The effectiveness of CO_2-based 'feebate' systems in the European passenger vehicle market context

An analysis of the Netherlands and the UK

A report for the International Council on Clean Transportation

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Executive summary

- The International Council on Clean Transportation commissioned Cambridge Econometrics to carry out an analysis of the effectiveness of CO_2-based vehicle taxation in reducing passenger-transport CO_2 emissions.
- In this study, we sought to identify the extent to which the observed reductions in CO_2 emissions rates in the Netherlands and the UK can be attributed to CO_2-based vehicle taxation.
- In our approach, we applied econometric techniques to model the demand for new-vehicle purchases, using detailed data on quarterly registrations. In particular, we sought to identify the responsiveness of new-vehicle demand to changes in CO_2-based taxation:
  - in the Netherlands, there is now a CO_2 component to both the registration and circulation tax, with the upfront registration tax by far the largest 'price' on CO_2
  - in the UK, there is only a circulation tax, payable each year on the CO_2 emissions rate of vehicles on the road
- Having identified the determinants of new-vehicle demand, we were able to estimate the change in the emissions rate in each country that would have been brought about by the taxation currently in place, in comparison to a state of the world with no CO_2-based taxation. We were then able to compare this to the reductions in CO_2 emissions actually exhibited in our data (which is why the reductions do not correspond to officially-reported changes in emissions rates).
- Table 1 shows that CO_2-based vehicle taxation has contributed to reductions in new-vehicle emissions rates. The contribution was larger in the Netherlands, (-6.3 gCO_2/km), than it was in the UK (-3.6 gCO_2/km). This compares to total reductions in the rate, of 46.8 gCO_2/km in the Netherlands and 32.5 gCO_2/km in the UK.
- The results are of a similar size to those reported by Klier and Linn (2012) in their analysis of France, Germany and Sweden although the comparison is not quite like-for-like owing to the fact that the results reported in this study are estimated over a longer time period, where the supply of vehicles cannot necessarily be assumed to be fixed. To that extent, our results are more long-term in nature and may well include some supply-side influences.

Table 1: Estimated Impacts of CO_2-Based Vehicle Taxation

ESTIMATED IMPACTS OF CO_2-BASED VEHICLE TAXATION

	Emissions rates (gCO_2/km)				Tax instrument
	Start (period)	**End (period)**	**Change**	**of which attributed to CO_2-based taxation**	
NL	168.0 (2005)	121.2 (2012Q1-Q3)	-46.8	-6.3	Mostly registration tax (circulation tax is small)
UK	167.3 (2005)	134.8 (2012)	-32.5	-3.6	Circulation tax only

Note(s) : Start and end periods given in brackets.
Source(s) : Cambridge Econometrics.

Glossary

Circulation tax	A tax charge incurred by the owner to keep using a vehicle on public roads. The frequency of the charge (quarterly/biannual/annual etc) varies by Member State.
Feebate	A taxation system that targets CO_2 emissions from vehicles. Feebate systems differ from conventional taxation in that they tax high-emissions vehicles (the 'fee') and offer a rebate on low-emissions vehicles (the 'bate'). Strictly, neither of the tax regimes considered in this study are feebate schemes: exemptions, rather than rebates, are offered on low-emissions vehicles.
Registration tax	An upfront tax levied on a vehicle when it is purchased/first registered.

1 Introduction

1.1 Research question

The aim of this project was to assess the effectiveness of CO_2-related vehicle taxation

The key aim of this project can be summarised in the following research question:

> *What has been the effect of CO_2-related vehicle taxation on CO_2 emissions from new passenger cars?*

We carry out an econometric analysis to answer the above, dividing the original question into two sub-questions:

1. How has CO_2-based vehicle taxation affected the demand for passenger cars, as measured by new-vehicle registrations?
2. How much of the observed change in CO_2 emissions levels in new registrations is attributable to CO_2-based vehicle taxation?

In our approach, the two are linked, with the answer to the second sub-question following on from the answer to the first.

1.2 Scope of the analysis

The scope of the project has changed since it first started

As originally specified, the project sought to:

- provide an overview of CO_2-based vehicle taxation schemes in the EU
  - this task was no longer necessary following the publication by DG MOVE of a report by van Essen et al (2012) on ‘An inventory of measures for internalising external costs in transport’
- carry out a Member State-level analysis of CO_2-based vehicle taxation for three countries
  - this is covered by the current report, although the statistical analysis covers just two countries: the Netherlands and the UK. This is because these were the only two countries for which the necessary data could be obtained. We provide some descriptive analysis for Austria, but the data are insufficient to carry out an econometric analysis in the same vein as for the Netherlands and the UK
- carry out an analysis of the effect of CO_2-based vehicle taxation at the EU level
  - from the analysis herein and the information in the DG MOVE report, the heterogeneity of taxation schemes is such that a model-based analysis may well prove too crude an exercise to shed much light on the pan-European effectiveness of CO_2-based vehicle taxation. This relates in part to the difficulty in adequately modelling the vehicle stocks of each Member State owing to a lack of data

The focus of this report is on two European Member States: the Netherlands (NL) and the United Kingdom (UK). These are the two countries for which we were able to source the necessary data on new-vehicle registrations.

1.3 Structure of this report

This report contains five further chapters. In Chapter 2 we compare and contrast the tax regimes in the two countries being studied. We set out our approach to the analysis in Chapter 3. Chapter 4 contains the descriptive analysis of the data and Chapter 5 presents the results from the statistical analysis. We provide conclusions in Chapter 6 and references in Chapter 7.

Further supporting information and analysis can be found in the appendices to this report. Appendix A provides further information on the data used in this analysis and we present the correlation matrices in Appendix B. Appendices C and D then provide the results from alternative equation specifications in the econometric analysis.

1.4 Acknowledgements

We are grateful to the ICCT for assistance in obtaining vehicle-registrations data for the Netherlands and the UK. We are also grateful to ICCT staff and various others for their helpful comments on earlier versions of the econometric analysis, through participation in telephone and email discussions, and a webinar.

2 Comparison of tax regimes

In this chapter we compare the tax regimes for new vehicles in the UK and the Netherlands.

2.1 Differences in registration and circulation taxes

In the Netherlands, the main CO_2 tax is an upfront registration tax…

In the Netherlands, there are two taxes that are applied to vehicles:

- A registration tax (Belasting van Personenauto's en Motorrijwielen)
- An annual circulation tax (motorrijtuigenbelasting)

The registration tax has a heavy emphasis on the CO_2 emissions of the vehicle, although there is also a list price component and a non-CO_2 emissions component for diesel vehicles. The annual circulation tax is based upon which region the vehicle is registered as well as the weight of the vehicle and the fuel used to power the vehicle. It should also be noted that petrol cars with CO_2 emissions below 102 gCO_2/km and diesel cars with CO_2 emissions below 91 gCO_2/km are exempt from both of these taxes.

…whereas in the UK the main CO_2 tax is an annual circulation tax

In the UK there is no registration tax, but there is an annual circulation tax (Vehicle Excise Duty). This circulation tax is based entirely on the CO_2 emissions of the car. Cars with CO_2 emissions below 100 gCO_2/km pay no tax and cars with emissions below 120 gCO_2/km are lightly taxed (£30 per annum). The heaviest emitters, those with emissions above 255 gCO_2/km, are taxed at £475 per annum. Although the UK has no registration tax *per se*, vehicle owners do have to pay different rates of the registration tax in the first year the car comes into usage. The profile of the tax rates is far steeper in this first year than in subsequent years. In the first year, cars with CO_2 emissions below 130 gCO_2/km pay no tax while those with CO_2 emissions above 255 gCO_2/km have to pay £1,030.

In order to see how the design of the tax systems affects ownership costs, it is instructive to consider how the tax incidence would differ if identical vehicles (in terms of their attributes) were registered in the two countries. Table 2.1 and Table 2.2 draw on the analysis in van Essen et al (2012) to show how the tax incidence differs for three distinct vehicles.

Table 2.1 presents the key attributes of the vehicles in question, from three different market segments, while Table 2.2 shows how those attributes translate into vehicle taxes in the Netherlands and the UK, identifying:

- the annual circulation tax paid each year
- the one-off up-front tax paid when the vehicle is first registered
- the tax on fuel (a running cost incurred over the life of the vehicle)

Overall, consumers pay much higher CO_2 taxes in the Netherlands than they do in the UK

Table 2.2 shows that vehicle owners in the Netherlands face much higher taxes than those in the UK: the annual circulation tax is much higher in the Netherlands, and new owners must also pay a large up-front registration tax (whereas, in the UK there is no such tax). The Netherlands also imposes an additional penalty on diesel cars, leading to a substantially higher circulation tax in the case of Vehicle B.

In terms of other running costs, taxes on petrol are somewhat higher in the Netherlands compared to the UK with the reverse for diesel. The tax on diesel is around 60% higher in the UK than in the Netherlands. The two countries have opted to tax diesel in different ways, with the Netherlands' tax regime targeting ownership of the vehicle while, in the UK, it is the act of using the vehicle that is taxed.

Table 2.1: Description of Representative Vehicles

DESCRIPTION OF REPRESENTATIVE VEHICLES

	Vehicle A	Vehicle B	Vehicle C
Model	207	Golf	Mondeo
Manufacturer	Peugeot	Volkswagen	Ford
Market Segment	2 Small	3 Lower Medium	4 Medium
Fuel Type	Petrol	Diesel	Petrol
CO_2 (g/km)	147	119	184
Fuel Efficiency (litres/100km)	6.34	4.49	7.93
Euro Emissions Standard Class	5	5	5
Engine Power (kW)	54	77	149
Engine Capacity (cc)	1,360	1,598	1,999
Weight (kg)	1,214	1,314	1,496
List Price (€)	12,283	22,115	35,280

Source: van Essen et al (2012), for DG MOVE.

Table 2.2: Comparison of Tax Regimes

COMPARISON OF VEHICLE TAX REGIMES

	Annual Circulation Tax (€)		
	Vehicle A	**Vehicle B**	**Vehicle C**
Netherlands	608	1,344	896
UK	157	350	250
	Vehicle Registration Tax (€)		
	Vehicle A	**Vehicle B**	**Vehicle C**
Netherlands	5,454	7,182	12,308
UK	-	-	-
	Fuel Tax (€/100km)		
	Vehicle A	**Vehicle B**	**Vehicle C**
Netherlands	6.45	2.73	8.06
UK	6.28	4.52	7.85

Source: van Essen et al (2012), for DG MOVE and IEA *Energy Prices and Taxes* (2012 edition).

2.2 Evolution of vehicle taxation in the Netherlands

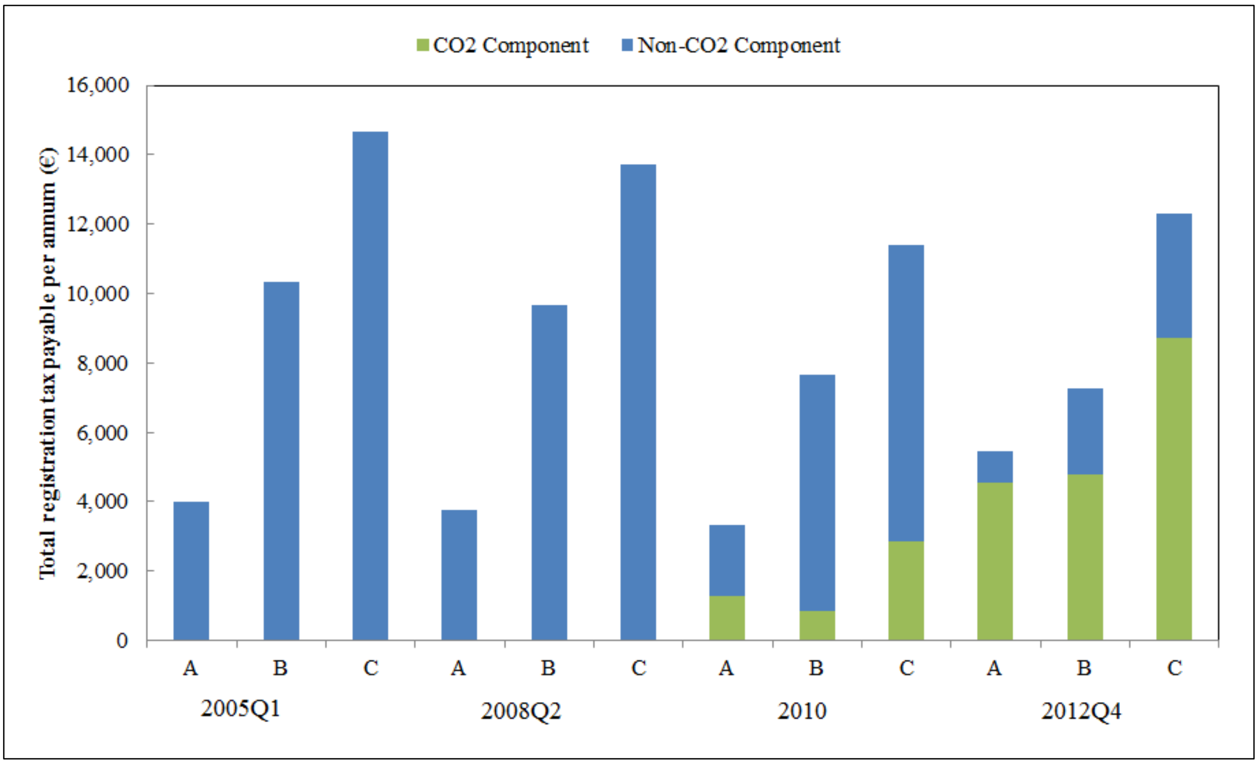
The total registration tax in the Netherlands has fallen over time, although more of it is now based on the CO_2 emissions rate

The Netherlands first introduced a CO_2 component into the registration tax in 2008. Prior to that, the tax was based entirely on the list price of the vehicle. Initially, the CO_2 part of the tax was only levied on the most polluting vehicles: petrol cars with CO_2 emissions above 233 gCO_2/km and diesel cars with emissions above 193 gCO_2/km.

The tax did not affect vehicles such as those shown in Table 2.1 and Table 2.2 until later on, as more of the registration tax was linked to CO_2, rather than the list price. In general, as the registration tax has become more CO_2-oriented, the overall size of the tax has fallen.

Figure 2.1 shows how the composition of the Dutch registration tax has changed since 2005, for the vehicles presented in the previous section. In 2005, none of the representative vehicles paid tax based on their CO_2 emissions while, by 2012Q4, the majority of the registration tax was linked to CO_2 emissions.

Figure 2.1: Evolution of NL Registration Taxes



2.3 Evolution of vehicle taxation in the UK

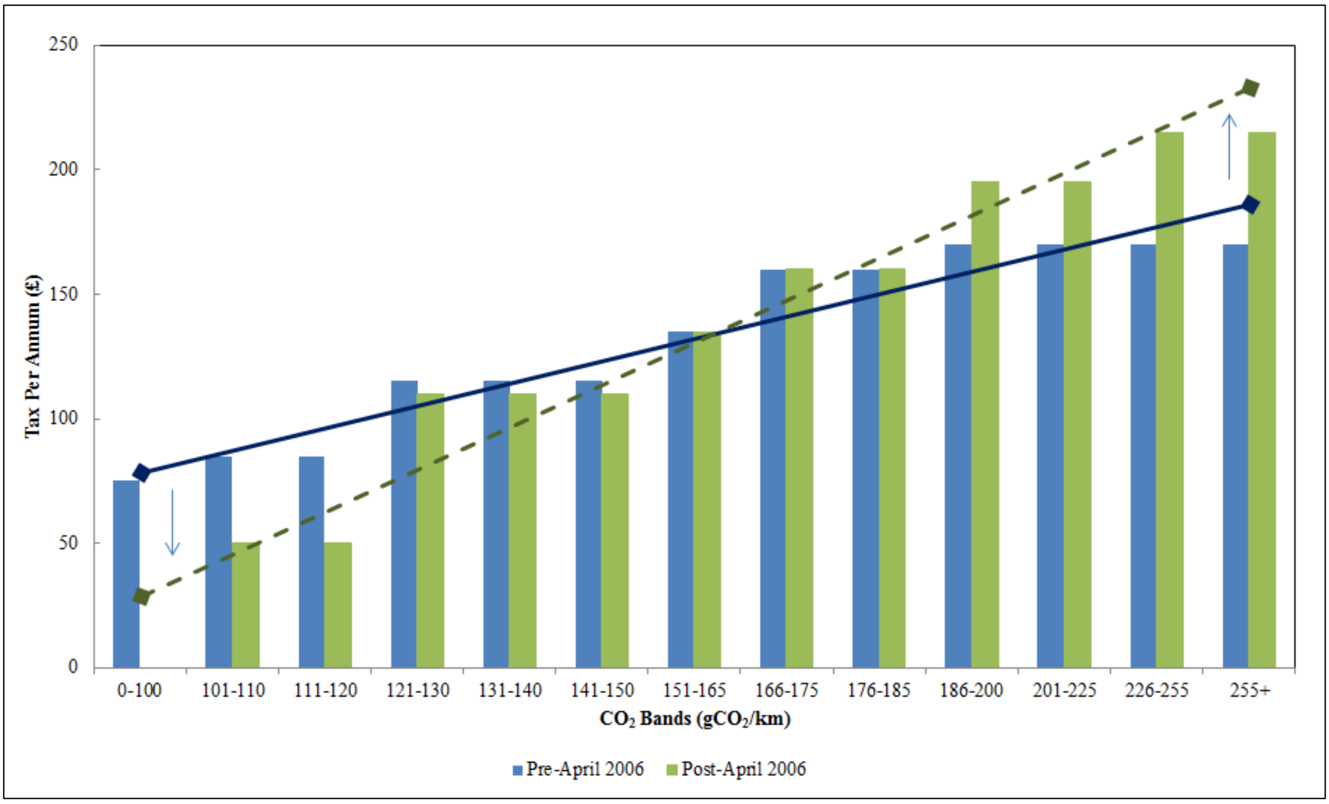
In the UK, the CO_2-based bands have become narrower, leading to a less stepped tax regime

The UK implemented CO_2-based vehicle taxation in April 2001; before then, the circulation tax was based entirely on engine size (which is related, albeit indirectly, to CO_2 emissions).

Until April 2006, the revised tax was divided into four CO_2 bands (the darker blue bars in Figure 2.2). From April 2006 onwards, a much finer banding system was implemented, leading to greater differentiation between vehicles, with the tax on the lowest band set to zero. Over time, the tax on less-polluting vehicles has fallen while that on more-polluting vehicles has risen. This has led to a steeper 'slope' to the tax curve ie a higher tax rate per gCO_2.

Other than a gradual increase in tax rates across the board, the only modification to the UK tax system came in 2010, when a higher tax was introduced for the first year a car is on road.

Figure 2.2: Evolution of UK Circulation Taxes



3 Approach

In this chapter we outline the research question that serves as the underlying motivation for the work. We then set out our approach to answering this research question, using statistical analysis.

3.1 Research question

We divide the overarching research question into two parts

As mentioned at the beginning of this report, the aim of the project was to answer the following research question:

> *What has been the effect of CO_2-related vehicle taxation on CO_2 emissions from new passenger cars?*

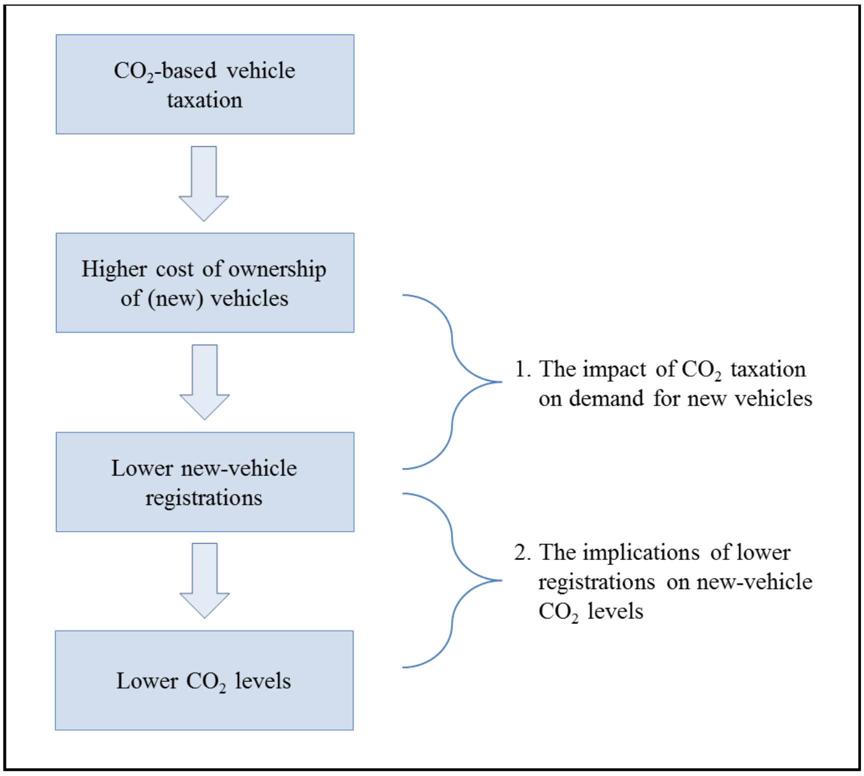
In answering the above question, we divide it into two:

1. How has CO_2-based vehicle taxation affected the demand for passenger cars, as measured by new-vehicle registrations?
2. How much of the observed change in CO_2 emissions levels in new registrations is attributable to CO_2-based vehicle taxation?

Broken down in this way, the underlying logic (presented graphically in Figure 3.1) is as follows:

- CO_2-based vehicle taxation raises the cost of owning a vehicle
  - depending on the design of the scheme, this will raise the upfront cost of registering a new vehicle (a registration tax) and/or raise the lifetime cost of continuing to run the vehicle (a circulation tax)

Figure 3.1: Approach to Identifying the CO_2 Impact of CO_2 Taxation



- higher ownership costs, other things being equal, curbs demand for new vehicles, lowering new-vehicle registrations
- by extension, lower new-vehicle registrations lower CO_2 emissions

The first of these points is a straightforward calculation based on the relevant characteristics of each vehicle and the structure of the tax regime.

The approach identifies the effect of CO_2-based taxation on demand reduction, but not substitution

The second point is the part of the logic chain that we seek to answer econometrically, to identify the determinants of new-vehicle registrations. Given the differing characteristics of available vehicles, including their emissions rates, it seems likely that some consumers, rather than simply choosing not to buy a car, will substitute away from higher-emissions to lower-emissions vehicles. The econometric model we describe below does not explicitly capture this effect. Instead, the model captures the idea that, if CO_2 taxation does indeed curb new-vehicle demand, it will tend to reduce demand for higher-emissions vehicles more than it does low-emissions vehicles.

In the additional analysis reported in the appendices, we do attempt to separate out the differential tax effects for different market segments (although the quality of these results is relatively poorer than the main ones). This goes part of the way to addressing the substitution issue but by no means fully captures these effects.

The final part of the analysis follows from that econometric analysis: having identified the determinants of new-vehicle registrations, we identify the portion of the observed change in vehicle CO_2-emissions levels that is attributable to CO_2-based taxation.

3.2 Analysing the determinants of new-vehicle registrations

The first part of the analysis identifies, econometrically, the determinants of new-vehicle registrations

CO_2-based vehicle taxation acts on CO_2 emissions by inducing changes in the demand for vehicles (through a higher price associated with higher emissions rates). As such, in our analysis, we do not model the CO_2-emissions level of vehicles directly. Instead, we model consumer demand for new vehicles. The introduction and/or increase in CO_2-related taxation raises the costs faced by prospective owners of new vehicles and should lead to reductions in demand. This in turn has consequences for the CO_2-emissions levels of new vehicles.

The aim of the econometric analysis is to identify the factors that affect demand for new vehicles (as observed in new registrations). The factor we are most interested in is the influence of CO_2-based taxes on the demand for vehicles. We include other variables in the regression to control for other confounding effects. Specifically, we model quarterly new-vehicle registrations as a function of:

- a measure of economic activity
- real running (ie fuel) costs
- CO_2-related taxes

The data are disaggregated both through time and by vehicle type, forming a panel dataset. In this context a 'vehicle type' is defined by a distinct combination of:

- model eg Volkswagen Golf
- fuel type
- engine characteristics (capacity and/or power)
- CO_2 emissions rate

The initial, general, econometric model takes the following form, with the *change* (the first-differenced natural logarithm) in quarterly vehicle registrations expressed as:

$$\Delta ln\, q_{it} = \alpha_0 \Delta lnRT_{it} + \alpha_1 \Delta lnRT_{it-1} + \beta_0 \Delta lnCT_{it} + \beta_1 \Delta lnCT_{it-1} + \delta_0 \Delta lnFC_{it} + \delta_1 \Delta lnFC_{it-1} + \gamma \Delta lnACTY_t + \varphi_i + \epsilon_{it}$$

where:

- q_{it} denotes the number new registrations of vehicle type i in quarter t
- RT_{it} denotes, where applicable, the CO_2 component of the registration tax on vehicle type i in quarter t (or the lag in quarter *t-1*)
- CT_{it} denotes the circulation tax on vehicle type i in quarter t (or the lag in quarter *t-1*)
- FC_{it} denotes the fuel cost of running vehicle type i in quarter t (or the lag in quarter *t-1*)
- $ACTY_t$ denotes the economic-activity indicator in quarter t
- φ_i denotes the vehicle-specific fixed effect

The above specification is similar to that of Klier and Linn (2012), who estimate equations for France, Germany and Sweden.

We combine detailed registrations data with other information on taxes, fuel prices and economic activity

The new-vehicle registrations data for the Netherlands and UK come, respectively, from:

- the Netherlands RDW
  - quarterly registrations data over 2005Q1-2012Q4
- the UK Department for Transport
  - monthly registrations data over 2005M1-2012M12, aggregated to quarterly frequency[1]

The tax variables correspond to those described in Chapter 2.

The fuel-cost variable represents an attempt to allow consumers’ expectations of future fuel costs of a vehicle to affect their purchasing decision. Following Klier and Linn (2012), where possible, we represent consumer’s lifetime-expected fuel costs of a vehicle as the vehicle-specific fuel consumption multiplied by the current end-user fuel price, under the assumption that fuel prices follow a random walk process such that the best estimate of future fuel prices is the current period fuel prices. This is not possible for the UK as our dataset does not contain information on fuel efficiency and we use the fuel price directly in this case.

The fuel-price data come from the quarterly IEA Energy Prices and Taxes publication. These data were available to 2012Q3, meaning that the last quarter of data for estimation was 2012Q3, even though registrations data are available for 2012Q4. These prices are expressed in 2005 terms, using the relevant GDP deflators from Eurostat.

To allow for possible delayed responses to changes in taxes and fuel prices, one-quarter lags are also included. In fact, in the final regressions, we find that it is the lags that are important, rather than the contemporaneous effects.

To account for the impact of national income on new-vehicle demand, we also include an indicator of economic activity. In earlier work we trialled quarterly real GDP and

[1] Although the data for UK was available from 2001M1, for the econometric analysis only a subset of the data (covering the same time period as the data for the Netherlands) was used to make the results for the two countries comparable. The full dataset available for the UK is used for the descriptive analysis. Additional regressions results using UK data since 2001 is provided in Appendix D.

household final consumption expenditure but our final regressions use, instead, measures of consumer confidence published by the European Commission Directorate General for Economic and Financial Affairs, either:

- overall consumer confidence
- the component of the consumer confidence indicator relating to the ‘intention to buy a car in the next 12 months’

The model includes a set of quarterly dummy variables to account for seasonal patterns in the vehicle registration data and a series of vehicle-specific fixed effects. This allows for any vehicle-specific factors that may influence quarterly registrations. These vehicle-specific impacts may be correlated with the explanatory variables.

Standard errors are clustered by market segment.

There are some differences to Klier and Linn’s (2012) approach

Other than a different selection of countries, the key differences with Klier and Linn’s (2012) work are:

- a longer timespan for estimation:
  - NL: 2005Q1-2012Q3 (from RDW)
  - UK: 2005Q1-2012Q3 (from the UK Department for Transport)
- a log-log specification to identify elasticities[2]
- the allowance for lagged (delayed) responses in vehicle registrations
- the exclusion of annual dummies and annual-quarter interactions

The first of the above, the longer time period, means that the results we report identify more long-run effects on vehicle registrations, rather than the short-term policy effect identified by Klier and Linn (2012). Indeed, Klier and Linn’s (2012) choice of countries was motivated by the desire to identify the demand-side impact of policy, focusing on situations in which the supply of vehicles could reasonably be assumed to be fixed.

Such analysis is not so straightforward for the Netherlands or UK, where tax shifts were introduced more gradually. As a consequence, the longer time period means that the regression results are likely to reflect some supply-side influences.

The final point relates to the exclusion of annual dummies and annual-quarter interactions. Klier and Linn (2012) include these in their regressions to control for a variety of factors not explicitly accounted for in their equation specification. In our approach, we seek to control for some developments through time, in the form of the economic activity indicator. As such, we prefer an economic indicator to these dummy variables.

We still retain the fixed effects in our equations, to capture underlying differences in vehicle types. In the appendices we present equations that use the vehicle characteristics in the data in place of the fixed effects, to see how sensitive the results are to this change in specification. The purpose of this alternative specification is to identify more explicitly, if possible, the determinants of vehicle demand, based on the characteristics of the available vehicles. For the purposes of identifying the tax response, the use of fixed effects (rather than vehicle attributes) is only problematic if those effects are absorbing statistical variation that should in fact be attributed to the

[2] Elasticities indicate the proportionate change in one variable from a change in other. For example, a tax elasticity of -0.5 for vehicle registrations should be interpreted as a 1% increase in tax leading to a 0.5% decrease in vehicle registrations.

taxation. In that sense, the fixed-effects approach is a pragmatic one although an equation that incorporates more vehicle-specific attributes lends itself better to overall economic interpretation.

3.3 Analysing the implications for CO_2 emissions levels

The second part of the analysis uses the estimated elasticities to identify the amount of the overall observed emissions-rate reduction attributable to CO_2 taxation

Having identified the individual effect of each determinant of new-vehicle registrations, we then use these results to analyse the extent to which CO_2 taxation has contributed to reductions in emissions levels. We calculate this using the equations estimated from the previous step to compare the implied CO_2-emissions levels of new vehicles with and without the CO_2 tax.

In this analysis, we hold all other elements of the demand equation constant, in order to isolate the contribution of CO_2 taxes to reductions in emissions rates. The impact of the CO_2 tax thus arises from a combination of:

- the estimated responsiveness of consumers to changes in the tax rates on CO_2
- the size of the CO_2 tax in place in the country

3.4 Limitations of the approach

A key limitation of the approach is that it likely includes some supply-side factors

When interpreting the coefficient estimates for the tax variables it is necessary to bear in mind that the CO_2-taxes have been phased in and increased gradually, in both the Netherlands and the UK. It is not reasonable to assume that both the set of vehicles and their characteristics are fixed over the estimation period (particularly given the lengths of the periods).

This means that the registrations series will reflect both changes in the supply offering as well as changes in demand for vehicles as a result of CO_2-related taxation. This makes it more difficult to separately identify the impact of the CO_2-related tax, compared to a context in which a tax is introduced over a short time period. In the latter case, an estimation of the short-run effect can be carried out. This is a key difference between the results reported by Klier and Linn (2012) (because they focused on countries with a clearer 'before' and 'after' in tax regime terms) and those reported in the next chapter.

A second point to note is that because we estimate a reduced form, rather than a structural equation, the coefficient estimate on the tax variable will include:

- the positive effect on registrations from a reduction in the equilibrium price
- the direct negative impact on registrations from CO_2-related vehicle taxation.

The coefficient estimates should therefore be interpreted as the net impact of these two effects and the impact thus resembles more closely a long-term elasticity, rather than a short-term one. This is because we cannot reasonably assume that the supply of vehicles is fixed over the entire period.

The approach is also limited in its ability to identify the substitution decisions of consumers

Finally, when considering the size of the estimated change in the average emissions rate it is important to note that the reduction arises from registrations of highly emitting vehicles falling relative to registrations of lower emitting vehicles. What the simulation cannot capture is:

- whether the fall in registrations of highly emitting vehicles is replaced with demand for lower emitting vehicles

- the supply-side impact on vehicle manufacturers and the entry of vehicles with lower emissions rates to the market

For the first of these points, we do attempt to separate out the tax responses by market segment (in the Appendices) but the results broken down in this way were too poor to be considered credible. This goes part of the way to considering the nature of substitution but by no means addresses the issue, even if the results were suitable for further analysis.

In the main equation, the tax-response parameter should be interpreted at the aggregate level, as the *percentage change in total registrations* from a 1% increase in the CO_2 tax. The way this regression is specified, increases in CO_2 taxation have the same *percentage* effect on registrations, regardless of the vehicle being taxed (although different vehicles do of course incur different *levels* of tax, by virtue of having different emissions rates).

An equation that separately identified the consumer response by vehicle type (as we attempt to identify in the robustness analysis) would be able to account for the potentially-differing effects of taxation by market segment. Consumers may respond differently to a 1% increase in tax in minis compared to small cars, for example (beyond the simple fact that different vehicles have different emissions rates).

Note that even this specification only captures part of the consumer decision: the relative responsiveness to an increase in taxes (which segments are relatively more/less affected by taxation).

In order to fully model the consumer decision, we would have to incorporate a system of relative attributes such that registrations of a particular vehicle depend not only on its own attributes but the characteristics of alternative vehicle choices (and, indeed, the option not to buy a vehicle at all). This system would also cover how the change in taxes affects the relative CO_2 cost between pairs of vehicle types. This approach goes beyond the scope of this current project and the available data, especially as the data do not support the more basic market-segmentation equation described above.

The last point, on supply-side factors, becomes more relevant as the period over which the estimation and simulation is carried out gets longer. When the estimation is confined to a shorter period, it is appropriate to assume that the characteristics of vehicles are fixed.

3.5 Pan-European implications of CO_2-based vehicle taxation

Vehicle stocks and taxation systems vary widely across Europe

One of the original aims of the project was to identify the EU-wide implications of CO_2-based vehicle taxation. The analysis in the DG MOVE report and the analysis in this report show how heterogeneous vehicle-taxation systems are across Europe, with different Member States applying market-based instruments very differently in order to internalise the environmental costs associated with private passenger vehicles. Moreover, the make-up of the vehicle fleets in each Member State can also differ markedly.

This presents a number of challenges when attempting to put CO_2-based vehicle taxation in a pan-European context because:

- the starting point in each Member State differs (its current tax system, which is potentially broader than taxes levied directly on vehicles, covering, for example, infrastructure and fuel)

- the vehicle fleets differ in composition (as do the structures of their new-vehicle markets)
- the behavioural responses of consumers to vehicle taxation may well vary

As such, the scope for extrapolating the likely impacts of a common European taxation system is quite limited, owing to data constraints (on vehicle stocks) and a lack of information on consumer responses for every Member State, as well as a heavy requirement to account for a transition from countries’ current tax system to the common one.

Consequently, we do not attempt to model the potential Europe-wide impacts of CO_2-based vehicle taxation as such analysis risks being overly crude in its approach.

4 Descriptive Analysis

In this chapter we present descriptive analysis of the registrations data for the Netherlands, UK and Austria.

For the Netherlands and the UK this forms a precursor to the more formal econometric analysis presented in Chapter 5. In the case of Austria, the data did not cover a sufficiently-long time period (nor were they of a suitably-high frequency) for us to carry out an econometric analysis. As a result the analysis of Austria is restricted to the descriptive analysis in this chapter only.

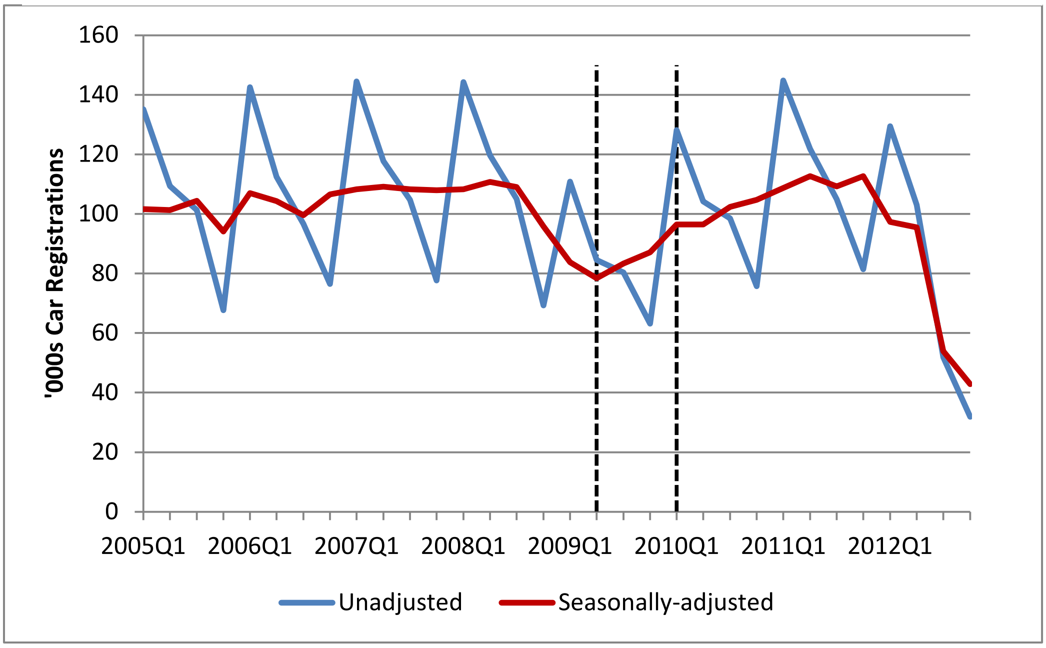
4.1 Descriptive analysis for the Netherlands

New car registrations

Figure 4.1 shows total new car registrations in the Netherlands from the RDW dataset (after processing and cleaning). Both the actual and seasonally adjusted values are shown, illustrating the strong seasonal pattern each year as well as the underlying trend in registrations. This pattern of seasonality is characterised by a peak in quarter one and a decline through to the fourth quarter of each year[3].

The deseasonalised series shows more clearly the long-term movements in new car registrations in the Netherlands. Registrations fell markedly in the recession and, after a gradual recovery through 2010-11, fell even more sharply in the second half of 2012 as the Netherlands re-entered recession.

Figure 4.1: Total New Car Registrations in the Netherlands.



Note: Dashed lines indicate start and end of scrappage scheme.
Source: RDW.

[3] This arises in part because new owners tend to defer purchase and registration until January, as the resale value of vehicles in the Netherlands is related to the year of registration. A vehicle registered in January commands a higher resale value than one registered in December of the previous year.

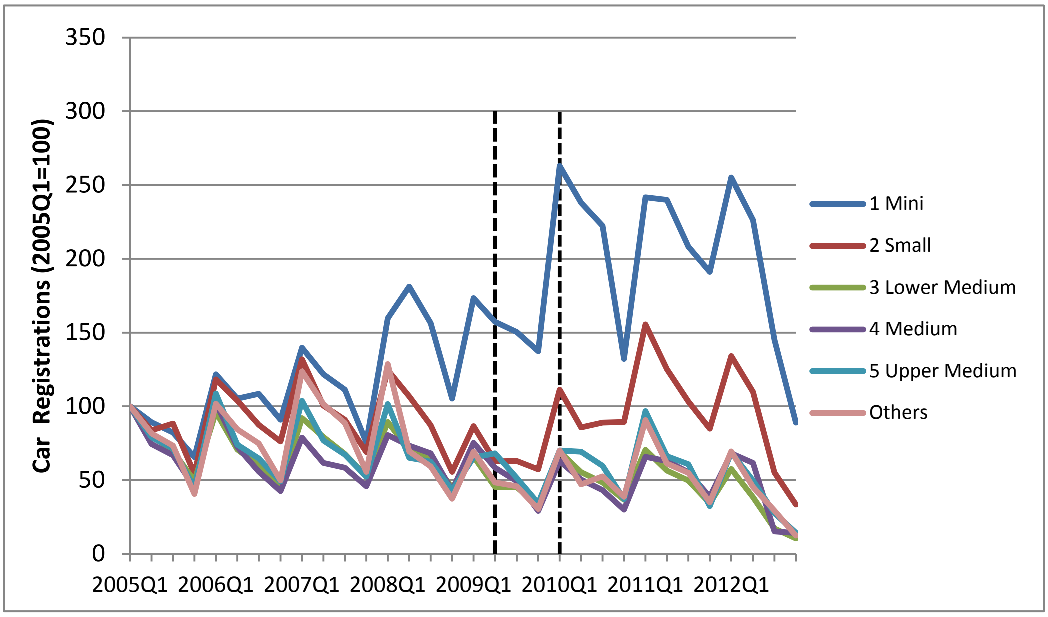
Registrations by market segment

Figure 4.2 shows the evolution of new-car registrations broken down by market segment (not seasonally adjusted). Before the further downturn in 2012H2, the mini market segment saw strong growth with new registrations more than doubling between 2005Q1 and 2012Q1. This is in contrast to the medium, luxury, sport and MPV market segments in which registrations fell by 30-80% over the same period.

Average CO_2 emissions of newly-registered cars

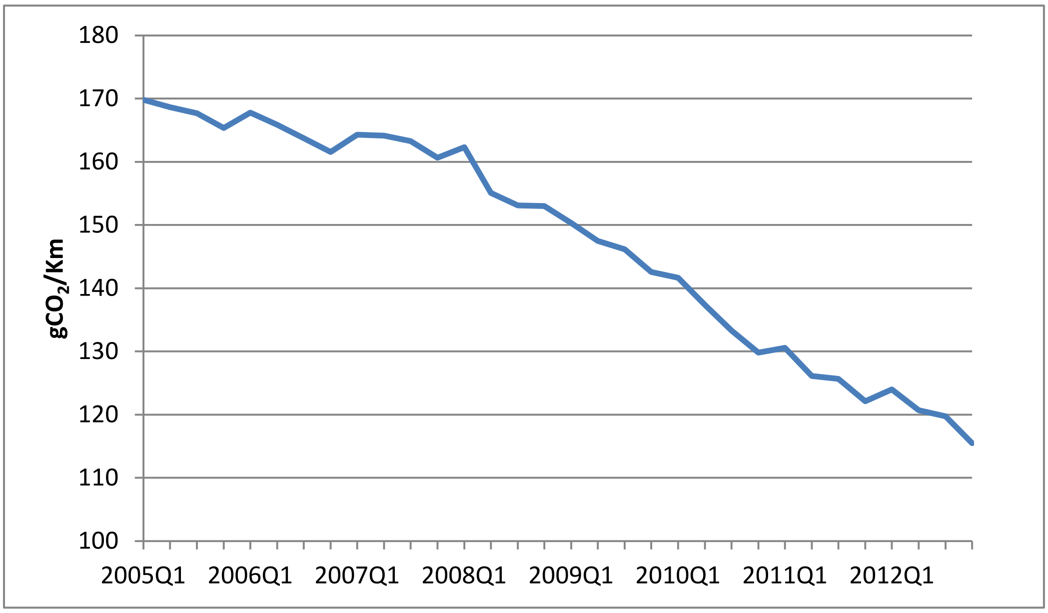
Figure 4.3 plots the average CO_2 emissions rate of newly-registered cars over the sample period. The average CO_2 emissions rate has fallen steadily from around 170 gCO_2/km in 2005Q1 to 117g CO_2/km in 2012Q4. The reduction in emissions rates

Figure 4.2: New Car Registrations in the Netherlands by Market Segment



Notes: Dotted lines indicate the start and end of the scrappage scheme.
'Others' category contains luxury, sports, off-road, and MPVs.
Source: RDW.

Figure 4.3: Average CO_2 Emissions in Total New Car Registrations in the Netherlands



Source: RDW.

over a period as long as this (relatively speaking) will have arisen from a combination of supply and demand-side factors:

- ‘supply push’: manufacturers producing more efficient, less polluting vehicles (spurred in part by regulation)
- ‘demand pull’: changing economic circumstances and policies to encourage behavioural changes in demand, in favour or more efficient and lower-emissions vehicles

Figure 4.4 and Figure 4.5 examine the evolution of emissions rates by market segment.

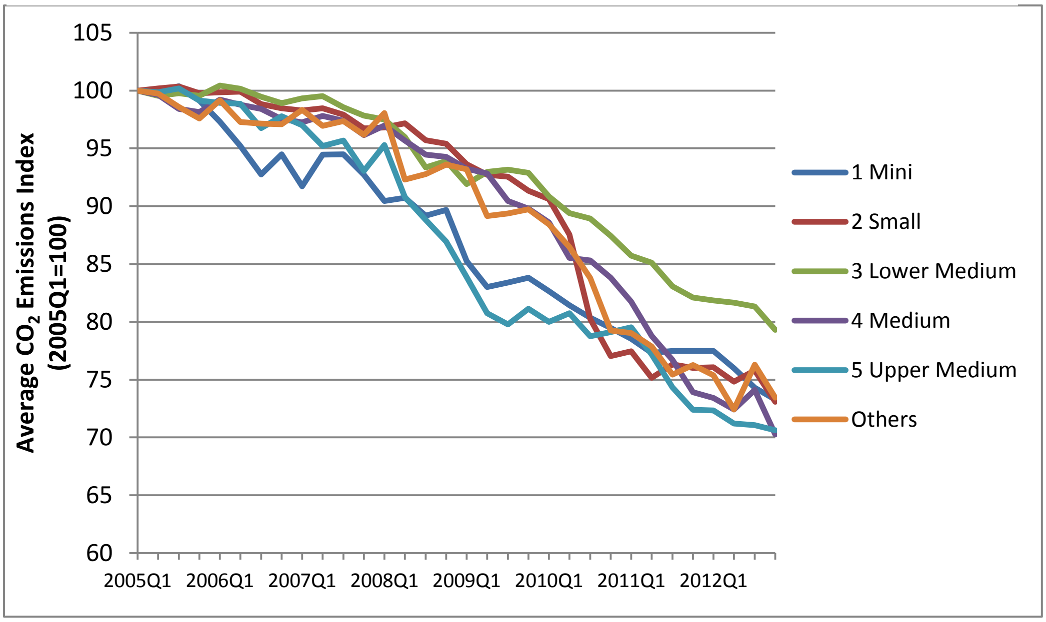
CO_2 emissions rates by market segment

Figure 4.4 shows how the emissions rate has fallen in all market segments, with a similar fall in all categories. The largest fall was in the medium market segment (30% over 2005Q1-2012Q3) while the smallest was in the sport segment (around 20%).

Market share by CO_2 emissions rate

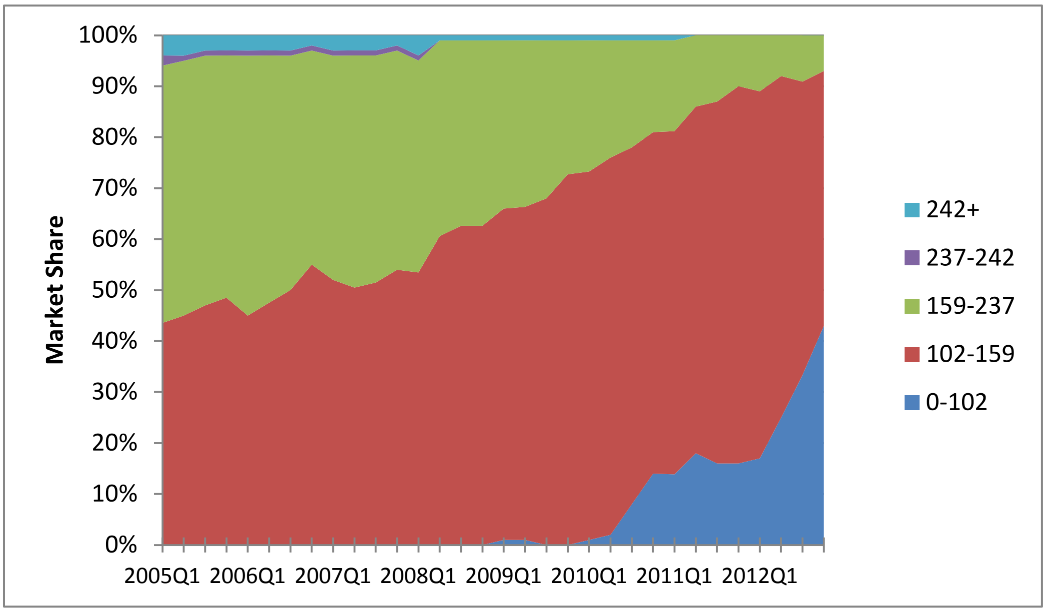
Alongside the reduction in emissions rate *within* market segment, there has also been a marked shift in the pattern of demand, away from relatively-more polluting vehicles (between 160-237 gCO_2/km) and towards cleaner vehicles (with emissions rates of 102-159 gCO_2/km). The former category accounted for just over half the new-vehicles market in 2005Q1 but this had fallen to just over 10% by 2012Q1. In contrast, the share of the lower band grew from 45% in 2005Q1 to three-quarters of the market by the start of 2012. Over this same period, vehicles in the most-polluting emissions bands have all but disappeared while there has been rapid growth in the share of new vehicles with emissions rates of 100 gCO_2/km or less. The market share of this lowest band was negligible before 2010 and rose to account for 17% of new registrations in 2012Q1. The Netherlands re-entered recession in 2012. In 2012H2, the markets for larger vehicles fared somewhat worse than for smaller vehicles but all market segments saw substantial reductions in demand.

Figure 4.4: Average CO_2 Emissions in New Car Registrations by Market Segment in the Netherlands



Note: ‘Others’ category contains luxury, sports, off-road, and MPVs.
Source: RDW.

Figure 4.5: Market Share by Average CO_2 Emissions (g/km) in the Netherlands



Source: RDW

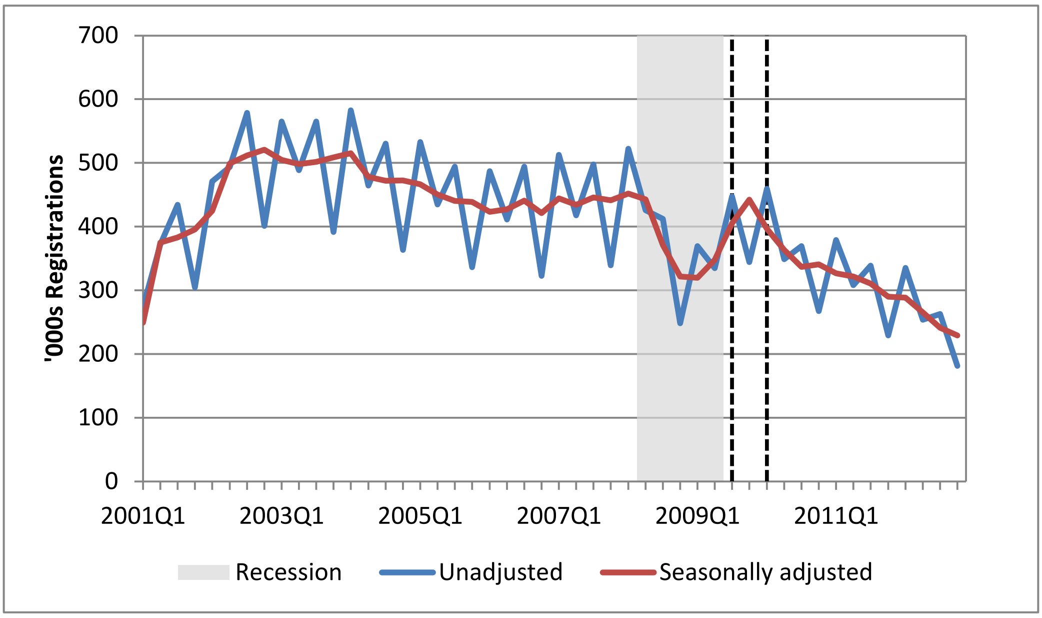
4.2 Descriptive analysis for the UK

New car registrations

Figure 4.6 plots total new car registrations from the processed and cleaned DfT dataset. As for the Netherlands, there is a high level of seasonality in the data, with peaks in the first and third quarters of each year (new number plates come out twice-yearly in the UK). Figure 4.6 also shows a deseasonalised version of the registrations series, to pick out the underlying trend.

Pre-recession, UK new-car registrations were relatively stable, at 1.5-2m each year. Registrations slowed substantially in the recession, with a brief pick-up at the end of

Figure 4.6: Total New Car Registrations in the UK



Note: The dotted lines indicate the start and end of the scrappage scheme
Source: Department for Transport

2009 and start of 2010 that coincides with the UK Vehicle Scrappage Scheme. Figure 4.6 shows a sustained downward trend in registrations thereafter, in the period where UK economic growth was either flat or negative.

Registrations by market segment

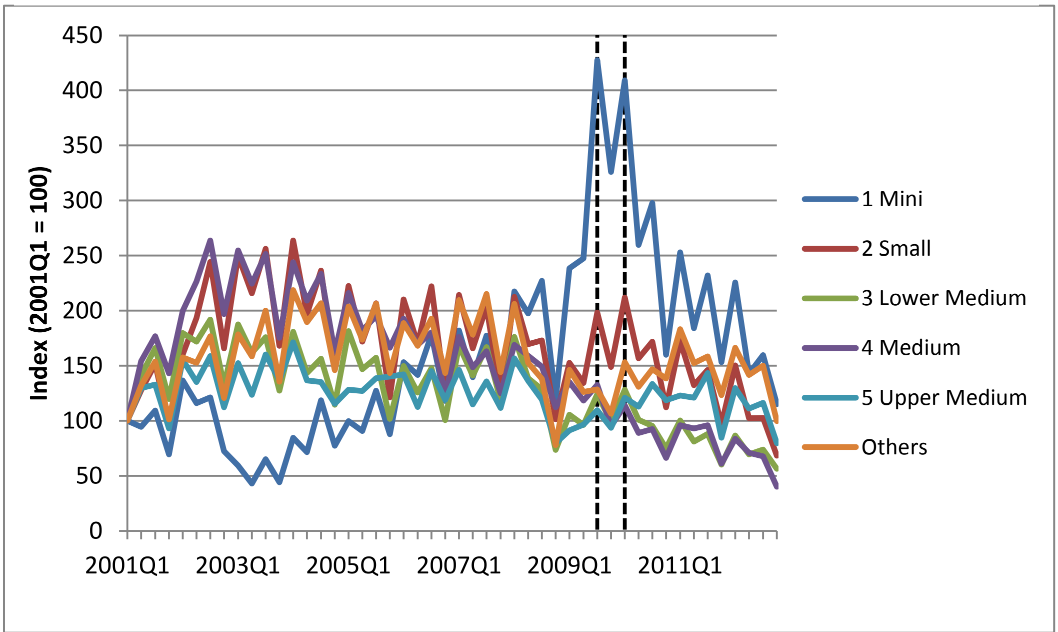
Figure 4.7 plots new-car registrations by market segment (indexed to 2001Q1). The most striking feature of Figure 4.7 is the surge in registrations in the mini market segment in the period that the Vehicle Scrappage Scheme was in operation[4].

The mini market segment has seen the largest growth over 2001-12 but it still remains a small part of the UK new-vehicle market, accounting for less than 10% of registrations in 2012. The UK market continues to be dominated by the small and lower-medium market segments (accounting for 60% of new registrations in 2012).

Average CO_2 emissions of newly-registered cars

Figure 4.8 plots the average CO_2 emissions rates of newly-registered cars in the UK. As in the Netherlands, the average emissions rate has fallen steadily over time, although in the UK the pace of the reduction has been slightly slower. In 2012Q4, the average emissions rate of new vehicles (from our data) was 135 gCO_2/km, compared to 175 gCO_2/km in 2001Q1.

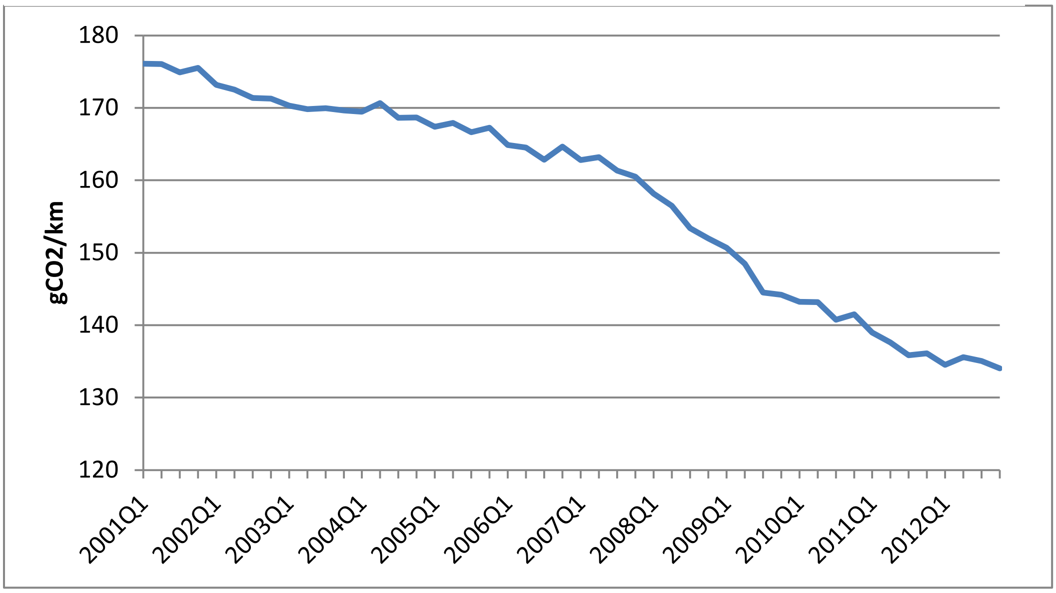
Figure 4.7: New Car Registrations in the UK by Market Segment



Note: The dotted lines indicate the start and end of the scrappage scheme. 'Others' category contains luxury, sports, off-road, and MPVs.

[4] This is consistent with figures from the Society of Motor Manufacturers and Traders (2010) that show that a large proportion of cars registered under the scheme were minis.

Figure 4.8: Average CO_2 Emissions in Total New Car Registrations in the UK

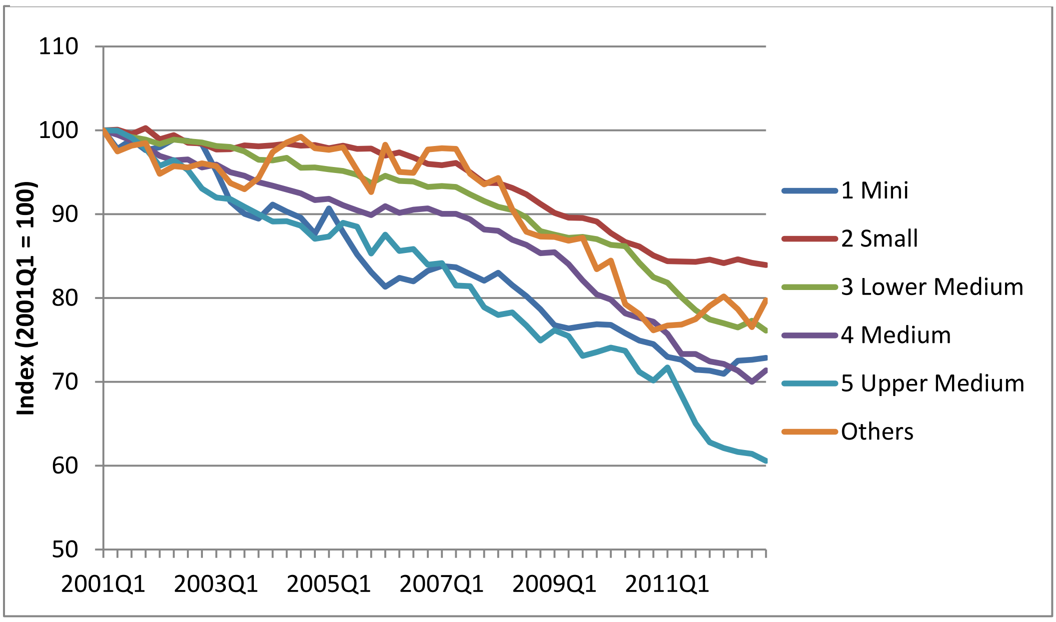


Source: Department for Transport.

Figure 4.9 plots the change in the average CO_2 emissions rate of newly registered cars by market segment. Reductions in UK emissions rates by market segment have been less uniform than in the Netherlands, with the largest reductions seen in the upper-medium segment (40% over 2001-12) and the smallest in the small market segment (just over 15%). Nevertheless, at 140 gCO_2/km, the average emissions rate of the upper medium segment is still higher than that of the small segment (125 gCO_2/km).

The gap in the average emissions rates of the highest and lowest-emitting market segments (others and mini) has narrowed, from 103 gCO_2/km in 2001Q1 to 91

Figure 4.9: Average CO_2 Emissions in New Car Registrations by Market Segment in the UK



Note: 'Others' category contains luxury, sports, off-road, and MPVs.
Source: Department for Transport

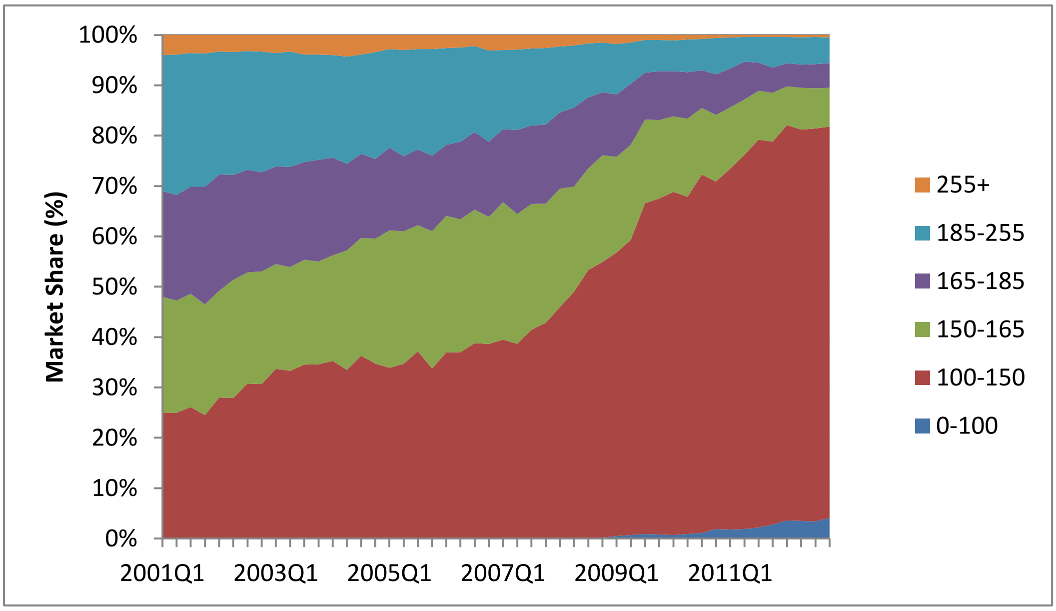
gCO_2/km in 2012Q4.

Market share by emissions rate

Figure 4.10 plots the market share in new registrations by CO_2 emissions rate. The most striking feature of the chart is the increase in the market share of cars with emissions rates of 100-150 gCO_2/km. In 2001Q1 vehicles in this band accounted for a quarter of new-car registrations; by 2012Q4, this share had increased to more than three-quarters, squeezing the market shares of more-polluting vehicles accordingly.

In contrast to the Netherlands, growth in the lowest CO2 band has been very modest, with that band only accounting for 4% of new registrations in 2012Q4.

Figure 4.10: Market Share by Average CO_2 Emissions (g/km) in the UK



Source: Department for Transport

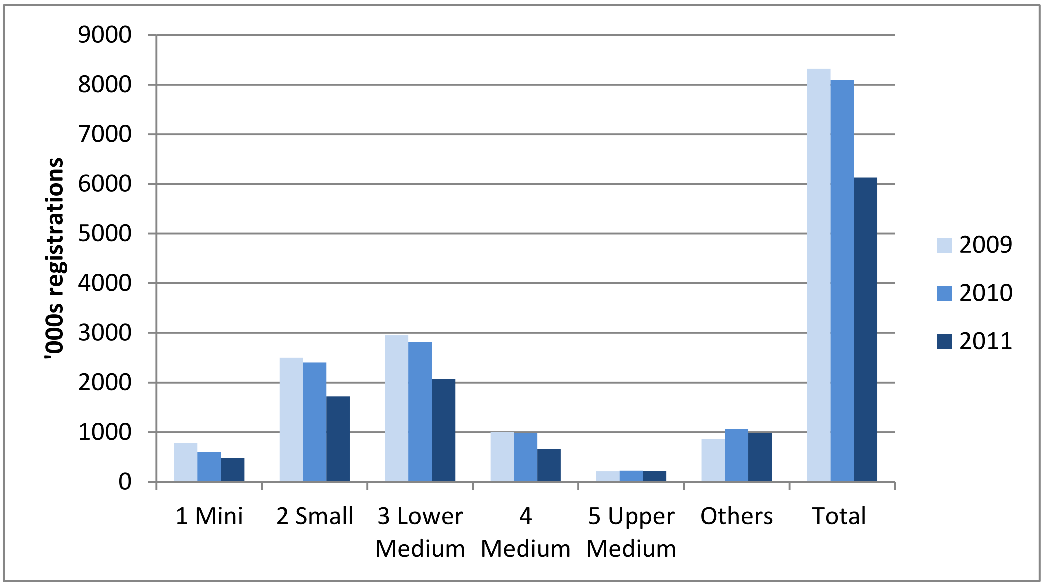
4.3 Descriptive analysis for Austria

New car registrations

Figure 4.11 charts new car registrations by market segment in Austria. Only three years of data are available from the EEA (with the final year of data, for 2011, still considered provisional). The short timespan of the data makes it difficult to get a sense of the long-term trends in registrations. The data are also only available at an annual, rather than quarterly, frequency. Consequently, we have not conducted any econometric analysis for Austria; we provide descriptive analysis, in this section, only.

Total new-car registrations have fallen over 2009-11 as a result of declines in sales in the majority of market segments. Registrations of upper-medium and other vehicles have been more stable, leading to mild increases in market share over time in these segments (by as much as 5 pp, in the case of other).

Figure 4.11: New Car Registrations in Austria by Market Segment



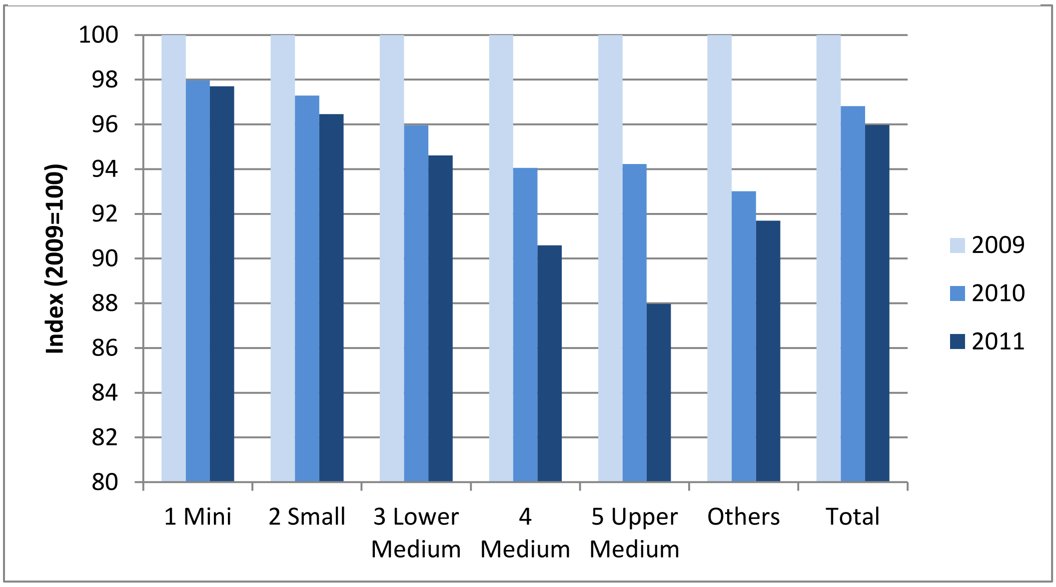
Note: 'Others' category contains luxury, sports, off-road, and MPVs.
Source: EEA

Average CO_2 emissions rates

In aggregate, the average CO_2 emissions rate in Austria fell by 4%, from 140 gCO_2/km in 2009 to 134 gCO_2/km 2011.

Figure 4.12 plots the average CO_2 emissions rate of new car registrations by market segment and shows that emissions rates have fallen in all market segments, with the largest reductions in the medium and upper-medium segments. The smaller reductions in CO_2 in the mini and small segments means that the gap between the highest and lowest-emitting vehicles has narrowed, from 65 gCO_2/km in 2009 to 53 gCO_2/km in 2011.

Figure 4.12: Average CO_2 Emissions in New Car Registrations by Market Segment in Austria

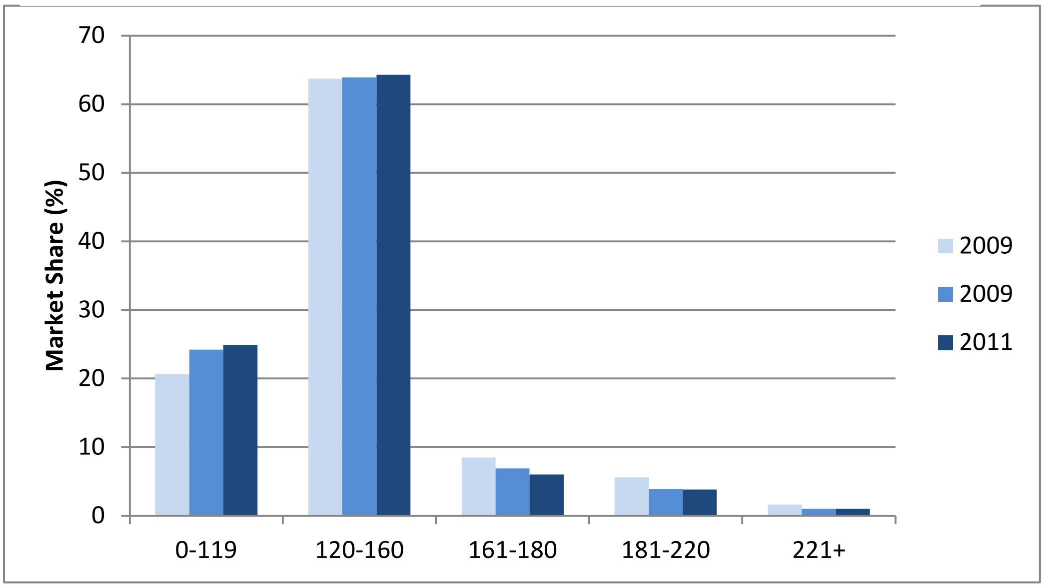


Note: 'Others' category contains luxury, sports, off-road, and MPVs.
Source: EEA

Market share by CO_2 emissions rate

Figure 4.13 plots the market share in new-car registrations by emissions rate. There have been modest increases in the market shares of less-polluting vehicles, at the expense of more-polluting vehicles. The largest increase in market share was for cars with the lowest emissions rates (up to 119 gCO_2/km), by 4 pp. The largest reduction in market share was for cars in the 161-180 gCO_2/km emissions band, with a reduction of 2.5pp.

Figure 4.13: Market Share by Average CO_2 Emissions (g/km) in Austria



Source: EEA

4.4 Summary of descriptive analysis

There are a number of similarities in the patterns of new-car registrations across countries

Despite the differences in time period and frequency, the descriptive analysis in this chapter reveals three common features of new-car registrations in the Netherlands, the UK and Austria:

- a reduction in average CO_2 emissions rates over time, both at the aggregate level and by individual market segment
- an increase in the market share of vehicles with lower emissions rates
- larger reductions in emissions rates of more-polluting vehicles, leading to a narrowing of the gap in emissions rates between the most and least-emitting vehicles

As mentioned previously these observed reductions can be separated, broadly, into:

- supply-side effects from manufacturers producing cleaner vehicles over time, from a combination of technological advancement (greater efficiency), environmental regulation and in response to consumer demand for cleaner vehicles
- demand-side responses on the part of consumers, from changes in preferences (eg greater environmental awareness), price effects (including taxation) and income effects (eg in the recession)

The aim of the analysis in Chapter 5 is to identify the component of the demand-side change that can be attributed to CO_2-based vehicle taxation.

5 Results

In this chapter we present the results from our final regressions, discussing the implications for reductions in emissions rates of new vehicles.

We present the results for the Netherlands and UK individually before comparing them against each other, and against the findings of Klier and Linn (2012) in the final section.

Results from the correlation analysis are provided in Appendix B.

5.1 Results for the Netherlands

Table 5.5.1 reports the final regression results for the Netherlands, with new-vehicle registrations explained by consumer confidence (which has the expected positive sign) and the lags (the values in the previous period) of:

- the registration tax
- the annual circulation tax
- fuel costs

Of the above, it is the registration tax that is of primary interest, as this is the principal tax instrument in the Netherlands for new vehicles.

The first column, labelled ‘Coefficient’ gives the elasticity on each variable: the amount by which vehicle registrations change as a result of a 1% change in that variable. The standard error[5] is given in the second column and the p-value in the third and final column. The p-value is the probability of finding a coefficient as large as the one observed, were the ‘true’ coefficient (based on the data) actually zero.

Whether the p-value is ‘high’ or ‘low’ is related to the value of the estimated coefficient relative to its standard error[6]. For a given coefficient value, the higher the

Table 5.5.1: NL Regression Results

NL REGRESSION RESULTS			
	Coefficient	**Standard Error**	**p-value**
Lag of Registration Tax	-0.296	0.079	0.01
Lag of Annual Circulation Tax	0.253	0.998	0.81
Lag of Fuel Costs	0.283	0.053	0.00
Consumer confidence	0.256	0.070	0.01
R^2	0.1983		
Observations (N x T)	48919		
Change in average emissions gCO_2/km	-6.3		

Source(s) : Cambridge Econometrics.

[5] The standard error is the square root of the statistical variance associated with the coefficient value. A higher standard error indicates a wider variance/‘spread’ in the coefficient estimate.

[6] The test statistic from which the p-value is calculated is formed from a ratio of the coefficient to some multiple of its standard error.

standard error, the larger the spread/variance associated with the coefficient and thus the higher the p-value will tend to be (because the coefficient is more likely to encompass zero as a result).

A p-value of less than or equal to 0.05 is typically interpreted as a 'statistically significant' result although one should be careful about applying such an (arbitrary) distinction too rigorously. The grounds for rejecting a coefficient with a p-value of 0.06 compared to one of 0.05 are weak, for example.

We also report the R^2 value of the equation as a measure of equation 'fit'. This is a measure of the extent to which the equation is able to explain the statistical variation in the data. An R^2 of 1.0 indicates that the equation is able to fully explain all variation in the data while an R^2 of 0.0 indicates that the equation explains none.

We find a statistically-significant coefficient on the registration tax, but not the circulation tax…

The coefficient on the lag of the annual circulation tax is positive (which is not in line with our initial expectations) but not statistically significant, with a p-value of 0.81. The coefficient on lagged fuel costs is also positive (and counterintuitive). This effect may be related to the positive correlation seen between economic activity and fuel costs (see Appendix Table B.1).

The fit of the equation is not particularly good, as judged by its R^2 value although the results from Klier and Linn (2012) find similarly poor values. Note that for the type of equation estimated here, a value close to one is highly unlikely. A reasonable value in this sort of equation is more in the region of 0.5 or less.

As mentioned above, the coefficients of interest are the tax coefficients, in particular, the registration tax. We find the tax effect to be on the lag of the registration tax, indicating a delayed response of vehicle registrations to changes in this tax. The coefficient takes a value of -0.296, which indicates that a 1% increase in the registration tax lowers registrations in the next quarter by 0.296%, all else being equal. This coefficient is statistically significant, with a p-value of 0.01.

…leading to an estimated reduction of 6.3 gCO_2/km attributable to taxation in the Netherlands

In simulating the impact of the tax, we find that CO_2-based vehicle taxation in the Netherlands has contributed to a reduction in emissions rates of 6.3 gCO_2/km. This compares to an overall reduction of some 47 gCO_2/km over the period covered by our dataset.

This result is not particularly sensitive to a change in the economic activity indicator from consumer confidence to the 'intention to buy a car in the next 12 months' (see Appendix C): the impact increases slightly to 6.5 gCO_2/km.

The results are somewhat more sensitive to the following variants:

- removal of the vehicle fixed effects (reduction of 5.7 gCO_2/km)
- separation of tax effects by market segment (reduction of 4.8 gCO_2/km)

However, in both of the above cases, the results do not yield coefficients that we consider readily interpretable or plausible (in terms of the relative responsiveness of different segments or body types to the tax).

In the first variant, we replace the vehicle fixed effects with the attributes of the vehicles recorded in our dataset. The aim is to identify an equation that more completely explains the differing levels of demand for vehicles, based on different combinations of attributes. This variant does not, by itself, identify the differing consumer responses to taxation (that is already captured in our tax variables), but does serve as a useful check as to whether the fixed effects might be absorbing effects that should otherwise be attributed to the CO_2 taxation[7].

In this first variant (reported in Appendix Table C.2), the estimated coefficient on the lagged registration tax is not much different to the main result reported here. The value is somewhat smaller, at -0.253, compared to the value of -0.296 reported in Table 5.5.1, leading to a somewhat smaller estimated effect on emissions rates (-5.7 gCO_2/km compared to -6.3 gCO_2/km). However, while the tax parameters are similar, it is more difficult to interpret the coefficients on the additional variables in economic terms. To that extent, we prefer the main equation reported here, on the basis that the fixed effects are not obviously affecting our tax-coefficient estimates.

Similarly, in the second variant (see Appendix Table C.3), not all the coefficients take values that are readily interpretable in the context of economic theory (eg the relative values of the variables that denote body type and/or market segment). While there is not a directly-comparable tax coefficient in this equation (because it varies by market segment) the final simulated tax effect is estimated to be -4.8 gCO_2/km. This value is 1.5 gCO_2/km lower than that estimated from our main equation.

Because not all the coefficients in these two equation variants make economic sense (and, in both cases, the fit is relatively poorer), it is likely that the equations are misattributing some of the variation in the data to these additional variables. In any case, the final estimated effects on emissions rates are not much different (in the range -4.8 – -6.3 gCO_2/km). Consequently, we prefer the more aggregate specification reported above, with the vehicle fixed effects retained.

Our analysis suggests that CO_2-based vehicle taxation has indeed contributed to reductions in emissions rates in the Netherlands, by some 6.3 gCO_2/km over 2005Q1-2012Q3.

[7] Provided that we find the equation satisfactory, from both a statistical and economic point of view.

5.2 Results for the UK

Table 5.5.2 reports the results from the final regression for the UK, which, as for the Netherlands, explains new-vehicle registrations as a function of economic activity and lagged:

- circulation taxes
- fuel prices (the DfT data did not include a fuel-efficiency variable with which to calculate vehicle-specific running costs)

The main variable of interest, the circulation tax, is statistically significant, while the coefficient on the price of fuel and consumer confidence are not statistically significant.

The overall fit of this equation is quite poor, with an R^2 of less than 0.13. The equation explains little of the variation in the data and we were unable to find a specification that yielded both a better fit and economically-plausible coefficient estimates.

We find a statistically-significant coefficient on the UK circulation tax, contributing to an emissions-rate reduction of 6.5 gCO_2/km

The impact of the circulation tax over the period 2005Q1-2012Q3 on UK CO_2 emissions rates is estimated to be 3.6 gCO_2/km, compared to a total reduction (as calculated from our dataset) of 32.5 gCO_2/km.

As with the analysis for the Netherlands, we also estimated alternative equation specifications, to test the impact of a different economic activity indicator, real GDP, and whether a breakdown by market segment yielded any further insight into the determinants of new-vehicle registrations (see Appendix Section D.1)

There is very little difference in the estimated impact on emissions rates of using the real GDP indicator as the activity variable. The sign of the real GDP coefficient is positive (as expected), but as with the main equation, the coefficient is not statistically significant. The tax coefficient is little different, leading to the similar reduction in CO_2 emissions rates of 2.9 gCO_2/km.

The exclusion of vehicle fixed effects and a separation by market segment (see Appendix Section D.2) does suggest a substantially different CO_2 impact, of just 1.2 gCO_2/km, but we note that this equation is extremely poor in terms of its ability to explain the variation in the data and, as a result, we would not consider that figure to be a credible or plausible result. Moreover, as with the same equation for the Netherlands, we find that the individual coefficients do not make much sense and are

Table 5.5.2: UK Regression Results

UK REGRESSION RESULTS

	Coefficient	Standard Error	p-value
Lag of circulation tax	-2.36	1.06	0.05
Lag of fuel costs	-0.32	0.22	0.19
Consumer confidence	0.01	0.09	0.92
R^2	0.13		
Observations (N x T)	45315		
Change in average emissions gCO_2/km	-3.6		

Source(s) : Cambridge Econometrics.

likely to be statistical artefacts of the data and estimation approach, rather than genuine behavioural responses. In this particular case, the tax coefficients are implausibly large in many cases, leading to implausibly-large implied effects[8].

5.3 Comparison of results

We find positive effect on new-vehicle CO_2 emissions rates in the two countries.

While the analysis above suggests that CO_2-based vehicle taxation has had a significant impact on reducing new vehicle emissions rates, the reductions in the two countries have been achieved differently:

- in the Netherlands, the main tax instrument is a large upfront tax on registering the vehicle, with the estimated consumer elasticity in response to this tax of -0.296
- in the UK, the sole tax instrument is an annual circulation tax which, while smaller overall than the tax faced by Dutch consumers, leads to a relatively smaller CO_2 reduction compared to the Netherlands.

We estimate a reduction in CO_2 emissions rates from CO_2-based taxation for 6.3g CO_2/km in the Netherlands and for 3.6g CO_2/km in the UK. This compares to an overall fall in emissions rates of almost 47 gCO_2/km in the Netherlands and 32.5 gCO_2/km in the UK.

It should be noted, however, that while the above results are based on comparable time periods (2005-2012) for the two countries, the CO_2 taxation has started in the UK in 2001. Additional regressions performed for the UK revealed that the contribution of the CO_2 based circulation tax since its implementation in 2001 until 2012 was -6.5 gCO_2/km, while the total fall in emissions rates over the extended period was almost 41gCO_2/km – very similar to the results for the Netherlands[9].

These results lie within the range reported by Klier and Linn (2012)

To put this in the context of other results, Klier & Linn (2012) estimate a reduction of 8 gCO_2/km from the French registrations tax and a reduction of 1.7 CO_2/km and 0.6 gCO_2/km from the German and Swedish circulation taxes, respectively. Our results for the Netherlands and the UK are somewhere between the results for France and the other two countries although Klier and Linn's (2012) results are estimated over a shorter time period that identifies better the short-term effect of a change in the tax regime whereas our results likely pick up more of a long-term impact owing to the longer time period (and more gradual introduction of CO_2-based vehicle taxation).

The size of these reductions in the average CO_2 emissions rates depend on:

- the size of the behavioural response (the estimated tax coefficient)
- the size of the tax change

In both cases, the fit of the final equations (as evidenced, *inter alia*, by their R^2 values) is relatively low, even for equations of the form we have estimated, for which low R^2 values are quite common. The implication is that these equations do not explain the quarterly demand for vehicles in these two countries particularly well.

However, the main aim of the analysis is not to explicitly identify *all* determinants of the demand for vehicles, only to isolate the component that is affected by CO_2-based vehicle taxation. There is not necessarily a problem with a poorly-fitting equation unless there are grounds for thinking that it is failing to account for one or more

[8] For example, a 1% increase in taxes would lead to a more-than-1% decrease in mini registrations, other things being equal, while the demand for off-road vehicles would actually increase. Clearly this is not a reasonable outcome.

[9] See Appendix Table D.1.A for the full set of results.

effects that are being *mistakenly attributed* to variables included in the equation. This is of potential concern if it leads to the equation not correctly isolating the tax effect, leading to so-called *omitted variable bias*.

The robustness analysis suggests some degree of stability in our estimates under alternative specifications but this does not preclude the possibility of omitted variables.

The most likely potential omitted variable is the price of new vehicles. It was not possible to construct a price variable at a level of detail that matched the disaggregation in the registrations data and the inclusion of such a variable (were it feasible) may well improve the fit and, possibly, lead to a change in the estimated tax coefficient.

Whether or not the tax coefficient might actually change depends on whether prices are correlated with any other variables in the equation[10]. While it is true that, in the Netherlands, the tax variable was originally related to the list price of the vehicles[11], the way our equation is set up, the tax variable only relates to the part levied on CO_2 emissions. The absence of a price variable may not necessarily bias the results, although this would ideally be tested.

However, in the current analysis, there seems to be little that can be done about such omitted variables, as we would require additional data at the same (high) level of detail as our existing dataset. These data were not available. This is a potential weakness of the current analysis and a key caveat.

[10] Correlation with other variables is a requirement for an omitted variable to affect the value of one or more coefficients, rather than simply the overall fit of the equation.

[11] The tax would be correlated with prices.

6 Conclusions

In this study, we have sought to identify the extent to which CO_2-based vehicle taxation in the Netherlands and the UK has contributed to overall reductions in CO_2 emissions rates in these two countries.

We have done this by estimating equations to identify the determinants of demand for new vehicles (as measured by new-vehicle registrations). Having obtained the contribution of each of the explanatory factors to new-vehicle demand, we then carried out a simple simulation exercise to estimate the change in CO_2 emissions rates by comparing the implied emissions rates had there been no CO_2-based tax and the implied rates under the current tax regime (holding all other factors constant).

We evidence that CO_2-based vehicle taxation has indeed contributed to emissions-rate reductions in the Netherlands and the UK

Table 6.6.1 summarises the results from the analysis, which shows that, from the information in our dataset:

- emissions rates have fallen by 46.8 gCO_2/km between 2005 and 2012Q1-Q3 in the Netherlands, of which we attribute 6.3 gCO_2/km of the reduction to taxation
- emissions rates have fallen by 32.5 gCO_2/km between 2005 and 2012 in the UK, of which we attribute 3.6 gCO_2/km of the reduction to taxation

These reductions are larger for the Netherlands than for the UK and they fall into the range of impact of CO_2 taxation reported by Klier and Linn (2012) in their own analysis.

We note, in contrast to the work by Klier and Linn (2012), that our estimates are more reflective of a long-term effect in which it is not reasonable to assume that vehicle-supply characteristics are fixed. The implication is that some element of the effect may well be picking up a supply-side effect. A short-term policy-impact analysis of the type conducted by Klier and Linn (2012) was not possible for the countries analysed here because of the nature of the (gradual) changes in taxation over time.

Overall, we conclude a shift to CO_2-based vehicle taxation has contributed to the observed reductions in CO_2 emissions rates, but that other factors have a combined larger effect. Given the relative similarity in the emissions rates across the two countries, one might interpret the changes as driven relatively more by technology, on the basis that manufacturers aim to produce vehicles that can be sold in multiple markets. The similarity in emissions rates may reflect, to a large degree, the changes in pan-European vehicle supply.

Table 6.6.1: Estimated Impacts of CO_2-Based Vehicle Taxation

ESTIMATED IMPACTS OF CO_2-BASED VEHICLE TAXATION

	Emissions rates (gCO_2/km)				Tax instrument
	Start (period)	**End (period)**	**Change**	**of which attributed to CO_2-based taxation**	
NL	168.0 (2005)	121.2 (2012Q1-Q3)	-46.8	-6.3	Mostly registration tax (circulation tax is small)
UK	167.3 (2005)	134.8 (2012)	-30.5	-3.6	Circulation tax only

Note(s) : Start and end periods given in brackets.
Source(s) : Cambridge Econometrics.

7 References

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Appendix A: Data

This appendix presents summary information on the variables used in the regression analysis.

A.1 Data: NL

Appendix Table A.1: NL Regression Variables

NL REGRESSION VARIABLES

Variable	Description	Source
Quarterly Registrations	The number of vehicle-specific new car registrations in each quarter	RDW
Registration Tax	CO_2-related component of the registration tax payable (000s euros in 2005 prices)	ACEA, Dutch Ministry of Finance
Annual Circulation Tax	Annual circulation tax payable (000s Euros in 2005 prices)	ACEA, Dutch Ministry of Finance, RDW
Real Fuel Costs	End-user fuel price per litre (Euros in 2005 prices) x fuel efficiency (litres/100km)	IEA Energy Prices and Taxes, RDW
Consumer confidence indicators	Consumer confidence Consumers’ intention to buy a car in the next 12 months	DG ECFIN
GDP deflator	2005 reference year; used to deflate other variables into ‘real’ terms	Eurostat

Source: Cambridge Econometrics.

A.2 Data: UK

Appendix Table A.2: UK Regression Variables

UK REGRESSION VARIABLES

Variable	Variable	Variable
Quarterly Registrations	The number of vehicle-specific new car registrations in each quarter	DfT
Circulation Tax	Circulation tax payable (000s GBP, 2005 prices)	ACEA, DfT
Real Fuel Price	End-user fuel price per litre (pence sterling in 2005 prices)	IEA Energy Prices and Taxes database
Consumer confidence indicators	Consumer confidence Consumers’ intention to buy a car in the next 12 months	DG ECFIN
GDP deflator	2005 reference year; used to deflate other variables into ‘real’ terms	Eurostat

Source: Cambridge Econometrics.

Appendix B: Correlation analysis

In this appendix we report the correlation matrices for the variables that enter the regressions. These are statistical relationships between pairs of variables (ie bilateral).

When interpreting these correlations it is important to note that they show only how two variables move with each other (over time and vehicle type) in the sample period and do not provide any indication of causality. Nonetheless, the sign of the correlation coefficients is a useful pre-cursor test to see if they are in line with our preliminary expectations, based on economic theory.

The variables are the first-differences of the logged values of the series.

B.1 Correlation analysis: NL

Appendix Table B.1 shows the correlation matrix for the Netherlands.

The first column of the table shows the correlation between the dependent variable (Dutch new-vehicle registrations) and the independent (explanatory) variables. The columns to the right do the same for the correlation between the explanatory variables. Strong correlation between pairs of explanatory variables is potentially problematic as it makes it more difficult to separately identify the influences of these variables (because they tend to move together).

The correlation between registrations and vehicle taxes is positive. This is not the result we would expect if vehicle taxation supresses the demand for vehicles but by no means conclusive that vehicle taxation is ineffective. Once other effects have been controlled for (as they are in the regression analysis), the tax effect may still be negative.

Appendix Table B.1: Correlation Matrix for NL

CORRELATION MATRIX FOR NL

	Registrations	Registration tax	Circulation tax	Fuel costs	Consumer confidence	Intention to buy car
Registrations	1.000 (n/a)					
Registration tax	0.161 (0.000)	1.000 (n/a)				
Circulation tax	0.102 (0.000)	0.252 (0.000)	1.000 (n/a)			
Fuel costs	-0.018 (0.000)	0.058 (0.000)	-0.353 (0.000)	1.000 (n/a)		
Consumer confidence	0.024 (0.000)	0.162 (0.000)	-0.155 (0.000)	0.173 (0.000)	1.000 (n/a)	
Intention to buy car	0.030 (0.000)	0.059 (0.000)	-0.051 (0.000)	0.096 (0.000)	0.313 (0.000)	1.000 (n/a)

Note(s) : p-values given in brackets

Source(s) : Cambridge Econometrics.

Of note in Appendix Table B.1 is that there is a positive correlation between fuel costs and the two candidate economic activity indicators. As we see in the regression results, this may be one factor that contributes to the positive coefficients on fuel cost, making it more difficult to separate the effect from economic activity. A similar correlation is noted between fuel costs and the (CO_2-related) registration tax.

B.2 Correlation analysis: UK

Appendix Table B.2 shows the correlation matrix for the UK.

For the UK, the correlation coefficients are generally of the expected sign with (the change in the log of) registrations being negatively correlated with taxes and fuel prices (as these raise the costs of ownership and operation) and positively correlated with economic activity (as proxied by the confidence indicators).

Interestingly, the tax variable is positively correlated with consumer confidence but negatively correlated with the intention-to-buy component of that confidence indicator. This may explain the difference in sign observed in the two alternative economic activity indicator equations although has no bearing on the final CO_2 impact.

Appendix Table B.2: Correlation Matrix for UK

CORRELATION MATRIX FOR UK

	Registrations	Tax	Fuel price	Consumer confidence	Intention to buy car
Registrations	1.000 (n/a)				
Tax	-0.033 (0.000)	1.000 (n/a)			
Fuel price	-0.045 (0.000)	0.102 (0.000)	1.000 (n/a)		
Consumer confidence	0.029 (0.000)	0.058 (0.000)	-0.110 (0.000)	1.000 (n/a)	
Intention to buy car	0.032 (0.000)	-0.052 (0.000)	-0.685 (0.000)	0.336 (0.000)	1.000 (n/a)

Note(s) : p-values given in brackets

Source(s) : Cambridge Econometrics.

Appendix C: Additional regression analysis – NL

In this appendix we provide additional regression results for the Netherlands, to show the sensitivity of the results to alternative equation specifications. We compare these results to the main findings presented in Chapter 3 of the report, that CO_2-based vehicle taxation contributed a reduction of 6.3 gCO_2/km over 2005Q1-2012. This compares to an estimated reduction (from the dataset used for estimation) of -46.8 gCO_2/km.

C.1 Alternative economic activity indicator

Appendix Table C.1 below shows the results from a regression that uses an alternative indicator of economic activity performance. In contrast to the regression presented in the main report, which used consumer confidence as an indicator, the regression below uses a measure of consumers’ intention to buy a car in the next 12 months.

As with the main regression results, the coefficient on the lagged annual circulation tax remains statistically insignificant while the coefficients on lagged fuel costs, and the activity indicator, are larger than in the main results:

- the fuel costs coefficient is 0.310 in Appendix Table C.1 and 0.283 in the main regression
- the activity indicator is higher in Appendix Table C.1: 0.540 compared to 0.256

The coefficient on the (lagged) registration tax, which is the principal tax instrument, is -0.320, which is somewhat larger than the main result of -0.296. This yields a slightly larger overall CO_2 impact of -6.7 gCO_2/km compared to the finding in the main report of 6.3 gCO_2/km.

There is nothing in particular to suggest that this equation is any better or worse than the one presented in the main report, with the R^2 value similar (and still low) and the final estimated CO_2 impact not much different to the main result.

Appendix Table C.1: NL Regression with Alternative Activity Indicator

NL REGRESSION WITH ALTERNATIVE ACTIVITY INDICATOR			
	Coefficient	**Standard Error**	**p-value**
Lag of registration tax	-0.320	0.077	0.00
Lag of annual circulation tax	0.429	0.998	0.68
Lag of fuel costs	0.310	0.057	0.00
Intention to buy a car	0.540	0.129	0.00
R^2	0.1985		
Observations (*N* x *T*)	48919		
Change in average emissions gCO_2/km	-6.7		

Source(s) : Cambridge Econometrics

C.2 Inclusion of vehicle characteristics rather than fixed effects

In the main regression results we control for differences between vehicle types (affecting their demand) by the inclusion of fixed effects in the econometric model. Appendix Table C.2 reports an alternative equation that replaces these vehicle fixed effects with the characteristics of the vehicles themselves (from the information available in the RDW data):

- engine power
- engine size
- weight
- whether the vehicle has a manual gearbox or not (a dummy variable)
- dummy variables to denote the body type of the vehicle (there reference group is MPVs)

The change in specification does not alter the tax effect substantially. The coefficient is somewhat smaller in value than in the main equation (-0.253 compared to -0.296) leading to a somewhat smaller estimated CO_2 impact (-5.7 gCO_2/km compared to -6.3 gCO_2/km in the main results).

Some of the coefficients are difficult to interpret from an economic point of view, such as a positive effect on registrations from higher vehicle weight: some coefficients may in fact be picking up other effects. In that sense, elements of the equation are not readily interpretable, hence our preference for the fixed effects in the main results.

Inspection of the other results in Appendix Table C.2 suggest that the fit of the equation suffers from the inclusion of vehicle-specific characteristics but that, overall,

Appendix Table C.2: NL Regression without Vehicle Fixed Effects

NL REGRESSION WITHOUT VEHICLE FIXED EFFECTS			
	Coefficient	**Standard Error**	**p-value**
Lag of Registration Tax	-0.253	0.061	0.003
Lag of Annual Circulation Tax	-0.082	0.994	0.937
Lag of Fuel Costs	0.204	0.049	0.003
Consumer confidence	0.059	0.066	0.403
Engine power	0.238	0.030	0.000
Engine size	-0.258	0.047	0.001
Weight	0.111	0.025	0.002
Manual gearbox	-0.040	0.012	0.010
Body Type: Cabriolet	0.020	0.015	0.215
Body Type: Coupe	0.025	0.019	0.224
Body Type: Armoured Vehicle	-0.423	0.016	0.000
Body Type: Hatchback	-0.030	0.014	0.068
Body Type: Sedan	-0.015	0.014	0.307
Body Type: Station wagon	-0.023	0.009	0.037
R^2	0.114		
Observations (*N* x *T*)	53837		
Change in average emissions gCO_2/km	-5.7		
Source(s) : Cambridge Econometrics.			

the final outcome is not particularly sensitive to whether fixed effects are used or not.

C.3 Separating tax effects by market segment

The final alternative equation specification attempts to identify separate tax responses for each market segment of new-vehicle registrations. Appendix Table C.3 shows an equation in which the tax variables have been interacted with dummy variables to indicate the market segment, and with market segment dummy variables included in the equation. The reference group for the market segments is the Mini.

The equation is an extension of the one reported in Appendix Table C.2, as it also uses vehicle characteristics, rather than vehicle fixed effects.

The results from this regression yield a range of different tax effects. For each market segment, the tax effect can be recovered by adding the relevant coefficient to the ‘Lag of registration tax’ variable, because the market-segment coefficients are *relative* to the Mini reference group.

The differences in sign and size of the coefficients by market segment are not particularly intuitive, suggesting, for example, that increases in circulation taxes increase new registrations of vehicles in the Sport segment (0.847 + 2.631), while lowering new registrations of vehicles in the Luxury segment (0.847 – 1.579). It is difficult to have much confidence in these more-detailed market-segment results as the equation does not seem to identify plausible responses.

The overall tax effect, once translated into an implied CO_2 emissions-rate reduction, is somewhat lower than the impact in the main results or the previous regressions in this appendix: -4.8 gCO_2/km compared to -6.3 gCO_2/km in the main results.

Appendix Table C.3: NL Regression Separating by Market Segment

NL REGRESSION SEPARATING BY MARKET SEGMENT			
	Coefficient	**Standard Error**	**p-value**
Lag of Registration Tax	-0.750	0.034	0.00
Lag of Registration Tax x Small	0.308	0.014	0.00
Lag of Registration Tax x Lower Medium	0.538	0.020	0.00
Lag of Registration Tax x Medium	0.589	0.021	0.00
Lag of Registration Tax x Upper Medium	0.597	0.021	0.00
Lag of Registration Tax x Luxury	0.492	0.024	0.00
Lag of Registration Tax x Sport	0.683	0.024	0.00
Lag of Registration Tax x Off-Road	0.213	0.023	0.00
Lag of Registration Tax x MPV	0.153	0.022	0.00
Lag of Annual Circulation Tax	0.847	0.240	0.01
Lag of Annual Circulation Tax x Small	-0.440	0.920	0.65
Lag of Annual Circulation Tax x Lower Medium	-3.445	0.760	0.00
Lag of Annual Circulation Tax x Medium	-0.342	0.676	0.63
Lag of Annual Circulation Tax x Upper Medium	0.917	0.529	0.12
Lag of Annual Circulation Tax x Luxury	-1.579	0.433	0.01
Lag of Annual Circulation Tax x Sport	2.631	0.663	0.00
Lag of Annual Circulation Tax x Off-Road	-0.625	0.533	0.28
Lag of Annual Circulation Tax x MPV	8.824	0.509	0.00
Lag of Fuel Costs	0.206	0.047	0.00
Consumer confidence	0.060	0.064	0.38
Engine power	0.241	0.029	0.00
Engine size	-0.264	0.052	0.00
Weight	0.169	0.083	0.08
Manual gearbox	-0.035	0.013	0.03
Body Type: Cabriolet	0.021	0.014	0.17
Body Type: Coupe	0.032	0.018	0.12
Body Type: Armoured Vehicle	-0.438	0.017	0.00
Body Type: Hatchback	-0.035	0.011	0.01
Body Type: Sedan	-0.015	0.014	0.29
Body Type: Station wagon	-0.025	0.009	0.02
Market segment: Small	0.013	0.011	0.27
Market segment: Lower Medium	-0.037	0.020	0.10
Market segment: Medium	-0.042	0.024	0.12
Market segment: Upper Medium	-0.038	0.029	0.22
Market segment: Luxury	-0.065	0.035	0.10
Market segment: Sport	-0.071	0.020	0.01
Market segment: Off-Road	0.001	0.031	0.97
Market segment: MPV	-0.061	0.035	0.12
R^2	0.116		
Observations (*N* x *T*)	53837		
Change in average emissions gCO_2/km	-4.8		

Source(s) : Cambridge Econometrics.

Appendix D: Additional regression analysis – UK

In this appendix we provide additional regression results for the UK.

In the main results, the coefficient on the lagged tax variable (Vehicle Excise Duty, a circulation tax) was -2.36. The fit of the equation was poor, with an R^2 value of 0.13.

The estimated reduction in UK CO_2 emissions rates was estimated to be -3.6 gCO_2/km. This compares to an overall reduction (in our dataset) of -32.5 gCO_2/km over 2005Q1-2012Q3.

D.1 Alternative time period and economic activity indicator

Appendix Table D.1 below shows the results from a regression that uses an alternative indicator of economic activity performance. This regression uses the real GDP, rather than the specific indicator on consumer confidence. The main coefficient on circulation tax variable is of similar magnitude as with the main regression, however it is not statistically significant. The overall fit of the equation is quite poor.

Appendix Table D.1: UK Regression with Alternative Activity Indicator

UK REGRESSION WITH ALTERNATIVE ACTIVITY INDICATOR

	Coefficient	Standard Error	p-value
Lag of tax	-2.047	1.086	0.45
Lag of Fuel Costs	-0.479	0.248	0.09
Real GDP	6.688	6.49	0.00
R^2	0.13		
Observations (*N* x *T*)	45315		
Change in average emissions gCO_2/km	-2.9		

Source(s) : Cambridge Econometrics.

Appendix Table D.1.A shows results of the CO_2 – based taxation since its introduction in 2001. In that respect, the results could be interpreted as reflecting the total impact of the CO_2 circulation tax. The contribution of the circulation tax to reduction of the CO_2 emissions is estimated to be 6.5 gCO_2/km - a result remarkably close to the results

Appendix Table D.1.A: UK regression with alternative time period (2001-2012)

UK REGRESSION WITH ALTERNATIVE TIME PERIOD

	Coefficient	Standard Error	p-value
Lag of circulation tax	-4.00	1.01	0.00
Lag of fuel costs	-0.88	0.12	0.00
Intention to buy a car	0.07	0.17	0.70
R^2	0.10		
Observations (*N* x *T*)	69699		
Change in average emissions gCO_2/km	-6.5		

Source(s) : Cambridge Econometrics.

obtained for the Netherlands for the period 2005-2012.

D.2 Inclusion of vehicle characteristics and separation of tax effects by market segment

As with the results for the Netherlands in Appendix D, we also estimated an equation to separate out the tax effects by market segment. In this regression, we also replace

Appendix Table D.2: UK Regression Separating by Market Segment

UK REGRESSION SEPARATING BY MARKET SEGMENT			
	Coefficient	**Standard Error**	**p-value**
Lag of Tax	-1.168	0.245	0.001
Lag of Tax x Small	-1.974	0.085	0.000
Lag of Tax x Lower Medium	0.574	0.194	0.018
Lag of Tax x Medium	-1.764	0.345	0.001
Lag of Tax x Upper Medium	2.853	0.461	0.000
Lag of Tax x Luxury	2.904	0.417	0.000
Lag of Tax x Sport	-2.448	0.433	0.000
Lag of Tax x Off-Road	1.421	0.447	0.013
Lag of Tax x MPV	-2.811	0.431	0.000
Lag of Fuel Price	-0.643	0.092	0.000
Intention to buy a car	-0.191	0.133	0.187
Engine Capacity	0.039	0.017	0.051
Mass	0.029	0.014	0.074
Body Type: Coupe	-0.034	0.014	0.040
Body Type: Estate	-0.005	0.017	0.786
Body Type: Hatchback	-0.038	0.025	0.165
Body Type: Hearse	-0.195	0.018	0.000
Body Type: Limousine	0.073	0.049	0.176
Body Type: Purpose Vehicle	-0.026	0.023	0.285
Body Type: Saloon	-0.009	0.020	0.658
Body Type: Sports	-0.045	0.009	0.001
Body Type: Tourer	0.106	0.022	0.001
Market segment: Small	-0.050	0.005	0.000
Market segment: Lower Medium	-0.015	0.010	0.196
Market segment: Medium	-0.018	0.015	0.264
Market segment: Upper Medium	-0.018	0.018	0.337
Market segment: Luxury	-0.059	0.030	0.088
Market segment: Sport	-0.013	0.019	0.533
Market segment: Off-Road	-0.054	0.019	0.020
MPV	-0.010	0.015	0.513
R^2	0.024		
Observations (N x T)	149146		
Change in average emissions gCO_2/km	-1.2		

Source(s) : Cambridge Econometrics.

the vehicle fixed effects with vehicle characteristics. We report these results in Appendix Table D.2 below. The reference market segment is the Mini, as for the Netherlands, while the reference body type is the convertible.

This regression suffers from the same problems as the corresponding one for the Netherlands: the coefficients make little sense from a theoretical point of view and thus provide little insight into the relative impacts of CO_2-based vehicle taxation across market segments.

Moreover, the fit of the equation suffers greatly, explaining almost none of the statistical variation in the data (the R^2 is 0.024). There is little to suggest that the results from this equation should be trusted and the small implied impact on UK new-vehicle emissions rates (-1.2 gCO_2/km over 2001Q1-2012Q3) can reasonably be ignored.