan et al., 2009; Gallachóir et al., 2009; Kok, 2011; Rogan et al., 2011; Klier & Linn, 2012a; Kok et al., 2013; Klier & Linn, 2012; Zimmermannova, 2012; Kok, 2015; Gerlagh et al., 2015). The focus of this study lies on policy changes and their ex-post experiences, taking into account car specifications and characteristics as well.

1.3. Layout

Firstly the different relevant factors in pollution will be discussed in Chapter 2 because those will be used in the rest of the paper. CO_2 is the main studied factor, but other pollutants are also discussed and important although not every author acknowledges this. Secondly the different types of tax systems will be highlighted in order to answer sub question 1. There are several different systems, tax tools and incentives used across Europe and this paper aims to describe them. In Chapter 3 these types of systems will be explained using the Dutch tax system as an example. Furthermore the last decade major adoptions have been made to car related tax systems around Europe, as will be described in Chapter 4. In this chapter we will also analyze the effects of the changes in tax systems as found in literature (sub question 2). This way contradiction between specific countries will show up (sub question 3) and a favourable system might be found. Furthermore will be looked if and how manufacturers react to changes in tax systems (sub question 5). Chapter 5 will discuss some critiques on the European Commission regulations because those seem to be unfair in terms of equality for consumers and manufacturers. Chapter 6 will discuss testing of car pollution (sub question 4); how do they perform testing, what are the flaws of the current testing models, and how this does affect current literature. In the last chapter the conclusion and discussion will be found. Appendix A summarizes the main literature reviewed for this thesis.

2. Different kinds of pollution, and diesel vs. petrol

This paragraph will explain some basics of emissions which will be mentioned, however not in detail since chemistry is not the focus of this study. There are multiple gasses emitted by the use of fuel for transport. In this study we focus on the transport sector, and to be exact the use of vehicles for personal travel. The so called Greenhouse gasses (GHG) are natural gasses in the atmosphere that reflect or absorb radiation causing the earth to be hotter than without the emission of those gasses. The emission of gasses adds to the natural occurring effect, and a huge rise in GHG emission has been started since the industrial revelation.

The biggest emission of GHG is carbon dioxide (CO_2), accounting for about half of future global warming, but other gasses emitted are carbon monoxide (CO), water vapour (H_2O), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), and chlorofluorocarbons (CFCs) (DeLuchi, 1991). Furthermore relevant gasses are nitrogen oxide (NO_x) which is also caused by the combustion of fuel and is especially relevant in the case of diesel vehicles. Diesel cars emit less CO_2 than petrol cars, however they emit far more other pollutants (e.g. particulate matter or PM) which can cause all kinds of health issues and also contribute to global warming. Diesel engines actually produce a higher amount of carbon emission per kilogram of fuel (around 15% more), however are also considerably more fuel efficient (20 to 40%) resulting in a CO_2 emission (in g/km) which is 10 to 20% lower than petrol (Air Quality, n.d.). Which fuel has a smaller negative effect on the environment and health is still under discussion.

Literature on the topic uses CO_2 because it is the main by-product (+-50% of GHG) of all fossil fuel combustion. Also CO_2 is directly related to fuel economy, every 1% increase in fuel used causes 1% more CO_2 emission (Pinto, G. & Oliver, M.T., 2008).

Panis et al. (2002) studied the diesel vs. petrol debate by calculating the external costs of emission in Belgium. This is very difficult because a large amount of uncertain variables have to be taken into account such as costs of global warming, PM-related mortality rates and technology also plays an important role. Older cars generate almost always more emissions than newer cars due to innovation and regulation. The results are that the use of petrol has a lower external cost in most cases because of lower direct health risks. However the study from Panis et al. (2002) also indicates that in rural areas (low amount of inhabitants) diesels are favourable because of their lower fuel consumption. In that situation fewer people are harmed by the direct effect of PM, and the lower CO_2 emission has a positive effect. Furthermore Panis et al. (2002) conclude that the use of PM filters can reduce the amount of emission of those particles by up to five times, reducing the external costs even more.

There are multiple stages where the emission can take place in the life cycle of fuels. Fabrication, leakage, distribution etc. however in this study only the end use so the combustion of fuel is taken into account. For electric vehicles it is hard to calculate the emission, since the energy is produced beforehand and only stored and used inside the car. So the pollution for that type of car mainly takes place earlier in the production cycle (DeLuchi, 1991). For electric cars research is needed on the total life cycle emission of cars, but this is still in its infancy (Brand et al., 2013). Although not many electric vehicles were sold in 2010, the market share of electric vehicles is increasing. So research on total life cycle efficiency is necessary in order to study the real effect of taxation on alternative fuelled vehicles. In this paper literature is used containing the use of those vehicles, however they are not the main focus of this study.

European emission standards (or EURO norms) define what the acceptable limits are for emissions of exhaust gasses of vehicles sold in the EU. The standards have a progressive nature; each new standard restricts the output of different emission gasses even further. Since 2014 the EURO 6 norm has been active for newly type-approved cars (European Union, 2011).

3. Type of tax instruments

In this chapter several types of government incentives will be discussed. Because it is too complex to examine all country specific policies, the general definition of the different tax instruments are given using the Netherlands as an example.

3.1.Vehicle registration tax (VRT[1])

VRT is also known as vehicle purchase tax, and is a tax paid when a new car is registered. In the Netherlands this tax used to be a fixed percentage of the purchase price added to the sale price of a new vehicle. In 2010 this was changed to a system based on the $C0_2$ emission of vehicles, with the idea that more polluting cars should cost more. With the introduction of hybrid and electric cars some additional rules were introduced to promote and stimulate the use of those types of vehicles, because they are environmentally friendly in use (Wet op de belasting van personenauto's en motorrijwielen 1992 (2009). VRT is one of the taxes which is adapted in numerous countries during the last decade.

3.2.Annual Motoring Tax (AMT[2])

AMT is an annual paid tax instrument and is also known as Vehicle Excise Duty (VED), vehicle road tax or annual circulation tax. Every year the owner of a vehicle needs to pay a certain amount of tax which is based on a couple of factors; the weight, type (car/van/truck), fuel type, private or business use, geographical position of the owner and age of the vehicle. Like VRT, this tax type has been modified towards a CO_2 based system and from 2010 Dutch cars with zero or low emission are exempt from this tax (Wet op de belasting van personenauto's en motorrijwielen 1992 (2009). This is also in order to stimulate sales of these environment friendlier vehicles. The government tries to stimulate growth in hybrid and electric cars, and without these stimulations it is likely that these new categories of cars would not have jump started this quickly, because those cars are more expansive, and more difficult to use in practise (because of mileage, need for charge locations etc.). The Netherlands and Norway have the highest share of plug-in hybrids (PHEVs) and battery electric vehicle (BEVs) (Kok, 2015).

3.3.Fuel tax

Users of cars pay tax in the form of duties on fuel usage resulting in high fuel consuming, environmental unfriendly car owners having to pay more. Fuel tax might be the easiest way to directly tax inefficient cars however this is politically seen a difficult subject. Also problems arise if tax would only be fined through fuel, all people living near the borders would easily get fuel abroad, and evade taxes. This would mean one tax system has to be adopted in the whole of the EU, which seems politically unlikely. Differences in fuel taxes are big across Europe; however this will not be taken into account in this study because of the complexity of the many types of taxes.

3.4.CCT

Lastly there are separate rules for business use of cars. A lot of people need a car for their occupation but also use it privately, and so specific rules are set for the use of company cars. For example in the Netherlands a significant part of the new car fleet consists of car in this category so it is of interest to take into account.

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[1] In Dutch BPM (Belasting van personenauto's en motorrijwielen)
[2] In Dutch MRB (Motorrijtuigbelasting)

3.5.Feebate

A feebate is a program which is a combination of fees (which is like VRT) and rebates (subsidy) and can be designed to be budget neutral in essence (Gallagher & Muehlegger, 2011). It is used to create a shift in purchasing habits, in this case in the transportation sector. Additional fees are places on high carbon emission cars and the government uses that income to rebate low emission vehicles (Brand et al., 2013). Although a budget neutral incentive system is desired, in practise it is really hard to predict consumer behaviour, making it difficult to design the right schemes. A feebate program can be a good way to influence the purchase of alternative fuelled vehicles, because the reward element is clear and transparent at the point of purchase (Gallagher & Muehlegger, 2011).

3.6.Vehicle scrappage incentives

Some countries introduced a policy for scrapping old, environmental unfriendly vehicles. While some governments just paid a cash price for the scrappage of older vehicles, others paid based on the replacement of those old vehicles. For the second category the government is in the position to set rules aimed at emission values of the replacement car. There is not a lot of research done on scrapping schemes and how much emission abatement is realised with it. This is because the schemes were introduced mainly to stimulate the car market, which was heavily impacted by the economic conditions between 2008 and 2012. This type of scheme was introduced in Germany, France, Italy and the UK (more about this in country specific paragraphs) according to Brand et al. (2013).

In France a CO_2 limit was set for the replacement vehicle, however this mainly caused vehicle owners to swap petrol for diesel cars which has disadvantages on other emissions (e.g. PM_{10} and NO_x) as described in Chapter 2. In the UK during 2009-2010 a GBP1000 incentive was given to replace a 10 year or older vehicle for a new one. During the period almost 400,000 cars were replaced using this stimulus, which was about 20% of the total new registered cars in that period (Brand et al., 2013). This resulted in a high costs for the government, and the results on emission saving are not known, so it might be just a subsidy for the car industry.

Hence it is important for governments to take into account rebound effects with policy making. Furthermore it is not known if the vehicles would have stayed on the roads and what the total mileage would have been without the incentive to scrap. Moreover no information is available on the total life cycle emissions of this type of schemes. Scrapping and manufacturing both results in extra pollution. These are factors which need to be topic of research in order to be able to examine the emission abatement of scrap schemes.

3.7. Tax policies in the Netherlands

Ahead of possible European Committee agreements, as described earlier, the Netherlands started changing the vehicle based taxes for passenger cars in 2006.

3.7.1. Vehicle Registration Tax (VRT)

From 1992 till 2008 the VRT in the Netherlands was based mostly on a fixed percentage of the net sale price of the vehicle, like shown in table 1.

Fuel type	VRT (% added to net sale price)		
	<2008	2008	2009**
Petrol	45.2 - €1540	42.3 - €1442	40 - €1288
Diesel	45.2 + €328*	42.3 + €307	40 + €366

Table 1 VRT calculation until 2008 (Wet op de belasting van personenauto's en motorrijwielen 1992, 2009)

*With exception of cars with emission of fine dust less than 5 particles a km
** Cars with less than 110gr/kg (petrol) or 95g/km (diesel) of CO_2 emission are VRT free

3.7.2. Energy label

The energy label has been used for a couple of years for cars and is similar to label systems used for consumer electronics. The label compares emission of a vehicle with other cars in its segment (which is mainly based on size of the car). A-C labelled cars are less polluting than average and D-G vehicles are more polluting. Based on the label a premium is paid or received beside the VRT (as percentage of sale price). This premium is similar to a feebate system. The label can be found in table 2 (Wet op de belasting van personenauto's en motorrijwielen 1992, 2009).

Energylabel	VRT premium 2007	VRT premium 2008/2009
A	- € 1.000,-	- € 1.400,-
B	- € 500,-	- € 700,-
C	*none*	*none*
D	+ € 135,-	+ € 400,-
E	+ € 270,-	+ € 800,-
F	+ € 405,-	+ € 1200,-
G	+ € 540,-	+ € 1600,-

Table 2. Energy label

From the year 2010 the fixed part of the VRT has been decreased annually and a CO_2 fee has been added based on the energy label of the car.

Year	VRT (% added to net sale price)	CO_2 Tax
2010	27.4	Based on energy label
2011	19	
2012	11.1	
2013	0	

Tabel 3. VRT 2010 – 2013 (Wet op de belasting van personenauto's en motorrijwielen 1992, 2009)

From 2013 onwards the VRT system is completely based upon CO_2 emission.

CO_2 boundary values (g/km)	VRT base (€)	VRT mark-up (€ per extra g/km)
<89	0	0
89 - 124	0	105
125 – 182	3,780	126
183 – 203	11,088	237
>203	16,065	474

Table 4. VRT 2013 and after (Wet op de belasting van personenauto's en motorrijwielen 1992, 2009)

Furthermore there are some exceptions on these rules; electric, fuel cell (nitrogen) driven, and A-class hybrid cars pay 0 VRT. For hybrid B class cars tax is lowered with €2500 when the electric motor provides more than 15% of the total power of the vehicle.

Figure 2. shows the curve of the 2013 registration tax and also includes CCT which will be described further on in 3.7.4.

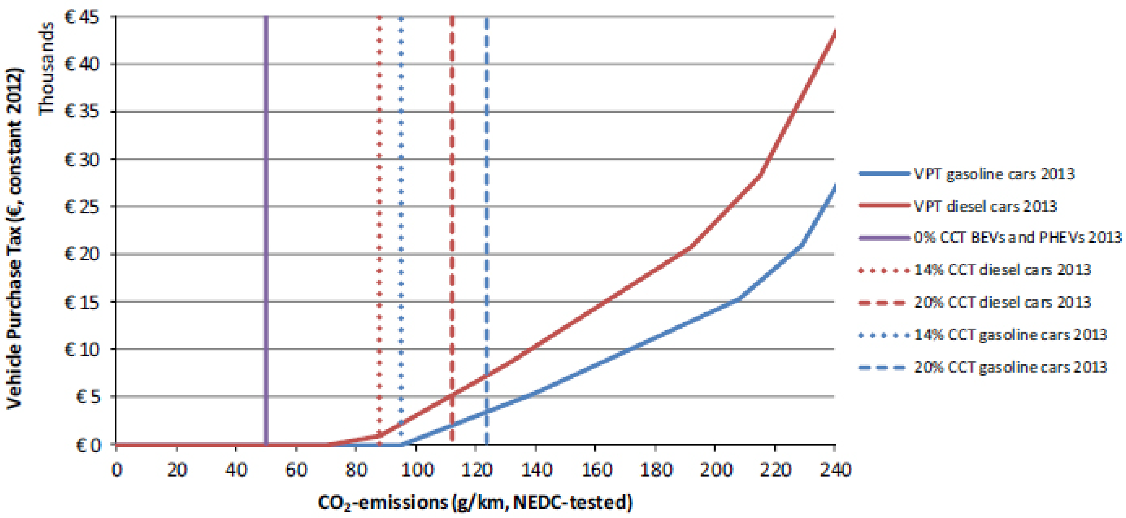


Figure 2. CO2 based VRT and CO2 based CCT incentives in the Netherlands in 2013 (Kok, 2015)

3.7.3. Annual Motoring Tax (AMT)

Owners of a vehicle in the Netherlands need to pay AMT, the amount of use of the car is not important for this tax. The height of this tax is based upon several factors; the weight, type (car/van/truck), fuel type, private or business use, geographical position, and until 2014 the age of the vehicle. Cars older than 25 year used to be AMT free because old cars mainly where used as collector's item and not for regular motoring. However the quality of cars became better and older cars were being used for daily driving so the classic car arrangement[3] was abolished (Wet op de belasting van personenauto's en motorrijwielen 1992 (2009).

From 2010 till 2014 cars with zero or low CO_2 emission were free of AMT. Diesel cars with a maximum of 95 g/km and petrol cars with a maximum of 110g/km fall into this category. Cars with an emission of less than 50g/km profit two more years of this arrangement, the rest of the cars have to pay AMT again after 2014.

[3] Oldtimer regeling

3.7.4. CCT

For the private use of a company vehicle in the Netherlands company car tax[4] has to be paid. This is a certain percentage of the sale price of the car added to the income tax. The percentage used to be, like VRT, a fixed percentage (25%) of the gross list price of the vehicle. Later, like VRT and AMT, this percentage is based on the CO_2 emission of the car. A couple of rates were set, from 0% on low and zero emission cars, 14% for cars that met certain standards, and 20 to 25% for cars with high emission. CCT is important to take into account in this study; about 50% of the Dutch new car fleet vehicles are company cars (Kok, 2015).

[4] In Dutch bijtelling

4. CO_2 abatement in the European Union

This chapter focuses on CO_2 abatement in the European Union, in other words how do European countries try to lower emissions? According to Gallachóir et al. (2009) a reduction of average CO_2 was realised, due to technological development of manufacturers, and growth in alternative fuelled vehicles. Ryan et al. (2009) also shows this as figure 3 indicates. Figure 4 shows a further decline, with acceleration after 2007.

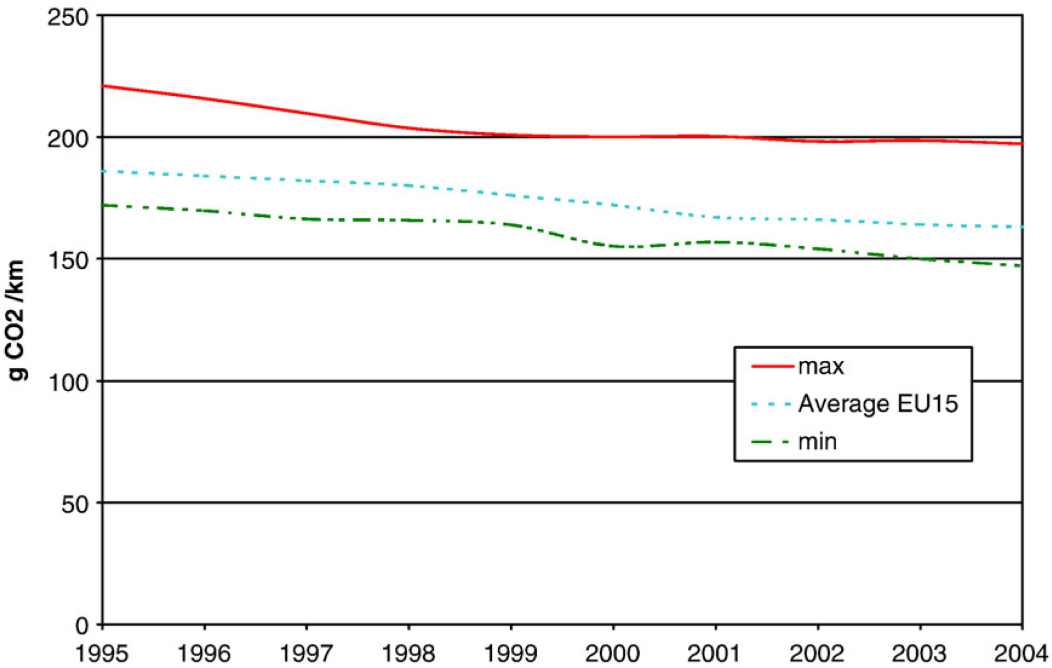


Figure 3. EU15 Member State fleet average CO2 emission 1995-2004 (Ryan et al., 2009)

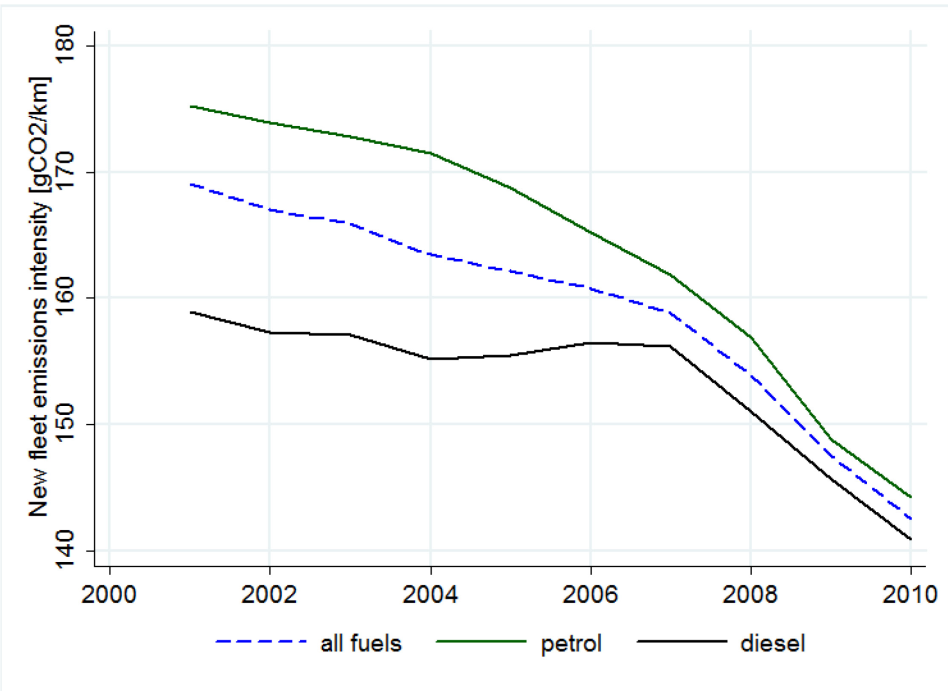


Figure 4. CO2 emission-intensity for new cars, EU15 average (Gerlagh et al., 2015)

However the pace is not high enough to meet the required target by 2012. In 2000 the average of CO_2 per car sold in the EU was 172.1 g/km, by 2006 this was reduced with 6.5% to 161.5 g/km. According to Ryan et al. (2009) the European Commission acknowledged in 2007 that without further measures it would not achieve the targets set, so additional measures were required. Furthermore the European Commission proposed a gradual exit of member states vehicle registration taxes (VRT) and an introduction of new annual circulation tax structures. These new tax systems should be linked to CO_2 emission of cars. However to date there has not been an agreement within the European Union on this matter (Ryan et al., 2009). Although the target in Europe is set, no cohesion can be found in the strategy towards that goal.

Although all EU member states have the same EU goal, the national tax policies differ quite a lot. Some countries have no or almost no purchasing or registration tax (e.g. Belgium, Germany and Italy) while other countries (e.g. Denmark, Ireland, the Netherlands and Portugal) tax a considerably high CO_2 based VRT (Kok, 2015).

Ryan et al. (2009) studied national car related tax measures in the EU, and the effect on car sales during the period of 1994-2004. They focus on the question ''how do taxes influence the carbon performance of the new car fleet?'' (Ryan et al., 2009). The study indicated that different types of taxation; fuel tax, VRT, and AMT, affected car purchasing behaviour differently. For example an increase in AMT on petrol powered cars causes a decrease in CO_2 emission because of people changing to more fuel efficient cars or swap towards diesel vehicles. However an increase of diesel AMT causes a rise in emission because of vehicle fuel switching. Petrol cars relatively have a higher emission of CO_2. Although diesel has a higher carbon emission per kilogram of fuel (around 15% more) diesel cars are also considerably more fuel efficient (20 to 40%) resulting in diesel cars emitting, like mentioned in chapter 2, 10 to 20% less CO_2. Changes in fuel prices cause a similar pattern in terms of emission. There was no evidence found for VRT having a big influence on the decision of what car to purchase. This can be caused by VRT being incorporated into the purchasing price and consumers automatically take this into account when selecting a new car. This could change because of the new policies introduced after 2004. The study of Ryan et al. (2009) is of interest, however the period of focus is just before major reforms, making it less usable nowadays.

Furthermore Ryan et al. (2009) found that fiscal policies affect the total amount of cars sold, the petrol share of these sales, and the CO_2 emission intensity. They also found that the average CO_2 emission intensity of the new car fleet does not seem to decrease during the time period (1994-2004) independent of member states fiscal measures. Ryan et al. (2009) conclude that the main factors influencing car sales are; fuel prices, annual motor tax, and GNI per capita. This last part represents the economic conditions, which has a logical influence on car sales. Fuel prices cause people to switch fuel type, or search for alternatives like public transport. Annual motor tax might have a big influence because car purchasers take those future costs into account when looking for a new car, however as we will see later other studies show different results. This might be because these results are, like mentioned above, based on data from 1994 till 2004 and that was prior to major tax reform. Although the study looked at changes in CO_2 emission caused by tax variation, the tax itself was not yet connected to the emission of CO_2.

According to Ryan et al. (2009) tax systems are designed for revenue generation and not environmental reasons initially. Because the old systems were not related to CO_2 emission, and historical systems are adapted, big differences across EU member states can be found (Ryan et al., 2009). Although this is the case, it might be interesting to take into account results from other countries in order to compare outcomes. Figure 5 shows big differences in average emissions across Europe for petrol cars.

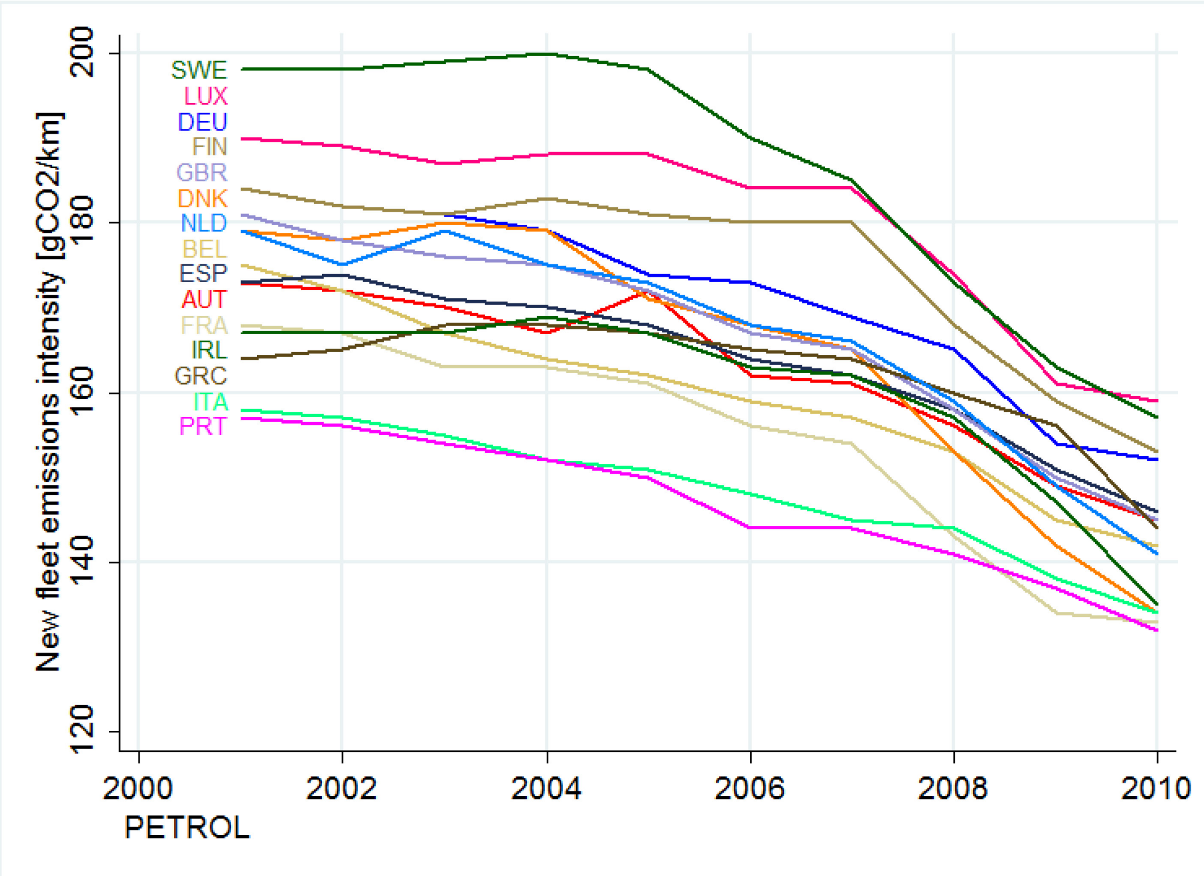


Figure 5. CO2 emission-intensity for new petrol cars, by country (Gerlagh et al., 2015)

Ryan et al. (2009) make use of a database with member states taxes, vehicle prices and CO_2 emission data for the period of 1995 till 2004. Furthermore fuel demand has shown to be correlated to CO_2 intensity so therefore fuel price elasticity models can be used to estimate CO_2. There are various studies into the effect of prices on the demand of fuel (e.g. Graham & Glaister, 2002; Odeck & Johansen, 2016), however most of the researchers do not incorporate vehicle taxes into the model.

Modelling by COWI (2002) shows the greatest reduction in CO_2 intensity could be gained by replacing old tax systems with fully CO_2-differentiaded tax systems. Which is discussed in the European Commission, however, as mentioned before, no agreement on this matter has been reached. Furthermore the study shows that the combination of CO_2 based registration and circulation tax results in higher CO_2 reduction than the taxes alone.

4.1.Relevant factors

It is important to realise that technological advances are only influencing the new car fleet, since cars generally are used for more than a decade (multiple owners) the effect of innovation is slightly postponed.

Due to technological advances, economic conditions, but also politics, car specifications and preferences change. This makes it more difficult to compare year to year results, and also to compare different countries. If we look to the EU there are a couple of rich countries (e.g. Luxembourg, Norway, and Switzerland) but also some less wealthy countries (Romania, Bulgaria and also we need to take into consideration candidate states). The car fleet in those separate groups will differ excessively by nature. Also we see in- and export between those categories of countries. The goals set by the EU count for the average of the whole of the Union, so exporting environment unfriendly cars to other EU countries does not solve the issue. Furthermore mileage is in real world conditions important for the amount of CO_2 emission. Zachariadis et al. (2001) show that older vehicles on average are used less often as can be seen in figure 6. However actual mileage in many studies is not taken into account.

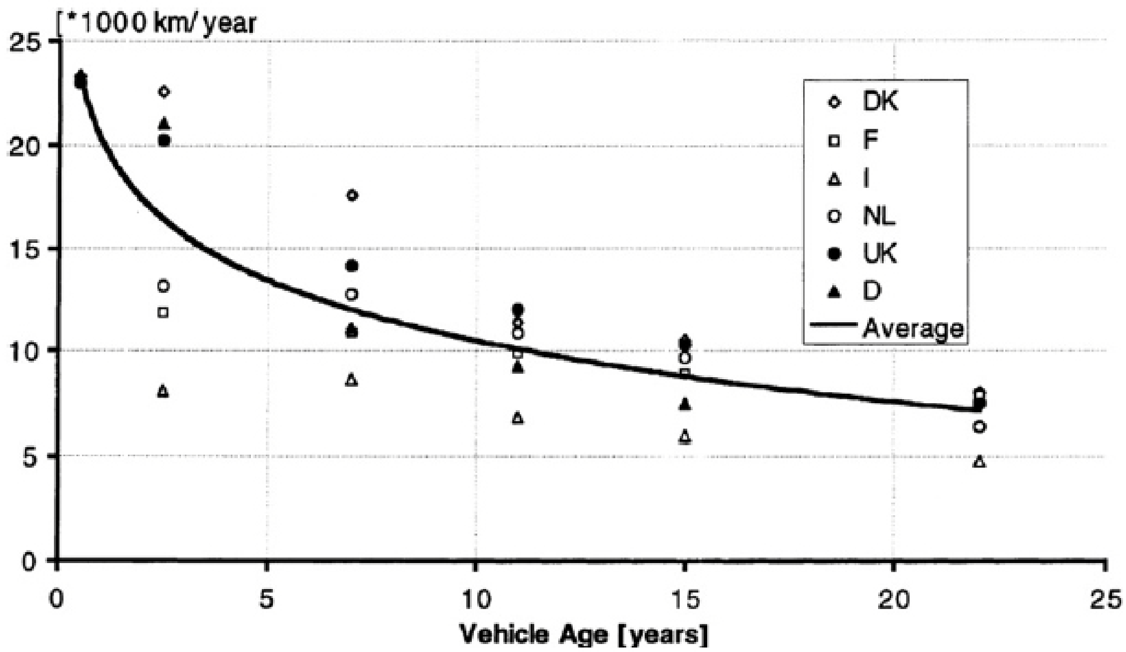


Figure 6. Mileage as a function of car age for six European countries (Zachariadis et al., 2001)

4.2. Country specific results

In the following chapter country specific results will be discussed. The green countries are depicted in separate or combined articles, and the dotted countries are the EU15, the first 15 countries in the European Union, which are used in several reports.

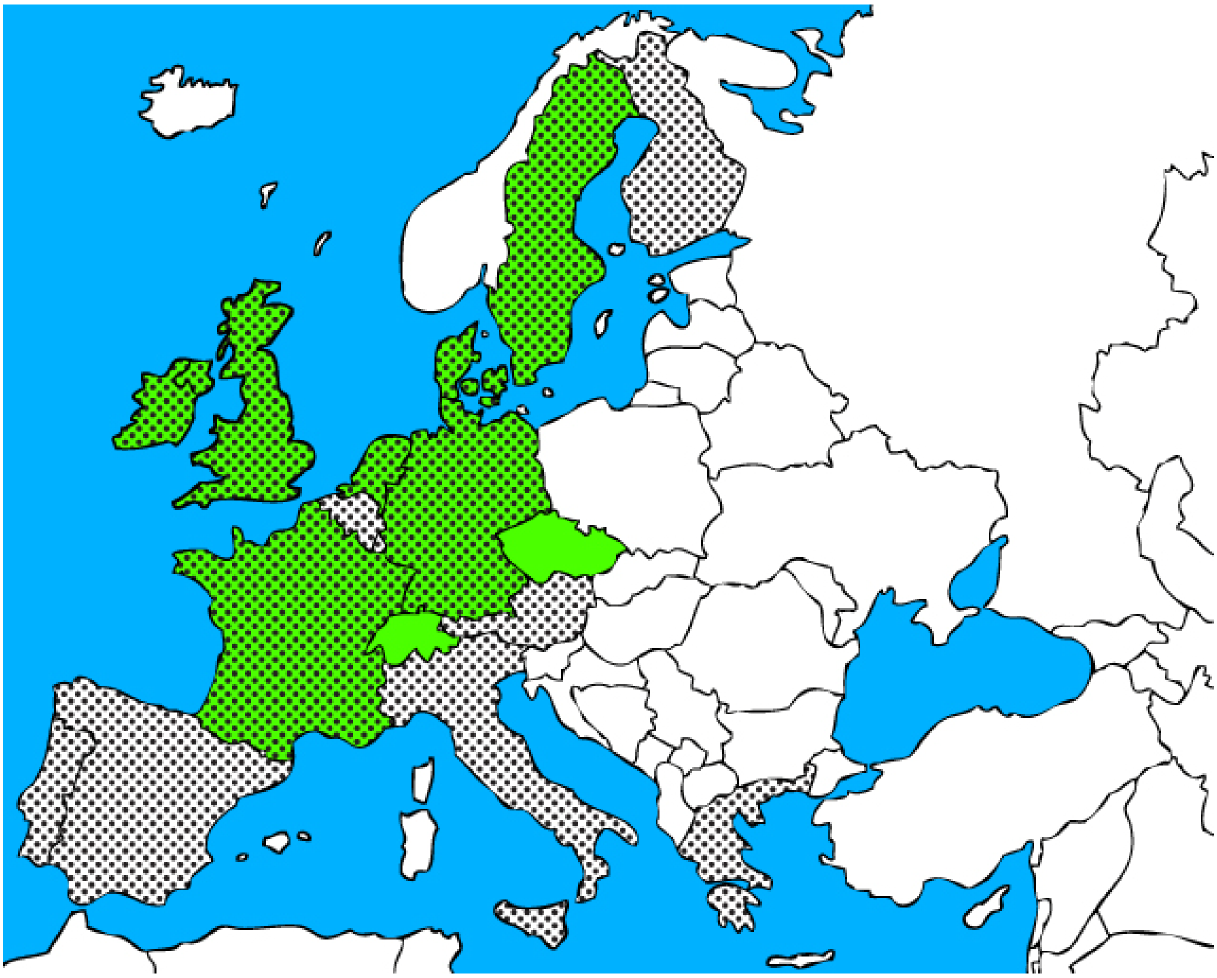


Figure 7. Map of included countries found in literature

4.2.1. Ireland

According to Kok (2011) research in Ireland shows that there is a large impact on new car sales by introducing a CO_2-differianted tax system (Gallachóir et al. (2009); Rogan et al. (2011)). Ireland had a relatively high polluting car fleet when looked to average CO_2 as shown in figure 8. This can partly be explained by the low share of diesel cars in Ireland as shown in figure 9.

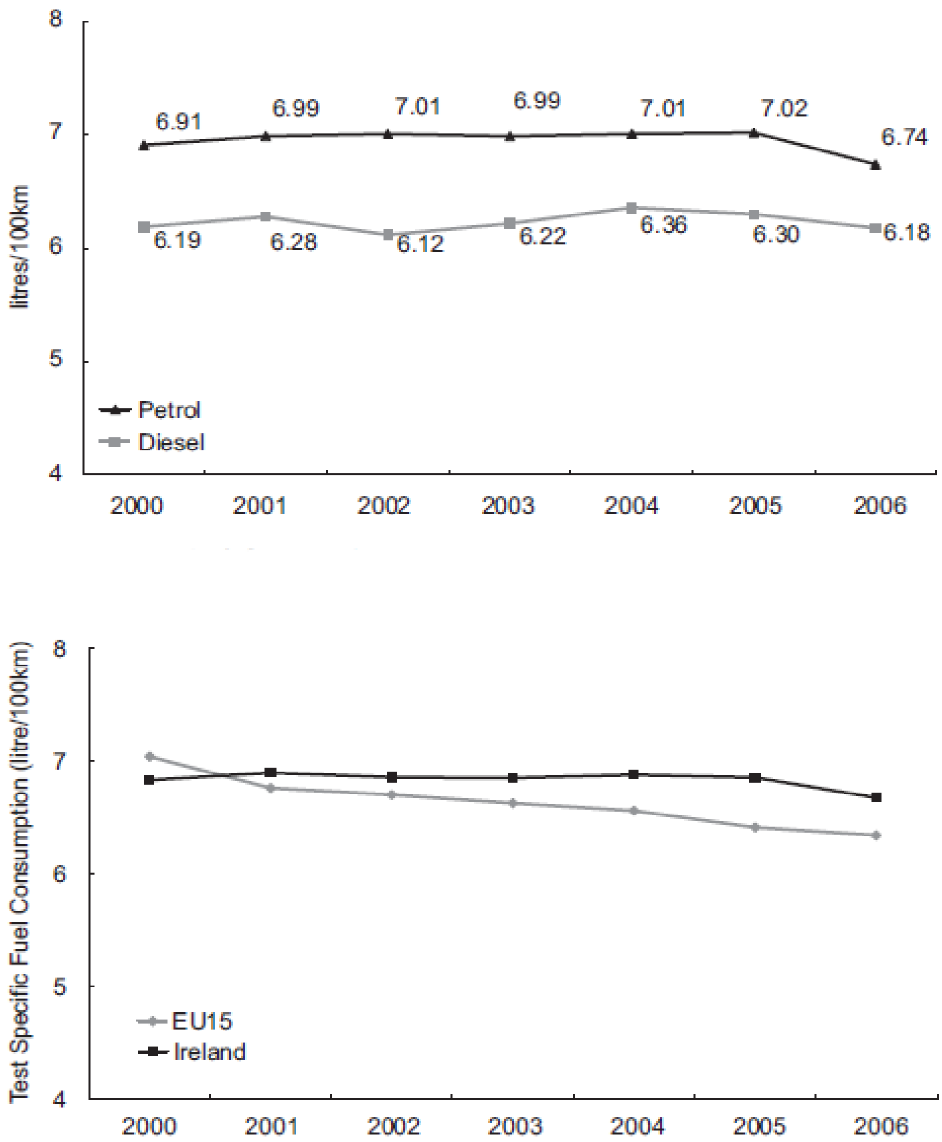


Figure 8. Comparing Ireland and EU-15 specifiic fuel consumption of new cars 2000-2006 (Gallachóir et al., 2009)

Shares of diesel fuelled private cars. Source: Association of European Car Manufacturers (ACEA)

Country	2000 (%)	2007 (%)
Ireland	10	27
UK	14	40
Germany	30	48
France	49	74
Western Europe	32	52

Figure 9. Share of diesel fuelled private cars (Rogan et al., 2011)

Gallachóir et al. (2009) focus on the relationship between the trend towards larger engines and CO_2 reduction targets in Ireland in the period 2000 till 2006 and the introduction of new CO_2 based taxes. Technological development does lower CO_2 emission by improving efficiency, however this reduction is offset by a change in purchasing trend towards larger vehicles. Ireland has set a goal to incentivise purchasing patterns in order to lower emissions by introducing a CO_2 based taxation system starting in 2008. Before the changes taxes used to be related to engine size. Now AMT rates are fixed prices depending on the CO_2 band the vehicle falls in. VRT is set as a percentage of the retail price, and this percentage is variable from 14% to 36% depending on the cars emission band. Results of the policy change are positive; the policy seems to be effective (Gallachóir et al., 2009). The average emission of the new car fleet dropped. However this change was mainly caused by a shift towards more diesel cars, not by a decrease in engine size. However Leinert et al. (2013) researched positive and negative effects of CO_2 reduction and expect a 28% increase of NO_x emission by 2020 because of dieselization.

Figure 10 also shows the high increase of diesel share for Ireland.

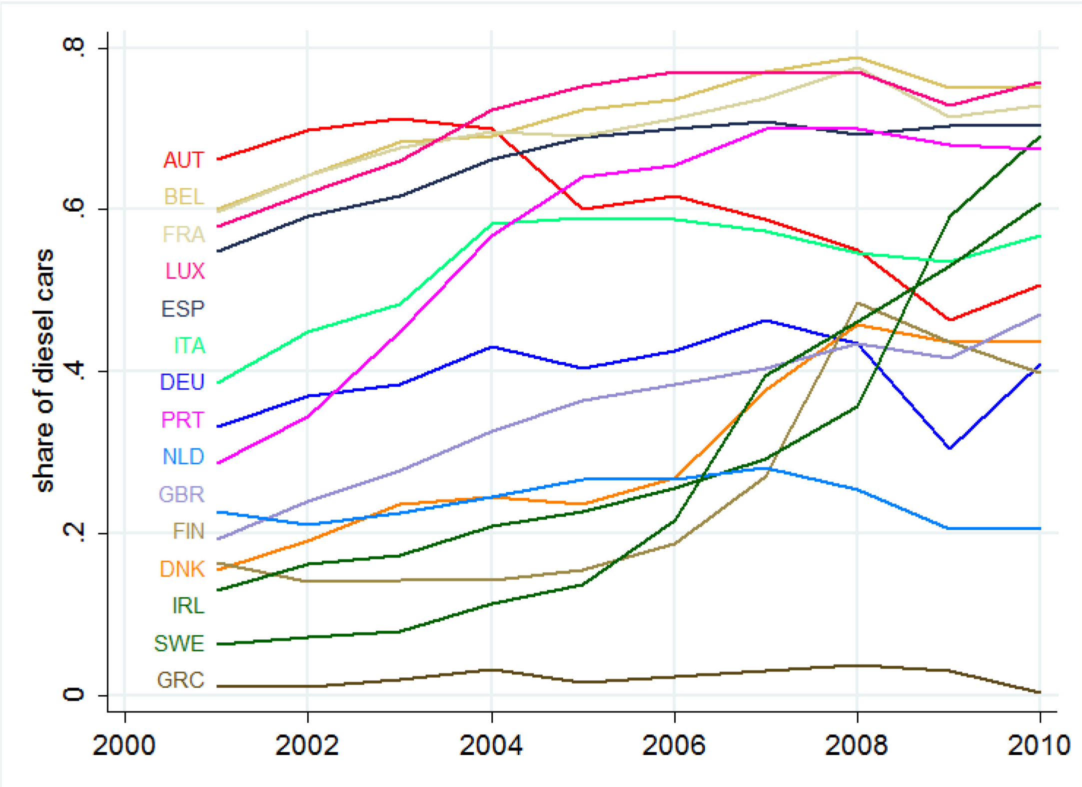


Figure 10. Share of diesel cars in new fleet (Gerlagh et al., 2015)

Next to average emissions of the car, it is also important to look at actual mileage of cars in order to calculate real emissions. It is interesting to mention that according to Gallachóir et al. (2009) cars in the heavier emission bands are used more often, but this is also explainable. For low annual mileage cars the fixed costs of driving are relatively high, so a small low emission car saves a lot on the car owner's budget. However high annual mileage drivers require more comfort etc. and tax is a relatively low expense compared to fuel costs. Additionally it is likely that car users in the high mileage categories are business drivers and costs are not influencing their personal budget directly. The fact that there is a skewed pattern in mileage in the emission bands is important. Only measuring average car fleet emissions based on test values does not reflect real-world emissions.

The study of Gallachóir et al. (2009) also reflects only the new car fleet. However the author also mentions the proportion of the import of second hand vehicles has increased significantly (from 8.1% in 2002 to 24% in 2006). This has a considerable (mostly negative) effect on the average emission of the total car fleet. So it is important to adapt policies in such a way that the total car fleet is influenced. And with policy changes the amount of import should be taken into account. A high rise in import might be an unwanted effect from policy change.

The author also shows a high link between energy use and gross domestic product (GDP) in Ireland (Gallachóir et al., 2009), as also has been found in other countries (e.g. Bosseboeuf et al., 1999; Soytas & Sari, 2003). This means that energy consumption is highly effected by the state of the economy, a factor that should be taken into account in every related study.

Rogan et al. (2011) also focussed on the impact of the introduction of the above mentioned CO_2 based tax policy. The change from Ireland's tax system was from engine size based to a CO_2 based tax system. Rogan et al. (2011) found that a significant reduction in CO_2 emission was realised with this, however at a high costs for the government in terms of tax revenue loss (-33%) in the first year. Though the reduction in emission was not caused by a reduction in engine size but by switching fuel type towards more diesel cars, which was not the intention of the program. Furthermore while the policy change was meant to be budget neutral, this was not realised in practise. This show it is difficult to design tax systems for specific purposes.

Moreover Giblin & McNabola (2009) studied the introduction of CO_2 based taxes in Ireland. They used a discrete choice model in order to analyse possible changes in customer behaviour caused by various AMT and VRT policies. Results show that the planned Irish policy changes reduced the emissions of new petrol and diesel cars by 3.8 and 3.6% respectively. Moreover a rise in diesel car share of 6% is estimated, and the average size of cars drops by 7% for petrol cars and 2% for diesel vehicles (Giblin & McNabola, 2009). Result by Gallachóir et al. (2009), as mentioned above, confirm these expectations. The costs for the government, caused by major tax revenue loss, are €191 million for a reduction of 0.16Mt of CO_2 which in terms of carbon saving is expensive. The results show that the largest part of this reduction is caused by the changes in AMT, which is not in line with other results in other countries (e.g. Klier & Linn, 2012). This will be discussed in 4.3.1. Also the biggest part of the revenue loss will be a result from a drop in VRT, which was less effective according to the model results. Hence a more effective and efficient design of the new schemes might be possible.

Giblin & McNabola (2009) also point out another important issue. Carbon-differentiated vehicle taxes, as we analyse in this study, differ from normal carbon taxes in the sense that a carbon tax is a direct tax on emission. Differentiated systems tax on what class of vehicle is owned, not the particular use of it. Carbon taxes, incorporated in the fuel, could be a more fair ''the polluter pays'' type of policy. However this idea is highly unpopular in public opinion as well as governing parties. E.g. in France the government tried to implement a more direct tax, but it was rejected by constitutional court (d'Haultfoeuille et al. (2014).

Conclusion Ireland

The introduction of CO_2 based tax system in Ireland proved to have a big impact on new car sales however maybe not as intended initially. There has been a major shift towards diesel cars instead of a planned decrease in engine size. Furthermore the observed period shows an increase in second-hand vehicle import which might increase the average emission of the total vehicle fleet. However this is not taken into account when looked at the average emission of the new car fleet, which is what the EU set its goals for. Policy changes might increase import because of different tax rules across Europe. To solve this issue an integrated tax system in Europe is needed. Additionally a high loss in tax revenue by the Irish government was realised, which was also not indented.

4.2.2. Germany, Sweden, and France

Klier & Linn (2012) study the effect of major tax reforms in Germany, Sweden and France on CO_2 emission figures. In 2008 France introduced a program subsidizing or taxing the purchase of new vehicles based on emission heights (so called feebate or bonus/malus program). E.g. the purchase of a car with an emission rate between 120g and 130g gCO_2/km was subsidized with €200,-, while more emitting vehicle purchases were taxed in different emission bands. This program did not replace the old taxation system; it was a supplement to the old taxation system based on vehicle's power. The government of France designed the plan in such a way that it would be budget neutral, however due to an unexpected high response the program cost 225 million in 2008. Slight changes to rates and tax bands were made in order to become budget neutral in 2010.

Germany and Sweden did not tax heavily on the purchase of new registered cars, but focussed taxation on the annual circulation tax. In 2009 Germany changed its old circulation tax system based on engine size to a linear increasing CO_2 emission based system. Sweden introduced a similar system already back in 2006. Moreover Sweden introduced a green car rebate, a subsidy of 10,000 SEK (around €1,300) for vehicles meeting the criteria of emitting less than 120g CO_2/km. This rebate program was used by a large amount of new car owners, costing the Swedish government close to 400 million SEK (€52m) (Klier & Linn, 2012). Both France and Germany also introduced vehicle retirement programs in 2009, offering, under circumstances, between €1,000 up to €2,500 for trading in old cars, in order to stimulate renewal of the car fleet.

For all three countries a statistically significant negative effect is found for the short term relationship between the policy changes and CO_2. So the tax policy changes have resulted in CO_2 reduction. The elasticity for vehicle taxes and vehicle registration emissions in France is -0.417, for Germany -0.322 and Sweden -0.244 (Klier & Linn, 2012). This means that in France the biggest reduction of CO_2 of the car fleet is realised with the policy changes, followed by Germany and Sweden. One of the explanations could be that consumers react heavier on more salient price and tax changes. France has a nonlinear tax system making it more salient to future buyers what the differences are between tax bands, increasing the effect on registrations. Another explanation they suggest is the difference in type of tax system; annual circulation or purchase tax (Klier & Linn, 2012). They suggest that consumers respond more to purchase taxes than to annual circulation taxes possibly caused by the time value of money. However this differs from results by Giblin & McNabola (2009) who claim that AMT has a stronger effect. Thirdly Klier & Linn (2012) argue that consumer preference across countries might simply explain the differences observed. All three explanations are not mutely exclusive and are hard to research.

Furthermore Klier & Linn (2012) researched the effect that tax bonds on cars manufactures produce. One hypothesis is that car manufactures adapt vehicles slightly to fit into a more favourable tax bond. They looked at modifications of cars that were slightly above a tax bond threshold. This is the amount of emission of CO_2 per km where a minor adaption would cause the vehicle to be in another tax bond, having to pay fewer or more taxes. However Klier & Linn (2012) did not find significant results for this hypothesis. A couple of reasons could be given for this. On the short run it is difficult to adapt vehicles because of engineering and registration difficulties. Furthermore on the long run it is difficult for manufacturers to align their products with the policies due to frequent changes. Moreover tax bonds differ per country because no uniform tax system exists. This last possibility could cause manufactures not to profit from slightly lowering emission rates, because that only has effect in a couple of countries. One European tax system would give a higher incentive for manufactures to reduce emission rates (Klier & Linn, 2012).

Conclusion Germany, Sweden and France

France introduced an additional feebate tax system, based on CO_2 emission and designed to be budget neutral. Germany and Sweden traditionally mainly focussed on annual taxation (AMT) based on engine characteristics but both countries replaced the old system with a variant based on CO_2 emission. Also all three countries introduced some form of scrappage scheme. For all three countries a significant negative effect on car registrations was found, however for France this effect was stronger than Germany and Sweden. This might be caused by how consumers react to the design of the tax systems, however also could be caused by different country specific consumer preferences.

Research also focussed on if manufacturers slightly adapt vehicles in order to be categorised beneficially in tax bonds, yet no evidence for this was found. This could be explained by different tax bond thresholds and different tax systems across Europe.

4.2.3. France

d'Haultfoeuille et al. (2014) study the effects of the French bonus/malus policy, as described above, a feebate scheme to reduce CO_2 emission. The feebate scheme was introduced in 2008 in France, and is similar to systems implemented in Austria and parts of Belgium. It was designed in such a way that it aimed at shifting the demand of consumers, and encouraged manufactures to develop lower emitting cars. To realise this last aim the government lowers the bands each two years. The authors use a demand model combined with annual mileage data from a transportation survey. This last data collection is very important. Other studies often only look at average CO_2 values, but do not take into account mileage. This ensures that the results of the modelling are closer to real-world emissions.

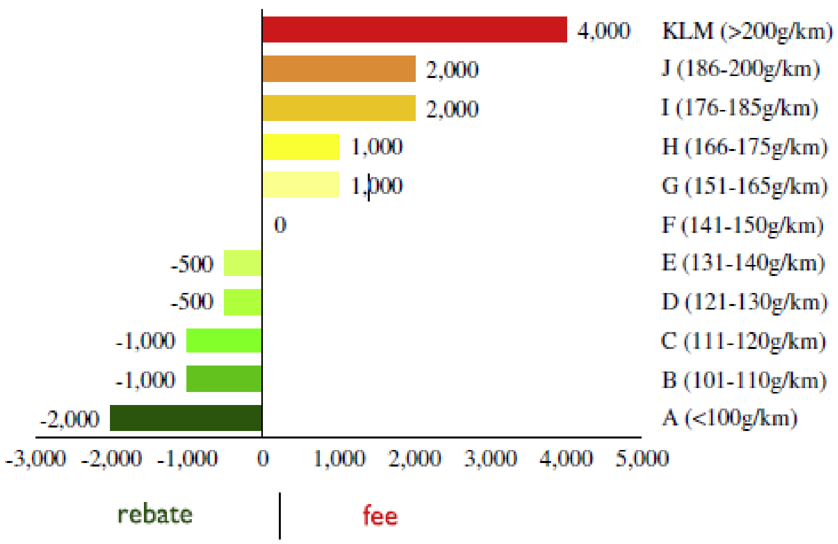


Figure 11 Fees and rebates (in GBP) of the ''medium'' policy ambition feebate scheme (CPT2, as will be described later under 4.2.7) for conventional fossil fuelled cars between 2011 and 2015 (Brand et al., 2013)

The results show that the feebate scheme enhanced the sale of new cars, however no large decrease in average emission was realised. Like mentioned in the previous paragraph the plan was meant to be budget neutral, but the costs turned out to be €285 million in 2008 (d'Haultfoeuille et al., 2014). Although the height of the costs seems to vary among authors, we can conclude the program was a big success in terms of consumer response, however not as intended by the government. A big part of the costs was caused by an increase in car sales, which was not expected, definitely because 2008 was in the period of economic crisis, and fuel prices were very high. The low decrease in average emission could be explained by consumers choosing cars just below certain thresholds, for which evidence is found. Figure 12 shows the vehicles which benefit by the rebates and those affected by a fee. Notice the rise in rebates around 2009, and the drop in fees.

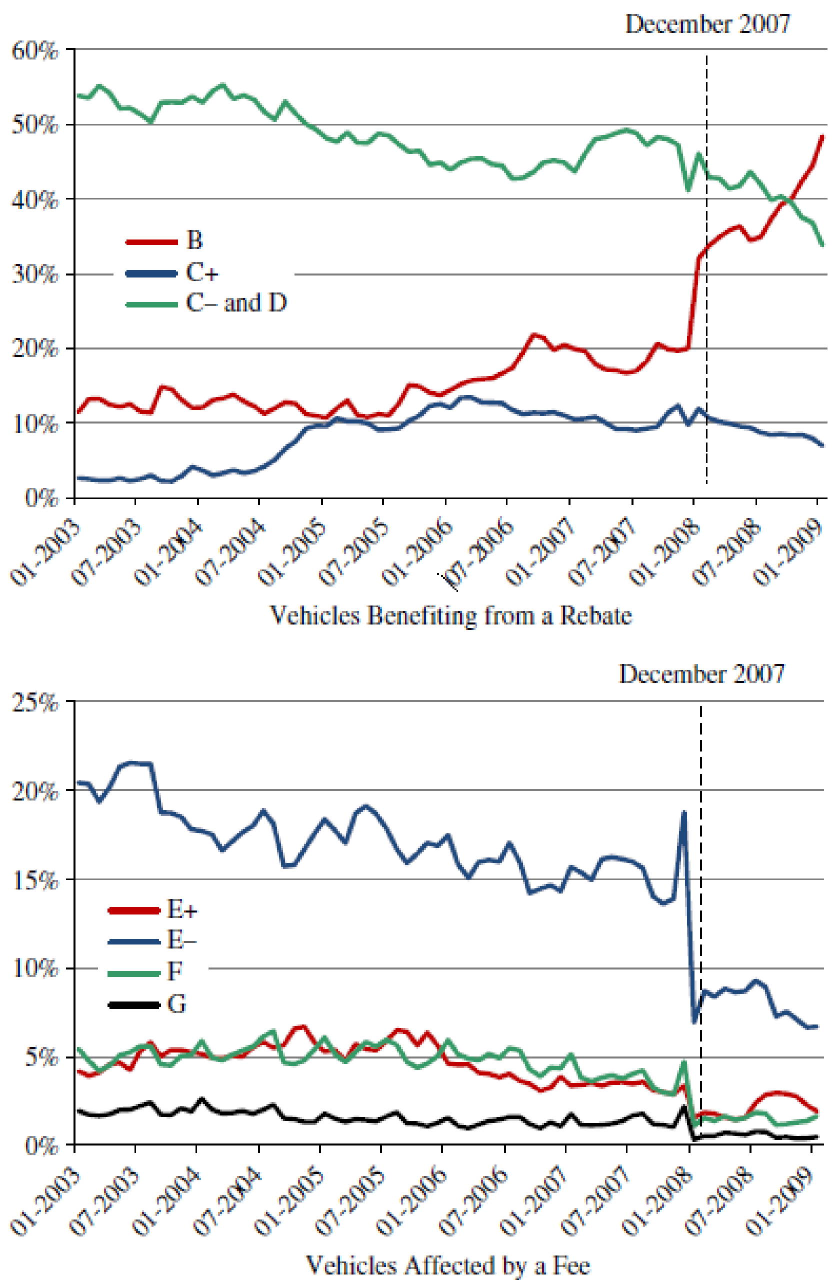


Figure 12. Evolution of the market shares of the different classes of CO2 emissions (d'Haultfoeuille et al., 2014)

From the supply side of the market no changes were found (on the short term), probably because changing car characteristics takes time, and registration cannot be completed within months.

d'Haultfoeuille et al. (2014) conclude that the feebate system had a big impact so the incentive worked, however because of errors in the design it did not result in the planned outcomes. It turns out to be difficult to choose the right thresholds and the pivot point in the bonus/malus scheme. E.g. in the French scheme the system was too generous in rebates and the pivot point between fees and rebates was set wrongly. The system should be designed in a way that the amount of cars sold decreases slightly or stays constant. The problem of designing this kind of tax systems occurs in other countries as well, as we will see later on.

Conclusion France

France introduced a feebate tax system which impacted car sales significantly. The program was designed to be budget neutral but caused a big tax loss in 2008. No large decrease in average emission was realised with the program. This might be caused by design errors in the feebate scheme.

4.2.4. The Netherlands

Kok (2011) studied the impacts of $C0_2$ differentiated tax policies in the Netherlands based on registration data of the Dutch Vehicle registration agency[5] from 2005 till 2010 and found a response of car sales in the Netherlands to price incentives by the government for low emission cars. One of the recommendations of Kok (2011) is to research tax bands and to lower these each year. Without changing tax policy only a short run effect will take place and a lot of tax revenues will be lost.

Kok et al. (2013) mention that the advice is adopted by the government. The study also shows a large anticipating effect by customers. Sales increase heavily just before a tax change and decrease largely just after. Also the difference in tax bands between diesel and petrol cars will decrease. The Netherlands used to tax diesels quite severely in the old system. One question which could arise is if CO_2 is the only emission that has to be looked at. The Netherlands is a small and crowded country so the health risks of diesel cars might be significant. Furthermore Kok et al. (2013) explain that in 2013 the VRT was totally based upon the emission of the vehicle, where e.g. in 2012 the VRT was still partly based on a fixed percentage of the car price (11.1%). This results that in 2012 VRT free cars saved customers more money than in 2013, lowering the benefit effect. Kok et al. (2013) question if taxing in bands is better than a linear system.

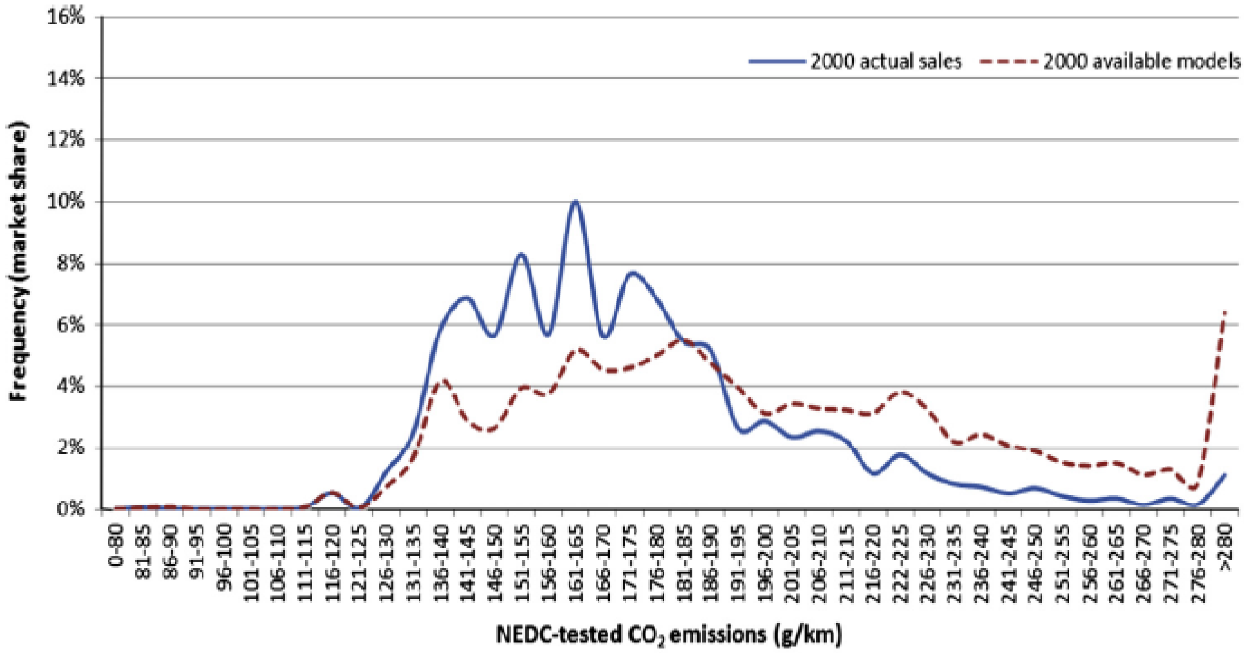
Kok et al. (2011) recommend further research on policies to induce behavioural change, because although incentives seem to have a big impact, the attempted goal is often not met. Furthermore more ex-post evaluation analysis of GHG mitigation in transport should be done. This might give an insight in what type of effects occur because of tax incentives. A couple of ancillary effects that exist in literature on this subject are; rebound and congestion, distortion, composition, fleet size, manufacturing scale and replacement rate effects (Kok et al., 2011; d'Haultfoeuille et al., 2014). The rebound effect occurs when average travel becomes cheaper (e.g. because of fuel efficiency) making it likely that drivers will travel more (d'Haultfoeuille et al., 2014). The congestion effect is the elasticity of traffic congestion with respect to fuel efficiency (Hymel et al., 2010). Distortion effects (e.g. tax-interaction and revenue-recycling) occur because the transport sector involves many

[5] RDW, Rijks Dienst Wegverkeer

distortionary taxes and those might interact with the broader tax system influencing consumer behaviour (Kok et al., 2011). A composition effect is the change in composition of the fleet of a country because of tax changes. The composition can differ on the size of cars, but also on fuel type. The fleet size effect is caused by fluctuation in the amount of cars in a country. Manufacturing scale relates to the supply side. Manufacturers choose what type of cars they produce and sell and so influence the potential car fleet. Replacement rate is the age at which a new car is bought (d'Haultfoeuille et al., 2014). A lot of different potential effects make it really difficult to design tax systems or incentives for a specific purpose.

Kok (2013) researches the effect on CO_2 emission in the Netherlands caused by changing consumer preferences and technological advances by isolating both separate effects. The study uses deterministic analysis to analyze the effect of shifts in car segments and fuel types. Furthermore regression analysis is used to research the effect of shifts within car segments (e.g. same car model but with smaller engine). From 2000 to 2008 a rise in consumer preference (larger cars, engines etc) was found. Although in the years after a slight decline is found. The isolated effect of technological advances is big, between 2000 and 2011 a decline of 59 g/km (from 189 to 130 g/km) could have been realised if all other factors would have stayed constant. However the isolated effect of the change in consumer preferences causes a disruption for the overall effect. The consumer preference effect for gasoline cars rose from 179 g/km in 2000 to 187 g/km in 2007 followed by a small decline towards 183 g/km in 2011. For diesel cars a similar effect has been found (technology caused a drop from 159 to 112 g/km, consumer preference accounted for a rise from 159 to 168 g/km). Noticeable is that the sub sequential decline in CO_2 caused by the customer effect for diesel cars started in 2009, two years later than was the case with gasoline cars, however the decline was stronger. Also it was found that for diesel cars consumer preferences are mainly captured by between segments shifts (change towards a bigger or smaller category car), whereas for gasoline cars between 2000 and 2007 this was both within- and between-segment shifts. But after 2008 for petrol cars this also changed to mainly being influenced by between-segment shifts.

It seems that the announcement of EU regulation in 2007 and the realisation in 2009 has had an acceleration effect on technological advances (Kok, 2013). Moreover the tax system changes, as explained before, have changed consumer behaviour which is also shown by Kok (2013). There are high volumes of cars sold just below the CO_2 thresholds, as we saw earlier in France, showing that customers respond to the tax system changes. Figure 13 shows the difference between 2000 and 2011 of frequency of average emission of vehicles sold. The dotted lines in the bottom figure show the tax thresholds, and peaks just under the thresholds are clearly noticeable.



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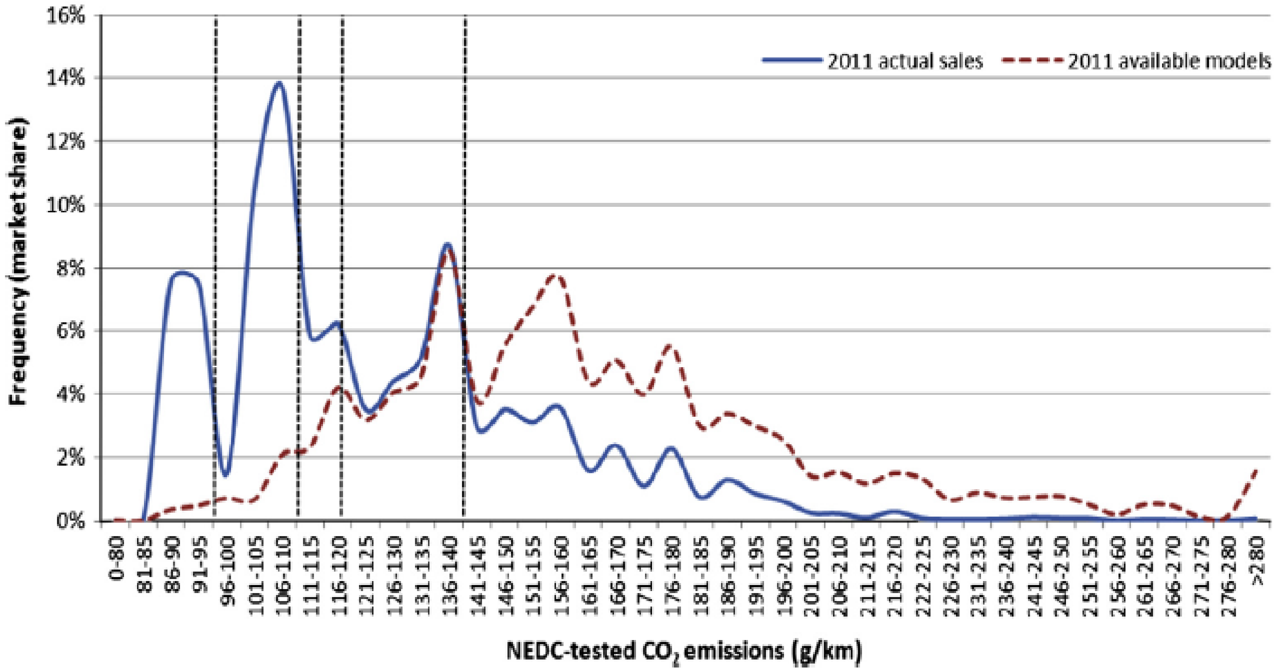

Figure 13. Distribution of available car models and actual sales across CO2-emission classes (Kok, 2013)

Kok (2015) studied the effects of CO_2 based tax reforms on customer purchasing behaviour in the Netherlands. Two scenarios were created; one which extrapolates the trends from 2000-2007, before the tax reforms, into the period 2008-2013; the other scenario is based on trends found elsewhere in Europe. With these two baseline scenarios the researcher can compare the real data with the extrapolated data, and isolate country specific trends in order to check for other trends in Europe. Kok (2015) mentions that car sales by nature fluctuate with economic conditions, GDP patterns, seasonality and like mentioned above the taxation. The study shows that consumers react heavily on tax reform announcements, even when the economy is in a recession.

When looked to average CO_2 emission of the new car fleet, the Netherlands was ranked 12th in Europe, with 164g/km in 2007, above the European average of 159g/km (Kok, 2015). From 2009 onwards the average emission of new cars in the Netherlands decreased rapidly, to under the European average and the Netherlands reached the first place in the lowest emission ranking. There is a big deviation noticeable from the Netherlands and other European countries. However this reduction came with at a high price tag and there are some limitations that decrease the effect (Kok, 2015).

Firstly the biggest effect of the tax incentives can be found in the company cars, private car buyers are less affected. However, as mentioned earlier, more than 50% of the new car fleet vehicles are company cars, and the amount of company cars has been rising for years. So there is still a high impact of the tax incentive. Secondly there is a big gap between type-approval test values, and real-world emission values. With efficiency measurements of the new car fleet those test values are used. This means that the CO_2 reduction effect appears to be higher than actually realised. More about this subject can be found in Chapter 5. Thirdly Kok (2015) studied another important factor in terms of government subsidy effectiveness. Old cars are, at the end of their life, either scrapped or exported. On average, (in 2013) this happens at the age of 17 years (CBS, 2015). However between 40 to 50% of diesel cars get exported before reaching the age of six. This can be explained by the large share of company cars, leasing contracts usually last for about five years. By exporting fuel efficient cars, part of the tax incentive's purpose is exported as well. This is called tax incentive leakage and is clearly not the intention of the government's subsidy. Kok (2015) calculated that about 15% of the CO_2 benefits of the subsidy are diminished with export. However this does not have to be negative since the exported car usually is replaced by a new car entering the fleet, which might be even more efficient. Furthermore exported fuel efficient cars that stay in Europe still lower the average fuel efficiency and CO_2 emission in Europe, just not specifically of the Netherlands in this case. Figure 14 shows the outflow of vehicles in the Netherlands, with a clear peak around 4 years, and after 15 years.

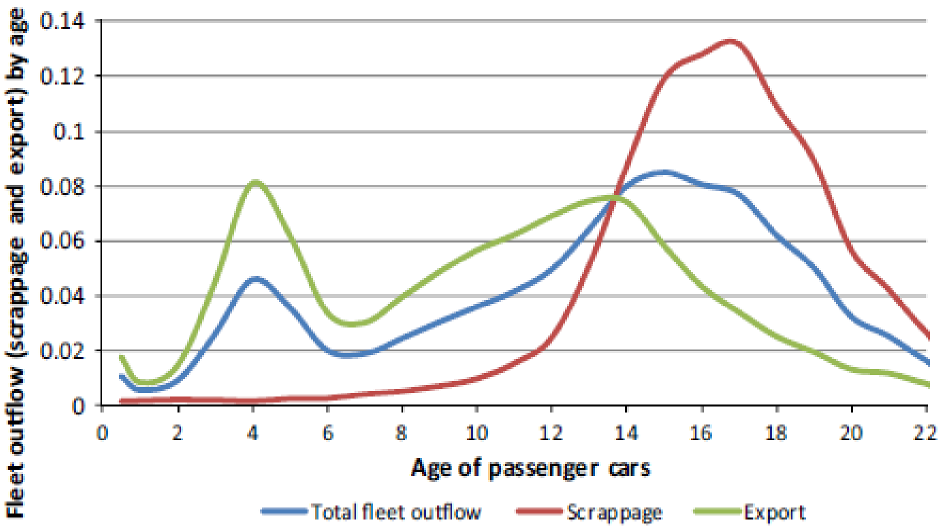

Figure 14. Age distribution of fleet outflow of passenger cars in 2013 in the Netherlands (Kok, 2015)

Kok (2015) calculated that in the period of introduction of the CO_2 based tax system (2008-2013) a total of 4.6 million tons of CO_2 was reduced. However if we take the above limitations into account the real abatement caused by the Dutch tax incentive is 3.5 million tons (which is a reduction of about 3% of the scenario without tax changes) at a cost of 6.4 billion euro lost in tax revenues in the given period. This is a considerably high cost per ton of carbon dioxide avoided. This result is in line with Giblin & McNabola (2009), Rogan et al. (2011) and Hennessy & Tol (2011).`

Figure 15 shows the impact of different factors on the average emission of the new car fleet in the Netherlands.

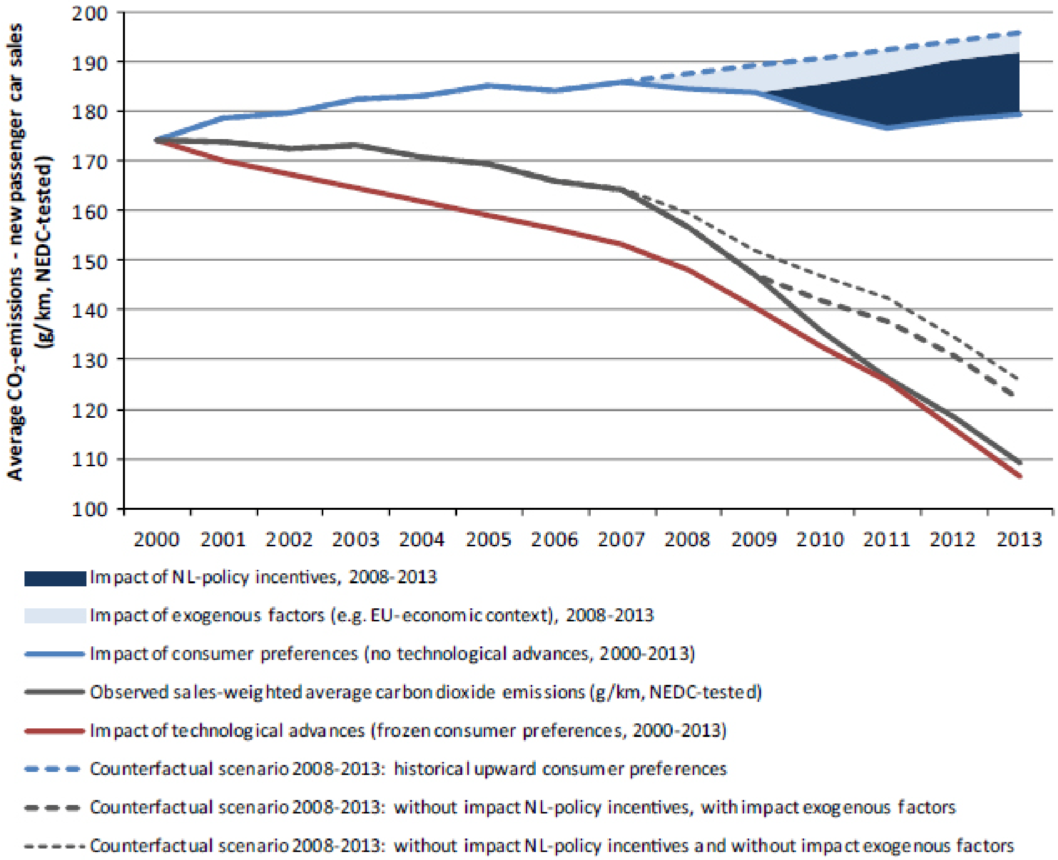

Figure 15. impact of consumer preferences and technological advances on CO2 emissions of new passenger cars sold (Kok, 2015)

Conclusion Netherlands

In the Netherlands a response to price incentives on low carbon vehicles was found. In order to make the program work on the long run, the recommendation of Kok (2011) to lower tax bands was adopted by the Dutch government. The costs for the government are still high, but would have been even higher without further adaption. There is evidence that a lot of cars sold fall just below a CO_2 threshold. Furthermore was found that consumers heavily anticipate on policy changes. The potential decrease in emission caused by technological advances is heavily disrupted by increasing consumer preferences. However from 2008 onwards this seems to have peaked and slowly is declining. From 2008 onwards the Netherlands showed a rapid decrease in average emissions, far above the European average. We can conclude from this that the tax incentives work, however the costs for the government are very high. Moreover a part of the subsidized vehicles is exported towards other countries causing incentives to leak away.

4.2.5. Sweden

Sprei et al. (2008) divided technological advancements by car manufacturers into physical and service attributes. Physical attributes influence fuel use directly; service attributes can be car space, top speed and acceleration specifications. The study concludes that larger sized, fast, and heavy vehicles would have 23% more fuel consumption without the technological improvements. Of which 10% is caused by the size, 8% by faster acceleration and the remaining 5% by the increase in weight. However with the technological improvements (e.g. low air drag and rolling resistance) fuel consumption is reduced with 12.4% between 1985 and 2002. In conclusion, 35% of the technological advances affect the fuel consumption directly; the remaining 65% affect the service attributes and mainly serve comfort and acceleration (Sprei et al., 2008). These results are similar to those found in Ireland (Gallachóir et al., 2009) a large part of potential fuel efficiency gain is disrupted by an increase in consumer preferences.

Conclusion Sweden

Approximately two thirds of the technological advances between 1985 and 2002 have increased service attributes (comfort, acceleration and space) and one third increased fuel efficiency directly.

4.2.6. Czech Republic

Zimmermannova (2012) studied the introduction of a registration fee based on emission in Czech Republic. This countries fee differs from other vehicle registration fees because it also incorporates the registration of used cars. Older cars that come into the country by import are also feed. The fee ranges from €0 for EURO 3 norm emission (or higher) vehicles, to 406 euro for cars meeting no EURO norm. This way older and environment unfriendly vehicles are taxed higher than newer cars which are usually more environmental friendly. The introduction of this policy resulted in a rise of new cars sold, and the registration of used cars dropping significantly. Furthermore a significant negative relation for the fee and emissions was found. This study does not take into account the amount of km's driven, so actual emission abatement cannot be calculated from this data. Important is to realise that the car fleet of the Czech Republic was on average significantly older than the average car fleet in Europe. In 2008 the average Czech car was 13.82 years old, while in EU15 this is only 7 to 8 years (Zimmermannova, 2012). So in the country of focus of this research a lot of CO_2 reduction can be gained by renewing the car fleet.

One important step for the government is to update the fee rates and parameters; otherwise the effect will decrease within years because newer generation imported cars will meet EURO norms. Kok (2011) recommended the government of the Netherlands similar adjustments to the tax bands as mentioned in the paragraph 4.2.5 about the Netherlands.

Conclusion Czech Republic

The Czech Republic introduced a registration fee based on the EURO norms of cars, both for new and second-hand vehicles. The countries car fleet composition differs from other EU countries mainly in age of the fleet. A negative relation between the introduction of the fee and emission was found.

4.2.7. UK

Brand et al. (2013) aim to fill the gap in assessment of environmental effects of car pricing and taxation instruments. Scenarios, created with real data and assumptions, are used in order to research which policy instruments accelerate fuel efficiency, technology and purchasing behaviour transitions in the UK, in a way that is most environmental friendly, budget neutral and has no adverse effect on car ownership and use.

Brand et al. (2013) explain there are two types of fiscal policies affecting vehicles; taxes affecting (1) vehicle ownership and those that affect the (2) use. Examples of the first are purchase taxes, feebates, scrappage subsidies and circulation taxes. The second type are e.g. distance based charges[6], fuel taxes, and carbon taxation. Brand et al.'s (2013) research focuses on the first type of policies which are also the type of taxes researched in this study.

Brand et al. (2013) created nine different scenarios, a mix of politically feasibility (low, medium, or high) and different tax policies and incentives; (1) purchase tax / feebates, (2) scrappage scheme, and (3) vehicle excise duties. Earlier work resulted in a UK Transport Carbon model (UKTCM) (Brand, 2010; Brand et al., 2012), which can be used to predict fuel demands and carbon emissions in the UK. The model in combination with the above depicted scenarios, which include real-life data and assumptions, resulted in several future outcomes. The scenarios are depicted in figure 16, as retrieved from Brand et al. (2013).

Policies	Policy ambition		
	'Low'	'Medium'	'High'
Purchase tax/ feebate	**CPT1** – simple tax of GBP2000 for new cars with $CO_2 > 225$ g/km, tightening every 5 years by one CO_2 band ***CPT1a**: variant with tighter limit of $CO_2 > 175$ g/km*	**CPT2** – feebate graded by fuel type and CO_2, tightening over time: (a) CO_2-graded tax up to GBP4000 (>200 g/km) (b) rebate up to GBP2000 (<100 g/km) (c) 50% tax discount for alternative fuels ***CPT2a**: higher top rebate of GBP4000* *CPT2b: higher top rebate of GBP3000; GBP0.06/ kWh electric fuel duty*	**CPT3** – feebate graded by fuel type and CO_2, tightening over time: (a) CO_2-graded tax up to GBP8000 (>200 g/km) (b) rebate up to GBP4000 (<100 g/km) (c) 50% tax discount for alternative fuels ***CPT3a**: GBP0.06/kWh electric fuel duty*
Vehicle excise duty/ road tax	**VED1** – road tax graded by fuel type, CO_2 rating and year of first registration (first year tax is higher)	**VED2** – as VED1 but tightening of CO_2 limits over time	**VED3** – as VED2 but with double duty rates
Scrappage rebate	**SCR1**: simple, threshold-based rebate of GBP2000, 2009–2010 only (SMMT, 2010)	**SCR2**: simple, threshold-based rebate of GBP2000, 2011–2050, tightening by CO_2 limits over time ***SCR2a**: variant assuming lower expected car life*	**SCR3**: rebate of up to GBP2000 graded by CO_2, 2011–2050, tightening by CO_2 limits over time

Note: normal typeface denotes core policy scenario; italic typeface denotes variant/sensitivity scenario.

Figure 16. Policy scenario's as used in Brand et al. (2013).

The results show that car purchase taxes and feebate policies cause the amount of cars bought to drop by 6% (Brant et al., 2013). Furthermore scrappage schemes cause the opposite effect, 18% more new cars are purchased (Brant et al., 2013). However, just like in the real-world, the scenario models showed a short-term rise of about 500,000 cars, but a similar drop just after the temporary scheme period. Feebate and high VED schemes showed to have the highest effect on reducing the average CO_2 intensity in the UK. The scenario's show a high increase in diesel car share, and a large rise in BEV's and PHEV's. By 2020 between one and eight percent of new vehicles would be electric, in 2030 33% and by 2050 it would rise to 69%. In the reference case this would have been 6% and 13% in 2030 and 2050 (Brand et al, 2013). In the reference case the average CO_2 intensity decreases

[6] Kilometerheffing in Dutch

throughout the years, but the feebate and VED policies mentioned above could accelerate this decline remarkably. Table 5 shows the percentage of cars below 80gCO_2/km derived from Brand et al (2013) and the effect is significant. Furthermore the overall GHG reduction is estimated, since CO_2 is not the only important emission factor.

	2020	2030	2050
Reference	2%	8%	15%
High VED and feebate	7%	21%	42%
CO_2 reduction	10%	21%	49%
GHG reduction cf. baseline	Up to 7.7%	n/a	Up to 20.2%

Table 5: percentage of cars below 80gCO2/km

Also remarkably, the scrappage schemes show to have little to no effect, or even a small negative effect, on the total GHG reduction in the scenarios (Brand et al., 2013). This is even the case for scrappage programs in the medium and high policy ambition which take into account a lowered CO_2 threshold over time. Moreover the results show that car ownership and use vary between -3% and 3% of the reference case, which expects a 27% increase in car use between 2010 and 2050 (Brand et al., 2013). The intention in the scenarios was not to affect car use. Average costs of using vehicles decreases with scrappage schemes and so an increase in car use is expected. From this we can conclude that scrappage schemes might not be the best way to decrease emission and in practise they might only subsidize the car manufacturer industry by driving up sales of new cars.

For tax revenue purpose the VED scheme seems most suitable because this system resulted in annual income in all cases and a loss for the government is impossible. Although, like we have seen in other cases, it's crucial to tighten the CO_2 limits over time. Otherwise too much cars will fall in low categories and technology catches up with taxation limits, which causes a high decrease in tax revenues without further emission savings.

The car purchase and feebate policy show to have the highest effect in lowering CO_2 and comply with the before mentioned preferences (accelerate low carbon technology uptake, reduce GHG emissions, no interruption of car use, and budget neutrality). However it is important to emphasize that the design of the program is really important and makes the difference. The registration and feebate systems seem to have a high impact because those transactions take place upfront rather than annual taxation. Consumers seem to react more to upfront price signals than to future costs (see Gross et al., 2009).

Generally the results of Brand et al. (2013) are in line with other research. On short term a shift towards diesel cars is found (like Ryan et al., 2009; Rogan et al., 2011; Gallachóir et al., 2009). Furthermore results from the US show similar effects of purchase rebates, they are not very effective and inefficient (Ross Morrow et al., 2010). Also results in France showed that a feebate program could lower emission values of the new car fleet to one of the lowest in the EU, however design is crucial as we saw in other countries (Giblin & McNabola, 2009; Rogan et al., 2011; Schipper et al., 2011; Zimmermanova, 2012; Brant et al., 2013; d'Haultfoeuille et al., 2014).

As Brand et al. (2013) mention a difference is found with the study performed by Ryan et al. (2009) as mentioned before. That study concluded that registration taxes do not have a large impact on the CO_2 intensity of the new car fleet. However Brand et al. (2013) conclude that a feebate program, which is a form of registration tax, has one of the highest impacts. This can be caused by different factors, circumstances (e.g. country specific factors) or differences in research methods but is noteworthy. Also the study shows that the potential rebound effects, people driving more because of lower average car user costs, are not that likely to cause a big disruption (Brand et al., 2013). However this is very depending on how fuel prices and real income of the population evolves, the assumptions made by the author.

Conclusion United Kingdom

Brand et al., (2013) created scenarios in order to research potential effects of tax policy changes in the UK. They found that registration tax and feebate policies have the highest potential effect on CO_2 reduction, within the set preferences. However design of the schemes is crucial. Scrappage schemes show to have little, no or even a negative effect on carbon emission reduction even when based on a tightening CO_2 limit over time.

4.2.8. Switzerland

De Haan et al. (2007) researched rebound effect and possible effect of tax rebates in Switzerland. They used data received from a survey in 2004 among all 2nd generation Toyota Prius owners in Switzerland (367 buyers). De Haan et al. (2007) analysed the existence of potential rebound effects of the hybrid car purchase; a potential increase in car size and the increase in vehicle ownership. The first could be a result from lower costs per km driven so car owners can drive larger and/or stronger cars. The second potential effect is an increase in vehicle ownership; people without a car buying a hybrid vehicle instead of people replacing an old petrol or diesel car. There are no results found for both potential rebound effects in Switzerland. Furthermore de Haan et al. (2007) conclude that tax incentives in form of a rebate have effect. The low fuel consumption of hybrid vehicles does not cause consumers to switch towards larger cars, and does not cause additional car ownership. A tax incentive of this sort is only effective when those conditions stay constant. Otherwise governments would stimulate the wrong factors. Lastly de Haan et al. (2007) conclude that hybrid vehicles are suited to play a role in tax schemes that target CO_2 reduction of the car fleet.

Conclusion Switzerland

In Switzerland no rebound effects were detected for tax rebates on hybrid vehicles. Incentives for hybrid vehicles seem to be an effective way to reduce CO_2 emission.

4.2.9. Denmark

In Denmark the registration taxes are very high. Because of this a large rebate for alternative-fuel vehicles (AFVs) can be given by the government without actually subsidising. Mabit & Fosgerau (2011) research the demand for AFVs in Denmark with a stated choice survey among new-car buyers (2146 respondents) and by applying a mixed logit model. They find that government incentives have a high impact on the amount of AFVs that are bought. The price (registration and annual) is important, but simulations show also that the range of electric cars seems to have a high impact on the share of AFVs. A 100km range increase, among a minor financial incentive would increase the share of electric vehicles significantly.

Conclusion Denmark

Denmark has high registration taxes and this makes it possible to use rebates without the government having to spent extra money. E.g. AFVs can be promoted by reducing the registration tax for those types of vehicles. This could potentially also work for low emission fossil fuelled vehicles, but more research is needed on that topic.

4.3. Europe, US or not country related

There are also some relevant studies which are not country specific or aimed at the whole of Europe or the USA. Even though the focus of this study is Europe, the car manufacturing industry is worldwide, so it is interesting to broaden the scope. First some literature about the EU15 (first 15 EU countries) and Europe is discussed. Secondly studies in the USA will be addressed. And lastly Cost-Effectiveness Analysis (CEA) will be debated. This is of interest because it describes different methods of how to measure emissions, and the potential deviation these different methods might cause. This is important because those measures are used to design tax systems, and different methods might cause different outcomes.

4.3.1. EU 15

Gerlagh et al. (2015) distinguish five categories of reasons why emission intensity decreases and categorised those in five pillars which party correspond (the first three) with pillars of the European commission (European Commission, 2011). The first category, and the first EC pillar, is aimed at pressuring manufactures to produce more fuel efficient cars. The second category is aimed at consumers; more information on fuel efficiency has to be made available in order to make consumers aware of their car choice. The third pillar is fiscal policies and related to national taxes on vehicles (registration and road taxes). The idea is that those pillars reinforce each other. More awareness, and high car ownership costs in case of environment unfriendly cars, makes customers demand cleaner cars from manufacturers. The other two categories that are added by Gerlagh et al. (2015) are fuel taxes, and income and economic conditions. Fuel taxes, and country welfare, differ significantly between countries in the EU, and are likely to have an impact on the car fleet and consumer behaviour.

The study of Gerlagh et al. (2015) focuses mainly on the third pillar, so to what extent fiscal policies have contributed to decarbonisation of new fleet vehicles.

From literature Gerlagh et al. (2015) depict that fiscal policies are good instruments to change car purchasing behaviour. Furthermore they state that taxing the purchase of a vehicle is more effective than annual taxes. This can be explained by near-sightedness or short term costs being more important for customers. This however is not in line with what is stated by Giblin & McNabola (2009) (as under Paragraph 4.2.1).

Moreover it is stated that tax reforms can result in fuel switching behaviour. Instead of customers switching to smaller more efficient petrol cars, more diesels were sold. This resulted in the planned decrease in CO_2, however, as Leinert et al. (2013) mention this also resulted in a raise in other GHG's e.g. NO_x linked to severe health risks. This last unforeseen circumstance is one of the bad results from policy changes, however the most focus goes towards CO_2. Governments should take secondary effects into account; otherwise changing tax policies might be an expensive way to substitute one emission problem for another.

Gerlagh et al. (2015) show that decreasing overall taxes on diesel powered cars result in a higher diesel car share of the total fleet. However this also causes existing diesel drivers to switch towards bigger and more polluting models. A CO_2 sensitive tax system switches the favours of consumers towards small diesel cars and raises the diesel share, reducing the overall CO_2 intensity of the car fleet. These results are in line with Ryan et al. (2009). But again other risks might be involved.

The study also mentions a drawback from having more fuel efficient cars, which is called the rebound effect (Gerlagh et al., 2015). Smaller and more efficient cars reduce the costs of driving, which might cause an increase in car travel. Although the average CO_2 intensity is lower, when looking to the absolute emission the gain might not be. Next to the efficiency side of the rebound effect there are several other problems that can arise from more travel e.g. traffic jams, parking space problems etc. However as Kok (2015) mentions the real rebound effect will be much smaller than the potential rebound effect, because the real-world fuel consumption is much higher than the NEDC type approval values make us believe. The tax system is based on test values, but the driving behaviour of the car owner is only influenced by the real consumption. This makes the rebound effect less strong. Gerlagh et al. (2015) furthermore mention that fuel taxes might be the most direct way to target CO_2 emission, because driving causes pollution, not ownership. Taxing on fuel will result in more efficient cars in the fleet, without the rebound effect.

Conclusion EU15

Gerlagh et al. (2015) conclude that purchases taxes are more effective as annual circulation taxes, and that taxes are good incentives to change consumer behaviour. Furthermore tax changes can cause fuel switching (mainly from petrol to diesel), which lowers average CO_2, however might also cause more health related problems. Moreover the study shows that the real rebound effects are not as strong as the potential effect, but to eliminate rebound effects fuel taxes are needed.

4.3.2. Europe

Fontaras & Samaras (2010) try to estimate the future characteristics of the average European passenger car in a way to reach the CO_2 level set by the European Commission. They identified the most important characteristics affecting fuel consumption. Next they made simulation for six different vehicles which are common in Europe. Analysis showed that reductions in weight and tyre rolling resistance, and a better engine efficiency is needed to even reach the 2008 target of <140 gCO_2/km. The current reduction of CO2 intensity is a result of improvement of efficiency of the engines, a shift towards diesels with improved efficiency and the promotion of smaller vehicles. Fontaras & Samaras (2010) estimated a 10% decrease in average weight, 10% increase in aerodynamics, a 20% reduction in tyre resistance and a 7.5% increase in power train efficiency is needed to meet the 2008 target. Further targets seem to be difficult to receive, and big additional technological improvements seem to be necessary.

Mehlin et al. (2004) wrote a very detailed report for the European Commission to assess and identify reasons for CO_2 reduction of the new fleet cars between 1995 and 2003. Although this is before the period of introduction of the CO_2 based tax systems this kind reports have been used to set those new policies. Mehlin et al. (2004) analysed whether carbon reduction during that period was caused by manufacturers (technological advances or changes in products) or by other changing conditions (e.g. consumer behaviour). They used three different methods; one descriptive and two econometric analyses. One of the econometric analyses was based on technological influences, the other on non-technological influences like vehicle taxes in member states.

During the period of research a lot of significant improvements have been made to engines efficiency especially in diesel engines. Petrol fuelled cars gained, depending on what class vehicle, between 17.6% and 19.9% of efficiency and diesel cars between 20.6% and 35.5% (Mehlin et al., 2004).

Similar to all other studies in this paper the increase in diesel share showed to have the highest effect on CO_2 reduction. Furthermore Mehlin et al. (2004) found that consumers were highly affected by the model range offered by manufacturers and a trend towards higher powered diesels was caused because consumers wanted similar drivability as petrol powered cars. Moreover the authors conclude that the labelling system, as described in Chapter 3, does not contribute to the reduction of CO_2. One factor that has a negative effect on CO_2 reduction is caused by the increased safety requirements. They show to have caused an increase of 2.4g/km because of added weight.

Furthermore they found that the main non-technological influences are GDP per capita, fuel prices, and annual circulation taxes. This is similar to some results we found earlier and different from other studies. It could be that VRT became a more important influence after the period of focus in this research, because newer studies show that VRT has the greatest affect.

For petrol cars a rise in GDP of 17% (20700 to 24200 euro) causes an average CO_2 rise of approximately 2.5 g/km, a reduction of average car taxes (from 170 to 124 euro in 2002) would cause a rise of +-1.4 g/km average, rising fuel prices (0.77 to 0.79) does not result in a big difference in CO_2. The last part might be explained by that fuel prices mainly affect small cars, since the higher class car owners are usually wealthier and less affected by fuel price changes. For diesel cars the same rise in GDP causes a smaller decrease of 1g/km average, probably because diesel cars are generally more expensive so more people can afford one. Fuel price (0.62 to 0.67 euro) causes a small reduction for diesel cars, probably because of lower average mileage. A circulation tax increase (146 to 243 euro) lowers the average emissions by 2.17g/km (Mehlin et al., 2004). From the data used Mehlin et al. (2004) conclude that the main cause for average CO_2 reduction of the car fleet is caused by technological advances, and not non-technological factors.

Conclusion Europe

Research by Fontaras & Samaras (2010) shows that considerable technological improvements are needed in order to reach the average CO_2 emission levels as set by the European Commission. Mehlin et al. (2004) showed that in the past the main drivers of CO_2 reduction have been these technological advances.

4.3.3. USA

Although not in Europe, results from the USA are interesting because of similar CO_2 reduction goals. The car market and use of vehicles in the USA is different than in Europe but this contrast might make it possible to find overlapping factors, like technological advancements worldwide.

Knittel (2011) researched the technological progress in the automobile industry from 1980, and focussed on the trade-offs faced between economy, weight and engine characteristics. Knittel (2011) found that in the US between 1980 and 2004 there was a big shift towards bigger cars, mainly small trucks, where a rise from 20% to 51% of all passenger vehicles sold was realised. Average power increased by 99% and weight by 26%. Estimates are that if power and weight would have held constant fuel economy could have increased by 60 % (Knittel, 2011). In real life only a 15% increase was realised. Downsizing of passenger cars is needed in order to meet requirements set in the

Obama standards. These results are similar to Europe, e.g. Ireland, where also increase in size and power offset potential CO_2 reduction.

4.3.4. Cost-effectiveness analysis (CEA)

Furthermore Kok et al. (2011) reviewed 33 selected studies about methodological issues causing variation in Cost-Effectiveness Analysis (CEA) of carbon emission abatement. This is relevant because policy discussions are based on costs and how effective the changes will be. The article aims to answer three questions; ''what are the key methodological differences in cost-effectiveness analysis for transport GHG mitigation?''; ''what is the potential impact of the choice of method on the resulting estimates of cost-effectiveness?''; ''How could the future practise of CEA be improved?'' (Kok et al., 2011). CEA can be horizontally and vertically measured. Horizontal CEA refers to two subjects of research (e.g. an electric and a hybrid car) compared with one method and set of assumptions. Vertical CEA compares the same measure, however by using different methodological approaches and assumptions.

Fourteen methodological issues are clustered into six identified groups. Kok et al. (2011) found that differences in results are caused by different or non-stated choices and assumptions making it hard to compare the different studies. This makes it impossible to perform well defined vertical analysis which can result in misinterpretations, confusion and misinformed decision making (Kok et al. (2011), which in turn can create conflicting policies across nations. Kok et al. (2011) estimate, based on the 33 reviews, differences per method can result in differences of 400 $ per ton CO_2 equivalent. Furthermore Kok et al. (2011) conclude that by indicating the specific purpose of CEA and pointing out its strengths and limitations the practise of using CEA in policy decisions could be improved. Now overviews of transport GHG mitigation, containing mixed measures, are used by policy makers which might result in arbitrary outcomes. Lastly Kok et al. (2011) introduce ways of making the use of CEA clearer, mention limitations of approaches, and underline that correct CEA will become even more important. The last mentioned is because more and more alternatives are found for petrol and diesel fuelled cars and these alternatives need to be compared to old means of transport and somehow be integrated in the existing tax systems. Because those alternatives fuelled cars have less direct CO_2 emission, but likely more indirect, it is important to measure the complete output of GHG's, to make a genuine comparison. Also Kok et al. (2011) mention the difference between real outputs and test-values, a subject we will treat in the next chapter. Having a more correct CEA framework might reduce differences in CEA outcomes and make it easier to compare potential policy changes.

Conclusion Cost-effectiveness analysis

There are different ways of calculating CEA and methods results in differences up to $400 per ton CO_2-eq. This might result in wrongfully drawn conclusions for policy making.

4.4. Summary chapter 4

The next table will summarize the gradation of importance of tax systems per country as found in the discussed literature. The table might not be conclusive. A ++ refers to a high focus on that particular tax type. The signs cannot be compared between countries (e.g. a ++ in Netherlands is not necessarily stronger than a + in Germany).

Country	VRT	AMT	Rebate	Feebate	CCT	Scrappage
Belgium		++				
Czech republic	++*					
Denmark	++		++			
France	++			++		+
Germany		++				+
Ireland	++	+				
Italy		++				+
Netherlands	++	++		+	++	
Portugal	++					
Sweden		++	+			
Switzerland			++			
UK		++				+

*also for second hand market

Table 6. Summary of focus of tax systems in Europe retrieved from discussed literature

5. Critique on regulations

In this chapter some critiques on the European Commission regulations will be discussed. Bampatsou & Zervas (2011) argue that there are four major concerns with the introduction of the regulations by the European Commission. The first is that the maximum values set for average emission of cars sold by manufacturers are average values over the entire product range. A higher emitting car can be compensated by a lower than average one. This in principal is not an issue; however manufacturers can group different brands and the regulation allows compensating in the total group. For example the Volkswagen Group consists of 8 passenger car brands, and low emitting VW UPs compensate for high emitting Audis. Moreover regulations state that brands with sales lower than 10.000 vehicles a year are excluded from the CO_2 limit regulations. This makes it possible that wealthy consumers e.g. the owners of Ferrari, Bugatti and Lamborghini (last two are part of the VW group) can drive cars with higher emissions than allowed which is unfair. ''This is not an acceptable ethical point of view, as the ''polluter-pays'' principle becomes ''someone who can pay, can pollute'' principle'' (Bampatsou & Zervas, 2011). Figure 17 shows the average CO_2 emission of vehicles by brand in 2008.

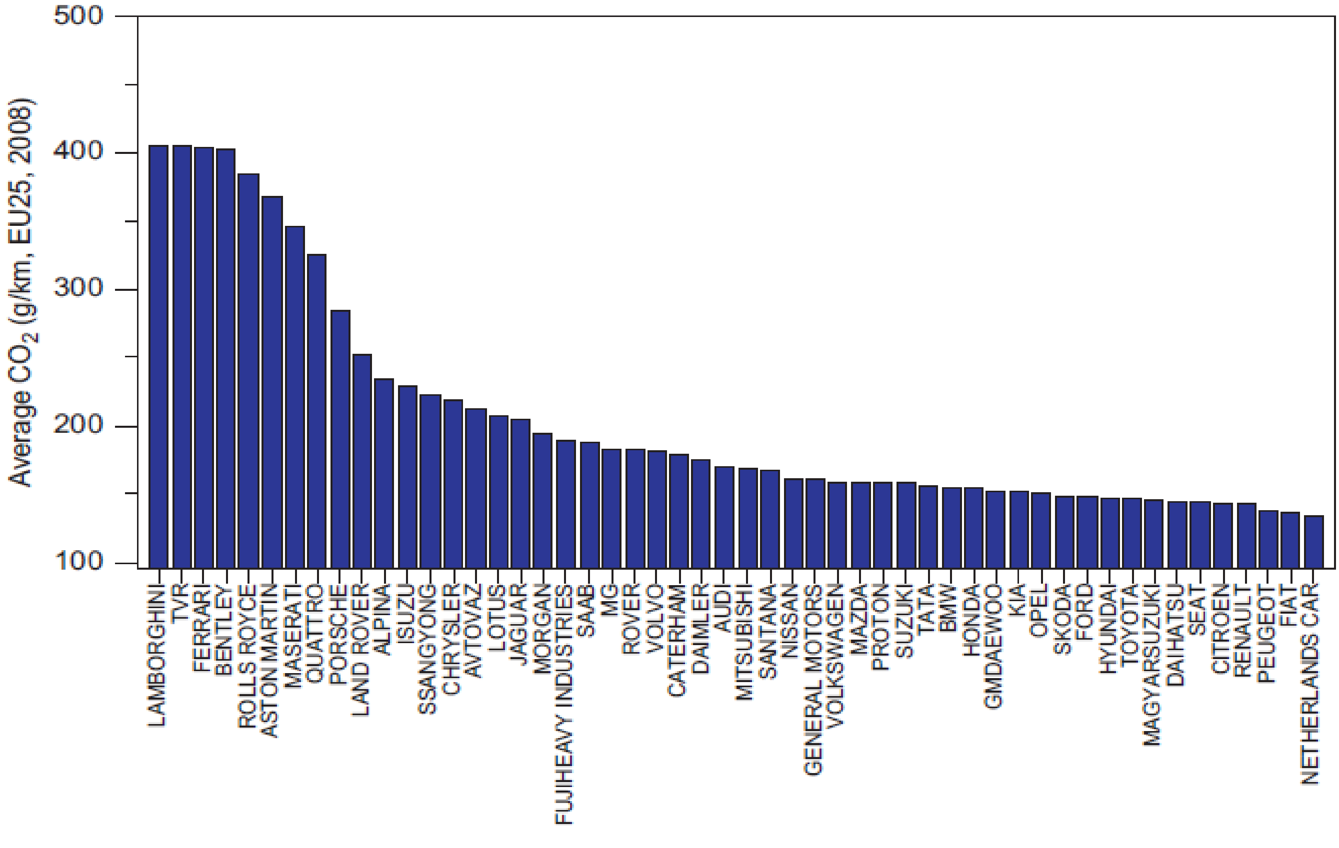

Figure 17. Avarage CO2 emissions in 2008 of new PCs for each firm of the European Market (Bampatsou & Zervas, 2011)

Another issue is that mileage is not taken into account. However results by Bampatsou & Zervas (2011) show that the higher class, generally more polluting vehicles, have higher average mileage than the lowest category of emitting cars. This way low mileage low emitting cars compensate for high mileage high emitting cars, which is not as intended by the regulations.

Thirdly a penalty is set on manufacturers exceeding the limit (€95 euro per CO_2g/km) which in practise will be paid by the consumer. Again this gives wealthy people the possibility to emit more than the limit (Bampatsou & Zervas, 2011).

Fourthly the target of 95g/km by 2020 does not seem reasonable when looked to the progress made in the last decades which we already saw in chapter 4 (Bampatsou & Zervas, 2011).

6. Test results

This chapter will discuss test results as used by all authors of literature on car taxes, governments and regulations. The aim of this chapter is to shown the issues with these values, and that they must be used with certain care. It is important to realise more than only CO_2 is measured, and especially a rise in NO_x for diesels is an important side effect of CO_2 reduction.

The Emission values which are used by manufactures and governments are based on New European Driving Cycle (NEDC) test results in the EU, Environment protection agency (EPA) and California Air Resources Board (CARB) testing in the USA, and Ministry of the Environment's (MOE) New Post Long-Term Standards testing in Japan (Delphi, n.d. ; Engeljehringer, 2014). Gallachóir et al. (2009) sum up the history of NEDC testing, which started in 1980. They conclude that during the years several versions of testing were introduced, each time an improved version with more test cycles. Those tests are performed under laboratory conditions in order to get comparable results. Figure 18 shows the New European Driving Cycle scheme.

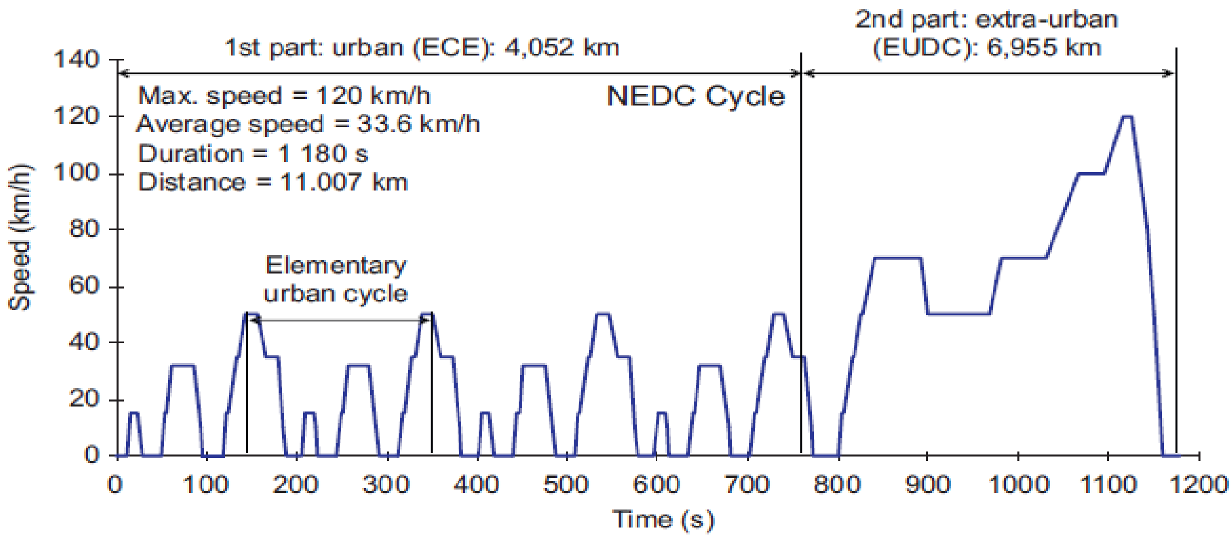

Figure 18. New European Driving Cycle (Bampatsou & Zervas, 2011)

However Merkisz et al. (2010) researched the correlation between NEDC test results and real road testing and found significant differences between test and real-road results. There are certain flexibilities in the procedures that can cause lower emission values without technological improvements (Kadijk et al., 2012). The report of Kadijk et al. (2012) sums up the flexibilities and the potential effect on different emission types. Car manufacturers adapt vehicles for testing by e.g. reducing weight by removing parts like the radio; decreasing drag by taping of the grill, and removing side mirrors; and reduce resistance by using special lubricants and riding low profile highly pressured tyres filled with special gas. Furthermore test temperatures are optimal and transmission shifting is perfected, all not realistic in real-world situations. However all of this can be performed legal as long as the manufacturers stay within the boundaries of the regulations. Moreover Kadijk et al. (2012) mention that the importance of utilizing those flexibilities has become more important, because of the stricter emissions regulations and heavily relying tax systems. The study estimates that the potential reduction in emission caused by the flexibilities between 2002 and 2010 is around 11% with a margin of 5% (Kadijk et al., 2012).

Pelkmans and Debal (2006) found similar results and concluded that manufacturers only have to focus on limited operation zones of the vehicles in order to meet the standards and real road results may be up to 10 times higher on certain emission values.

Gerlagh et al. (2015) mention that NEDC tests report lower emissions compared to realistic road conditions and also that the difference is the biggest in the category of low emission cars. Moreover they mention a rise in this difference from about 8% in 2001 to a 21% difference in 2011 (Mock et al. 2012; Mock et al. 2014). So probably emission values used in research and by governments are too optimistic nowadays and need to be used with caution. Also it is noteworthy that between 2001 and 2011 emission and fuel efficiency values became far more important due to the tax reforms, which might suggest that manufacturers focused on passing test as efficient as possible. Kok (2015) calculated that only 37% of the total reduction of type-approval CO_2 emission was actually realised in real driving conditions.

In 2017 or 2018, the NEDC tests will be replaced by the Worldwide harmonized Light vehicles Test Procedures (WLTP), and other countries tests will follow (Delphi, n.d. ; Engeljehringer, 2014). In these tests the amount of flexibilities will be reduced. However Kadijk et al. (2012) mention that there still be flexibilities in the new test cycle.

Ligterink and Bos (2010) analysed the difference between NEDC testing and real-world fuel consumption in the Netherlands by comparing test results with fuel pass data from business travel. They found that the lowering test values do not fully translate into lower fuel consumption. In line with the results of Gerlagh et al. (2015) the lowest category emission cars show the highest deviation. The cause of this is embedded in the test itself, the test mainly focus on low speed tests, while main part of the actual use of the business cars will be on the highway. Ligterink and Eijk (2014) extend this research with data from the period 2004 to 2014 and find similar results. The gap between type-approval and real-world values is rising. Furthermore hybrid cars are taken into account in this study. Hybrid cars are type-approved with values based on a considerate amount of electric driving, however in the reality the electric use is between 15 and 30%. This causes the actual fuel consumption to be up to three times the test value.

Conclusion Test results

The emission tests do not reflect real-world conditions very well, and this flaw results in a difference between the official emissions figures and real emission of vehicles. This can potentially have a big effect on the environment and related tax systems. Furthermore almost all literature utilizes NEDC figures, as can be seen in appendix A, and the values used can be questioned.

6.1.VW diesel scandal

In September 2015 the American Environmental Protection Agency (EPA) found that the Volkswagen group diesel cars where equipped with a ''defeat device'', software that could reduce the amount of emission during emission testing. Because of this software the car would be tested way more efficient and clean than it actually is in normal road conditions. The result is that the cars were declared clean enough and given a certain emission rating, while on the road the cars emitted up to 40 times the amount of NO pollutants. VW admitted that up to eleven million cars were included in this fraud, from which around eight million in Europe (Hotten, 2015). At the moment of writing the total damage or penalties for Volkwagen are unknown, but VW registered its first quarterly losses in 15 years. Although this is not the focus of this research, fraud test results can have an enormous impact on tax systems, since test results are used to rate vehicles or to put them into CO_2 bands. Diesel cars that fall into low tax paying category might actually pollute considerably more than expected. Furthermore this scandal raised the question whether test results are reliable and if other manufacturers also commit test fraud. Recent news articles do suggest that other manufacturers have been messing with tests (Autoweek, 2015; Transportenviroment, 2015; Guartz, 2015; Dailymail, 2015; Nu, 2016)

Conclusion VW diesel scandal

Fraud like in the VW case can potentially cause major problems for emission based tax systems. Further research on the effects of the scandal is required.

7. Conclusions and Discussion

In this study results are compared from different studies in the field of taxation on vehicles and the effect on the car market in the European Union. The tax systems have been adapted in the last decade in such a way to stimulate sales of efficient and less environmentally unfriendly cars. The aim of the European Commission is mainly to lower the average emission of CO_2 of the new car fleet, by stimulating manufacturers to produce more efficient and less polluting vehicles, and by stimulating consumers to buy low emission cars.

Even though efforts are made to compose a Europe wide tax system, no agreements have been made, and all countries have their own separate, historically developed, tax systems. Although there is no cohesion on vehicle tax systems in Europe, the trend has been towards more and more CO_2 based systems. Also this paper does not argue that a Europe wide system is favourable, because there are big differences in the car markets in Europe (mainly due to economic conditions). The main tax tools and incentives are VRT, AMT, fuel tax, CCT, and vehicle scrappage incentives (sub-question 1).

Overall we can conclude that governments have tools, in form of tax instruments, which can influence consumers significantly. However it is difficult to design an efficient tax system in advance. The introduction of emission based systems came with high costs for governments, in form of incentives and loss in tax revenues. The tax incentives do not always cause a big drop in emission, so costs per g of CO_2 reduction are very high. Furthermore parts of subsidy on environmentally friendlier vehicles are exported away towards other countries.

After analysing different tax incentives or tools in different countries in Europe can be concluded that overall CO_2 based VRT, AMT, and feebates systems have a high potential influence on car buyers. However the last one comes potentially with high losses in tax revenues, because the design of fees and rebates, in terms of thresholds, pivot points and the height of the fees and bates is extremely difficult to set right. Moreover different effects occur after adapting tax systems towards CO_2 based versions. One of the biggest effects is the change towards diesel cars, as shown in figure 19 below. Changing towards diesel engines does result in a lower average CO_2 emission, however causes a high rise in other pollutants (e.g. NO_x is expected a 28% rise by 2020 in Ireland) which can result in a higher risk for the health of inhabitants. E.g. Ireland, as discussed in chapter 4, shows an enormous increase in diesel share and lowered the average CO_2 emission significantly. However negative effects to health will not show on short term (sub-question 2).

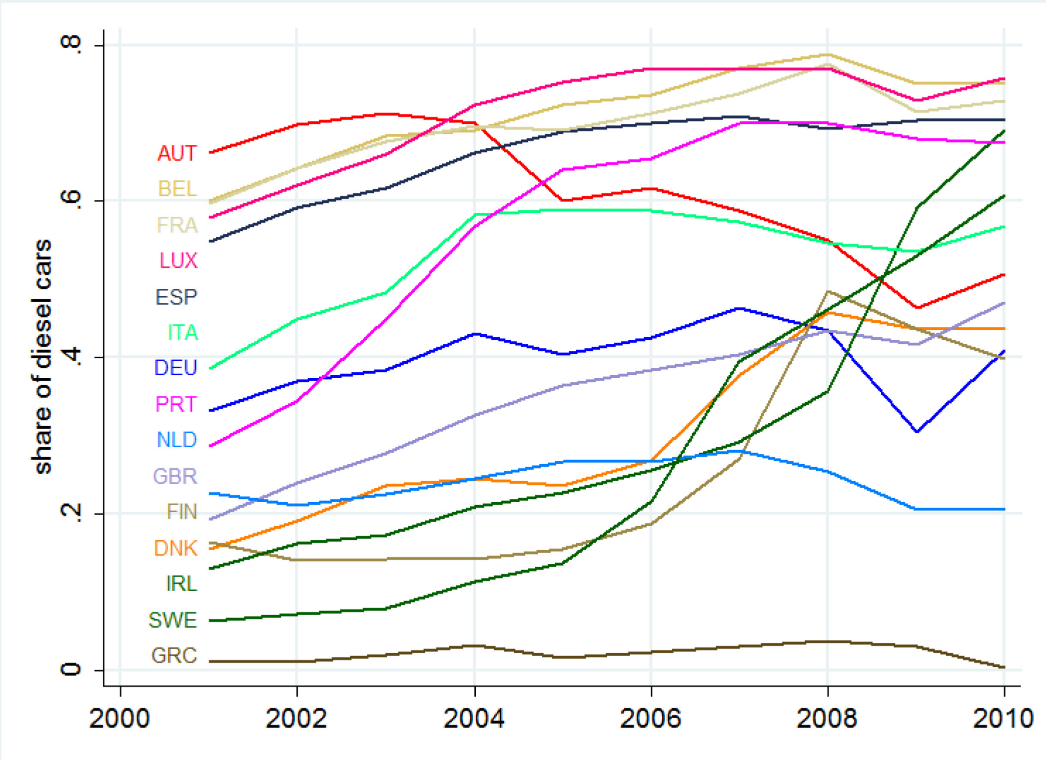

Figure 19. Share of diesel cars in the new car fleet (Gerlagh, 2015)

Moreover changes in consumer behaviour cause other car specifications to shift. Before the emission based tax systems there was a rise in bigger, faster and heavier cars but with the introduction of the CO_2 based systems this trend reversed; on average cars in many countries became smaller in weight, size and engine capacity. Partly this is because of innovation; manufacturers can get more power out of less displacement. Taxes and incentives, in combination with the economic conditions, are the main other driver for the decrease.

Scrappage schemes which are introduced in a couple of countries showed to be largely popular with the public, came with a high cost, however did not show to have any significant environmental benefits. Scrappage schemes can actually cause a rise in car use because average costs of owning a car are lowered. This is not the intention of the government, and also considerable costs are involved, and in practise a neutral budget plan does not work (Brand et al, 2013). Overall, policy choice, design and timing play a crucial role in the introduction of new tax systems (Brand et al., 2013).

Gallachóir et al., (2009) mention the importance of the second hand market. Change in tax policies might increase the amount of second hand import. Governments should take this into account. Also misconfigured policies might stimulate consumers to keep older, more polluting vehicles longer. The main focus of all literature on this subject focuses on new fleet vehicles, because the European commission set standards on those, however the second hand market, and in/export should also be researched further. One policy in Czech Republic (Zimmermannova, 2012) does take registration of second hand vehicles into account and this might have potential for other European countries. Also has to be taken into account that borders are open for travel and trade, and vehicles may be in and exported, so it is important that different countries communicate about this, and configure the systems in such a way that benefits received by in or export are limited.

Furthermore no evidence is found in literature for the hypothesis that manufacturers on the short term slightly adapt their vehicles to make it fall in a lower tax band. Manufacturers already try to test it efficient as possible and adapting models and registration takes time. Also tax rules differ across all European countries so it would be impossible to get one specific emission figure that benefits in all markets (sub-question 5).

NEDC tests give manufacturers flexibilities to maximize emission reduction during the test phase. However in real world conditions the efficiency of cars is lower and the emissions are higher. This potentially has a negative effect on tax revenue, because vehicles fall unfairly in lower tax categories. Analysis of all discussed literature shows that most studies make use of average emission data received from registration agencies and tested during standardized test procedures like the NEDC (see appendix A). This does not automatically mean the conclusions are not wrong, but these might be based on wrong values, which might make it look better than real world results (sub-question 4). With this paper we would like to plea for a better test. In the future the NEDC tests will be replaced by the WLTP which will minimize flexibilities for manufacturers. However the correctness of the tests should be researched and continuously examined.

Table 6 summarizes the focus on tax systems per country retrieved from literature as explained in chapter 4.4. (sub-question 3)

Country	VRT	AMT	Rebate	Feebate	CCT	Scrappage
Belgium		++				
Czech republic	++*					
Denmark	++		++			
France	++			++		+
Germany		++				+
Ireland	++	+				
Italy		++				+
Netherlands	++	++		+	++	
Portugal	++					
Sweden		++	+			
Switzerland			++			
UK		++				+

*also for second hand market

Table 6. Summary of focus of tax systems in Europe retrieved from discussed literature

One of the limitations of this study is that most literature is only on wealthy countries. It would be interesting to perform similar studies in countries like e.g. Greece or Bulgaria. Those countries often have older tax systems, and an older car fleet. It would be interesting to see how less wealthy countries absorb these kinds of tax changes.

Lots of studies take into account the average emission values of newly sold cars. However car density (amount of cars per adult) and car use is also important, because that results in actual emission. More research could be performed to measure actual emission, and the effects of tax systems. Now the tax rules are most relevant to people who have low mileage, because average costs are high. Wealthier and more miles driving consumers are less likely to adapt their behaviour, but are far more polluting. For example a small low emission car (100g CO_2/km) used for 10.000 km a year has the same effect on the average as an often used (100.000+ km) high emission vehicle (200g CO_2/km). This is measured this way because the European Commission set goals with this standard, but is not the best way. Research should be conducted in how to make the registration of emission better and fairer. Also research in actual emission makes it easier to compare BEV's and PHEV's to diesel and gasoline vehicles. The forecasts are that those categories will grow fast in the near future, and research would benefit if figures will be comparable to calculate real emission differences.

A clear and fair overview of country specific emissions makes it possible for policy makers to review the current policies and work on ways towards the goal; reducing emission as far as possible in a efficient way.

8. Literature

- Air Quality (n.d.). Air pollution. Retrieved at 21-4-2016 from http://www.air-quality.org.uk/26.php
- ANWB auto Survey (2011). Dit vindt Nederland als het om autorijden gaat. Retrieved at 10-10-2015 from http://www.anwb.nl/auto/nieuws/2011/april/enquete-autorijden
- Autoweek (2015). CO2 emissions Verschillen in test en real life. Retrieved at 26-10-2015 from http://www.autoweek.nl/forum/read.php?1,5490478
- Bampatsou, C., & Zervas, E. (2011). Critique of the regulatory limitations of exhaust CO 2 emissions from passenger cars in European Union. Energy Policy, 39(12), 7794-7802.
- Bampatsou, C., & Zervas, E. (2011). Critique of the regulatory limitations of exhaust CO 2 emissions from passenger cars in European union. Energy Policy, 39(12), 7794-7802.
- Blow, L., & Crawford, I. (1997). The distributional effects of taxes on private motoring.
- Bosseboeuf, D., Lapillonne, B., & Eichhammer, W. (1999). Energy efficiency indicators: the European example. Paris: ADEME.
- Brand, C. (2010). UK Transport Carbon Model: User Guide v1. 0. UK Energy Research Centre. *Energy Demand Theme, Oxford*.
- Brand, C., Anable, J., & Tran, M. (2013). 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: Policy and Practice*, *49*, 132-148.
- Brand, C., Tran, M., & Anable, J. (2012). The UK transport carbon model: An integrated life cycle approach to explore low carbon futures. *Energy Policy*, *41*, 107-124.
- Bureau, B. (2011). Distributional effects of a carbon tax on car fuels in France. Energy Economics, 33(1), 121-130.
- CBS, 2015. Motorvoertuigen; sloop, export en overige uitval, leeftijd auto. Statistics Netherlands, The Hague (in Dutch). Retrieved from http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=80357ned&D1=a&D2=1-2&D3=a&D4=l&VW=T
- Dailymail (2015). New European cars produce 'up to 50 PER CENT more CO2 than lab tests show': Environmental group claims VW emissions rigging is just part of a much wider scanal. Retrieved at 26-10-2015 from http://www.dailymail.co.uk/news/article-3252186/New-European-cars-produce-50-CENT-CO2-lab-tests-Environmental-group-claims-VW-emissions-rigging-just-wider-scandal.html
- de Haan, P., Peters, A., & Scholz, R. W. (2007). Reducing energy consumption in road transport through hybrid vehicles: investigation of rebound effects, and possible effects of tax rebates. Journal of Cleaner Production, 15(11), 1076-1084.
- Delphi (n.d.). 2015-2016 Passenger Cars & Light Duty Vehicles. Retrieved from http://www.delphi.com/manufacturers/auto/powertrain/emissions_standards at 25-3-2016
- DeLuchi, M. A. (1991). Emissions of greenhouse gases from the use of transportation fuels and electricity. Volume 1, Main Text (No. ANL/ESD/TM--22-Vol. 1). Argonne National Lab., IL (United States). Energy Systems Div..
- d'Haultfoeuille, X., Givord, P., & Boutin, X. (2014). The environmental effect of green taxation: the case of the french bonus/malus. The Economic Journal, 124(578), F444-F480.

- EC, (2009). Regulation No. 443/2009 of the European Parliament and of the Council. Setting Emission Performance Standards for New Passenger Cars as Part of the Community's Integrated Approach to Reduce CO2 Emissions from Light-duty Vehicles. Official Journal of the European Union, Brussels.
- Engeljehringer, K. (2014). Passenger car emission regulations. Retrieved from https://www.avl.com/documents/10138/1027860/AVL-Italy+TechDay+-+Light-Duty+Emission+-+2014-10-21b.pdf/da9591d9-3e75-42c2-9157-d7cc9a680b1f at 25-3-2016
- European Commission (2011). Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system, COM (2011) 144 final, Brussels.
- European Union (2011). Verordening (EU) Nr. 582/2011 van de Commissie van 25 mei 2011. Retrieved at 21-4-2016 from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:167:0001:0168:NL:PDF
- Fontaras, G., & Samaras, Z. (2010). On the way to 130gCO 2/km—Estimating the future characteristics of the average European passenger car. Energy Policy, 38(4), 1826-1833.
- Gallachóir, B. P. Ó., Howley, M., Cunningham, S., & Bazilian, M. (2009). How private car purchasing trends offset efficiency gains and the successful energy policy response. Energy Policy, 37(10), 3790-3802.
- Gallagher, K. S., & Muehlegger, E. (2011). Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology. Journal of Environmental Economics and Management, 61(1), 1-15.
- Giblin, S., & McNabola, A. (2009). Modelling the impacts of a carbon emission-differentiated vehicle tax system on CO 2 emissions intensity from new vehicle purchases in Ireland. *Energy Policy*, *37*(4), 1404-1411.
- Graham, D. J., & Glaister, S. (2002). The demand for automobile fuel: a survey of elasticities. Journal of Transport Economics and policy, 1-25.
- Gross, R., Heptonstall, P., Anable, J., & Greenacre, P. (2009). What policies are effective at reducing carbon emissions from surface passenger transport?-a review of interventions to encourage behavioural and technological change.
- Guartz (2015). All car companies cheat on emissions tests—it's just that most do it legally. Retried at 26-10-2015 from http://qz.com/511064/all-car-companies-cheat-on-emissions-tests-its-just-that-most-do-it-legally/
- Hennessy, H., & Tol, R. S. (2011). The impact of tax reform on new car purchases in Ireland. Energy Policy, 39(11), 7059-7067.
- Hotten, R. (10 December 2015). Volkswagen: The scandal explained. BBC news. Retrieved from http://www.bbc.com/news/business-34324772 at 8-2-2016.
- Hymel, K. M., Small, K. A., & Van Dender, K. (2010). Induced demand and rebound effects in road transport. Transportation Research Part B: Methodological, 44(10), 1220-1241.
- Kadijk, G., Verbeek, M., Smokers, R., Spreen, J., Patuleia, A., van Ras, M., Norris, J., Johnson, A., O'Brien, S., Wrigley, S., Pagnac, J., Seban, M., Buttigieg, D. (2012). Supporting Analysis Regarding Test Procedure Flexibilities and Technology Deployment for Review of the Light Duty Vehicle CO2 Regulations, Service Request #6 for Framework Contract on Vehicle Emissions (No. ENV.C.3./FRA/2009/0043), European Commission's DG CLIMA.
- Klier, T., & Linn, J. (2012a). Using vehicle taxes to reduce carbon dioxide emissions rates of new passenger vehicles: Evidence from France, Germany, and Sweden.

- Klier, T., & Linn, J. (2012b). New-vehicle characteristics and the cost of the Corporate Average Fuel Economy standard. The RAND Journal of Economics, 43(1), 186-213
- Knittel, C. R. Dec. 2011. Automobiles on steroids: Product attribute trade-offs and technological progress in the automobile sector. American Economic Review, 101(7), 3368-3399.
- Kok, R. (2011, October). The effects of CO2-differentiated vehicle tax systems on car choice, CO2 emissions and tax revenues. In ETC 2011: European Transport Conference, Glasgow, UK, 10-12 October 2011. Association for European Transport (AET).
- Kok, R. (2013). New car preferences move away from greater size, weight and power: Impact of Dutch consumer choices on average CO 2-emissions. Transportation Research Part D: Transport and Environment, 21, 53-61.
- Kok, R., Annema, J. A., & Van Sloten, R. (2013). Effecten van stapsgewijze aanscherping CO2-zuinigheidsgrenzen voor autobelastingen. In Colloquium Vervoersplanologisch Speurwerk 2013, Rotterdam, 21-22 november 2013. Stichting Colloquium Vervoersplanologisch Speurwerk (CVS).
- Kok, R., Annema, J. A., & van Wee, B. (2011). Cost-effectiveness of greenhouse gas mitigation in transport: A review of methodological approaches and their impact. Energy Policy, 39(12), 7776-7793.
- Leinert, S., Daly, H., Hyde, B., & Gallachóir, B. Ó. (2013). Co-benefits? Not always: quantifying the negative effect of a CO 2-reducing car taxation policy on NO x emissions. Energy Policy, 63, 1151-1159.
- Ligterink, N. E., & Bos, B. (2010). CO2 uitstoot van personenwagens in norm en praktijk-analyse van gegevens van zakelijke rijders.
- Ligterink, N. E., & Eijk, A. R. (2014). Real-world fuel consumption of passenger cars. In 20th International Transport and Air Pollution Conference 2014, Graz, Austria, 18-19 September, 1-12.
- Mabit, S. L., & Fosgerau, M. (2011). Demand for alternative-fuel vehicles when registration taxes are high. Transportation Research Part D: Transport and Environment, 16(3), 225-231.
- Mehlin, M., Guehnermann, A., & Aoki, R. (2004). Preparation of the 2003 review of the commitment of car manufacturers to reduce CO2 emissions from M1 vehicles: Final report of task A: Identifying and assessing the reasons for the CO2 reductions achieved between 1995 and 2003. Berlin: German Aerospace Center-Institute of Transport Research.
- Merkisz, J., Fuc, P., Lijewski, P., & Bielaczyc, P. (2010). The Comparison of the Emissions from Light Duty Vehicle in On-road and NEDC Tests (No. 2010-01-1298). SAE Technical Paper.
- Meyer, I., Leimbach, M., & Jaeger, C. C. (2007). International passenger transport and climate change: A sector analysis in car demand and associated CO2 emissions from 2000 to 2050. *Energy Policy*, *35*(12), 6332-6345.
- Mock, P., German, J., Bandivadekar, A., & Riemersma, I. (2012). Discrepancies between type-approval and “real-world” fuel-consumption and CO. The International Council on Clean Transportation, 13.
- Mock, P., Tietge, U., Franco, V., & German, J. (2014). From Laboratory to Road: A 2014 Update of Official and “Real-World” Fuel Consumption and CO2 Values for Passenger cars. Derived from http://www. theicct. org/sites/default/files/publications/ICCT_LaboratoryToRoad_2014_Report_Engli sh. pdf.

- Morrow, W. R., Gallagher, K. S., Collantes, G., & Lee, H. (2010). Analysis of policies to reduce oil consumption and greenhouse-gas emissions from the US transportation sector. *Energy Policy*, *38*(3), 1305-1320.
- Mueller, M. G., & de Haan, P. (2009). How much do incentives affect car purchase? Agent-based microsimulation of consumer choice of new cars—Part I: Model structure, simulation of bounded rationality, and model validation. Energy Policy, 37(3), 1072-1082.
- Nu (2016). Mitsubishi zat in 1991 al fout met tests benzineverbruik. Retrieved at 27-4-2016 from http://www.nu.nl/economie/4252838/mitsubishi-zat-in-1991-al-fout-met-tests-benzineverbruik.html
- Odeck, J., & Johansen, K. (2016). Elasticities of fuel and traffic demand and the direct rebound effects: An econometric estimation in the case of Norway. Transportation Research Part A: Policy and Practice, 83, 1-13.
- Pelkmans, L., & Debal, P. (2006). Comparison of on-road emissions with emissions measured on chassis dynamometer test cycles. Transportation Research Part D: Transport and Environment, 11(4), 233-241.
- Pinto, G. & Oliver, M.T. (2008). Using the relationship between vehicle fuel consumption and CO2 emissions to illustrate chemical principles. Journal of Chemical Education, 2008, 85.2: 218.
- Potoglou, D., & Kanaroglou, P. S. (2007). Household demand and willingness to pay for clean vehicles. *Transportation Research Part D: Transport and Environment*, *12*(4), 264-274.
- Rogan, F., Dennehy, E., Daly, H., Howley, M., & Gallachóir, B. P. Ó. (2011). Impacts of an emission based private car taxation policy–first year ex-post analysis. Transportation Research Part A: Policy and Practice, 45(7), 583-597.
- Ryan, L., Ferreira, S., & Convery, F. (2009). The impact of fiscal and other measures on new passenger car sales and CO 2 emissions intensity: evidence from Europe. Energy Economics, 31(3), 365-374.
- Schipper, L., Saenger, C., & Sudardshan, A. (2011). Transport and carbon emissions in the United States: the long view. *Energies*, *4*(4), 563-581.
- Shepherd, S., Bonsall, P., & Harrison, G. (2012). Factors affecting future demand for electric vehicles: A model based study. Transport Policy, 20, 62-74.
- Soytas, U., & Sari, R. (2003). Energy consumption and GDP: causality relationship in G-7 countries and emerging markets. *Energy economics*, *25*(1), 33-37.
- Sprei, F., Karlsson, S., & Holmberg, J. (2008). Better performance or lower fuel consumption: Technological development in the Swedish new car fleet 1975–2002. Transportation Research Part D: Transport and Environment, 13(2), 75-85.
- Transportenviroment (2015). Mind the Gap 2015: Closing the chasm between test and real-world car CO2 emissions. Retried at 26-10-2015 from http://www.transportenvironment.org/publications/mind-gap-2015-closing-chasm-between-test-and-real-world-car-co2-emissions
- United Nations, (n.d). Kyoto Protocol. Retrieved at 21-4-2016 from http://unfccc.int/kyoto_protocol/items/2830.php
- Wet op de belasting van personenauto's en motorrijwielen 1992 (2009). Retrieved at 29-3-2016 from http://wetten.overheid.nl/BWBR0005806/2009-07-01/1

- Zachariadis, T., Ntziachristos, L., & Samaras, Z. (2001). The effect of age and technological change on motor vehicle emissions. Transportation Research Part D: Transport and Environment, 6(3), 221-227.

9. Appendix A

Author (year)	Countries of focus	Period (*scenarios)	Types of tax systems	Focus of research	Results	Recommendations	Limitations	Data used	Emission test values used?	Type of research	Data method
Kok (2011)	Netherlands	2005-2010	VRT	Influence of CO2 tax differentiation in the Netherlands on car purchasing trends; weight, power, segment, diesel vs. petrol. And the use of tax bonds.	Dutch consumers respond to price incentives for low CO2 emission cars. Major growth in VRT free sector (50% in 2010). Low government tax revenues on VRT.	Government should lower VRT free tax bonds	-	Car registration data trends, car tax revenues.	Car registration data by Dutch Vehicle Registration Agency (RDW).	ex-post	Data analysis
Kok et al. (2011)	n/a	n/a	n/a	Meta analysis of CEA; Key differences, the potential impact of choice of method, and possible improvements	Differences in measuring methods, up to $400 per tonne of CO2 equivalent caused by not well defined assumptions and methods can potentially cause arbitrary policy decisions. CEA could improve by clearly indicate specific purpose of the analysis, and assumptions that are made. Furthermore overviews of GHG mitigation consisting of vertical CEA should be compared with a sceptical view.	Using CEA; well define methods and assumptions. Further research: Behavioural change is underrepresented in transport GHG mitigation studies. More ex-post analysis of GHG mitigation in transport is recommended. More research should be done on rebound and congestion effects, and on tax-interaction and revenue-recycling effects.	-	Academic papers, research documents, government reports, credible internet sources, research reports. Focus on ex-ante assesments of measures.	CO2 values from secondary sources.	n/a	Literature study

Kok et al. (2013)	Netherlands	2000-2013	VRT	Effects of latest tax reforms (CO_2 and VRT free bands) on car sales.	From 2000 until 2008 the amount of cars sold was quite steady, with a decline in 2008 which can be explained by the financial crisis. However from 2009 tax policy was changed, which resulted in a increase in car sales. The avarage paid taxes on cars were reduced, increasing the amount of sales. The tax policy made customer preferences change towards smaller and more efficient cars, resulting in less emissions. However later changes in tax bands stabalised the tax effect. Evidence is found for an tax anticipation effect by customers. Tax revenue for the government has decreased a lot.	Some follow up questions: How to form the tax policy in such a way that it works efficient en effectly on the long run? How to stimulate new car types like hybrid or electric cars? And there is a need to get insight in the difference between test value based and real emission based efficiency of cars.	-	Car registration data	Car registration data by Dutch Vehicle Registration Agency (RDW). Also is adressed that there might be a difference between test values and real road values.	ex-post	Data analysis
Kok (2013)	Netherlands	2000-2011	n/a	Isolate the effect on CO_2	From 2000 up there was a	-	-	Car registration data	Car registration data	ex-post	Data analysis

				emission caused by changes in consumer preferences and from technological advances.	rising trend in car specifications but since 2008 consumer preferences have been moving towards smaller, lighter, less powerful cars. Shifts in car segments and in fuel type, but also within car segments (e.g. smaller engines). The study shows a CO2 decreasing effect caused by isolated technological improvements, however the change in preferences causes this effect to disrupt the decrease of CO2 emission. It seems that manufactures have responded to EU regulation, technological advances have speeded up after the announcement. Furthermore results are found for a respondin			trends.	by Dutch Vehicle Registration Agency (RDW).		

					g effect of consumers on car related tax changes. Most sales are just below tax tresholds.						
Kok (2015)	Netherlands	2008-2013	VRT, AMT, CCT	Examines tax changes in the Netherlands and assesses the impacts on consumer purchasing behaviour as well as the effect of tax incentives for low carbon emitting cars. Did the Dutch fiscal policies attribute to the decrease in avarage CO_2 emission of the new car fleet?	The study showed that technological advances accounted for 70% of the CO_2 reduction of the new car fleet in the Netherlands between 2007 and 2013. 25% was caused by the Dutch tax reforms and 5% by exogenous factors. Furthermore is shown that around 70% of the reduction caused by tax is explained by the CCT tax. However also is concluded figures on CO_2 are based on type approval tests, and that only 37% of the CO_2 reduction on new fleet cars is actually realised when looked to real world driving conditions. Furthermo	More research is needed on the gap between test values and real world fuel economy.	-	Car registration data. Avarage CO_2 emission and share of electric vehicles data. Car specifications. Dutch travelcard data. Dutch export statistics.	Dutch road autority	ex-post	Data analysis

					re a part of the subsidy is exported away with (mainly diesel) cars. At the end the tax reform (2008-2013) resulted in a CO2 reduction of about 3.5 million tons, at the high price of 6.5 billion euro.						
Gallachóir, B. P. Ó., Howley, M., Cunningham, S., & Bazilian, M. (2009)	Ireland	2000-2006	VRT and AMT	CO2 emission; the battle between the trend towards larger cars vs technical improvements	Changes in purchasing patterns in Ireland offset efficiency improvements by car manufacturers. Promising results are found for CO2 emission based tax policies to lower the emission of new fleet vehicles. Furthermore a significant rise in second hand imports was found.	Tax second hand imports the same as new car registrations.	-	New fleet car registration data. Emision data. Fuel price data. Economic growth data.	Data provided by commission of the european communities. Transport energy related CO2 emission data by Howley et al (2007). CO2 testing is explained.	ex-post	Data analysis
Rogan, F., Dennehy, E., Daly, H., Howley, M., & Gallachóir, B. P. Ó. (2011)	Ireland	2008	VRT and AMT	Impact of CO2 based tax policy on car purchasement. The change from Ireland's tax system from engine size to CO2 based tax system.	Significant changes in purchasing patterns due to tax policy changes in Ireland. This resulted in emission savings, but also in revenue loss.	Methodology used should also be usable for other countries.	-	Tax revenue and car purchasing trends.	Vehicle Registration Unit (Ireland) and Vehicle Certification Agency (UK)	ex-post	Data analysis

					Consumers did not downsize, but changed fuel type.						
Ryan, L., Ferreira, S., & Convery, F. (2009)	EU (15 countries)	1995-2004	VRT and AMT	Impact of national fiscal measures on car sales and CO2 intensity of the new car fleet. Petrol vs diesel.	National tax policy has impact on car sales and CO2 emission. Different taxes have disparate effects. No real evidence that voluntary agreement of manufactures is working. Year on year decrease in CO2 intensity. Increase in petrol circulation tax, decreases CO2 output. GNI per capita is positively related to CO2 of fleet and vehicle price index. A rise in vehicle circulation tax or rise in fuel pricers causes fuel switching. Registration tax appears not to have a big impact on CO2 intensity.	Further research could be done on the influence of the voluntairy agremeents on CO2 intensity of the car fleet.	-	Member states car related taxes, vehicle prices, CO2 emission, petrol vs. diesel data, absolute and relative fuel prices. Data on new car fleet!	Vehicle Certification Agency (UK) and European Commission.	ex-post	Data analysis
Klier, T., & Linn, J. (2012)	France, Sweden and Germany	2005-2010	VRT and AMT	Effect of major tax reforments on CO2 reduction. France focusses	In France a negative short run effect was found of registration tax on	Further research could be done on how manufacturers adapt	-	Vehicle registration and characteristics data, annual tax guide	CAFE standards and european data obtained by R.L	ex-post	Data analysis

				on a purchase tax, Germany and Sweden on circulation tax.	CO_2 intensity (elasticity -0.4). Slightly smaller results for Germany and Sweden on CO_2 based circulation tax. Voluntary and mandatory manufactures standards have contributed to overall downwards trend in CO_2 intensity. In France there was a large response to subsidy on <130gr of CO_2/km cars. Same in Sweden (although cut-off point is 120gr). Tax changes have larger effect than fuel prices, particularly in France and Germany. France's tax changed into a non linear CO_2 based purchase tax (2008). In Sweden (2006) and Germany (2009) a CO_2 based linear annual circulation tax was	their product portfolio to tax systems.		of European automobile manufactrues association, and fuel price data.	Polk & Co.		

					introduced. Consumers respond more to purchase tax than annual taxes. No significant results for manufactures slightly lowering CO2 intensity of models around cut off points in tax bands.						
de Haan, P., Peters, A., & Scholz, R. W. (2007)	Switserland	2004	Rebate	Rebound effects and cost of tax debates of hybrid vehicles.	No results where found for the 2 potential rebound effects; people do not switch from small, fuel efficient cars to hybrid cars, and hybrid cars mostly enter multiple car households and replace older vehicles. Furthermore the hybrid cars do not cause switching towards larger cars, so they might play a role in reducing CO2 emissions. A tax incentive is only really effective when car owners dont	Further research on similar hybrid cars from other brands	Switserland car market is not representative for Europe; a lot of AWD vehicles because of the landscape and high wealth level.	Car registration data.	Toyota CO2 values used, source not clear.	ex-post	Survey

					upgrade specifications.						
Mabit, S. L., & Fosgerau, M. (2011)	Denmark	2007	VRT	Tax rebates on alternative-fuel vehicles	Government incentives seem to have a large impact on the share of AFVs in the car fleet. Next to price (annual and registration) the range of a vehicle seems to be really important.	-	-	Car sales are used to send questionair to actual buyers, car market figures.	Not used.	ex-ante	Stated choice survey
Sprei, F., Karlsson, S., & Holmberg, J. (2008).	Sweden	1975-2002	n/a	Divide technological advancements in the car industry into physical and service attributes.	Larger cars with increased acceleration and weight would have resulted in 23% more fuel use without technological advancements. 35% of the technological advances affect the fuel consumption directly, the remaining 65% affect the service attributes and mainly serve comfort and acceleration.	-	-	Vehicle registration and characteristics data.	EPA and EU driving cycle	ex-post	Data analysis
Knittel (2011)	USA	1980-2006	n/a	Estimate technological progress and the trade-offs between fuel consumpti	Without the shift towards larger and powerful cars fuel consumption could have	In order to meet Obama standards downsizing of the vehicle fleet is necessary.	-	Vehicle registration and characteristics data, fuel prices.	CAFE standards	ex-post	Data analysis

				on, weight and power.	decreased with 60% between 1980 and 2006.						
Gerlagh, R., Van den Bijgaart, I., & Nijland, H. (2015)	EU (15 countries)	2001-2010	VRT, AMT and CCT	To what extent have national fiscal policies contributed to decarbonisation of passenger cars.	Fiscal policies have significant impact on emission intensity of new car fleet. Increasing the CO2 sensitivity of registration tax, and/or raising fuel tax does result in more efficient vehicles being bought. However increasing annual road taxes does not show to have a positive effect. A large part of the increase in fuel efficiency is caused by fuel switching. Innovation of car manufactures also has a big role in the decrease of CO2 intensity.	Test-cycles need an update to make more reliable predictions of real-life use. More research could be done on the difference between private and business consumers.	Study takes into account that car related taxes are linear, however some studies suggest consumers react more to tax breaks. Secondly the study does not destingish company cars from private cars, which can affect the results because employers have different tax benefits. Thirdly the study does not take into account scrap subsidies, which in other studies have proven to be of a big difference.	Manufacturer price tables (EC), fuel and road tax guides (ACEA), passenger car datasheet (EC), economy data (Eurostat)	European commission and CO2 intensity data by Campestrini and Mock (2011), NEDC explained.	ex-post	Data analysis
Fontaras and Samaras (2010)	Europe	2008-2015	n/a	Possible changes to European vehicles in order to meet 130g/km CO2 standards in 2015	Current reduction of CO2 intensity is a result of improvement of efficiency of the engines, a shift towards diesels with improved	-	Actual driving factors are not taken into account: speed profile, terrain type, climate conditions, use of assessories and tyre	Vehicle specifications.	NEDC	ex-ante	Simulation

					efficiency, and the promotion of smaller vehicles. In order to approximately meet the 2008 emission target a 10% decrease in avarage weight, 10% increase in aerodynamics, a 20% reducement in tyre resistance and a 7.5% increase in powertrain efficiency is needed.		conditions.				
Zimmermannova (2012)	Czech republic	2009-2011	Registration fee (new and 2nd hand)	The impacts of the car registration fee in Czech Republic on car sales and enviromental factors.	There is a strong positive relation between the registration fee and sale of new cars, used car registrations dropped. Furthermore there is a negative relationship between the fee and emissions. Also the category of used cars that declined the most are the oldest cars, which is a good outcome for the government.	Fee rates and parameters need to be updated, otherwise the effect will decrease within years because newer generation older cars will meet EURO norms.	Does not take into account milage of cars and so no actuall reduction of emissions is calculated.	Car importers association statistics	Car registration CO, CO2, NOX, PM	ex-post	Corrolation analysis
Brand et al. (2013)	UK	up to 2050*	VRT, AMT, feebates and	Aims to fill the gap in assessment of	Scrappage incentives cause more new	Research the effect of combinations of	Calculation depended on energy	Economic growth, price informati	Earlier study results	ex-ante	Scenea rio modelling

			scrappage	environmental effects of car pricing and taxation instruments. The study searches for the fastest way to accelerate fuel, technology and purchasing behaviour transitions, in a way that is most enviromental friendly, budget neutral and has no adverse effect on car ownership and use.	cars to be sold, however no real GHG reduction is realised with them. Feebate and VED schemes show to have the biggest result on CO2 emission intensity. A high increase in AFV is expected, and also a higher share of diesel cars. The design of feebate and other tax programs is one of the most important factors.	different tax schemes e.g. a VED scheme with a registration tax. Furthermore research is needed on AFV and fuel taxation.	prices and efficiency of electricity sources is held constant.	on of fuel and electricity, tax information, car market information			
Giblin & McNabola (2009)	Ireland	2006 onwards*	VRT and AMT	Researches the demand for petrol and diesel cars based on different AMT and VRT schemes in Ireland. Takes into account new cars only.	The model suggests that the Irish reforms of the tax system will result in a 3.6-3.8% decrease in CO2 emission intensity, at a cost of €191 M.	Revisit the model in a couple of years to assess accuracy. Furthermore the autors suggest an adapation to the Irish plans; a higher reduction of CO2 can be gained at a lower price for the government.	New cars only, only diesel and petrol. Does not take into account all descision factors (e.g. choice for public transport).	CO2 incentives, registration taxes, circulation taxes, fuel taxes, socio-economic features of car buyers, car prices and costs, vehicle characteristics.	Emission data from road agency.	ex-ante	Descrete choice model
d'Haultfoeuille et al. (2014)	France	2008	Feebate	Estimate impact of bonus-malus feebate program in France on the short and long run.	France customers reacted heavily on the tax incentive, however the goal was not reached. This is caused by the design of the	-	Manufacturers' reactions are not included	Monthly car registration data, transportation survey	Data set on the registration of new cars (CCFA)	ex-post	Discrete-continious choice model

					program. It is crusial to set the right pivot point and to set thresholds correctly to stimulate CO2 reduction. In France the pivot point was set too high and the rebates were too generous.						
Mehlin et al. (2004)	Europe	1995-2004	n/a	Identify and assess reasons for achieved CO2 reductions in the period 1995 to 2004.	The main reasons for CO2 reduction during the period 1995 to 2004 are technology related.	-	Used models asume that all variables stay fixed except for the simulated variable. All results in terms of CO2 reduction should therefore be used seperately and not be added. Furthere more different data from several countries was combined, which could have an effect on the results.	Annual monitoring reports by European commission, registration data (by POLK marketing systems), ADAC catalogus, motor-presse Stuttgard, ACEA tax guide, Eurostat and worldbank data.	by POLK	ex-post	Data analysis