Vehicle Tax Design and Car Purchase Choices: A Case Study of Ireland

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Abstract

This paper utilises a difference-in-differences model to study the impact of a vehicle tax reform on purchasing choices over a period of 10 years. In line with many other European countries, on the 1st of July 2008 the motor taxation regime in the Republic of Ireland was reformed to try and stem rising CO2 emissions from the passenger car fleet. To achieve this, both vehicle purchase and circulation taxes switched from an engine capacity basis to a CO2 emissions rating per kilometre basis. The aim of this study is to quantify the effectiveness of this (and subsequent) vehicle policy changes at achieving this goal. Using a difference in differences quasi-experimental design, we attempt to recreate the missing counterfactual (in the absence of the policy change(s)) of vehicle purchasing patterns in Ireland using the trend in UK new passenger car emissions over the same period. The findings suggest that the initial taxation policy change reduced average rated CO2 emissions from new passenger cars by between 8 to 11 g CO2/km. Some subsequent policy changes, such as the introduction of a scrappage scheme in 2010 also had an impact at stimulating the purchase of lower-emitting vehicles. This effect however was achieved by a substantial switch towards diesel powered vehicles, with other consequences for the environment, and a significant drop in tax revenue for the exchequer.

keywords: vehicle taxes, externalities, difference-in-differences models, passenger cars, CO2 emissions

1 Introduction

In the EU, roughly 12% of total CO2 emissions come from passenger car use, which is also the main cause of local air pollution in cities (EEA 2018). Pollution from passenger cars is a classic example of a negative externality - which is typically defined as cost borne by a party (or parties) not involved in the original market transaction.[1] From an economic perspective, the existence of externalities associated with passenger car use gives justification for government intervention (Parry, Walls, and Harrington 2007). Typically, governments attempt to correct for such externalities using fuel taxes, vehicle standards and/or purchase taxes/subsidies. Revenue generated from taxation is also used in the provision of public goods such as road infrastructure and maintenance.

Of all of the externalities associated with passenger car use, local and global environmental pollution associated with the emissions produced by internal combustion engines has received particular attention by governments in recent years. Of the 28 members of the European Union, 20 member states levy passenger car taxes which are partially or totally based on the cars' CO2 emissions and/or fuel consumption (ACEA 2018).

In 2008, the Irish government changed its basis for vehicle taxation from engine capacity to a carbon dioxide (CO2) emissions rating per kilometre (Ryan, Kelly, et al. 2018). The policy shift was announced in the budget for 2008 as part of a broader package of environmental measures which included stricter standards for the energy efficiency of light-bulbs and proposals for carbon taxation (O'Halloran 2007). The introduction of the new vehicle registration tax (VRT) and annual motor tax (AMT) regimes came at a time when the private vehicle fleet was responsible for a rising share of CO2 emissions in Ireland, accounting for 12% of total emissions in 2006 (O'Gallachoir et al. 2009). This initial policy change was however, only the start of series of vehicle policy changes aimed at stimulating the purchase of low-emitting vehicles.

The purpose of this paper is to attempt to quantify the effect of this transition in the vehicle taxation system in Ireland on car purchasing behaviour, and to disentangle the effect of subsequent vehicle policies. We do this in two steps. First, using a difference-in-difference quasi-experimental design, we examine the effect of the taxation regime changes on the rated CO2 emissions of newly registered passenger cars. The findings suggest that the initial policy change in 2008 is responsible for reducing the fleet average CO2 emissions rating of newly registered passenger cars in Ireland by roughly between 8 to 11 gCO2/km. Some subsequent policy changes (such as the introduction of a scrappage scheme) have also had an effect at stimulating the purchase of low-emitting vehicles.

[1] Although the environmental externalities associated with passenger car use typically receive the most attention, they are not the only cost imposed on third parties. Other externalities associated with passenger car use include: congestion, oil dependence, accident risk, noise and obesity. (Parry, Walls, and Harrington 2007)

Secondly, we go further and attempt to identify the underlying reason for this effect by examining the type of vehicles purchased in terms of fuel type. What we find is that the decrease in rated emissions is driven by a significant shift towards diesel-powered vehicles, with resulting increases in other types of pollutants such as NOx emissions. This highlights the potential for trade-offs in policy outcomes unless full impact analysis is carefully undertaken ex-ante.

The rest of this paper is organised as follows: Section 2 provides some background to the policy transition and previous literature. Sections 3 and 4 present the data and methodology used in our analysis. Section 5 presents the results of our study, and Section 6 provides some conclusions.

2 Policy Background and Related Literature

Vehicle taxes are implemented in Ireland through two mechanisms: (1) a one-time tax at the time of vehicle purchase, called the vehicle registration tax (VRT), calculated as a percentage of the Open Market Selling Price (OMSP) but effectively hidden in the car price; and (2) an annual ownership tax called the annual motor tax (AMT), payable in instalments or as an annual tax. The transition to CO2 emissions-based vehicle taxation in Ireland involved a combination of changes to these two schemes, with the fundamental shift occurring in 2008, followed by subsequent incremental changes. Before 2008, vehicle taxes were levied on the basis of engine capacity. This paper examines the effects and outcomes of each phased change, as listed in Table 1. This provides a comparative basis for quantifying the impact of individual policy adjustments, in addition to the overall change from engine size to emissions rating.

Table 1: Policy Implementation for Emissions-Based Vehicle Taxation

Policy Phase	Effective Date	Summary of Change
Initial Policy Implementation	1st July 2008	Transitioned from engine capacity to CO_2 emissions taxation basis and introduced initial A-G emissions ratings for VRT and AMT
Interim Policy Change A	1st January 2009	Slight increases (4-5%) in AMT amounts and no change to VRT
Interim Policy Change B	1st January 2012	Substantial increases (up to 54%) in AMT amounts and no change to VRT
Final Policy Change	1st January 2013	Introduction of graduated A and B ratings (A0, A1, A2, A3, A4, B1, B2) and introduction of lower AMT rate for electric vehicles

Even a cursory examination of the data would indicate that the vehicle tax reform had a significant effect - the share of A- and B-rated cars (see Table 2 for definition) grew from just 17% in 2007 to approximately 90% of new cars

sold in 2011, and VRT and AMT revenues fell by 71% and 2.4%, respectively over the same period (Department of Finance 2012). While the 2008 economic crisis most certainly played a role in depressing total car purchases (new car sales had dropped by more than half from 2007 to 2010), the government noted that the high share of lower-emitting vehicles contributed considerably to the fall in revenues. As a result, the Department of Finance announced substantial AMT rate increases, as part of the 2012 national budget, with a rise of 54% and 44% in tax for A- and B-rated cars, respectively, and smaller increases (7-8%) for vehicles in higher bands, as shown in Table 2.

Table 2: Interim Policy Adjustments

			1st July 2008		1st Jan 2009		1st Jan 2012		1st Jan 2013	
Category	Lower Limit(>)	Upper Limit(<=)	AMT(€)	VRT(%)	AMT(€)	VRT(%)	AMT(€)	VRT(%)	AMT(€)	VRT(%)
A0	0	0	100	14	104	14	160	14	120	14*
A1	1	10							170	14
A2	80	100							180	15
A3	100	110							190	16
A4	110	120							200	17
B1	120	130	150	16	156	16	225	16	270	18
B2	130	140							280	19
C	140	155	290	20	302	20	330	20	390	23
D	155	170	430	24	447	24	481	24	570	27
E	170	190	600	28	630	28	677	28	750	30
F	190	225	1000	32	1050	32	1129	32	1200	34
G	225		2000	36	2100	36	2258	36	2350	36

In 2013, the government updated the emission bands more dramatically, creating several subcategories to capture the evolving variation in performance among highly rated cars. The 2013 changes included a more granular scale for A and B rated cars, as shown in Table 2, and reduced AMT for electric vehicles (EVs). EVs were already eligible for VRT relief of up to €5 000 for fully electric vehicles and €2,500 for plug-in hybrid cars. Whilst the 2012 changes to AMT and VRT rates were simple rate increases, the introduction of new vehicle ratings (A0, A1, A2, etc.) represented a more visible signal to consumers.

Concurrent with the period during which the Irish Government made adjustments to the rated emissions bands under the VRT and AMT schemes, officials also introduced a scrappage scheme intended to stimulate the purchase of new vehicles in Ireland in the wake of the 2008 economic recession. The conditions of the scheme were such that cars aged 10 years or older were eligible for VRT relief of up to €1,500 when traded in for a new vehicle, provided that the new vehicle was A or B rated (i.e. rated at CO2 emissions of 140g/km or less). The scheme was initially slated to run until 31 December 2010, and was subsequently extended until 30 June 2011, albeit at a reduced rate of €1,250 from 1 January 2011 (Citizens Information 2010).

In terms of policy interactions, CO2 emissions-based vehicle taxation is one of several policy measures currently in place in Ireland to encourage the uptake of low-emission vehicles, some of which could also contribute toward the uptake of A-rated vehicles, particularly electric cars. In addition, up to €5,000 relief

on VRT is available for electric vehicles and €2,500 for plug-in hybrid cars. In 2017, government also introduced a 0% benefit-in-kind rate for electric company cars. Other EV incentives include a grant for installation of home EV charging, worth up to €600, which was introduced in January of 2018.

By transitioning to vehicle taxation on the basis of average CO2 emissions, the new tax regime placed an indirect cost on the carbon emitted from personal cars (a direct incidence of tax would be linked to usage, i.e. fuel cost). The explicit intent of Ireland's vehicle taxation regime was, of course, to encourage drivers to purchase more fuel-efficient vehicles, or low-carbon vehicles, and to consequently reduce greenhouse gas emissions from the transport sector. However, as noted by (Hennessy and Tol 2011), and explored further in this paper, an outcome of CO2-based car taxes, was a rise in the share of diesel cars, which can lead to rises in other pollutant emissions such as NOx and particulate emissions.

Other authors have predicted a similar effect of the Irish tax policy change on passenger car fleet composition. Giblin and McNabola (2009) used a car choice model to predict the effect of the 2008 tax shift on car purchases and government revenue. Their findings predicted a reduction of 3.6-3.8% in CO2 emissions intensity and a reduction in annual tax revenue of €191M. Using a car purchase model, Hennessy and Tol (2011) predicted a modest fall in CO2 emissions. However, the authors also predicted a large increase in the market share of diesel vehicles, in the region of 25-58% as a result of the tax change. Taking a European perspective, Ryan, Ferreira, and Convery (2009) found that national vehicle and fuel taxes in the EU have had an influence on the CO2 emissions intensity of the passenger car fleet. In a more recent study, Gerlagh et al. (2018) have also found that increased CO2 sensitivity of national vehicle registration taxes has lead to a reduction in the CO2 emissions intensity of new passenger cars. The authors also find however that increases in the sensitivity of circulation taxes (such as the AMT in Ireland) does not have a significant effect on CO2 emissions intensity. Ciccone (2018) and Yan and Eskeland (2018) have carried out a similar analysis of the impacts of the vehicle tax reform in Norway. Both papers found that the switch to CO2-differentiated taxes shifted consumers towards low emissions vehicles and in particular increased the market share of diesel vehicles.

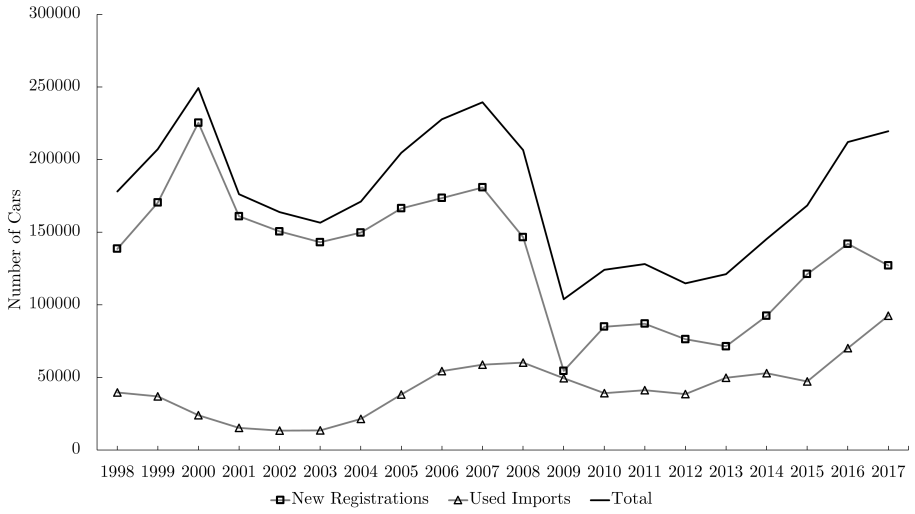
Although the above studies predict an effect of the Irish tax reform on car purchase choices, they are limited in terms of their post-policy data in order to establish a long-term policy effect. In addition, although these studies consider the initial tax policy change in 2008, they do not take into account the effect of some of the subsequent vehicle tax policy changes outlined above. We attempt fill this knowledge gap using 10 years of ex-post policy change micro-data, and disentangle the effects of subsequent vehicle policy changes.

3 Data

The vehicle registration data used in the following analysis is compiled from the Society of the Irish Motor Industry (SIMI) , the UK Society of Motor Manufacturers and Traders (SMMT) and the Central Statistics Office (CSO) of Ireland.

Figure 1 presents the total number of passenger cars registered for the first time in Ireland, disaggregated as new domestic registrations and used imports. While new registrations have declined since 2008, there has been a steady rise in the total number of used imports as a share of first registrations. Used imports in this context are second-hand passenger cars registered for the first time in the Republic of Ireland. The majority of these come from the United Kingdom (UK), which is Ireland's largest trading partner, and sells right-hand drive vehicles.

Figure 1: Passenger cars registered for the first time in Ireland - annual new registrations and used imports



It is clear from Figure 1 that the 2008 economic crisis appears to have had a considerable impact on the total number of vehicle registrations in Ireland. This impact appears to have been driven by a decline in new registrations, while used imports appear to have been largely unaffected. Around 2008, the exchange rate between the euro and sterling reached close to parity for a time, which would certainly have offered added incentive for consumers to purchase vehicles from the UK. This may explain why used imports remained relatively stable while new registrations declined sharply.

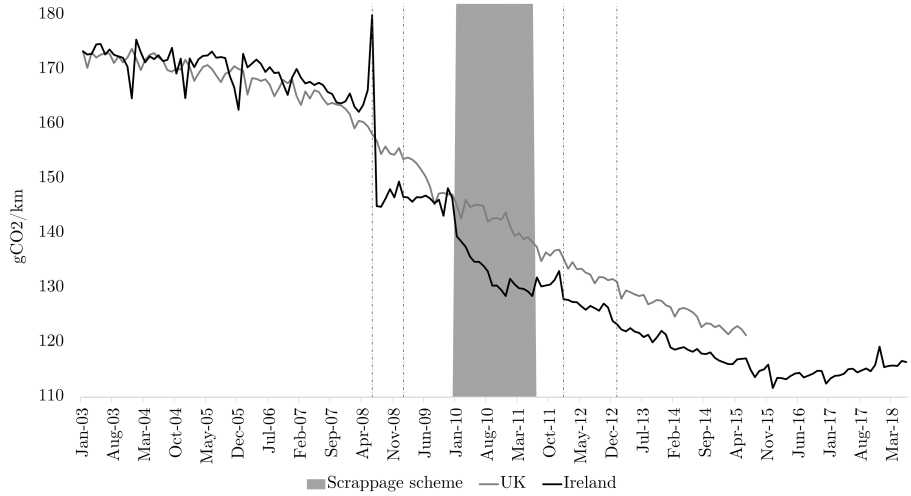
On a monthly basis, new domestic registrations experience a high degree of

volatility, while used imports exhibit a much more stable pattern. In particular, new domestic registrations peak every year in January, and subsequently decline throughout the year. This trend is likely attributable to a behavioural response to the system for license plate registrations in Ireland, by which registration year is presented as the first three digits (two before 2013) on the licence plate of newly registered passenger cars. Individuals who wish to purchase a new car typically wait to register the vehicle until January of the following year, as this improves the vehicle's resale value.

4 Methodology

In order to assess the impact of the change in the registration and circulation vehicle tax regime on CO2 emissions of passenger cars, this analysis focuses specifically on registrations of new vehicles in Ireland. Although used imports constitute a significant proportion of Irish vehicle registrations, reliable CO2 ratings data for used imports prior to 2008 are not available, and hence the change in import CO2 ratings attributable to the 2008 tax regime change cannot be observed. Figure 2 presents the average CO2 rating of new passenger cars registered in Ireland and in the United Kingdom over the period from January 2003 to June 2018.

Figure 2: Average CO2 rating of first registration of new passenger cars



The dashed lines in Figure 2 represent years in which various changes to the vehicle tax regime took effect in Ireland, as discussed in the Introduction. The data demonstrate a significant decline in the average CO2 emissions rating

of new passenger cars in Ireland over the period 2002 to 2018. The average rated CO2 emissions of new passenger cars in Ireland has declined from approximately 170 gCO2/km to less than 120 gCO2/km in the span of 10 years – an improvement of 30%. This decline was particularly pronounced around the time of the first change in the motor tax regime (July 2008), as average CO2 rating decreased by approximately 35 gCO2/km over one month. Interestingly, in the month prior to the change in the tax regime, average CO2 rating of new cars exhibited a sharp increase. This suggests a behavioural response whereby individuals may have hastened the timing of their purchase of high-emitting vehicles in order to avoid being subject to the new tax regime. Indeed, only vehicles registered on or after the effective date of the policy change were subject to the new system.

In addition to the sharp decline in average CO2 emissions rating of new passenger cars in 2008, Figure 2 also shows that the average CO2 emissions ratings declined considerably from 2010 to 2011. This is likely attributable to a government-led scrappage scheme which was proposed in Budget 2010 and came into effect on 1 January 2010, as discussed in the Introduction (the scrappage scheme is depicted in the grey box in Figure 2).

Volatility in average CO2 emissions rating at precisely the time of the change in the motor tax regime in 2008, and of the scrappage scheme in 2010, is a strong indication of an immediate response to the policy change. However, the data also demonstrate a downward trend in the CO2 emissions profile of newly registered vehicles in the years prior to and following the effective date of the policy. This underlying downward trend suggests that the CO2 intensity of new passenger cars may have improved over time, even in the absence of changes in the vehicle tax regime, and may be affected more acutely by supply side effects (i.e. manufacturers producing less CO2 intensive cars) rather than by a consumer response to the change in vehicle taxation policy. It is therefore useful to construct a counterfactual prediction of what might have occurred without any policy change, in order to measure the relative effect of adjustments to the tax regime.

Identifying a reasonable counterfactual for changes in Ireland's average CO2 emissions ratings in Figure 3 requires using data from a comparable market. To approximate this counterfactual, the emissions profile of corresponding vehicle registrations in the United Kingdom for the same period has been used.

The United Kingdom provides a suitable counterfactual for the Irish market for a number of reasons. First, prior to the tax regime change in Ireland in 2008, the average CO2 emissions rating for newly registered passenger cars in Ireland and the United Kingdom appear to be on a very similar trajectory, as shown in Figure 2. This relationship meets the parallel trends assumption which is central to the application of difference-in-difference analysis applied here (Angrist and Pischke 2008). Second, there were no substantial changes to

the UK motor taxation system over the period from March 2001 to April 2017, other than the introduction of a small first year ("show-room") tax in April 2010. Since March 2001, the annual motoring tax, Vehicle Excise Duty (VED), in the United Kingdom has been calculated based on CO2 emissions ratings. Third, the United Kingdom and Ireland share similar road infrastructure and driving rules. Both jurisdictions operate under Left-hand Traffic (LHT) rules, and nearly all vehicles registered in both countries are Right-hand Drive (RHD). These characteristics, coupled with the close proximity of the two markets, suggest a similar product offering by car manufacturers in both jurisdictions.

Using the United Kingdom as a comparison case, this paper uses a difference-in-difference econometric methodology to estimate the magnitude of the effect of the 2008 policy change and subsequent adjustments in Ireland on the average CO2 rating of newly registered passenger cars. In this application, the difference-in-difference approach uses the UK data to estimate the probable trajectory of Irish average CO2 ratings, if no policy change occurred. It then compares the no-change trajectory to one based upon the observed data for Ireland, incorporating the implemented policy changes. As per Angrist and Pischke (2008), the basic form for a difference-in-differences analysis with two periods and two countries in a regression framework is as follows:

$$Y_{ist} = \alpha + \gamma IRL_s + \lambda d_t + \delta(IRL_s \cdot d_t) + \epsilon_{ist} \tag{1}$$

In the above, Y_{ist} is the CO2 rating of vehicle i in state s and time t. IRL_s is an indicator variable equal to 1 if the registration is in Ireland and equal to 0 if otherwise (i.e in the UK). d_t is a dummy variable which switches from 0 to 1 at the policy change date. Finally δ is the treatment effect of the policy.

However, since we only have aggregate values for the CO2 ratings for both Ireland and the UK at each point in time (in a manner similar to Wing, Simon, and Bello-Gomez (2018)) in our case this reduces to:

$$Y_{st} = \alpha + \gamma IRL_s + \lambda d_t + \delta(IRL_s \cdot d_t) + \epsilon_{st} \tag{2}$$

This means that the standard errors produced are likely to be understated, however this nonetheless can give us an indication of the magnitude of the effect of the policy. The above specification relates to a two period – two group model. However, since we have multiple time observations for each country, we also include monthly fixed effects, in the more general model (as per Wing, Simon, and Bello-Gomez (2018)) as follows:

$$Y_{st} = \gamma_s + \lambda_t + \delta D_{st} + \epsilon_{st} \tag{3}$$

In the above γ_s is the state (country) fixed effect and λ_t is the time fixed effect. δD_{st} is an interaction term of treated units after the treatment date (i.e. $IRL_s \cdot d_t$). The results of the above specification are presented in column (1) of Table 3.[2]

As a second specification, we would like to estimate the individual effects of each of the interim policy changes which occurred in Ireland between 2008 and 2013 (i.e. the increases to AMT which occurred in 2009 and in 2012, and the scrappage scheme which was in effect from 2010-2011). Equation (1) above has been expanded to include interaction terms for each of the interim policy changes and are reported in column (2) in Table 3.

For our third specification, we control for state specific covariates which vary over time and may influence vehicle purchase decisions as follows:

$$Y_{st} = \gamma_s + \lambda_t + \delta D_{st} + X'_{st}\beta + \epsilon_{st} \tag{4}$$

These X'_{st} include household income, as well as the price of diesel and petrol fuels and are presented in column (3) of Table 3. Finally, as a robustness check, we also include a state-specific linear trend as follows (Angrist and Pischke 2008):

$$Y_{st} = \gamma_{0s} + \gamma_{1s}t + \lambda_t + \delta D_{st} + X'_{st}\beta + \epsilon_{st} \tag{5}$$

The results of the above are presented in column 4 of Table 3

Next, we further explore the underlying reasons for potential change in CO2 emissions ratings by examining a change in the composition of new registration by fuel type and carry out a separate estimation for the share of diesel cars. This analysis again uses a difference-in-differences quasi-experimental design to quantify the proportion of the shift in diesel share that is attributable to the 2008 policy change. The first iteration of the difference-in-differences specification examines the single policy change in 2008, then adds the remaining changes, controls and country-specific trends to the model in the same manner detailed for the estimation of the CO2 emissions ratings. The results are presented Sections 5.2 and 5.3.

[2]Since there are only two (aggregate) observations per country in each time-period, this means that the standard errors produced are likely to be understated. However, using a difference-in-differences specification in this manner can nonetheless give us an indication of the magnitude of the effect of the policy.

5 Results

5.1 CO2 Ratings

Testing solely for the effect of the 2008 policy change (column 1), average CO2 rating of newly registered passenger cars decreased by approximately 8.4 gCO2/km relative to the counterfactual trend of no policy change. Although this is a significant result, it does not disaggregate the effect of subsequent changes to the VRT and AMT following the initial policy change (as discussed in Section 2). As such, the effect of the 2008 change may be under - or overstated in column 1.

Table 3: Difference–in-difference results – CO2 emissions rating

	(1)	(2)	(3)	(4)
Initial policy change (2008)	-8.4341 ***	-10.2867 ***	-9.1726 ***	-11.0948 ***
	(0.5305)	(1.2322)	(1.5756)	(1.7125)
Interim policy change A (2009)		4.4843 ***	4.6711 ***	4.1186 ***
		(1.3622)	(1.5178)	(1.5029)
Scrappage scheme		-5.8059 ***	-6.5564 ***	-6.2573 ***
		(0.9632)	(1.0403)	(1.0262)
Interim policy change B (2012)		-2.0461 *	-2.4954 **	-3.3853 ***
		(1.0769)	(1.1108)	(1.1415)
Final Policy Change (2013)		-0.1239	0.1249	-0.9659
		(0.987)	(1.0086)	(1.0741)
Household consumption			0.0124 *	-0.0001
			(0.0064)	(0.0079)
Price of petrol			-0.0098	-0.0050
			(0.0126)	(0.0125)
Price of diesel			0.0026	0.0001
			(0.0133)	(0.0131)
Adjusted R^2	0.9867	0.9893	0.9895	0.99
Country-specific trend	No	No	No	Yes
N	300	300	300	300

*** Statistically significant at $p < 0.01$
** Statistically significant at $p < 0.05$
* Statistically significant at $p < 0.1$

In order to analyse the effect of each of the policy changes individually, Equation (2) includes interaction terms at each of the policy change dates, with results presented in column 2. Adding the interaction terms for each policy change increases the size of the coefficient associated with the 2008 policy change to approximately 10 gCO2/km. Interestingly, the first interim policy change, which occurs in 2009, actually reduces the difference in average CO2 rating by 4.5gCO2/km. Although this is counterintuitive, as mentioned previously, this effect is a comparison between the difference in the observed and counterfactual emissions rating after the 2009 change, compared with the difference prior to the change. Thus, while the Irish average emission rating is still lower than the

no-change trajectory, the difference between the two trajectories has narrowed after the 2009 policy change. Per Figure 3, the period after the 2009 change was defined by falling average CO2 emissions ratings in the United Kingdom, which is the basis for the Irish no-change counterfactual. During the same period, emission ratings appear to have stagnated in Ireland, resulting in a smaller effect from the 2009 policy change. The stagnation in average emission ratings in Ireland may also be a correction following a strong response by consumers to the initial policy change in June 2008.

Another finding from the second specification of the difference-in-difference model is that the scrappage scheme had a significant impact on the emissions rating of new passenger cars in Ireland, reducing average rated emissions by an additional 6.6 gCO2/km compared to the previous period. This result is consistent with expectations, as a condition of the scheme was that newly purchased vehicles had to be at least B-rated or better in terms of CO2 emissions per kilometre. The 2012 interim policy change also had a small but significant effect on average emissions rating, which decreased by an additional 2gCO2/km. The interim policy change in 2012 increased the circulation tax rate specifically for lower rated vehicles (A and B in particular). An explanation for this effect may be, however, that the policy change may have been a signal as to the significant financial benefits associated with purchasing a lower CO2 rated vehicle.[3]

The third specification of the difference-in-difference model (column 3) includes a number of control variables which may influence vehicle purchasing decisions, and which vary by country and over time. Household consumption per capita exerts only a weakly significant effect on average emission rating, whereby an increase in household consumption increases the average CO2 rating of newly registered cars by a small amount. This effect may be due to individuals purchasing vehicles with bigger engines (both diesel and petrol) in periods with high per capita consumption. It may also be explained by a switch from diesel to petrol pwered vehicles, which tend to have higher rated CO2 emissions.

Finally, as a robustness check, the fourth specification of the difference-in differences model includes tests for country-specific trends. Reassuringly, the findings are of a similar effect of the policy changes across all of the coefficients, with the exception of household consumption per capita, whose effect is insignificant.

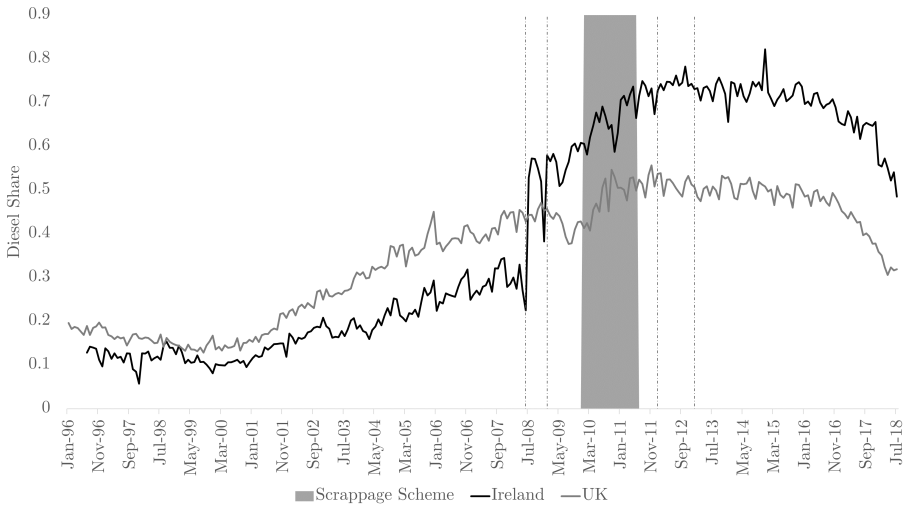
[3]In other words, it may have confirmed to buyers of new vehicles the significant financial savings associated with purchasing an A or B rated passenger car.

5.2 Diesel Share - New Registrations

The previous results demonstrate a significant decrease in the average CO2 rating of newly registered passenger cars in Ireland as a result of the relevant policy measures. Here we present the results for the analysis of the impact on the share of diesel vehicles. The analysis distinguishes between the first registration of a new vehicle (new registrations) and the first registration of used import vehicles (import registrations).

Figure 4 presents the diesel share as a proportion of new domestic car registrations in Ireland and the United Kingdom. Prior to 2001, the diesel share trend in the United Kingdom and Ireland appears to be the same, with the United Kingdom consistently experiencing a slightly higher share of new vehicles registered as diesels. After 2001, however, the two trends begin to diverge slightly, which may be attributable at least in part to the United Kingdom's introduction of CO2 emissions-based taxes in March 2001.[4] From this point forward, the diesel share of new vehicle registrations in the United Kingdom was consistently higher than in Ireland, until June 2008.

Figure 3: Diesel share - New domestic registrations



In July 2008, in the month following the introduction of the CO2 tax regime in Ireland, the proportion of diesel vehicles registered in Ireland shifted dramatically. The diesel share of new registrations in Ireland increased by almost 40%

[4]Source: `https://www.rac.co.uk/drive/advice/buying-and-selling-guides/car-tax-bands-explained/`. It is interesting to note however that there does not appear to have been an immediate response in the diesel share of vehicle registration in the UK immediately following the tax regime change in March 2001.

over the course of one month, reaching approximately 80% of new registrations. Furthermore, the shift appears to have been a sustained, as the years following the 2008 tax regime change saw the diesel share of new registrations remain consistently higher than in the United Kingdom. As in the previous section, this analysis uses a difference-in-differences quasi-experimental design to quantify the proportion of the shift in diesel share that is attributable to the 2008 policy change. The first iteration of the difference-in-differences specification examines the single policy change in 2008, then adds the remaining changes, controls and country-specific trends to the model in the same manner detailed in the previous section. The results are presented in Table 4.

Table 4: Difference–in-difference results – Diesel Share of New Registrations

	(1)	(2)	(3)	(4)
Initial policy change (2008)	0.2898***	0.1827***	0.2352***	0.2570***
	(0.0006)	(0.0027)	(0.0028)	(0.0028)
Interim policy change A (2009)		0.0523***	0.0707***	0.0731***
		(0.0032)	(0.0034)	(0.0034)
Scrappage scheme		0.0395***	0.0353***	0.0497***
		(0.0021)	(0.0022)	(0.0022)
Interim policy change B (2012)		0.0731***	0.0383***	0.0996***
		(0.0025)	(0.0025)	(0.0026)
Final Policy Change (2013)		-0.0029	-0.0198***	0.0368***
		(0.0018)	(0.0019)	(0.0020)
Household consumption			-0.0002***	-0.0000***
			(0.0000)	(0.0000)
Price of petrol (adjusted)			0.0000***	0.0000
			(0.0000)	(0.0000)
Price of diesel (adjusted)			0.0001***	-0.0000
			(0.0000)	(0.0000)
Adjusted R^2	0.0824	0.0825	0.0826	0.0827
Country-specific trend	No	No	No	Yes
N	49,449,524	49,449,524	49,449,524	49,449,524

*** Statistically significant at $p < 0.01$
** Statistically significant at $p < 0.05$
* Statistically significant at $p < 0.1$

From Table 4 we can see that the major difference between the results for diesel share and the results for CO2 rated emissions (Section 5.1) is that in the case of diesel share we have the underlying micro data for all passenger cars registered in Ireland and the United Kingdom for our period of study. This amounts to a total of 49,449,524 passenger cars registered from January 1998 to December 2017.[5]

Column 1 in Table 4 shows that including only the 2008 tax regime change in the difference-in-differences estimation produces a positive and significant effect of approximately 29% on the diesel share of new registrations in Ireland. Including the subsequent policy changes in column 2, however, reduces the size

[5]Of these, 2,924,440 were registered in Ireland, and the rest were registered in the UK - reflecting the larger size of the UK passenger car market.

of the effect of the initial policy change to roughly 18%. Column 2 however also shows that the subsequent policy changes also had a significant impact on the diesel share of new registrations in Ireland. The second biggest impact appears to have been the policy change in January 2012, which increased the diesel share by approximately 7%. As with the explanation for CO2 ratings, this may be attributable to a signalling effect of the policy change, whereby consumers were reassured that buying a lower-emitting vehicle would be beneficial in terms of the associated tax savings. The policy change in 2009 also had a positive and significant effect, increasing the diesel share by approximately 5%. As with the finding in the previous section, however, this may be attributable to a residual effect from the initial policy change.

Finally, the scrappage scheme also appears to have had a significant (albeit comparatively small) impact in increasing the diesel share in Ireland. This suggests a possible switching of fuel type by individuals availing of the scheme, as cars which were scrapped (being older than 10 years) were more likely to be petrol. The final policy change in 2013 does not appear to have had a significant impact on diesel share.

Column 3 in Table 4 shows the results of adding control variables to the difference-in-differences model. Household consumption appears to have a significant and negative effect on diesel share. Since we are using household consumption per capita per month as a proxy for household income,[6] this suggests that as income increases, the diesel share decreases. This is consistent with our finding in Section 5.1, where we find that increases in household income have a positive effect on emissions, since petrol vehicles tend to have higher rated CO2 emissions.

We also find significant, but small effects of the price of petrol and diesel on diesel share.[7] The coefficient on the price of petrol is positive, suggesting that as petrol prices increase, the diesel share increases. This is consistent with our expectations since as petrol prices increase it becomes more costly to operate a petrol powered vehicle in comparison to a diesel powered one. Interestingly however, we also find a positive effect of the price of diesel on diesel share. This appears conterintuitive as we would expect the opposite to be true. Nevertheless, since the coefficient values are close to zero, the effect for both variables is negligible.

As a robustness check, the model was run controlling for country-specific time trends as per Angrist and Pischke (2008), and the results are presented in column (4). The size, significance and direction of the coefficients on the initial

[6] We obtain household consumption expenditure data from eurostat (table: `namq_10_pc`). Household consumption per capita for both the UK and Ireland is expressed in euro terms, and is adjusted for inflation with a base year=2015

[7] Both petrol and diesel prices in the UK and Ireland are inclusive of taxes and are expressed in euro terms. As with household consumption, both variables are also adjusted for inflation with a base year of 2015.

policy change, policy change A (2009) and the scrappage scheme all appear to be relatively unaffected by the inclusion of such trends, which gives us confidence in our estimates. The effect of interim policy change B (2012) however appears to be larger in magnitude, while the effect for the final policy change (2013) has changed direction. We therefore cannot be certain of the direction of the effect on the final policy change. Of the control variables used, only household consumption per capita has a significant (and negative) effect on diesel share, which is consistent with our third specification (column 3). Since we do not find a significant effect on petrol and diesel prices however, we cannot conclude that petrol and diesel prices have had a significant effect on the diesel share of new registrations in Ireland.

5.3 Diesel Share - Including Used Imports

The previous section compares the diesel share of Irish registrations of new passenger cars to the diesel share of registrations in the United Kingdom. As noted previously, a sizeable portion of first vehicle registrations per year in the Republic of Ireland, however, are used imports, primarily from the United Kingdom. For example, in 2017, approximately 41% of all private cars registered for the first time in Ireland were used imports. In Figure 4, the diesel share of all vehicle registrations in Ireland per month (including used imports) have been plotted against UK vehicle registrations per month.[8]

Figure 4 shows that the diesel share when including used imports (80%) is similar to the diesel share of new domestic registrations alone, and appears to have been affected similarly by the 2008 taxation policy change. Mirroring the effect shown solely in new domestic registrations, the diesel share of total passenger car registrations increases considerably precisely in the month following the 2008 tax regime change and appears to have had a persistent effect. To quantify the magnitude of this effect, this analysis employs the same difference-in-differences methodology detailed in prior sections, with the same variations in model specification. The results are presented in Table 5.

The 2008 policy change, examined on its own (column 1) appears to have had an even larger effect on the diesel share of total registrations than for new cars alone. This increase in diesel share confirms the prediction made by Hennessy and Tol (2011), and is very close to their estimate of the increase in diesel share attributable to the policy change.[9] As before, the size of this effect is smaller

[8]Note, the UK figures used are the same as those used in Section 5.2, and do not include second-hand vehicles imported into the UK. Second-hand imports in the UK however constitute a very small proportion of the vehicle stock. In 2017, only 2.4% of the passenger car stock in the UK were used imports (Source: author correspondence with SMMT).

[9]Hennessy and Tol (2011) estimated that the overall market share of diesels in Ireland will increase from 25% to 58% as a direct result of the policy shift (an increase of 33%) which is strikingly similar to estimate of the single policy effect (32% - column 1 of Table 5) and the

Figure 4: Diesel share - Including Used Imports

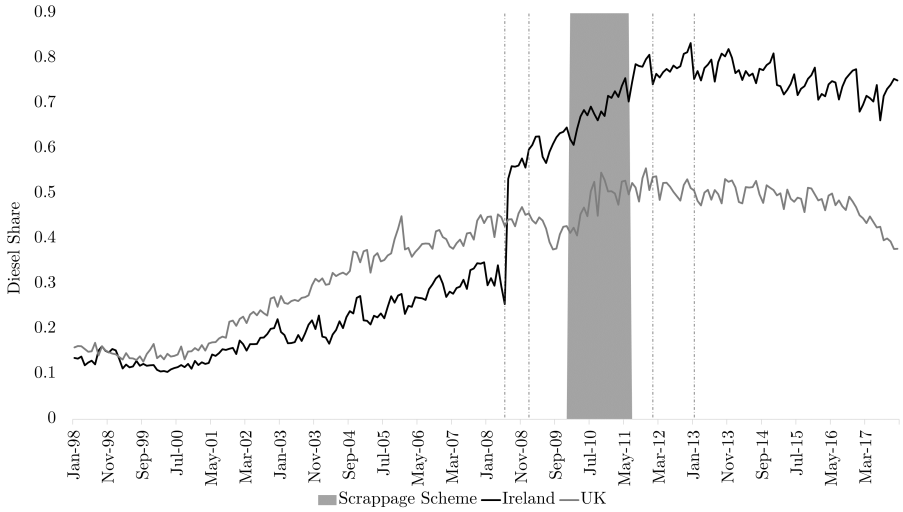


Table 5: Difference–in-difference results – Diesel Share Including Used Imports

	(1)	(2)	(3)	(4)
Initial policy change (2008)	0.3169***	0.1823***	0.2133***	0.2348***
	(0.0005)	(0.0020)	(0.0021)	(0.0021)
Interim policy change A (2009)		0.0960***	0.0943***	0.1009***
		(0.0023)	(0.0025)	(0.0025)
Scrappage scheme		0.0058***	0.0046**	0.0159***
		(0.0016)	(0.0017)	(0.0017)
Interim policy change B (2012)		0.0545***	0.0259***	0.0803***
		(0.0019)	(0.0020)	(0.0021)
Final Policy Change (2013)		0.0062***	-0.0109***	0.0379***
		(0.0015)	(0.0016)	(0.0017)
Household consumption (adjusted)			-0.0002***	-0.0000
			(0.0000)	(0.0000)
Price of petrol (adjusted)			0.0001***	0.0001***
			(0.0000)	(0.0000)
Price of diesel (adjusted)			0.0000***	-0.0000***
			(0.0000)	(0.0000)
Adjusted R^2	0.0881	0.0883	0.0884	0.0885
Country-specific trend	No	No	No	Yes
N	50,305,356	50,305,356	50,305,356	50,305,356

*** Statistically significant at $p < 0.01$
** Statistically significant at $p < 0.05$
* Statistically significant at $p < 0.1$

when combined with interaction terms for the subsequent policy changes. The 2009 and 2012 policy changes had a significant and positive effect on diesel share, with the change in 2009 appearing to play a more significant role. Adding the covariates of household consumption and fuel price yields only marginal changes the size of the coefficients, shown in column 3, with the exception of the final policy change (2013) interaction term, which which changes sign. Again, this points to an inconclusive effect of the final policy change on diesel share.

Among the control variables, household consumption shows a significant and negative effect on diesel share, which is consistent with the findings in Section 5.2. Petrol and diesel prices again appear to have had a positive effect on diesel share in our third specification. However when we include state-specific trends, we find that the price of diesel appears to have a negative effect on diesel share. Since the effect changes sign across specifications we cannot be certain of its direction. Household consumption also does not appear to have a significant effect with the inclusion of state-specific time trends. Importantly however, and as in the previous analyses, adding country-specific time trends does not change the direction, size and significance of the estimated coefficients of the initial policy change, interim policy change A (2009) and the scrappage scheme.

6 Conclusion

In summary, the change in the tax regime and subsequent policy changes have had a sizeable impact on the purchasing behaviour of Irish motorists, decreasing the average CO2 ratings of newly registered passenger cars by between 8 and 11gCO2 relative to what they would have been under a no policy change scenario. The biggest contributing factors appear to be the initial tax regime change in July 2008 and the scrappage scheme in 2010. Closer examination shows that this effect appears to have been driven by increased purchases of diesel-powered vehicles, which tend to have lower-rated CO2 emissions but higher emissions of other harmful pollutants such as NOx emissions (Dey, Caulfield, and Ghosh 2018). This confirms the results of other papers that demonstrate that consumer purchases adjust directly in response to incentives and can be used to achieve CO2 reductions in the private car transport sector. It also highlights the care that is needed to design efficient policy instruments in order to avoid unintended consequences.

This study has developed a novel difference-in-difference model using UK vehicle sales to provide a counterfactual scenario of Irish vehicle sales in the absence of the policy reform. Further improvements can be made in future work by taking advantage of micro-data in order to create more precise estimates of the standard errors of the estimated coefficients in the CO2 rated emissions

combined effect of the disentangled individual policy measures (47% - column 4 of Table 5).

model. Robustness tests such a permutation-based hypothesis tests can also be employed in order to improve confidence in our estimates [10]

In terms of policy implications, our results clearly show that carbon - differentiated vehicle taxes have had an impact on vehicle purchasing decisions in Ireland. Vehicle tax incentives will therefore likely be an important tool in decarbonising the transport sector in the future. However, careful policy analysis is also needed in order to identify and correct unintended outcomes, such as the increase in other air pollutants due to the increase in diesel share - which can lead to localised pollution and adverse health effects. Progress in this area is being made, as the latest budget published by the Irish government includes a proposed surcharge of 1% on the VRT of both new and imported diesel vehicles from January 2019 (McAleer 2018). Future research should focus on how further vehicle tax incentives may be used in order to stimulate the adoption of ultra-low or zero emissions vehicles such as EV's, and consider the wider societal implications of such measures.

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[10] E.g. see for example Young (2018), Ernst (2004), and Kennedy (1995) for more details on using permutation-based hypothesis tests for exact inference.

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