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The Impact of Climate Policy on Private Car Ownership in Ireland

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Abstract: We construct a model of the stock of private cars in the Republic of Ireland. The model distinguishes cars by fuel, engine size and age. The modelled car stock is build up from a long history of data on sales, and calibrated to recent data on actual stock. We complement the data on the number of cars with data on fuel efficiency and distance driven – which together give fuel use and emissions – and the costs of purchase, ownership and use. We use the model to project the car stock from 2010 to 2025. The following results emerge. The 2009 reform of the vehicle registration and motor tax has lead to a dramatic shift from petrol to diesel cars. Fuel efficiency has improved and will improve further as a result, but because diesel cars are heavier, carbon dioxide emissions are reduced but not substantially so. The projected emissions in 2020 are roughly the same as in 2007. In a second set of simulations, we impose the government targets for electrification of transport. As all-electric vehicles are likely to displace small, efficient, and little-driven petrol cars, the effect on carbon dioxide emissions is minimal. We also consider the scrappage scheme, which has little effect as it applies to a small fraction of the car stock only.

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1. Introduction

Private car transport has seen some considerable changes in the period of rapid economic growth in Ireland. Increased levels of ownership combined with changes in car choice have meant that the private car stock in Ireland now is very different than a decade previous (Howley et al., 2007a). If government plans come to fruition, the car stock will again look very different in 10 years time.

Private car transport emits carbon dioxide through its fuel consumption. As elsewhere, transport emissions as a share of total emissions in Ireland are high and rising (Howley et al., 2007a). The Government of Ireland has attempted to change this trend by a range of policies, including recent changes in taxation. Car transport has always been subject to a heavy tax burden. This was in part due to its negative externalities but also due to the inelastic demand schedules associated with driver behaviour. Furthermore, the Government favours the adoption of electric vehicles. Ambitious targets of 230,000 electric vehicles by 2020 (more precisely, 10% of the stock) have been announced (DCENR, 2009). This has the ultimate aim of making private transport more sustainable both in terms of environmental impact and oil dependence. This paper evaluates the impact of government policy on car ownership, and assesses the prospects of all-electric vehicles.

Modal shifts, commuting patterns and efficient driving can also have a substantial impact on emissions. These aspects are beyond the scope of this paper. We focus solely on emission improvements brought about by changes in the composition of the car stock. Emissions from private car transport are driven by fuel consumption. Quantifying these emissions requires data on the composition of the car stock, the associated fuel efficiency and distance travelled. We project these output variables using the ISus Car Model. The evolution of the car stock follows a standard scrap and sales approach which allows us to project the stock by size, age and fuel type. This allows us to examine exogenous shocks to the car fleet, focusing on the composition of the car stock and its resultant emissions. The scenarios we simulate are the inclusion of electric vehicles, a reform of the tax system and the impact of a scrappage scheme.

Estimating CO_2 emissions directly attributable to private car transport is not an exact science. O'Gallachoir et al. (2009) estimate that private car transport accounted for 6.0 Mt CO2 in 2006. This represents approximately 40% of total transport CO_2 emissions and 12% of total CO_2 emissions in Ireland. Kelly et al. (2009) present a methodology for converting data taken from the National Car Test (NCT) into total CO_2 emissions. Broadly similar estimates of private car CO_2 emissions are found. However, neither of these two studies examines the future links between the car stock composition, vehicle kilometres travelled and CO_2 emissions.

Giblin and McNabola (2009) examine the recent tax changes in Ireland using a Danish version of the COWI cross-country car choice model. They find that the tax change will result in a 3.6-3.8% decrease in the carbon intensity of new car purchases along with a €191 million fall in tax revenue. Ryan (2009) highlights the bias towards CO_2 emissions over NOx emissions in the recent Irish tax change.

The future prospect of electric cars in Ireland has attracted significant research efforts. Smith (2010) simulates the possible future CO_2 reductions associated with significant electric and plug-in hybrid vehicle penetration. He concludes that substantial reductions can be made assuming that vehicle usage increases 1% per annum. The level of CO_2 reduction associated with electric vehicles will depend on the carbon intensity of the power generation sector. Leahy et al. (2009) assesses the possibility of electricity storage in Ireland and its benefits for both wind power generation and electric vehicles.

Section 2 describes of the data used in the model. In Section 3, we outline the equations and modular components used in construction of the model. The results of the model applications are displayed in section 4 along with the assumptions needed to implement these scenarios. Finally, we conclude in section 5 with a discussion of the results and their implications to current policy analysis.

2. Data

2.1 The total number of private cars

According to the Central Statistics Office, the stock of private cars in the Republic of Ireland in 2006 was 1,778,861.[1] While precise, this number need not be accurate. Census 2006 data suggest that the actual stock is 1,944,914, a difference of 8%. However, a certain amount of this discrepancy can be explained by cars which are exempt from motor tax. Another explanation is the use of vehicles in private transport that may be taxed as public service vehicles or goods vehicles.

Until recently, Ireland enjoyed high levels of economic growth which in turn led to an expansion of the car stock. A crude measure of saturation is the number of cars per 1000 people. In this respect, Ireland has converged on comparative countries (Howley et al., 2007a) and is close to this level of saturation at present. However, future emissions and efficiency are driven by the composition rather than the size of the car stock.

2.2 The stock of cars by engine size and fuel

Vehicle Licensing Statistics are collected by the CSO[2]. These data divide registrations of private cars into 10 different engine size categories from 1965. Data are provided monthly but have been aggregated to annual observations for this paper. These data initialize our model and allows us to compute a stock (after correcting for scrappage).

Our other main data source is the anonymised 2004/05 Household Budget Survey (HBS), which is a survey of a representative sample of private households in Ireland. In 2004/05, 6,884 households participated in the survey which was carried out by the CSO. This survey has many transport related variables including the number of cars per household, the amount spent on different fuel types and the amount of motor tax paid per household. Motor Tax rates in 2004 were the same for both petrol and diesel powered cars. We compared the summary statistics of the HBS with information available from the 2006 Census. The comparisons are shown in Table 1. Although

[1] CSO data based on Vehicle Licensing Statistics
[2] Available on CSO website

there is a disparity in the some of the variables, this difference is not substantial. In terms of fuel type, the sample is representative of our Department of Transport data for the year 2004, the year of the survey.

In July 2008, the car taxes changed. Taxation levels are now based on (expected) emissions per kilometre rather than engine size. Thus, both Vehicle Registration Tax and Motor Tax rates were changed into seven bands with Band A representing the lowest emission band. We have constructed concordances (Table 2) for both petrol and diesel powered cars in line with recent new car registrations. The major shift towards midsize diesel cars (E-H in ISus categories) is evident here with a significant decrease in tax incidence apparent.

The CSO vehicle licensing data was disaggregated by fuel type only in 1997. This disaggregation was not broken down into engine size components. Thus, we used a different source of data to compute the stock of diesel cars. As of 2009, this registration data is available by fuel type, emission band, make, and price and engine size. We used data obtained from the Department of Transport which gives detailed information on the stock of cars in Ireland from 2001-2007 by fuel type, engine size and age. From the Bulletin of Vehicle Licensing Statistics, we know total diesel sales in each year back to 1986. To interpolate the new vehicle registrations of diesel cars from these data sources, we assume that the scrappage overtime of petrol and diesel cars are equal. From this we can then compute new registrations of diesel cars from the period 1985 to present. We initialise our diesel car stock in 1985 and build up our diesel stock in the same way as the total stock.

2.3 Fuel Efficiency

Data on fuel efficiency is constructed using two different sources. The most recent data is taken from Sustainable Energy Ireland (SEI) and is available for 2000 up until 2007. This dataset provides estimates of fuel efficiency by fuel type and by engine size (at a more disaggregated level than CSO engine size categories).This fuel efficiency data has been constructed by weighting new car registrations with a database of new car attributes provided by the Vehicle Certificate Agency (VCA) in the UK. This data is based on test statistics so a 20% on-road factor is applied to account for normal road driving. In order to correspond to the CSO engine size categories, we simply compute average values for each CSO category. In this time period, there has been a steady improvement in terms of fuel efficiency in each engine category (Figure 1).

Since we initialise our stock of cars in 1965, we require historical data on fuel efficiency. No previous work in Ireland has investigated fuel efficiency back to this time. Some transport models[3] simply impose an assumed 1% fuel efficiency gain in each year from 1965. Using the Irish Times newspaper digital archives, we constructed a dataset of tested fuel efficiency for the years 1965-1999. The data was again averaged to correspond to the CSO categories (A-K). Categories E, F and G were combined to give an average fuel efficiency of this new category (1301-1600cc).

2.4 Distance and Age Distribution

Two other important variables needed in accessing the environmental impact of the car stock are the average distance travelled and the age distribution of this stock. The distance figures are taken from CSO estimates. These are based on odometer readings taken as part of the National Car Test[4]. This test is compulsory on all vehicles that are 4 years old or older. The CSO have merged this data with data collected on cars that are less than 4 years old which makes the sample more robust. This data is available for the years 1999-2008 and is disaggregated by fuel type and engine size. We assume a constant fuel efficiency of a car over its lifetime as in Kelly et al. (2009). This gives us the mean values for distance travelled but we can also examine distributional characteristics from this data. Figure 2 shows that the distance profile differs considerably across the engine classes.

Data on the age distribution of the car stock is taken from the Bulletin on Vehicle Statistics. This data analyses the stock of cars by its year of first purchase and thus provides information on the car stock disaggregated by 15 age categories and is examined for the time period 1986-2007. This data is used to compute the survival probabilities of the ISus Car model. We calibrate this parameter to represent the historical data. However, it should be noted that the presence of imports are observed in the data and this complicates the computation of a scrappage parameter. Figure 3

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[3] Tremove – a Transportation model designed for the European Union
[4] See Kelly et al. (2009) for a full description of the testing procedure

shows how the average age of the car stock decreased sharply up until the year 2000 and has slowly risen back to its level in 1986, our first year of car vintage data. It should be noted that these age averages are biased downward because no age distinction on vehicles that are 15 years old and cars that are older than this.

3. Model

3.1 Prevalence of Car Ownership

The notion of saturation is crucial in forecasting the future level of the car stock. At the saturation point, changes in the car total stock are directly proportional to the changes in the population or its demographic components.

HERMES is a macroeconomic model, used for making forecasts about the Irish economy, including a forecast of the car stock *C* at time *t* (Fitzgerald et al., 2002):

$$(1) \qquad \Delta \ln \frac{0.8}{C_t / P_t \text{-} 1} = \alpha + \beta \frac{Y_t}{P_t}$$

where *Y* is the level of disposable income and *P* is the population between 15 and 64. This model saturates the rate of car ownership at 0.8 cars per adult population and uses an error correction procedure to predict the car stock. This gives us a stock of private cars, forecasted out until 2025.[5]

3.2 Type of Car

Once we have a future level of car ownership, we then estimate what the share of this stock will be in terms of engine size. We use information from the Household Budget Survey (HBS) on expenditure on motor tax to establish the engine size of the car owned. We specify a multi-nominal regression with the 9 categories of engine size as the dependent variable and estimate an income elasticity for each engine size. We also ran separate regressions by fuel type and the estimates were very similar. Thus, we chose to use the aggregated income elasticities; see Table 4. We then use these

[5] Nolan (2009) estimates the drivers of car ownership from household data. Applying her equation to the same scenario of economic growth leads to an almost identical projection of the future car stock.

income elasticities to forecast the number of cars per engine size using information on future levels of disposable income, taken from the HERMES model.

The historical progression of the diesel car stock in tracked in the model but we cannot simply extrapolate this trend out to predict the future size of the diesel car stock due to recent policy changes. This has essentially caused a structural break in the series. For this reason, we apply a breakeven distance methodology[6] along with information on the mileage distribution by engine size, to forecast the diesel car stock by engine size. This works as follows. Diesel cars are more expensive to buy and to own, but cheaper to drive. So, a diesel is more attractive to people who drive long distances – anyone who drives more than the break-even distance. The mileage distribution function specifies the fraction of the population who drive more than any distance, and thus also gives the market share of diesel cars. This type of approach has been used previously to explain the share of diesels in new car sales (Rouweldal, 1999; Mayeres and Proost, 2001). Similar approaches have also been used to examine the model share of rail in freight choice (Van Schijndel et al., 2000). Existing research (Mayeres and Proost, 2001; Verboven, 2002) on the share of diesel cars is limited by the assumption that all diesel cars are homogenous and will be distributed evenly across all engine classes. Our methodology is disaggregated by engine size which allows us to predict the diesel share in each of the engine classes that have been constructed within the model.

We estimate these using various data sources on new cars to construct representative cars. This gives us computed Break-Even distance figures for each engine class. However, this alone tells us little about the rational share of diesel sales. We use mileage distribution data to compute these diesel market shares. This distribution data shows that there are clear differences in the driving profiles of the different engine classes. This allows us to compute a market share for each engine class.

6 A mathematical derivation of the Break-Even distance is detailed in the appendix.

3.3 Stock Demographics

The car demographic model distinguishes 10 engine sizes and 25 age classes. The dynamic equations are

(3a) $C_{t,1,s,f} = S_{t,1,s,f}$

(3b) $C_{t,a,s,f} = \left(1-\rho_{t,a,s,f}\right) C_{t-1,a-1,s,f}; a = 2,3,...,24$

(3c) $C_{t,24,s,f} = \left(1-\rho_{t,24,s,f}\right) C_{t-1,24,s,f} + \left(1-\rho_{t,25,s,f}\right) C_{t-1,24,s,f}$

where $C_{t,a,s,f}$ is the stock of private cars in year t, of age a, of engine size s and of fuel f; S is the sales, and

(4) $\rho_{t,a,s,f} = 1 - \frac{0.015(a-1)}{1+0.03(a-1)}$

is the probability of scrapping which is independent of time, size and fuel.

The demographic model is driven by historical data on new car registrations starting in 1965 and a scrappage parameter which affects the probability of scrappage. Under the assumption that the life cycle of cars is no longer than 25 years, then the modelled car stock is representative of the real stock from 1990 onwards. From 1985, the diesel car model is initialized. The same dynamic equations are used and assuming that diesel cars last no longer than 15 years, then the model becomes representative of the population in 2000. The stock of petrol cars can then be simply calculated by differencing the two stock variables. Thus from 2000, the stock is representative of both fuel types and the corresponding total.

The scrappage parameter (ρ_a – Equation (4)) has been calibrated to the age distribution data taken from the Bulletin of Vehicle Statistics. The scrappage parameter is time invariant and assumes that the durability of cars remains constant.

3.4 Distance Model

For the distance driven per year, we follow Hayashi et al. (2001), accounting for the impact of change in the composition of the car stock. Specifically, distance D_i is given by:

$$(5) \qquad D_{t+1} = \left(1+\varepsilon_{i,t}\left(1-\frac{P_{t+1}}{P_t}\right)\right)D_t\Delta\frac{C_{i,j,t}}{C_t}$$

where C_{ijt} is the number of cars of size i and fuel j at time t; $\varepsilon_{i,t}$ is the price elasticity of distance travelled for engine size i in time period t. The elasticities are similar to those reported in Hayashi et al. (2001) [7]. In theory, this elasticity should be lower for higher engine sizes as the higher incomes associated with larger cars make the owners more inelastic in the consumption patterns. Conversely, the elasticity estimates are higher for small cars. This is indeed the case with elasticities on the 2 largest engine sizes not being statistically different from zero. We calibrated Equation (5) against data on distance travelled from the years 2000-2008 (See Table 6).

Thus, Equation (5) estimates distance driven by engine size and is driven by the elasticity estimate and the change in the relative price. This dynamic equation is weighted by the change in new car sales per engine class. This essentially takes into the account that changing consumer preferences for cars does not equal different preferences for vehicle kilometres travelled.

3.5 Emissions

To convert to emissions, we need to compute how many litres of each fuel is consumed. As we have approximated the composition of the car stock and the distance travelled, all we need is the fuel efficiency for each of representative cars.

From the SEI fuel efficiency estimates, we simply extrapolate the trend out to 2025. This combined with our earlier data gives a fuel efficiency estimate of each car by its engine size, age and fuel type. Since the National Car Test compels cars to remain road worthy, we also assume that there is no depreciation of cars in terms of fuel efficiency and that any significant effects of age on efficiency will result in scrappage. One litre of diesel fuel has greater emissions than one litre of its petrol substitution. The conversion factors are as in Howley et al., 2007a (see Table 7). Note that a litre of diesel takes one further, so that the emissions per kilometre travelled are lower for diesel cars (of equivalent size).

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[7] Hayashi (2007) reports price elasticity estimates of -0.23. This is the value for the entire stock and is not disaggregated by engine size. It is consistent with other short-run elasticity estimates like Goodwin et al. (2004) who estimates a mean price elasticity of -0.25.

4. Applications:

4.1 Baseline Projections:

The ISus Car Model described above calculates projections of the car stock by engine size, age and fuel type (Figure 4). The projections are driven by forecasts of the economy and the population (Bergin et al. 2009). These results show a small dip in the car stock due to the current depression, but steady increase in the car stock after 2010 when an economic recovery is expected. We project to have nearly 2.4 million private cars in Ireland by 2025. This represents a significant slow down in growth rates compared with the boom period. This is in line with earlier analysis of the convergence to a saturation rate that has been apparent in Ireland.

Between 1990 and 2008, the average engine size of the car stock increased significantly. Projections based on the income easticities suggest that this trend will continue once the economy recovers. See Figure 5.

There will be a minor increase in carbon dioxide emissions (Figure 6). The switch to diesel offsets the project increase in vehicle kilometres travelled. This is largely because of the tax reform of 2009, without which CO2 emissions would be almost one million tonnes higher in 2025. Stabilisation of emissions, however, would still exceed the government target on emissions from private car transport.

4.2 The effects of tax reform

In July 2008, the car tax system in Ireland was revamped so that the tax rates are now based on the emissions of the vehicle in contrast to the engine size. Monthly sales data from the CSO show a very significant increase in the market share of diesel cars. Figure 7 shows how this change in market share evolves over time and feeds into the car stock. The share of diesel car grows considerable. This implies an improvement in the car stock efficiency (Figure 8) and reduces associated emissions (Figure 6). These emissions will only transpire if the increase in diesel share has no effect on average vehicle kilometres travelled.

The diesel market shares in each engine class are estimated using the break-even distance methodology described previously. As can be seen from Table 6 and in

Figure 9, the effect is especially strong on mid size diesel cars. Conversely, there is little effect on small cars with an engine size less than 1.3 litres. The key aspect is the differences across engine classes in terms of the mileage distribution. Consumers who drive a lot place a greater weight on efficiency than consumers who drive little; those who drive more than the break even point will chose a diesel fuelled car. The lower driving costs make up for the higher price of the diesel car.

4.3 The prospects for electric vehicles

Recent government announcements have praised the ability of electric vehicles to curb fossil fuel consumption and lower carbon dioxide emissions from private car transport. The current government target is that 10% of all vehicles in the private car stock be fully electric by 2020. At present, the car stock includes a small amount of hybrid vehicles and a smaller amount of plug-in hybrids.

To examine the impact of electric vehicles on the car stock in terms of its efficiency and emissions, we run various scenarios where a certain percentage of new car sales are electric. We make assumptions about fuel efficiency of electric vehicles along the lines of best current thought (Smith, 2009; see Figure 1). Reflecting government policy, we examine solely Battery Electric Vehicles (BEV's) as opposed to plug-in hybrid vehicles.

The penetration of electric vehicle depends on replacement rates within the current stock. The effect on emissions depends on what cars are replaced by BEV's. Our model does not allow us to examine whether these new BEV's replace old high emitting vehicles or are they only purchased by environmental sensitive consumers who already had a relatively low emission vehicle already. A discrete choice model of consumer preferences to assess the impact of the consumer on BEV purchase along the lines of Train et al. (1999) would be required. We would also need detailed information on the various attributes of electric vehicles. As such information is not available, we instead run simulations of electric vehicle sales taking into account what they replace and how certain targets will be reached in terms of market share of sales.

The scenarios are described below and all assume that electric vehicles make up about 10% of the car stock by 2025.[8]

- Scenario 1 is based on a constant 10% market penetration from 2012-2025. The share of electric vehicles is distributed equally across other fuel types and engine sizes.

- Scenario 2 is based on a growth rate of 10% in the share of electric vehicles with initial market penetration being 5% in 2012. Again, these electric vehicles are distributed equally across other fuel types and engine sizes.

- Scenario 3 is based on a market penetration as in Scenario 1 but these electric vehicles predominantly replace cars that emit most (such as petrol SUVs).

- Scenario 4 is again based on a market penetration as in Scenario 1 but electric cars replace low emitting cars (such as small petrol and medium diesel cars).

Figure 10 shows the effect on emissions. BEV's reduce emissions in all scenarios. However, the effect is small if BEV's disproportionally replace small cars, as seems likely given that electric cars are small and light. This means that not alone do we end up replacing the most efficient cars but we also end up replacing ones that have the lowest average driving distances. This highlights the importance of modelling a disaggregated car stock when making policy conclusions.

We assume that all electric vehicles are homogenous in terms of emissions. The fuel mix of the electrical generation sector is crucial when computing the emission directly attributable to electric vehicles. In turn, this potential fuel mix may be determined by the way in which electric vehicles are used and subsequently recharged. Leahy et al. (2009) highlight the mutual benefits of increasing wind power and electric vehicle penetration. When electric vehicles are recharged at night, excess capacity that is generated by wind power can help meet this demand and this greatly reduces the associated emissions. These factors mean there is a certain level of uncertainty in our estimation of emissions from the electric car fleet. We estimate that the electric vehicle stock, which accounts for 10% of the total stock in 2025, will account for between 2-3% of total vehicle emissions (Figure 11). This shows the

[8] Current government policy aims to meet this target by 2020

potential of electric vehicles to reduce emissions, assuming that they are used efficiently and the power generation sector increases its share of renewables in time.

4.4 Scrappage Scheme

In Budget 2010, a car scrappage scheme was introduced. This amounted to a subsidy (in the form of a VRT reduction) of €1500 on the purchase price of a new car in exchange for the scrappage of a car greater than ten years old. The model does not explicitly consider the decision to scrap a cap; see Equation (4). Nonetheless, we have knowledge of some of the most important factors. The number of cars that are 10 years or older has greatly increased since 2000 (Figure 3). We examine the impact of the scrappage scheme by changing our scrappage parameter for vehicles with age greater than 10. We increased the probability of scrappage for all vehicles that are ten years or older by 5 per cent. This change has little effect on overall emissions, because the number of extra cars replaced due to the scrappage scheme is extremely small when compared with the total car stock. In terms of emissions, the recent scrappage scheme will have little or no effect (Figure 12).

5. Discussions and Conclusions

We construct a model of private cars by age, engine size and fuel type to examine CO_2 emissions from transport in Ireland. We find that emissions from private cars are likely to continue to increase over the next 15 years, albeit at a slower rate than in the past. The rise in emissions is due to an increasing car stock and a preference for larger cars. This is partly offset by the switch towards diesel cars. The 2009 reforms of the vehicle registration tax and motor tax have substantially increased the market share of diesel engines. This structurally improves the fuel efficiency of the car stock over time, but as distances driven do not change (and indeed may even increase), the drop in emissions is limited. Emissions in 2020 will be well above the policy target.

The expected characteristics of electric vehicles are such that they will likely substitute already relatively efficient cars. Therefore, the government's target of a 10% share of all-electric cars by 2020 will have a minimal effect on carbon dioxide emissions. The impact of the scrappage scheme for old cars is even smaller because few cars are eligible.

There are caveats to the results in this paper. The car choice model is simple, and should be replaced with a more realistic representation of car purchases and how they respond to prices, taxes, and technical specifications (e.g., range). This would require micro-data and econometric analysis that is well beyond the scope of the current paper. Our specification of car scrappage is simple, probably too simple. However, we are not aware of data that would permit a more realistic model. The model similarly lacks a representation of the market in used cars. All this is deferred to future versions of the model. Transport is, of course, wider than the ownership of private cars. Freight accounts for about half of transport emissions in Ireland. The current paper also leaves to future research biofuels, modal choice, and settlement and lifestyle patterns that drive mobility. In the long term, these factors may have a greater effect on emissions than the three policy options explored in the current paper.

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Appendix: Breakeven Distance Model of Fuel type choice:

The cost of a car consists of the cost of purchase, operation, maintenance, and sell value:

(1) $$C_i = P_i(1+\alpha_i) + \beta_i + \sum_{t=0}^{T_i} \frac{M_{i,t} + \gamma_{i,t} + \left(\pi_{i,t} + \delta_{i,t}\right)\varepsilon_{i,t} D_t}{\left(1+\rho\right)^t} - \frac{S_i}{\left(1+\rho\right)^t}$$

where

- C_i is the net present cost of a car of type i;
- P is the purchase price;
- α is the value added tax and stamp duty;
- β is the vehicle registration tax;
- M is the annual maintenance;
- γ is the annual motor tax;
- π is the price of fuel;
- δ is the excise duty on fuel;
- ε is the fuel efficiency of the car;
- D is the annual distance drive;
- ρ is the discount rate;
- T is the life-time of the car; and
- S is the sell value of the car.

If we hold all parameters constant over time and at their current value (as a car buyer might), then (1) simplifies to:

(2) $$C_i = P_i(1+\alpha_i) + \beta_i + \frac{(1+\rho)^{T_i} - 1}{(1+\rho)^{T_i}} \frac{1+\rho}{\rho} \left[M_i + \gamma_i + \left(\pi_i + \delta_i\right)\varepsilon_i D\right] - \frac{S_i}{\left(1+\rho\right)^{T_i}}$$

When choosing for a car that is more expensive to buy but cheaper to drive (a diesel, that is) but has the same life-time, the break-even distance is then given by:

(3) $$D^* = \frac{\frac{(1+\rho)^T}{(1+\rho)^T - 1} \frac{\rho}{1+\rho} \left[\Delta\left(P(1+\alpha)\right) + \Delta\beta - \frac{\Delta S}{\left(1+\rho\right)^T}\right] + \Delta M + \Delta\gamma}{\Delta\left((\pi+\delta)\varepsilon\right)}$$

where the Δs denote the difference between car type i and j.

Table 1. Fraction of the population that own no car, one car, two cars, or three or more cars according to three alternative sources.

No. of Cars	0	1	2	3
Census2006	0.20	0.38	0.33	0.09
Census2002	0.22	0.41	0.30	0.07
HBS 2004	0.18	0.46	0.31	0.05

Table 2. Tax rates before and after the 2009 reform.

Diesel						Petrol					
Tax[a]	ISus	VRT[b]		MT[c]		Tax[a]	Isus	VRT[b]		MT[c]	
		bef	aft	bef	aft			bef	aft	bef	aft
A	A	22.5%	14%	165	104	A	A	22.5%	14%	165	104
B	B	22.5%	16%	165	156	B	B	22.5%	16%	165	156
B	D	22.5%	16%	275	156	B	D	22.5%	16%	275	156
B	E	25%	16%	320	156	C	E	25%	20%	320	302
B	F	25%	16%	343	156	D	F	25%	24%	343	447
B	G	25%	16%	428	156	D	G	25%	24%	428	447
C	H	25%	20%	550	302	E	H	25%	28%	550	630
E	I	30%	28%	800	550	F	I	30%	32%	800	1050
G	J	30%	36%	1150	2100	G	J	30%	36%	1150	2100

* This table shows how the engine size classes in the ISus car model (A-J) are transformed into new emissions bands (A-G). Note this is an illustrative example. The concordance table used to create emissions bands is based on actual sales in 2008-2009. This shows that petrol with the same engine size do not necessarily end up in the same emission bands

[a] Classification in the tax code

[b] Vehicle Registration Tax, ad valorem

[c] Motor Tax, specific duty, €/year

Table 3: Income Elasticities

Engine size	Income semi-elasticity	
	Mean	St.dev
<900 cc	-0.3301	0.0934
900-1000 cc	-0.3301	0.0934
C	Not observed	
1001-1300 cc	Not observed	
1301-1400 cc	-0.0898	0.0808
1401-1500 cc	-0.0640	0.1029
1501-1600 cc	0.4114	0.0874
1601-2000 cc	0.5691	0.0861
2001-2400 cc	0.7287	0.1220
>2400 cc	1.1377	0.1938

Table 4: Average distance (1000 kilometre per year) by fuel type and engine size

Mean Distance for Petrol Cars										
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
<900 cc	10.9	11.0	10.9	10.5	10.2	9.8	9.6	9.1	8.9	8776
900-1000 cc	13.9	14.0	14.1	13.6	13.5	13.2	13.0	12.4	12.2	11883
1001-1300 cc	14.4	14.5	14.6	14.2	14.0	13.8	13.5	13.1	12.9	12623
1301-1400 cc	17.2	17.4	17.3	17.0	16.8	16.5	16.3	16.0	15.7	15520
1401-1500 cc	19.8	20.2	20.0	19.0	18.8	18.4	18.1	17.5	17.3	17154
1501-1600 cc	19.5	19.5	19.5	19.0	18.8	18.5	18.4	18.1	18.0	18046
1601-2000 cc	19.6	19.6	19.4	18.8	18.5	18.4	18.4	18.2	18.2	18275
2001-2400 cc	20.5	20.3	19.9	19.1	18.9	19.0	19.1	18.9	19.1	19634
>2400 cc	17.8	17.8	17.8	17.2	17.0	16.8	17.1	16.9	17.2	17176
Mean Distance for Diesel Cars										
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
<900 cc	34.5	33.1	33.1	33.5	29.7	29.2	33.5	35.3	36.5	33923
900-1000 cc	11.3	11.9	12.9	13.9	13.7	12.8	12.8	12.6	12.4	12427
1001-1300 cc	17.7	18.3	20.9	19.3	20.0	20.6	20.9	20.9	21.6	21970
1301-1400 cc	18.6	18.5	17.7	21.0	22.3	23.0	23.7	24.4	24.6	24382
1401-1500 cc	23.1	23.1	22.1	20.2	21.2	22.3	22.2	22.6	22.8	23744
1501-1600 cc	22.4	21.3	19.1	17.9	16.9	17.2	17.6	17.6	19.0	20114
1601-2000 cc	26.5	26.8	26.7	26.1	25.6	25.4	25.2	25.1	25.0	25625
2001-2400 cc	27.4	27.7	27.9	27.4	27.4	27.4	27.8	27.8	27.7	28300
>2400 cc	25.6	25.8	25.9	25.5	25.4	25.4	25.6	25.4	25.4	26181

Source: CSO

Table 5: Effect of tax reform on break-even distance

	year	
Engine size	2007	2008
< 900 CC	50.7	51.6
901-1000 CC	50.7	51.3
1001-1300 CC	27.2	23.5
1301-1400 CC	26.4	18.3
1401-1500 CC	21.2	9.7
1501-1600 CC	27.5	14.4
1601-2000 CC	14.0	8.6
2001-2400 CC	18.1	5.6
> 2401 CC	17.8	10.3

Table 6: Emission coefficients.

Fuel	Consumption	Emissions
Petrol	1 litre	2.31 kg CO_2
Diesel	1 litre	2.68 kg CO_2

Source Howley, M., O'Leary, F., & Gallachoir, B. 2007

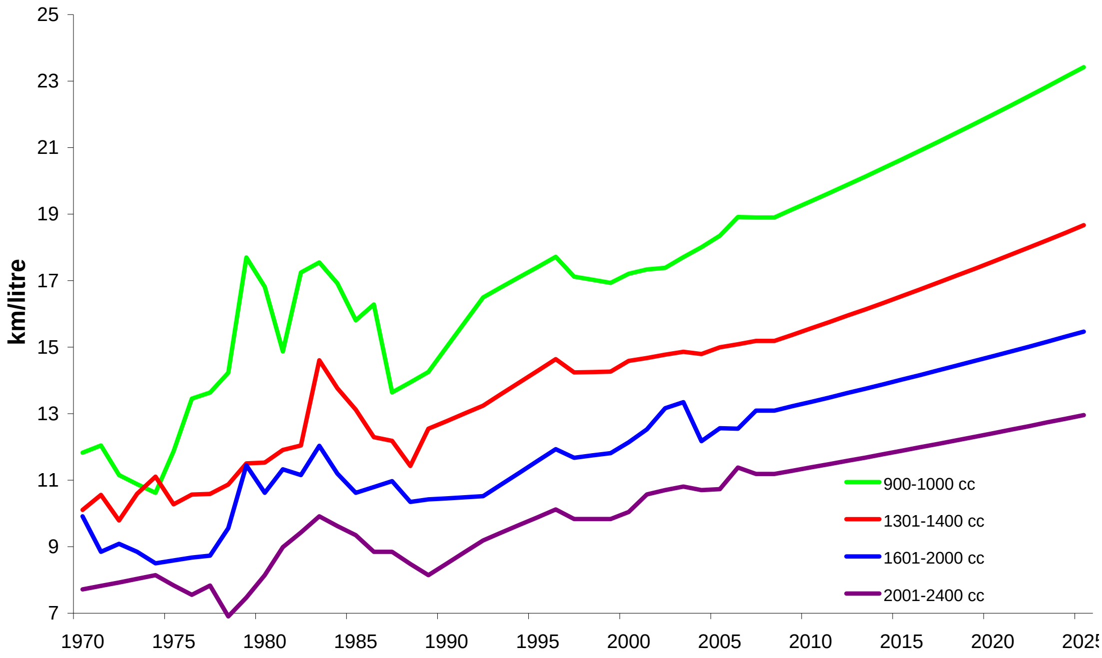

Figure 1. Fuel efficiency of new cars per petrol engine size.

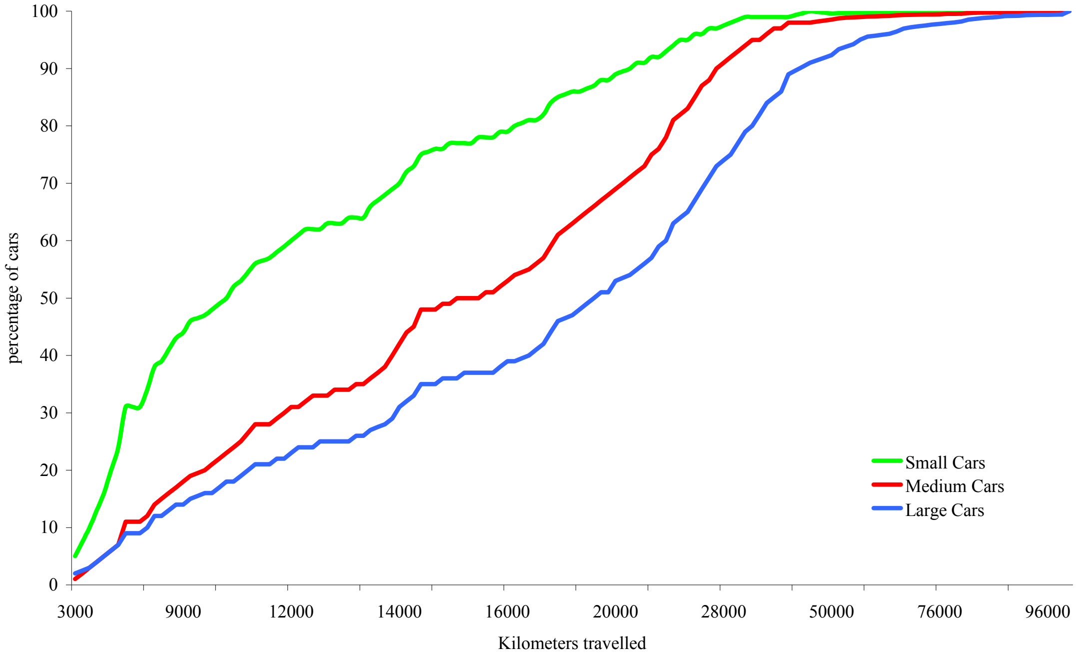

Figure 2: Cumulative distribution of mileage by engine size

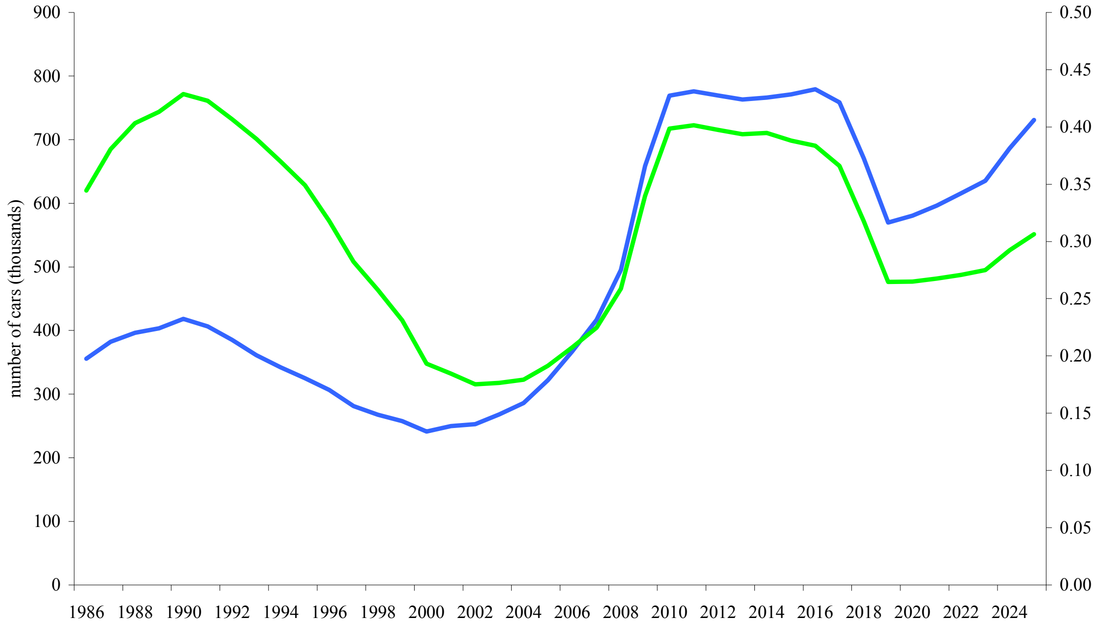

Figure 3: The number of cars that are 10 years old or older (left axis) and the fraction of the total car stock (right axis).

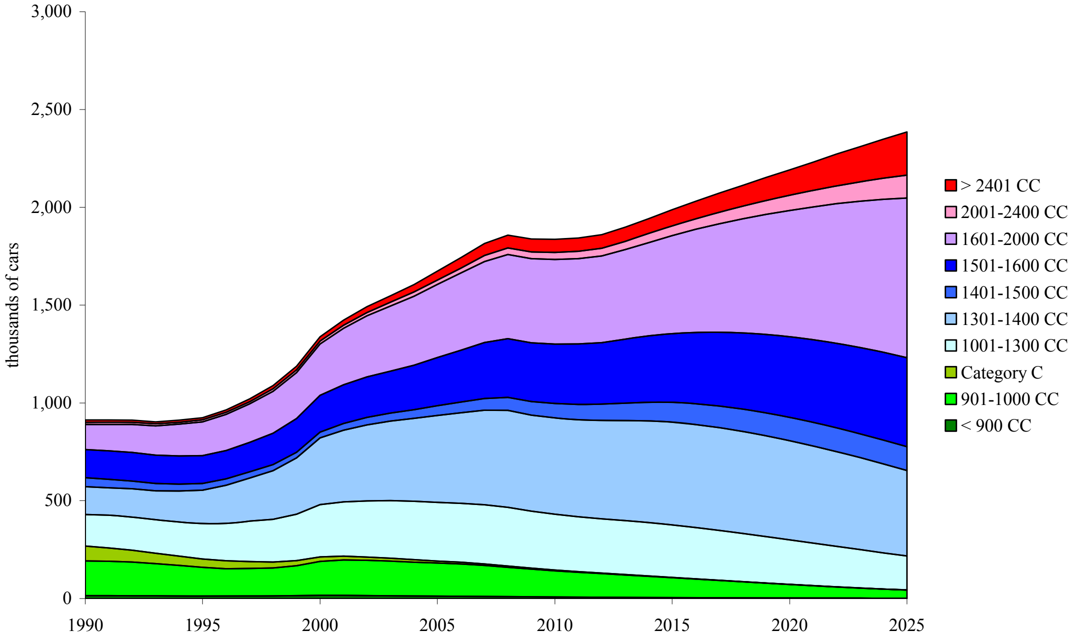

Figure 4: The observed and projected number of cars by engine size

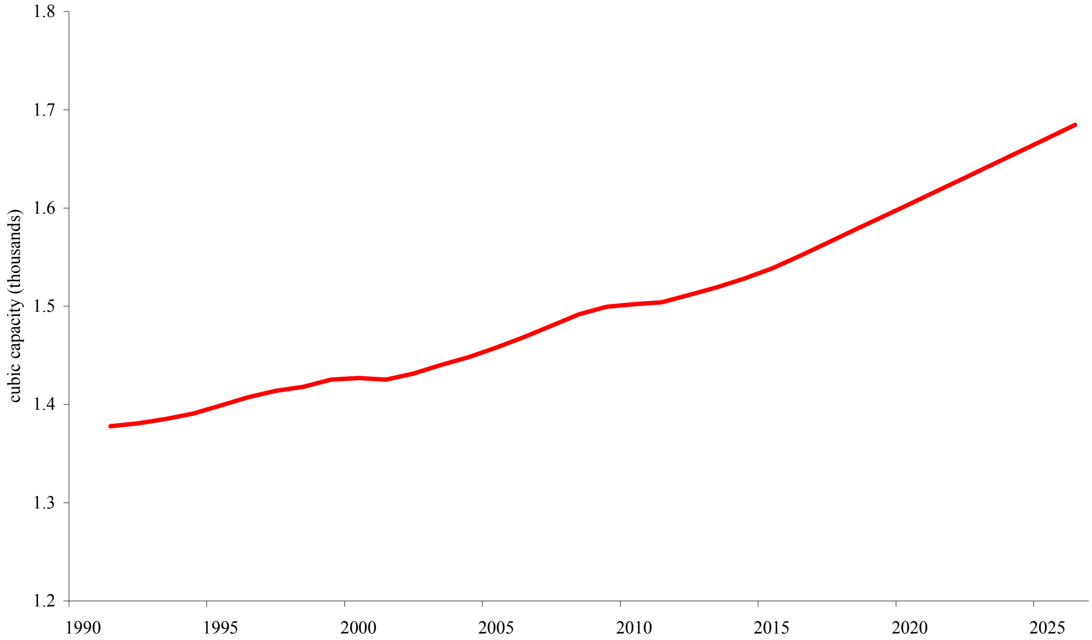

Figure 5: The average engine size of the car stock

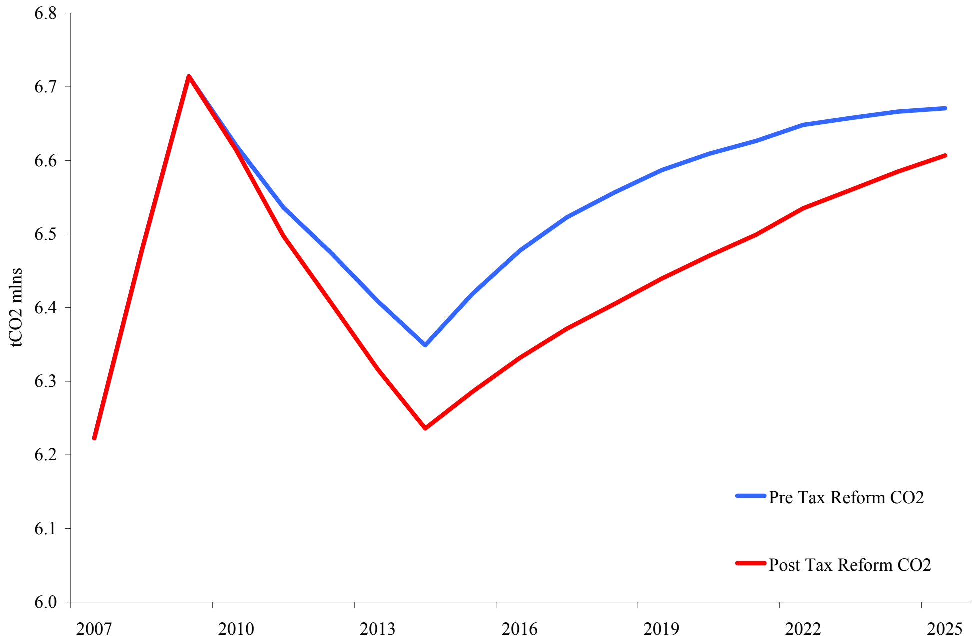

Figure 6: The effect of tax reform on CO_2

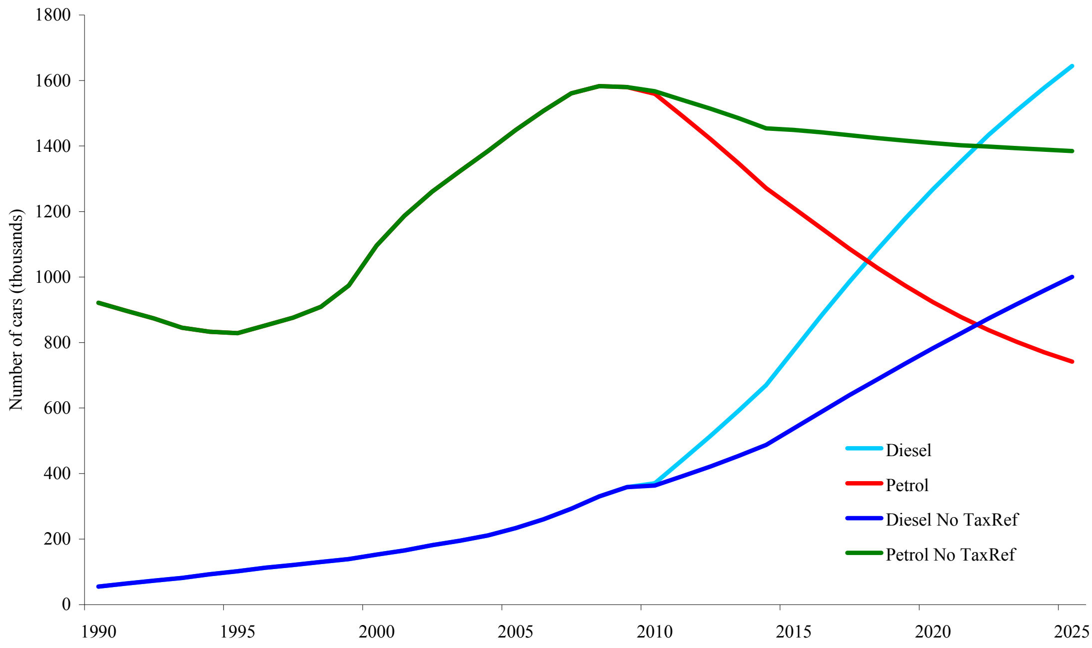

Figure 7: The impact of the recent tax reform on the number of diesel and petrol cars

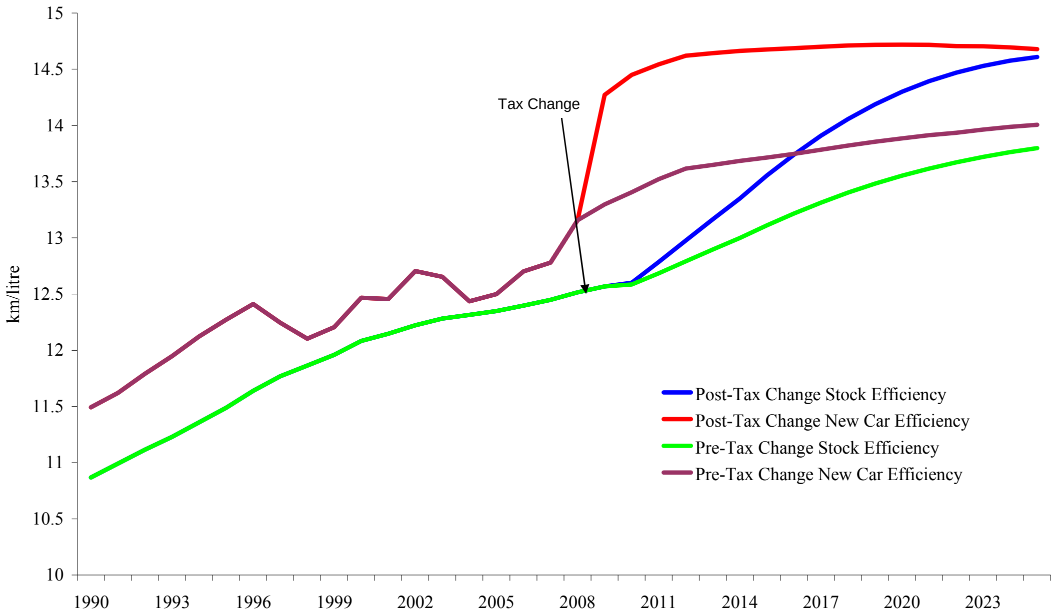

Figure 8: The effect of tax reform on the efficiency of the car stock

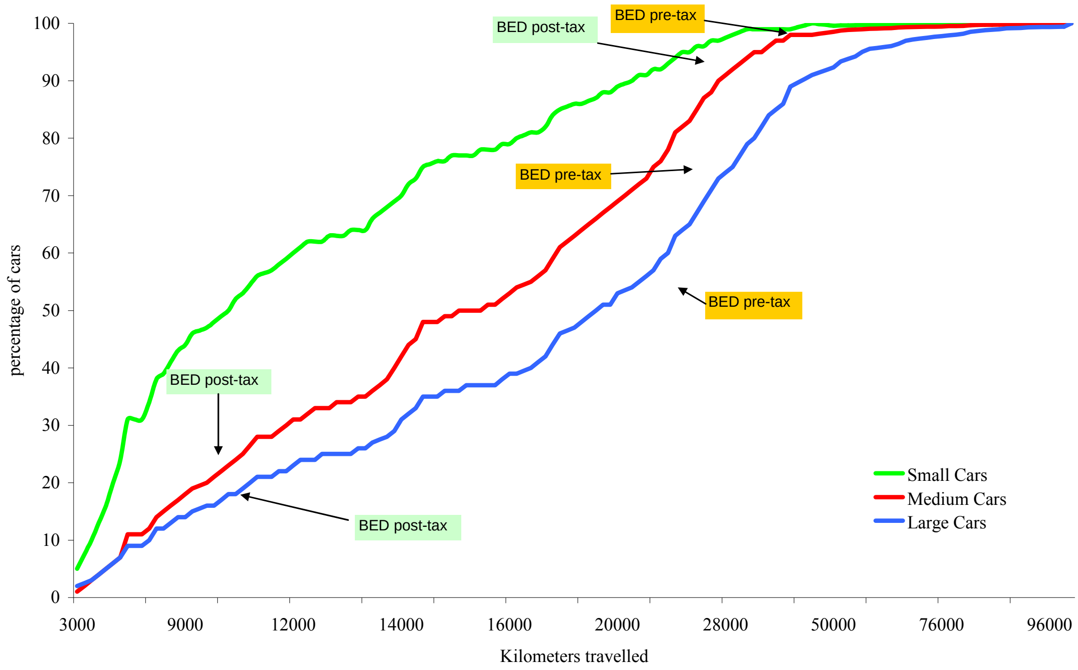

Figure 9: The effect of tax reform on break-even distance

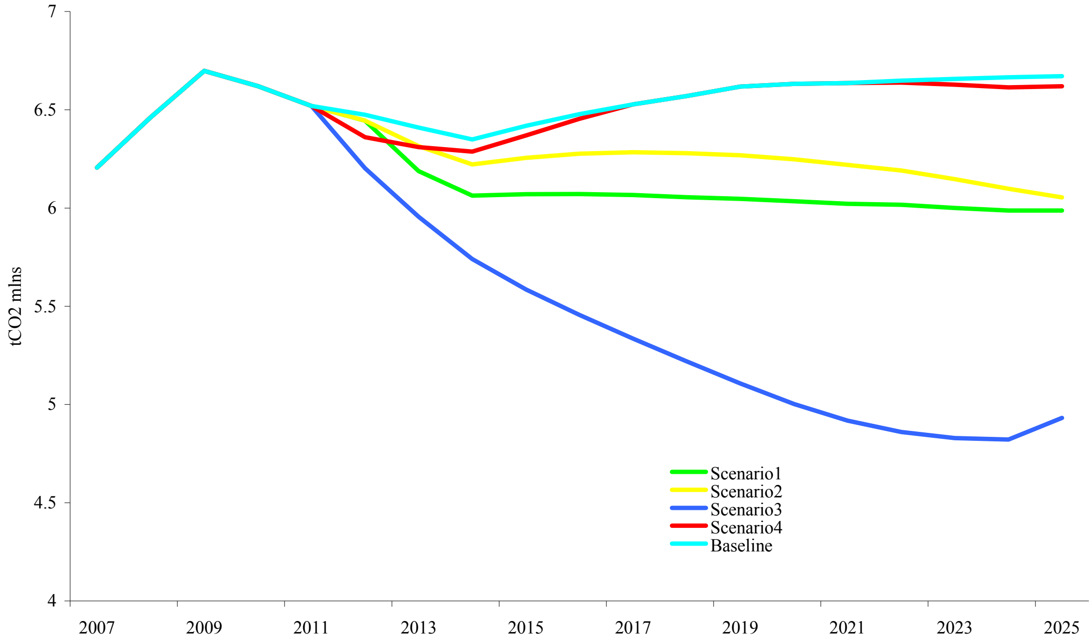

Figure 10: The effect of electric vehicles on carbon dioxide emissions

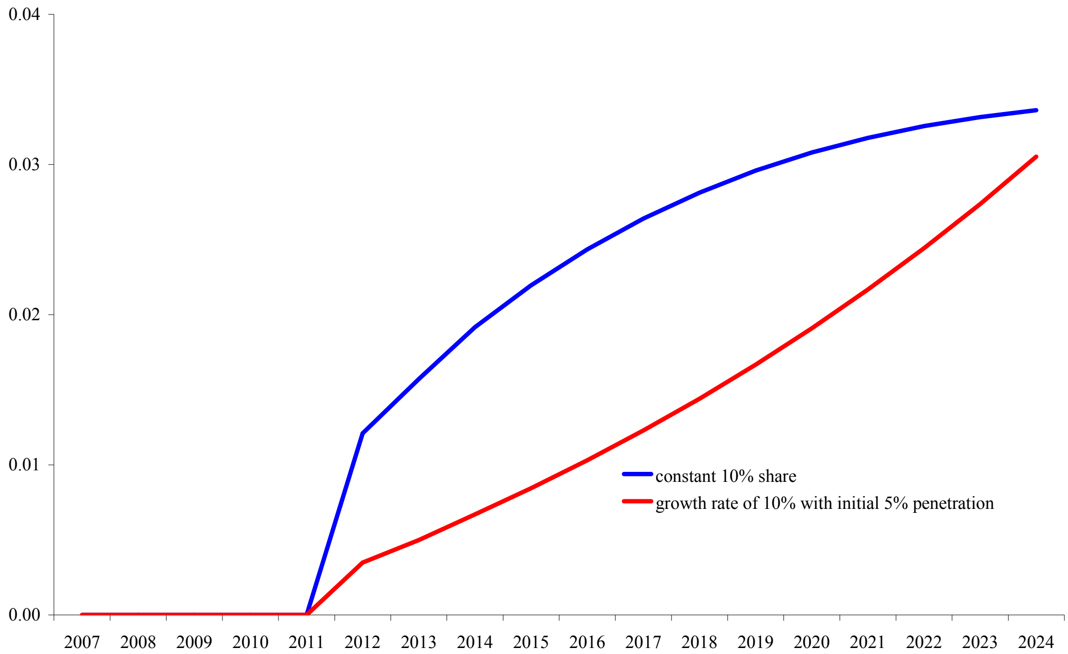

Figure 11: Shares of total private car transport emissions

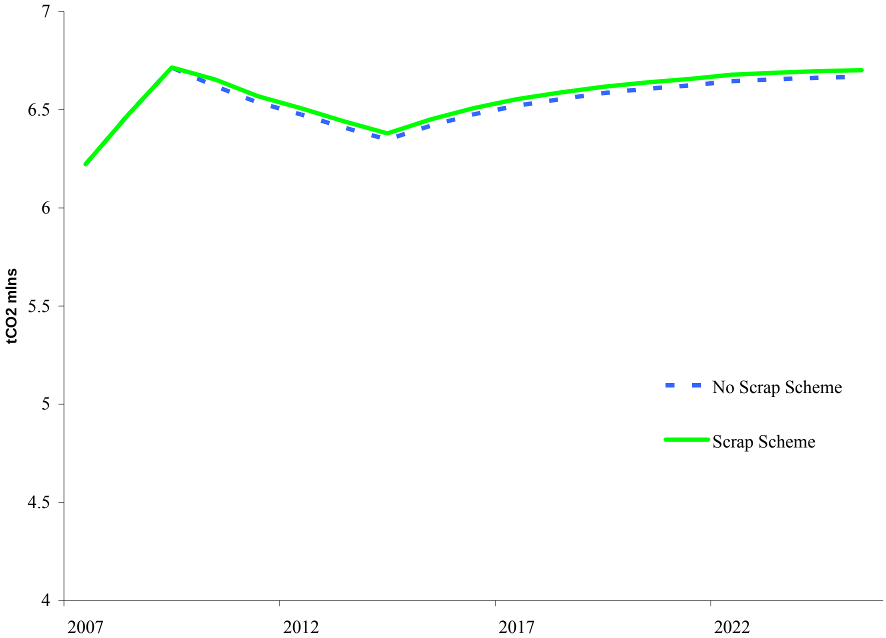

Figure 12: The effect of the scrappage scheme on carbon dioxide emissions

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