Impact of an emissions-based car tax policy on CO2 emissions and tax revenue of private cars in Ireland

Vera O'Riordan, Fionn Rogan, Brian Ó Gallachóir, Hannah Daly*

Corresponding Author. E-mail Address: vera.oriordan@ucc.ie

Working Paper – 02 -2021

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Abstract

This paper assesses private car CO_2 emissions and car tax revenue in Ireland over the 10-year period following the introduction of an emissions-based car taxation policy in 2008. We build on a model of the Irish car stock, which uses new car sales, activity, and carbon intensity data to develop a bottom-up picture of historic CO_2 emissions from the car fleet. Without the tax intervention, and following EU-wide trends, carbon intensity of the total car fleet would have been 168 gCO_2/km. This study calculates a cumulative CO_2 saving of 1.6 Mt CO_2 from 2008 to 2018 because of the tax change. The tax change also led to a fall in annual motor tax revenues. Recorded receipts from annual motor tax were €0.77 billion in 2018, which would have been nearly €1 billion under the pre-2008 tax regime. Differences between the test-rated and on-road carbon intensity grew over the period, which diminished both the CO_2 savings and tax revenue from cars. The cost of abatement was €684 per tonne of CO_2 avoided. This paper demonstrates how ex-post analysis can be used to learn from the past and provide insights for taxation policy approaches to reduce future transport related CO_2 emissions.

Keywords

private car transport, Ireland, CO2 emissions, climate policy, technology stock model, tax revenue

1 Introduction

1.1 Policy context

In the European Union (EU), cars are responsible for around 12% of total CO_2 emissions [1]; for Ireland it is 15% [2]. In the EU, transport emissions targets are set under the EU Effort Sharing Regulation (ESR) 2018/842 covering non-emissions-traded sectors (non-ETS) [3]. In Ireland, despite a commitment to a 20% reduction in non-ETS emissions by 2020 relative to 2005 levels, a reduction of 8% has been achieved [4] . According to 2019 EPA projections, without the impact of COVID-19, transport emissions would have been only 2.7% lower [5]. This makes meeting Ireland's 2030 target of a 30% reduction in non-ETS emissions even more challenging. Therefore, policymakers are now focusing on other policy measures to decarbonise private car transport. To that end, the Irish government issued a Climate Action Plan in 2019 which outlines ambitious future policy measures and instruments to reduce CO_2 emissions from the transport sector, focused on car electrification, rail electrification, and bus system updates [6]. In light of this, it is necessary to ask: to what extent can future policy reduce emissions? Some insight to this question can be achieved by looking at the impact of previous policy. Transport emissions are lower due to the recession, but also due to government policy, which is something this paper seeks to quantify. This will be true not just in Ireland, but in every country that is seeking to reduce emissions particularly in the transport sector, by common consensus one of the most difficult sectors to decarbonise.

One policy instrument to reduce CO_2 emissions from private cars, which is at the heart of this study, is changing the car taxation regime to favour low-emitting cars. Such a measure was previously introduced in Ireland in 2008 so that the motor tax rates reflected the carbon intensity (carbon dioxide [CO_2] emissions per kilometre driven) rather than engine size [7]. Vehicle Registration Tax (VRT) was changed from a tax based on the car sales price to one based on the emissions class of the car. Annual Motor Tax (AMT) was changed from a rating based on engine size to one based on CO_2 emissions intensity [8]. This study looks at the implications of this taxation change on private car CO_2 emissions in Ireland, and consequences for exchequer income from car tax.

1.2 Past policy analysis

An ex-ante 2008 study of projected impacts of a carbon-emission differentiated car tax system on CO_2 emissions intensity from new car purchases in Ireland showed that the car tax change would result in a reduction of 3.6 – 3.8% in CO_2 emissions intensity and a reduction of annual tax revenue of €191 million [9]. The study specified a potential for future work in the revisiting of the modelling exercise following several years of the operation of the July 2008 tax system to assess the accuracy of model predictions, this paper aims to address this recommendation. Other ex-ante studies of the car tax change included a total life-cycle cost model, which is used to estimate the mileage break-even point at which the purchaser will opt for the more efficient car and choose a diesel [10]. This ex-ante model assumes rational behaviour in purchase choice and aggregates an average annual distance travelled across all car types. The ex-ante analysis anticipated that the cost of carbon dioxide emissions abatement per tonne under the new taxation regime would be “high, if not very high.”

Shifting the focus to ex-post analysis, a study on the impact of the 2008 car tax changes include a one-year analysis of the 2008 change in Irish car tax, which found that in the first year of the policy, average specific emissions intensity of new cars fell by 13% to 145 gCO_2/km [11]. This study used a disaggregated stock profile and monitored trends in emission bands, engine sizes and fuel types in the year following the introduction of the taxation change to quantify the weighted CO_2 emissions of new cars and expected car tax payments. Dennehy et al. adopted the car stock-model simulation approach for an ex-post decomposition analysis over the period of 2005 – 2015, examining the impact of seven underlying factors in driving energy demand. This analysis saw the increasing new diesel car purchases and overall diesel share in the Irish car fleet. It also highlighted the historical difference between average laboratory test values and on-road performance for the Irish car stock [12].

Looking further afield for ex-post studies on the impact of emissions-based car tax systems, a six-year ex-post analysis of the Dutch car taxation change found that the tax incentives were remarkably effective in encouraging changes towards lower-emitting cars. This contributed to a 6% reduction in private car emissions. The study noted the growing gap between rated performance and on-road performance, and how the scheme was not revenue neutral [13].

Across the EU, Dineen et. al., studied the implications of the CO_2 emissions taxation across all member states [14]. The qualitative study analysed factors, in particular national car taxes. The study noted the influence of confounding factors such as economic instability in the EU. By observing the trends in new passenger car carbon intensity, the analysis found that the majority of member states that shifted to CO_2-based car taxes were found to have improved their new passenger car emissions intensity more than other EU member states that did not change to CO_2 based car taxes [14]. Ex-post policy analysis is particularly challenging, especially because of the interaction of multiple factors impacting car purchase and usage decisions; however, without an understanding of the impact of past policy interventions, future policy planning and implementation is more at risk of an unsuccessful fate. For example, this can happen when an unintended consequence of a policy is falsely asserted as being part of the original policy goals, the net effect of which can undermine future policy planning capability. The key innovations in this paper include developing a car stock counterfactual scenario based on historical Irish new car sales with respect to EU-wide new car sales, the development of a tool to calculate the revenue for different car taxation regimes based on the car stock model.

1.3 Outline

The paper is structured as follows: Section 2, we describe the methods used for this analysis, the Irish car stock model, the factual and counterfactual scenarios for exploring the impacts of the car tax change and the method. In Section 3, the results section, we highlight: i) the emissions trends over the period of 2008 – 2018 for the factual and counterfactual cases, ii) the stock carbon intensity impacts, iii) the revenue impacts of the taxation change and iv) the impact of "on-road factors", which are factors applied to account for the growing disparity between manufacturer specified car emissions and emissions in on-road, real-life conditions over the period of 2001 - 2018. Section 4, the discussion section, covers areas of uncertainty in the analysis and draws comparisons with other ex-ante and ex-post studies on the car tax change. The conclusion section discusses these results and draws insights for policy makers.

2 Method

2.1 Irish Car Stock Model

The model used in this paper is a technology stock simulation model, which relies on revealed preferences of car choice. This was selected over a cost optimization model to estimate car choice, due to the unavailability and uncertainty associated with cost data on car private cars across various dealerships that is needed for a techno-economic optimization model. This paper builds from a technological stock model of the Irish private car fleet, which was first developed in Daly & Ó Gallachóir, [16]. The car stock and activity profile are disaggregated by car technology, engine class, fuel type and age (or car vintage) to produce a detailed look at private car activity and energy consumption over the period 2000 to 2008. An overview of the private car transport model is provided in Figure 1 (below), which includes the relationship between the inputs (left), the calculation programs (centre) and the output calculations (right). The model combines distance travelled, information on the fuel consumption performance with cars with the number of vehicle sales and survival rates of older cars in the Irish car stock. The code base and data input files for the model are available on Open Science Framework [17].

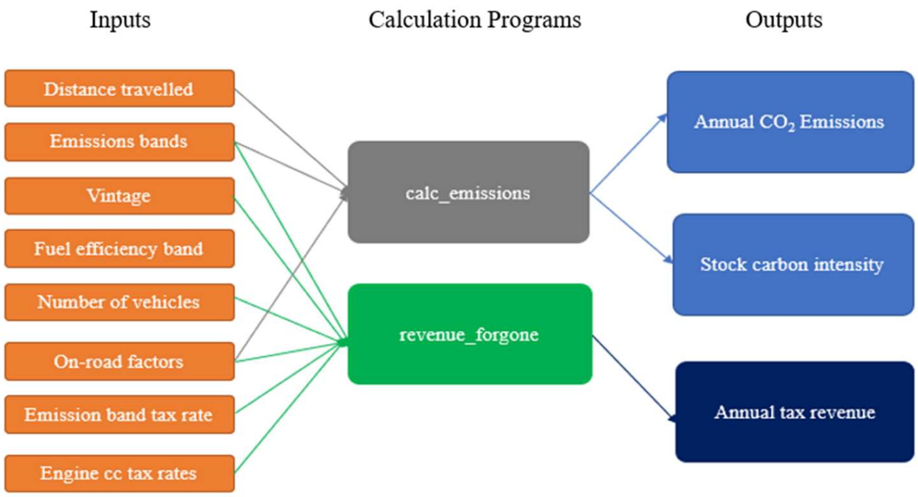

Figure 1 - Overview of private car stock model

2.2 New car sales 2001-2018

Figure 2 shows the proportion of new car sales in Ireland by fuel type and engine size, as recorded by the Central Statistics Office [18]. This scenario provides the basis for the factual scenario for the Irish Car Stock Model, which uses the new car sales proportions from 2001 – 2018 as inputs.

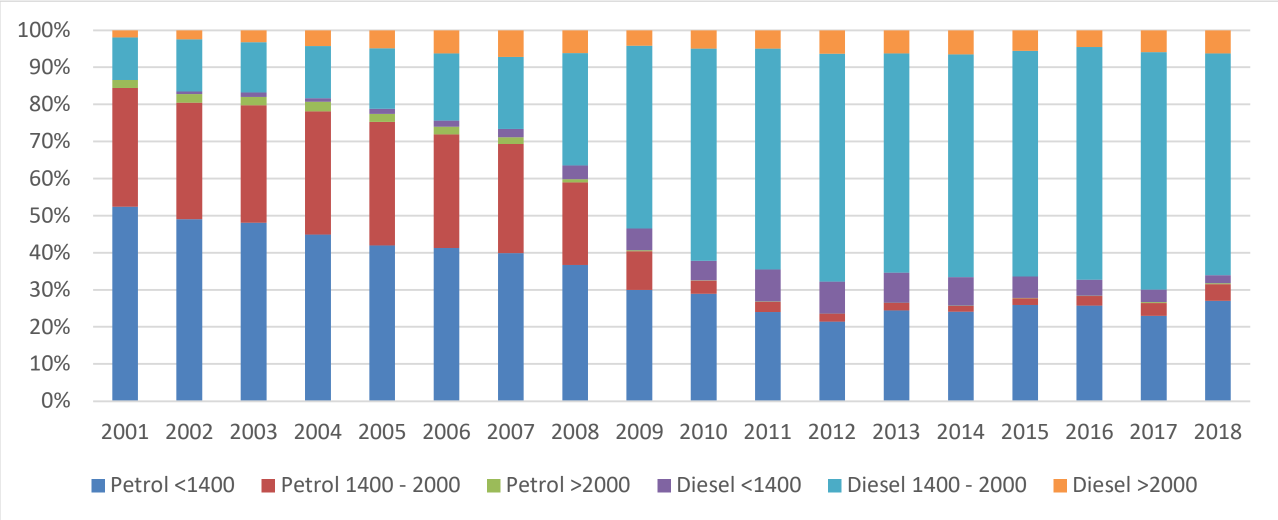

Figure 2 - Proportion of new car sales in Ireland by fuel type and engine size

Figure 3. shows the proportion of new car sales in the EU by fuel type and engine size, as recorded by Eurostat [19]. The relationship between the EU figures and the Irish figures over the period of 2001 – 2008 is used to project a counterfactual scenario whereby the Irish car sales followed EU-wide trends in new technology sales.

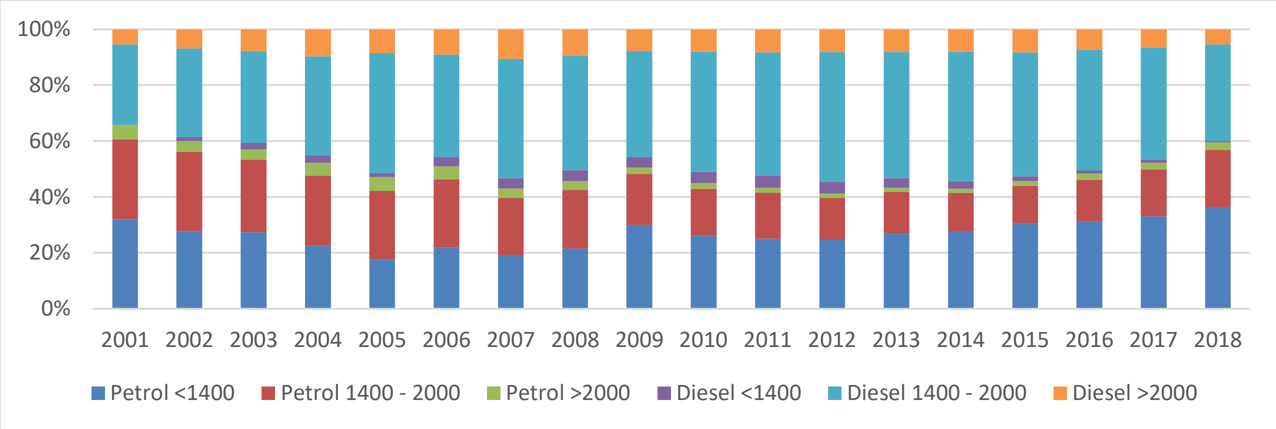

Figure 3 - Proportion of new car sales in the EU by fuel type and engine size

2.3 Counterfactual new car sales, 2001 – 2018

The counter factual scenario reflects the pre-2008 trends in purchasing patterns in Ireland relative to the EU. Over the period of 2001 – 2008, regressions of market trends between Ireland and the EU of car share by fuel type and engine cc are examined. A simple regression analysis is adapted to project a counterfactual for the period of 2008 – 2018, with which to compare. The regression is developed for cars of different engine cc types and the total number of sales of new cars each year and the net average distance travelled by cars in Ireland remains constant. To counteract the impact of changing car choices with varying average mileages by car type, the average distance travelled by each car type category is adjusted proportionally, such that the net sum of all vehicle kilometres travelled by cars is equal to the factual. The step-by-step process for showing the counterfactual is outlined below.

1. We determine the ordinary least squares regression with 3-year moving average of the changing sales proportion of the engine size and fuel type.
2. We calculate a projection of car sales by fuel type and engine cc for Irish cars based on EU-wide trends (Figure 3) over the period of 2008 – 2018.
3. We calculate the total car stock by applying new car sales and historical survival rates of cars greater than 1 year in age.
4. We adjust of relative distance travelled by each car with respect to the behaviour of the factual scenario, to ensure that the vehicle kilometres serviced in the factual is the same as the counterfactual scenario.

The counterfactual new car sales calculated in Step 2. is shown in Figure 4 (below).

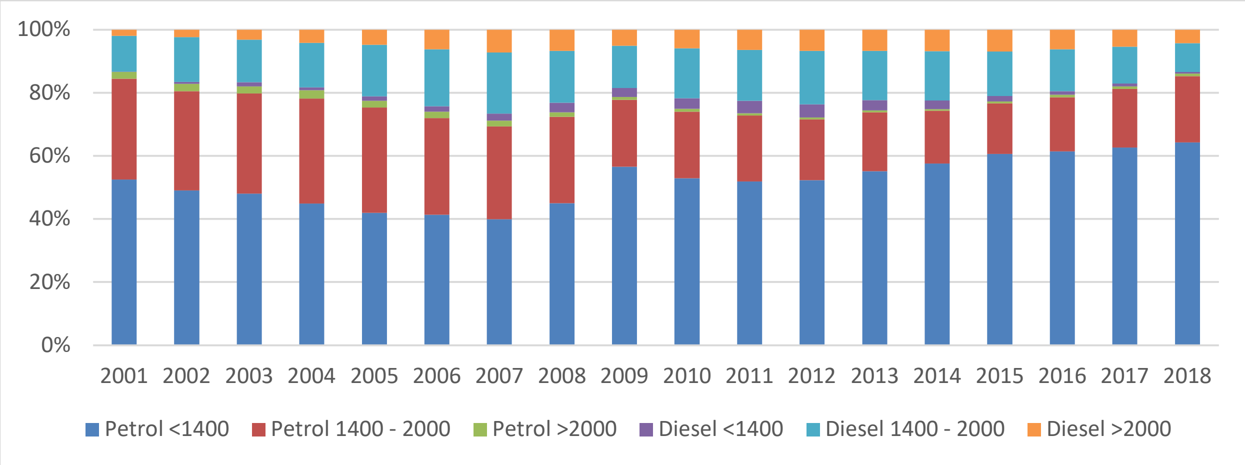

Figure 4 - Counterfactual proportion of new car sales in Ireland by fuel type and engine size

2.4 Total car fleet CO2 emissions, 2001-2018

CO_2 emissions are calculated as described in Equation. (1).

$$Emissions = \sum_{f,v,e} S_{f,v,e} \times D_{f,v,e} \times FC_{f,v,e} \times CI_f \times ORF_{f,t} \qquad (1)$$

where $S_{f,v,e}, D_{f,v,e}, FC_{f,v,e}, CI_f$ are the car stock (number of cars), distance travelled (km/year), fuel consumption per kilometer (litres/km) and the fuel carbon intensity (gCO_2/l) disaggregated by car fuel *f,* vintage (age) *v* and engine cc *e*. $ORF_{f,t}$ is the on-road factor which outlines the difference between the test values (or rated values) and actual, or on-road, fuel consumption. Data is sourced from a range of national publicly available sources (see Appendix A).

The activity-weighted carbon intensity took the distance travelled by each car type into account. It is important to weight by activity because this is the most representative of actual fleet emissions, representing the fact that different car types have different annual mileages. Based on information gotten from the National Car Test centre on annual distance travelled, new cars travel further than cars of older vintages and cars of a larger engine cc also travel further.

2.5 Stock carbon intensity

'Stock carbon intensity' is defined as the grams of carbon dioxide emitted for each kilometre driven by the Irish private passenger transport fleet. It considers the variation in distance travelled by cars of different ages; fuel types and engine cc. The stock carbon intensity is calculated from the distance travelled by cars and the total number of cars, as highlighted in Equation 2 (below).

$$Stock\ carbon\ intensity = \frac{Emissions}{Total\ distance} \qquad (2)$$

2.6 Annual motor tax revenue

Revenue from annual motor tax is recorded by the Government Climate Action and Tax Strategy Group [8]. These values are compared with the revenue calculated from the stock model. The stock model calculates the revenue as follows: Tax revenue from cars registered before 2008 (Equation 3):

$$Revenue = Taxation\ rate_{engine\ cc} \times Number\ of\ vehicles_{engine\ cc,\ year} \qquad (3)$$

For cars registered after 2008, the revenue generated from annual motor tax is calculated as a function of the manufacturer specified emissions band as follows (Equation 4):

$$Revenue = \ Taxation\ rate_{emission\ band} \times Number\ of\ vehicles_{emission\ band,\ year} \qquad (4)$$

2.7 On-road factor

The on-road factor (ORF) is derived from a study conducted on the on-road performance from passenger cars. Earlier literature [12], [20] estimated the on-road factor by comparing the manufacturer specified specific fuel consumption with household consumption of fuel figures for both petrol and diesel from the Household Budget Survey conducted by the Central Statistics Office. The on-road factors derived from the Household Budget survey highlighted the increasing trend also noted in a study on passenger cars conducted in Germany [21].

This study was selected as it disaggregated on-road factors by engine capacity (engine cc) and year of manufacture. This level of disaggregation is particularly useful to integrate with the Irish Car Stock model which records car numbers by engine cc and year of manufacture. The German study was corroborated with a method for calculating the collective car stock on-road factor by using a top-down estimate from Irish household budget spends on fuel, as described in [12], [16]. The study calculated an increasing on road factor from a mean divergence of 13% in 2008 to 33% in 2014 for gasoline cars, 16% in 2008 to 39% in 2014 [21], and the Household Budget Survey determined an increase in on-road factor from 14% in 2008 to 30% in 2015 for gasoline cars, and 22% in 2008 to 43% in 2015 for diesel cars [12]. As the laboratory study recorded the on-road factor for a car of a given build year, the on-road factors from the German passenger car study were applied to this stock model.

To investigate the impacts of the on-road factor, an on-road factor counterfactual scenario is calculated for the modelled Irish car stock, it is assumed that on-road factors for the factual scenario do not change from 2008 rates. The comparison highlights the impacts of increasing on-road factors have on the growing gap between expected carbon dioxide emissions savings based on manufacturers ratings and realized carbon dioxide emissions savings based on real-life driving conditions.

3 Results

3.1 Overall car fleet emissions

The results for overall car fleet emissions from the counterfactual scenario compared with the actual private car carbon dioxide emissions are shown in Figure 5 (below). Compared to actual emissions in 2018, the emissions in the counterfactual scenario for 2018 are 2.8% higher. This results in a net annual saving of 0.16 MT of CO_2 in 2018 compared to the counterfactual, and a cumulative saving of 1.6 MT of CO_2 over the 2008 – 2018 period.

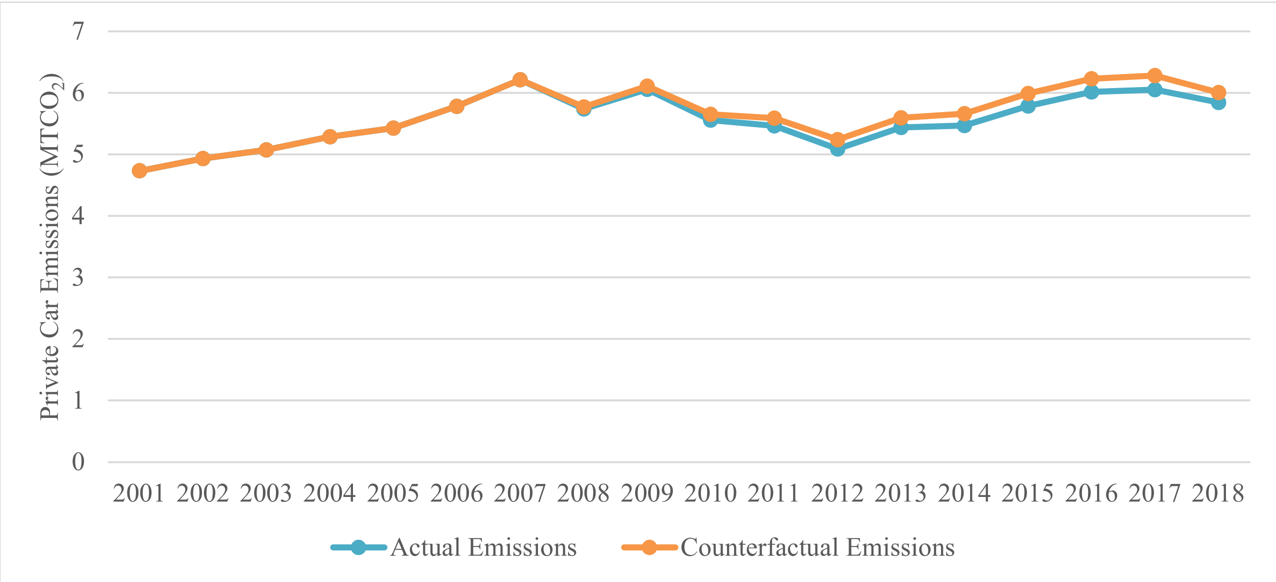

Figure 5 - Annual CO2 emissions from the car stock simulation model (2001 - 2018)

3.2 Stock carbon intensity

For 2018, the actual carbon intensity of the car fleet of 164 grams of carbon dioxide emissions per kilometre compared to counterfactual scenario, which is 168 grams of carbon dioxide emissions per kilometre. The progression of actual stock carbon intensity with respect to the counterfactual stock carbon intensity of cars in the Irish car fleet is shown in Figure 6.

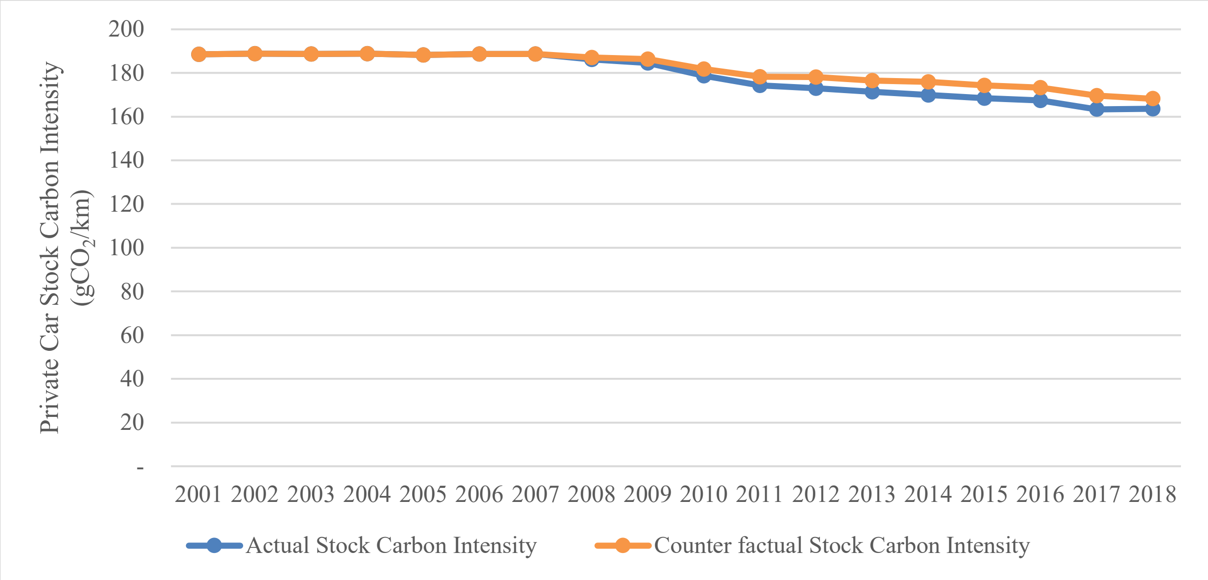

Figure 6 - Stock carbon intensity of the Irish car fleet (gCO2/km)

3.3 Impact of the increasing on-road factors

We discuss the increase in the on-road factor over the period of 2008 - 2018 in Section 2.7. Here, we evaluate the impact increased on-road factors have had on the anticipated carbon dioxide emissions savings from manufacturer values versus the realised carbon dioxide emissions savings from car use on Irish roads. The year-on-year progression of private car emissions with the actual on-road factors, and with no change in on-road factors post-2008 is highlighted in Figure 7 (below). If on-road factors had not increased from 2008 values, emissions from car use in Ireland over the period of 2008 – 2018 would be 0.8 MT of CO_2 lower. Annual emissions in 2018 would have been 0.2 MT of CO_2 lower.

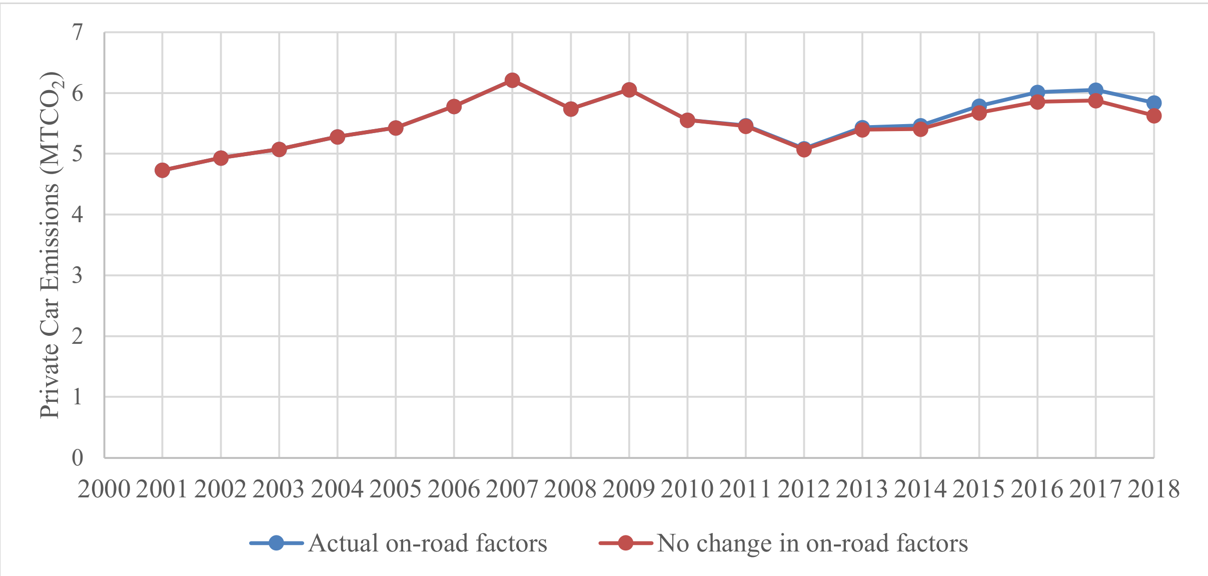

Figure 7 - Impact of increasing on-road factors on private car emissions in Ireland.

3.4 Revenue

The revenue from Annual Motor Tax for the following scenarios were recorded:

1. **Recorded Receipts**: These are the documented revenues from the Parliamentary Budget Office [22].

2. **Actual recorded revenue:** This was the expected revenue over the period of 2001 – 2018, which applied the tax bands and the stock of cars as recorded in the Irish Car Stock Model. The calculations factor in the change in taxation for cars registered after 2008.

3. **Counterfactual revenue:** This is the revenue calculated based on the counterfactual car stock scenario as described in the methods section (Section 2.3). All cars in the stock have a motor tax based on the pre-2008 engine cc-based rates as documented in Appendix D.

4. **On-road factor revenue:** This is the revenue calculated based on tax charged based on the "on-road" emissions performance instead of the manufacturer specified CO_2 emissions over the period of 2008 – 2018. The calculations factor in the change in taxation from cars registered after 2008, with the engine cc-based rate applied to pre-2008 cars and the emissions band calculate rate applied to cars registered after 2008.

The actual scenario underestimated the revenue by 9%. Differences between the recorded receipts and the revenue with no on-road factor could be determined by overdue payments of the fee which would not have yet been recorded for the latter years i.e., 2017, 2018, and as modelling discrepancies as the emission band is approximated across the car fleet from aggregated efficiency band calculations. By 2018, tax revenue in the actual scenario was calculated as €0.7 Billion, revenue which is €0.3 Billion lower than the counterfactual scenario, which calculated a revenue intake of €1 Billion. Looking to on-road factor revenue, which includes the on-road performance factor to determine the appropriate taxation band for cars, we see that had car emissions bands better reflected their on-road emissions, revenue would be €1.25 Billion for 2018.

Progression of the revenue generated from the Annual Motor Tax based is illustrated in Figure 8 (below).

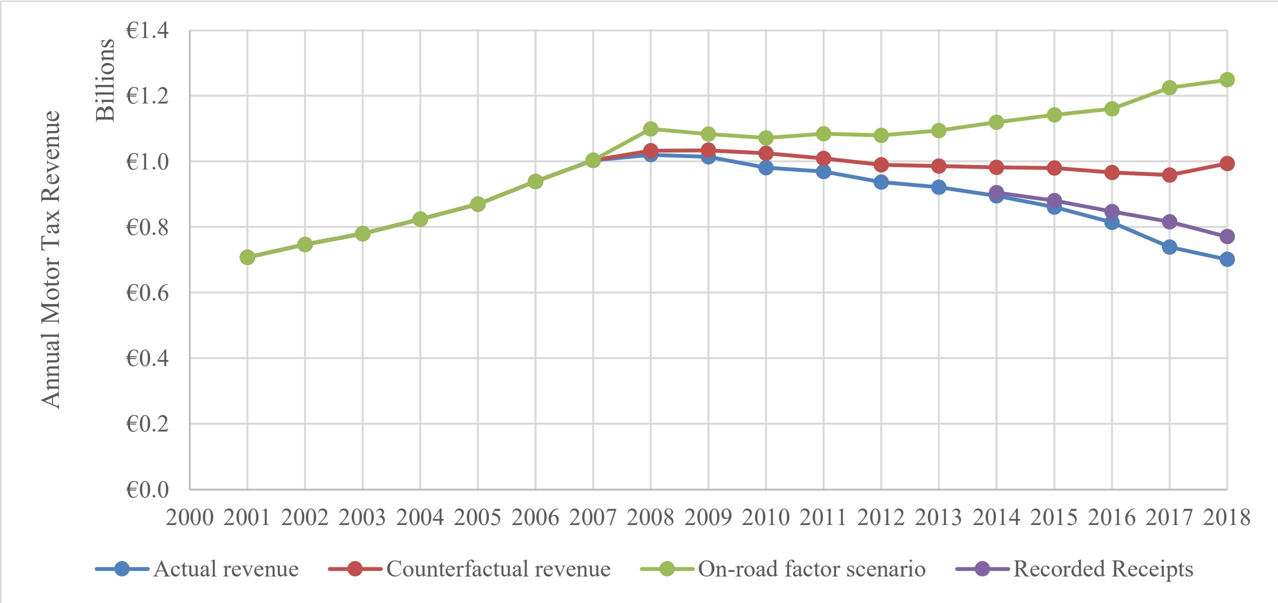

Figure 8 - Revenue generated from the Annual Motor Tax

3.5 Summary of Results

Tabulated data from the results displayed in Figure 5 – 7 are summaries in Table 1 (below).

Table 1 - Summary of emissions model results

	3.6 Overall car fleet emissions		Impact of the increasing on-road factors		3.8 Stock carbon intensity	
Year	Actual Emissions	Counterfactual Emissions	Emissions with on-road factors	Emissions without on-road factors	Actual stock carbon intensity	Counterfactual stock carbon intensity
	$MTCO_2$	$MTCO_2$	$MTCO_2$	$MTCO_2$	gCO_2/km	gCO_2/km
2001	4.7	4.7	4.7	4.7	188.54	188.54
2002	4.9	4.9	4.9	4.9	188.75	188.75
2003	5.1	5.1	5.1	5.1	188.62	188.62
2004	5.3	5.3	5.3	5.3	188.86	188.86
2005	5.4	5.4	5.4	5.4	188.18	188.18
2006	5.8	5.8	5.8	5.8	188.66	188.66
2007	6.2	6.2	6.2	6.2	188.67	188.67
2008	5.7	5.8	5.7	5.7	186.13	187.11
2009	6.1	6.1	6.1	6.1	184.63	186.25
2010	5.6	5.7	5.6	5.6	178.73	181.72
2011	5.5	5.6	5.5	5.5	174.35	178.32
2012	5.1	5.2	5.1	5.1	172.99	178.10
2013	5.4	5.6	5.4	5.4	171.44	176.45
2014	5.5	5.7	5.5	5.4	169.88	175.94
2015	5.8	6.0	5.8	5.7	168.45	174.37
2016	6.0	6.2	6.0	5.9	167.38	173.32
2017	6.1	6.3	6.1	5.9	163.41	169.56
2018	5.8	6.0	5.8	5.6	163.67	168.24

4 Discussion

Ex-ante modelling of the impact of the VRT and AMT changes had predicted a shift in purchasing trends towards lower-emissions cars but also a shift towards smaller cars [9]. Examining the full cohort of new private car sales, this anticipated shift has not been borne out by the data. Rogan et al.'s 2009 one-year ex-post analysis of the 2008 car tax change projected a 3% reduction in total CO_2 emissions from private car transport for 2009 [11]. The actual emissions calculated in this study evaluated a total CO_2 emissions reduction of 0.9% compared to the counterfactual for 2009. In 2018, the actual emission in this study suggests a 2.8% reduction in annual private car CO_2 emissions relative to the counterfactual private car emissions. However, absolute private car carbon dioxide emissions are higher in 2018 when compared to 2008, with private car CO_2 emissions being 1.7% higher in 2018 than total private car emissions in 2008. In the counterfactual case, private car emissions in 2018 would be 3.9% higher than 2008. These insights suggest that while the annual motor tax reduced private car carbon dioxide emissions compared to the counterfactual case, net carbon dioxide emissions from private cars in Ireland have been increasing.

Regarding the overall carbon intensity of the private car fleet, Rogan et al. also concluded that the average specific emissions of new cars fell by 13% to 145 g/km. The policy measure resulted in a 5.9 kt reduction in CO_2 emissions [11]. However, this study did not expect the increase in on-road factors and the growing discrepancy between manufacturer specified emissions and realized on-road emissions from private cars on Irish roads.

Alongside the unexpected increase in on-road factors, there was an unintended switch to diesel because of the taxation changes, [11] and the ensuing "Diesel Gate" scandal, which highlighted the extremely high NOx values from new diesel cars [23]. The switch to diesel also led to interaction with the Biofuel Obligation Scheme [24], [25]. The switch to diesel enabled Ireland to achieve a higher share of renewable energy in transport (due to double weighting), than would have been the case without such a switch [26]. Biofuel mixing rates in Ireland over the period of 2001 – 2018 can be seen in Appendix F.

Another unexpected occurrence when the car tax scheme was introduced was the increase in second-hand car imports over the period of 2001 – 2018. In 2019, they now account for nearly 50% of new car registrations [27]. While accounted for in the car stock model through calculating the average car age of the car stock, the impact of second-hand imports is a research question worthy of deeper analysis. Furthermore, car scrappage schemes were introduced over the period of 2001 – 2002 and 2007-2008, this may have increased the perceived impact of the 2008 car tax changes, however this was not considered in the scope of this study. Further information on scrappage schemes can be found in van Wee et. al., [28] and Kagawa et. al., [29].

4.1 Uncertainty

Uncertainty in emissions calculations was also discussed in the one-year ex-post analysis of the car tax change in Ireland. In Rogan et al. [11] the on-road factor was highlighted as a potential source for uncertainty. The values used for carbon intensity for each private car comes from standardised tests, and it is well established that these figures are much lower than the actual carbon intensity of the car whilst driving. This is due to factors such as driving technique, road surfaces and engine conditions. For this study, data from the Irish household budget survey is corroborated with a study of on-road factors of new German passenger cars [21]. Data on on-road factors up to 2015 is available, however data from 2016 – 2018 is not readily available and 2015 rates are applied in this study up to 2018.

Uncertainty also comes from a multiplication of two averages. In the final calculation of total carbon dioxide emissions, the average energy intensity by “micro-category” is multiplied by average mileage by “micro-category.” This issue was also highlighted in Rogan et al. [11].

A third source of uncertainty arises in the counterfactual scenario. The counterfactual is based on a least-squares regression between Irish car sales with respect to EU-wide car sales. The ordinary least squares (OLS) regression used for this counterfactual scenario is of the 3-year moving average of the market share of Irish new car sales of a specified engine size and fuel type with respect to EU-wide new car sales in the pre-emissions tax era. The counterfactual scenario assumes that the trends in Irish new car sales in the 2001 – 2007 era with respect to EU-wide new car sales persist. In this period, the R numbers are between 0.91 – 0.96. For the Petrol > 2000 engine cc micro-category, the average weighting of Irish new car sales with respect to European car sales is applied rather than the OLS trend, as values oscillate between -60% and -40% of EU sale values and no clear growth trend is established. Also in this period, the R number for the Diesel 1400 – 2000 cc micro-category is only 0.3, however the trend in Irish new car sales with respect to EU wide car sales only fluctuated between +59% and +55% more Irish sales than the EU average. As there was no prevailing increasing or decreasing trend of Irish new car sales with respect to EU sales for this micro-category, the average value over the period is taken.

The uncertainty issue is one aspect of the discussion on whether energy systems models are fit for purpose [48]. Gilboae et al. [49] argue that economic models are most usefully seen as describing specific, theoretical systems rather than general rules, and as such, are simply one source of knowledge alongside other data such as experimental or empirical results. A simulation technology stock-based model should be seen as a source of possible storylines rather than of fundamental truth. The situations modelled by ex-post analysis cannot be fully observed and measured, and do not exhibit a reliability of structure in time and across variations in conditions not specified in the model; therefore, they cannot be properly validated [30]. However, by comparing the results with car choice models such as Hennessey and Tol. [10], Giblin et al. [9] and Rogan et al. [11], we can gather valuable insights.

In addition, the model does not consider the rebound effect of such reductions in carbon dioxide emissions intensity, whereby perceived improvements in technology, efficiency and emissions will be coupled with an increase in kilometres travelled. This may act to negate the positive effects of this tax policy change and further measures should be put in place to protect the predicted carbon dioxide savings.

5 Conclusions and Policy Implications

5.1 Conclusions of the ex-post study

Several important findings arise from this study.

The 2008 car tax change influenced purchasing patterns. This change in purchasing patterns caused a slight shift in new car purchasing trends towards more efficient cars. For 2018, actual private car carbon dioxide emissions are calculated as 2.7% lower than in the counterfactual "no-tax change" scenario case. There is cumulative emissions savings over the 10-year period following the introduction of the tax change amounted to 1.6 MT of CO_2, when compared to the counterfactual. However, despite a significant increase in new-car efficiency arising from this policy, this did not cause a net annual decrease in private car transport emissions over the 10-year period itself. There was a strong fall in emissions after 2008, but this was caused by the economic crash of 2008 and private car emissions rebounded alongside the economy [30]. Net carbon dioxide emissions from private cars in 2018 were 1.7% higher than in 2008. This suggests that internal combustion engine efficiency improvements do not mitigate emissions sufficiently and will need to be complemented by changes to mobility and fuel type. Irish policy is reflecting this: a ban on new fossil fuel cars by 2030 is currently under discussion [6].

Observing the stock carbon intensity of the car fleet, we observed that the average carbon intensity of the fleet has reduced from 189 gCO_2/km in 2007 to 164 gCO_2/km in 2018. However, the years preceding the tax change already saw a slow improvement in the average new-car emissions intensity. The counterfactual scenario, which applied EU-wide trends to new sales in the Irish car stock, results in a carbon stock intensity of 168 gCO_2/km in 2018.

As for whether the policy was revenue neutral, it is estimated that annual motor tax receipts would have be €292 million higher in 2018 without the policy. This happened because the design of the taxation bands did not correctly anticipate the consumer purchasing trends towards cars in lower emissions classes. It also resulted in a tax-cut in disguise, as emission band tax rates were lower overall than their engine cc counterparts for most cars. This loss of revenue was anticipated in the ex-ante car choice model study from 2009 by Giblin et al. [9]. The study found that the introduction of new carbon-based taxes in Ireland would result in a reduction of 3.6 – 3.8% in CO2 emissions intensity and an annual revenue loss of €191 million. The one-year ex-post analysis of the 2008 car tax also noted that the scheme, which was intended to be revenue neutral, was not [11]. Based on this counterfactual comparison, the 1.6MT CO_2 of avoided emissions by this policy came at a cost of €1.1 billion over the period of 2008 – 2018 when comparing modelled revenue with the new taxation regime, with the counterfactual case, thus resulting in an abatement cost of

€684 per tonne of CO_2. Hennesey and Tol's [10] ex-ante cost-based car-choice model for the car tax regime showed that the cost of carbon dioxide emissions abatement would be "high, if not very high.". Our results verify these assessments and concludes that the loss in revenue from the car tax change is increasing with each year.

Our study highlights that the growing gap between rated and actual emissions intensities of new cars has reduced the impact of this environmental policy and led to a half-billion-euro reduction in potential exchequer income from annual motor tax for 2018. Annual Motor Taxes are charged based on the rated CO_2 emissions, rather than the "on-road" CO_2 emissions. If rated emissions intensity values reflected on-road intensity values, cars would fall into higher taxation bands based on their emissions and revenue tax earnings would be significantly greater. Recorded receipts from annual motor tax stood at €0.77 billion in 2018. If on-road factors were accounted for in the manufacturer's values and hence in the tax payment, revenue generated from the annual motor tax would be €1.25 billion.

5.2 Policy Implications

Since 2021, the Irish government has introduced an update to the annual motor tax [31]. The new taxation scheme includes a greater number of subcategories for emissions classes, with additional subdivisions for the emission band category, which allows for a greater specification of super low emission cars (those with a less than 50 gCO_2/km emissions intensity). However, the emission band taxation rates for the higher emissions categories have largely remained unchanged. In addition, the new taxation rates will only apply to cars registered in Ireland after 2021.

This study highlighted the importance of monitoring developments in revenue from taxation changes in the years proceeding a taxation change, as the policy results in a reduction of car tax revenue when compared to the pre-2008 engine cc-based rates. Overall, emissions from private cars in 2018 are higher than emissions in 2008, which suggest that the taxation policy was not sufficient to stem the increase in emissions from private vehicles, rather, it only stems an even greater growth in emissions. As noted in Dennehy et al., activity effects mitigate from efficiency savings from private car emissions [12]. The finding illustrates the importance of car transport demand management in parallel with financial incentives to encourage a switch to low emission and high efficiency cars. The issue of managing car activity increases also emerges in the guideline for making transport based emissions reduction policy from the Department of Transport, Environmental Protection Agency and the IPCC [32]–[34]. They recommend following the sequential Avoid-Shift-Improve framework, which focuses initially on avoiding transport demand with demand management strategies, then perusing a course to encourage modal shift to public transport or active modes of travel and as a last resort, improve the fuel efficiency or fuel type of the car through technology adoption and financial incentives. The car tax strategy focuses on the "Improve" aspect of the framework, and regarding the new car tax as a financial mechanism to reduce carbon dioxide emissions, our study found that the cost of the policy per tonne of carbon dioxide abated was high if not very high, and that finance measures are helpful, but not core to tackling the overarching drivers of passenger transport emissions in Ireland, such as transport demand and mode choice.

The tax policy also highlights the pitfalls of setting an environmental policy based on laboratory-based manufacturer specified measurements that cannot be continually monitored on the road. The manufacturer specified emissions used to set the Irish car tax rate were subject to 'gaming' in what is now known as the "diesel gate" scandal. While ratings of nitrous dioxides (NOx) and sulphur dioxides (SOx) emissions intensity, rather than carbon dioxide (CO_2), were in the spotlight throughout the scandal, the growth of carbon dioxide (CO_2) "on-road factors" in Ireland over the period of 2008 – 2018 as shown in Figure 7 (Section 3.3) note the difference between manufacturer specified and on-road CO_2 emissions highlighted that carbon dioxide emissions were also growing. This impacted the tax revenue collected by the Irish government as it was based on the underestimated emissions band rating. As internal combustion engines are emitting more than the tax policy specifies, the relative tax benefit of switching to a no-emission vehicle, such as an electric car, is subsequently reduced. Increasing the relative difference between the emissions bands, combined with the new World Harmonized Light Vehicle Test Procedure (WLTP), would result in a stronger price signal for switching to super low emission vehicles such as EVs could be helpful towards Ireland's 2030 EV uptake and sustainable energy in transport targets. Retrospectively updating taxation rates on higher emission vehicles is also an option to be considered, as current updates to the taxation policy only focuses on cars registered after the date of implementation. An iterative approach to taxation policy allows for continual monitoring of tax revenue from the new taxation schemes and prevents the revenue losses suffered because of the 2008 car tax rate changes. The 2008 car tax change ultimately culminated as a tax cut in disguise for car owners and resulted in the high cost of carbon abatement of €684 per tonne of CO_2.

6 Acknowledgements

The authors acknowledge support from the Climate and Energy Modelling Services to the Technical Research and Modelling (TRAM) Group: Services under Grant RFT2016/01213/12806.

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Appendix A. Data Sources

Metric	Unit	Sources
Fuel efficiency bands	l/100km	[15] ,[35]
Number of vehicle sales		[35]
Emissions band	gCO_2/km	[35]
On-road factors	%	[12], [15], [21]
Engine cc tax rates	€	[36]
Emission band tax rate	€	[36]
Vehicle vintage	Year	[15], [37]
Distance Travelled	km	[38]

Appendix B. On-road factors derived from the Household Budget Surveys

	Petrol	Diesel
2005	0.06	0.14
2006	0.09	0.16
2007	0.12	0.19
2008	0.14	0.22
2009	0.17	0.25
2010	0.2	0.28
2011	0.22	0.32
2012	0.25	0.36
2013	0.28	0.39
2014	0.29	0.41
2015	0.3	0.43
2016	0.3	0.43
2017	0.3	0.43
2018	0.3	0.43

Appendix C. Private Households in Permanent Housing Units 2011 to 2016 (Number) by County and City, Motor Car Availability and Census Year Census 2016 [39]

Number of households	Number of cars	Total cars in household
696684	1	696,684
567414	2	1,134,828
95238	3	285,714
30413	4.3	130,776
All households		**2,248,002**

Appendix D. Taxation rates based on the engine cc.

Engine CC	Annual Payment
Not over 1,000	€199
1,001-1,100	€299
1,101-1,200	€330
1,201-1,300	€358
1,301-1,400	€385
1,401-1,500	€413
1,501-1,600	€514
1,601-1,700	€544
1,701-1,800	€636
1,801-1,900	€673
1,901-2,000	€710
2,001-2,100	€906
2,101-2,200	€951
2,201-2,300	€994
2,301-2,400	€1034
2,401-2,500	€1080
2,501-2,600	€1294
2,601-2,700	€1345
2,701-2,800	€1391
2,801-2,900	€1443
2,901-3,000	€1494
3,001 or more	€1809

Appendix E. Engine cc-based taxation rates (Source: DTTAS, 2019)

Band	CO_2 emissions-grams per km	Annual Payment
A0	0	€120
A1	1-80g	€170
A2	More than 80g/km up to and including 100g/km	€180
A3	More than 100g/km up to and including 110g/km	€190
A4	More than 110g/km up to and including 120g/km	€200
B1	More than 120g/km up to and including 130g/km	€270
B2	More than 130g/km up to and including 140g/km	€280
C	More than 140g/km up to and including 155g/km	€390
D	More than 155g/km up to and including 170g/km	€570
E	More than 170g/km up to and including 190g/km	€750
F	More than 190g/km up to and including 225g/km	€1200
G	More than 225g/km	€2350

Appendix F. Biofuel mixing rates by energy content (2001 – 2018)

	Bioethanol	Biodiesel
2001	0%	0%
2002	0%	0%
2003	0%	0%
2004	0%	0%
2005	0%	0%
2006	0%	0%
2007	0%	0%
2008	0%	0%
2009	0%	0%
2010	1.8%	2.7%
2011	3.4%	3.8%
2012	3.6%	3.0%
2013	3.9%	3.8%
2014	3.9%	4.4%
2015	4.6%	4.4%
2016	5.3%	3.6%
2017	5.4%	5.4%
2018	5.5%	5.0%

FUNDED BY:

Ireland's European Structural and Investment Funds Programmes 2014-2020
Co-funded by the Irish Government and the European Union

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European Regional Development Fund

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