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EFFECTIVENESS OF FISCAL AND OTHER MEASURES TO MANAGE GREENHOUSE GAS EMISSIONS FROM THE AUTOMOBILE SECTOR: EVIDENCE FROM EUROPE

Lisa Ryan, Susana Ferreira, and Frank Convery
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Abstract

This paper models annual new car average CO\(_2\) emissions intensity in EU Member States over the period 1995-2004. It attempts to explore the relationship, if any, between national vehicle and fuel taxes and the EU voluntary agreement in reducing CO\(_2\) emissions from the passenger car fleet. Our results indicate that (i) vehicle taxes are likely to be significant in reducing CO\(_2\) emissions intensity of passenger cars, and that (ii) the CO\(_2\) emissions intensity of EU new passenger cars has fallen over the time period studied. We hypothesise that this time trend may be attributable to the voluntary agreement.
1. Introduction

In the EU, CO₂ emissions from transport have increased by 24% since 1990 and are forecast to increase to 31% above 1990 levels by 2010 (EEA, 2005). Road transport produces over 70% of transport CO₂ emissions, of which passenger cars make up over half, and these emissions continue to grow strongly.

Most developed countries have introduced a portfolio of policy measures to reduce CO₂ emissions from passenger cars and much has been written on the subject (Plotkin 2001; Goldberg 1998; Gerard and Lave 2003; Austin and Dinan 2005; Greene, Patterson et al. 2005). Within the EU, the approach has been to use a mix of policy measures comprising three pillars:

- Voluntary Agreements (VA) committing the automobile manufacturers to reduce CO₂ emissions intensity from passenger cars by 25 percent over the period 1995-2008/9, mainly by means of improved vehicle technologies.
- Improvements of consumer information on the fuel-economy of cars
- Fiscal measures to influence motorists' choice in favour of more fuel-efficient cars

With these three measures the Commission has focussed mainly on improving the efficiency of the fleet rather than travel behaviour, which is a challenge considered better addressed at a local level. Figure 1 illustrates the average CO₂ emissions intensity of new passenger cars in EU15 Member States from 1995-2004.

The VA is a supply-side, Europe-wide measure, committing manufacturers to supply passenger cars with reduced CO₂ emissions in all Member States (EU15) at the signing of the agreement. It does not directly influence the type of passenger cars consumers would like to buy. Thus, without further policy intervention, there is the risk that although low-CO₂ emitting cars may be available for purchase, personal preferences will dictate that people opt for vehicles with higher CO₂ emissions instead.
Automobile manufacturers have called for an integrated approach to achieving improvements in the fleet average CO₂ emissions intensity, encouraging Member States to introduce fiscal measures to push consumers to choose low-emitting-CO₂ vehicles (CEC 2005). There is a considerable range of fuel consumption and CO₂ emissions within a particular vehicle model class². There is therefore scope for consumers to purchase more fuel-efficient vehicles, even if they remain within the same vehicle size class. In 2002, CO₂ emissions from all new passenger cars on the market ranged from 90g/km to 263g/km.

Consumer information on new car CO₂ emissions and fuel consumption is provided by EU legislation since 2001³. To date, it has not been possible to harmonise vehicle taxes across Member States, although a Commission proposal for a directive on the alignment of Member State vehicle taxes exists⁴. This Directive proposes the gradual phasing out of registration tax, with a refund system to apply in the meantime, and the introduction of a new annual circulation vehicle tax structure linked to CO₂ emissions⁵.

Individual EU countries impose a range of taxes on cars. These include:

² For example, in the subcompact petrol vehicle size class (Ford Focus, Volkswagen Golf etc. size), CO₂ emissions range from approximately 140g/km to over 200g/km, measured with the standard driving test cycle. For an indication on the variation of CO₂ emissions intensity of new cars among European countries, please see Figure 1.
³ EU vehicle-labelling Directive 1999/94/EC.
⁵ To date, it has not been possible to find a common position within the Community on this subject and the UK is the only Member State with vehicle taxes differentiated according to CO₂ emissions.
At the time of purchase, a registration tax, and value added tax (VAT) which is based on the before tax sale price of the car

- An annual circulation tax
- Excise duties on fuel (diesel and petrol).

Most tax regimes have been designed with revenue generation as a primary motive. This has resulted in vehicle taxes which differ greatly by amount charged and the method by which they are calculated. The parameters used to determine the tax level can vary—from the price of the vehicle to physical vehicle characteristics such as the engine size or power. Politics often determine the level of fuel tax and the way in which it is applied, even within the EU (Rietveld and van Woudenberg 2005). For example, some countries use fuel taxes to favour diesel fuel due to its better energy efficiency, while others prefer to support petrol, since there are lower particulate matter emissions associated with petrol combustion. Although there are some minimum (fuel) tax levels mandated at EU level, in effect, vehicle and fuel fiscal measures are determined at a national level and hence there are 15 different vehicle and fuel tax regimes across EU15. This provides a rich source of variegated evidence from which to address the question: how do taxes influence the carbon performance of the new car fleet?

Despite much rhetoric, there is a gap in the evidence addressing the influence of different types of taxes on the EU passenger car fleet CO₂ emissions intensity and, by association, on the attainment of the voluntary agreement targets. The voluntary agreement has been in operation since 2000 and therefore the impact of taxes can be examined before the agreement started and for the period since 2000. This paper makes use of a unique dataset comprising Member State taxes, vehicle prices and CO₂ emissions data for the period 1995-2004, to shed light onto this question.

Passenger car CO₂ emissions are essentially a function of vehicle fossil fuel energy demand and therefore econometric models employed to estimate elasticities of fuel consumption intensity are relevant here for the estimation of CO₂ emissions (per kilometre driven) of the passenger car fleet.⁶

Pindyck (1980) postulates that transportation energy demand is dependent on existing vehicle stocks, the use of those stocks (travel behaviour), and the fuel efficiency of the stock. The last variable is found to be particularly significant; when consumers have little choice in the use of their vehicles; if, for example, they are only required for transport between work and home, the choice of a more fuel efficient vehicle can have a significant impact on the amount of fuel consumed in their daily use. If in each successive year the CO₂ emissions intensity of new car

<sup>⁶</sup> Vehicle fuel intensity is correlated with vehicle CO₂ emissions intensity: petrol and diesel vehicles emit on average 69.4kg and 73.4kg of CO₂ per MJ respective fuel (IPCC emissions factors).
fleets improves, then the vehicle stock will show a gradual overall improvement in carbon efficiency over time.

Many researchers have attempted to empirically estimate the effect of price on transport fuel demand, both at micro and macro levels (see Goodwin et al. (2004) and Graham and Glaister (2004) for recent reviews). Some studies estimate transport fuel demand and related issues such as vehicle ownership using household decision models (for example, Bresnahan 1987; Eltony 1993; Pakes, Berry et al. 1993; Berry, Levinsohn et al. 1995; McCarthy 1996). While there are advantages associated with detailed analysis of household decisions with regard to passenger car purchases, the data requirements are considerable and may not be available for many countries. Other studies use aggregate country data to estimate the effect of price and income on total fuel consumption (Sterner 1991; Sterner et al. 1992; Eskeland and Feyzioglu 1997). Some researchers decompose vehicle stock into new vehicle purchases and depreciated car stock, and total fuel consumption per passenger car into fuel consumption per kilometre or vehicle efficiency and travel demand (Johansson and Schipper 1997; Storchmann 2005).

However, few of these studies explicitly incorporate policy variables such as taxes in their econometric models. Johansson and Schipper (1997) include a tax variable in their vehicle fuel intensity model and find that it has a significant and negative impact on the mean fuel intensity of the car stock and on the vehicle stock. In a consumer survey study, Lehman et al. (2003) examined the impact of graduated vehicle excise duty on consumer vehicle purchase behaviour in the UK and found that the most important factors influencing peoples’ car purchase decisions are overall price, fuel efficiency, size, reliability, and comfort rather than environmental concerns and road tax.\(^7\)

Other notable exceptions are recent studies commissioned by the EU to inform transport CO\(_2\) emissions mitigation policies. COWI (2002) finds that a scheme to replace current registration and circulation taxes with pure CO\(_2\) differentiated taxes provides the greatest reduction in CO\(_2\) emissions intensity of new passenger cars. Additionally, a combination of both registration and circulation taxes differentiated for CO\(_2\) emissions achieves a greater CO\(_2\) emissions reductions than either of the taxes applied exclusively. Another study by TIS (2000) assessing the trade barriers created by vehicle taxation finds that the abolishment of registration taxes would have a positive impact on the functioning of the internal market.

There are even fewer studies which provide an ex-post analysis of the effectiveness of the VA between the Commission and the automobile industry. Mehlin et al (2004) showed that specific automobile technical improvements directed at reducing CO\(_2\) emissions have been

\(^7\)The current difference in tax between tax bands is £10-30 and only 16% of respondents said that this would be sufficient for them to consider switching to lower CO\(_2\)-emitting vehicles.
successful in improving CO$_2$ emissions intensity even while there has been unfavourable vehicle characteristic development -in vehicle weight, height and engine power- over the same period. They argue that these improvements can potentially be attributed to the requirements of the VA and might not have taken place otherwise.

This paper adds to the body of literature in several ways. First, it contributes to the transport economics literature on elasticities of transport demand by assessing the influence of prices, taxes, income, socio-economic effects, and vehicle characteristics on new car CO$_2$ emissions intensity for the period 1995-2004, based on data collected at EU Member State level. CO$_2$ emissions intensity of passenger cars is the metric chosen in the model since this is the metric of the VA target in 2008/2009. While Mehlin et al. (2004) examined the influences of technical characteristics on CO$_2$ emissions and non-technical characteristics only to explain passenger car sales, our work is a first attempt to model Member State CO$_2$ emissions intensity using both technical (vehicle mass, engine capacity and power) and non-technical factors (GNI per capita, population density, fuel price, vehicle taxes, and a country vehicle price index). By affecting car sales, non-technical factors may be an important determinant of CO$_2$ emissions intensity.

Second, this paper supplements studies on vehicle tax adjustment as a measure to reduce the CO$_2$ emissions intensity of the passenger car fleet in the EU. The model estimated in Section 2 includes data at EU Member State level on vehicle (registration, circulation and VAT) and fuel taxes. This gives us the opportunity to judge which type of vehicle or fuel tax is more likely to provide a reduction in the CO$_2$ emissions intensity of passenger cars. While Mehlin et al. (2004) partially investigated the effect of vehicle tax on passenger car sales, circulation tax was the sole vehicle tax modelled, and then only for six EU Member States. It is appropriate to include other vehicle taxes such as VAT and registration taxes for EU15 Member States, given the Commission proposal to abolish registration taxes in the long-term as a result of the findings of COWI and TIS (2002).

The ratio of petrol to diesel vehicle sales is key in determining the CO$_2$ intensity of the passenger car fleet. Therefore the models presented in this paper estimate the impact of fuel and vehicle taxes not only on new vehicle sales, passenger car CO$_2$ emissions intensity, but also on the ratio of petrol to diesel sales. We have not found any examples in the literature of estimates of this last important indicator for passenger car CO$_2$ emissions.

This paper should be useful to academics, as well as policymakers, since it provides estimates for three factors contributing to the amount of CO$_2$ emissions from the passenger car fleet. New vehicle sales determine the order of magnitude of fleet emissions, while CO$_2$ emissions intensity and the ratio of petrol to diesel vehicle sales are indicators of the fleet efficiency. The rest of this paper is organised as follows: Section 2 describes the methodology
used in the analysis, Section 3 presents the results of the econometric analysis and Section 4 concludes.

2. Methodology

This work attempts to determine which variables are the most important drivers of car CO\textsubscript{2} emissions intensity in the EU over the period 1995-2004. This period was chosen, since although the VA was only implemented in 1999, the reference year for CO\textsubscript{2} emissions measurement is 1995, and data are available since that year.

The average CO\textsubscript{2} emissions intensity of the new passenger car fleet is determined by the fleet composition, which reflects the types of cars purchased in the market. The passenger car fleet is made up of a large number of different car models. A key factor influencing CO\textsubscript{2} emissions is the choice of engine as regards fuel type – diesel engines are much more carbon efficient than petrol engines.

The CO\textsubscript{2} emissions intensity of any particular fleet composition is thus the result of a number of supply-side, demand-side variables and socio-economic factors, to the extent that these factors affect consumers’ purchasing decisions.

2.1 Estimation strategy

We estimated two models, a first model to determine the relationship between vehicle sales registrations and demand-side and socio-economic variables (Model 1), and a second model to examine the influence of all variables, including technical features, on the passenger car CO\textsubscript{2} emissions intensity across Member States (Model 2). Model 1 was estimated with two versions of the dependent variable: (i) total new vehicle sales, and (ii) the ratio of petrol to diesel sales. The ratio of petrol to diesel vehicle sales provides an insight into the fleet composition and therefore the CO\textsubscript{2} emissions intensity, while the total vehicle sales indicates the impact that the CO\textsubscript{2} emissions intensity of the fleet will have on total CO\textsubscript{2} emissions.

The dataset includes the 15 ‘old’ Member States, since tax information is only available for these Member States over the period of analysis and these are the countries included in the VA between the automobile manufacturers and the EU Commission, as adopted in 1999. Given the panel structure of our data set, we estimated both models with pooled data (i.e. cross-section and time series) as this is more efficient than using pure time series or cross-sectional data (Baltagi and Griffin 1984; Baltagi 1995).

It has been recognised for some time in the economics literature that it is important to treat vehicle ownership and fuel demand models as dynamic (Sterner, Dahl et al. 1992; Dargay and Vythoulkas 1999; Goodwin, Dargay et al. 2004). There is considered to be a period of demand adjustment due to “pervasiveness of habits, uncertainty, and imperfect information
regarding alternatives and prices, costs of adjustment, transaction costs, search costs, expectations and arguments concerning life-cycle, and permanent income” (Dargay and Vythoulkas 1999). Static models provide estimates only of the short-run effects (i.e. one year adjustment) on vehicle ownership and fuel demand (Sterner, Dahl et al. 1992; Johansson and Schipper 1997), while dynamic models include the effects of time lags between changes in the independent and the dependent variables. Therefore a dynamic (rather than a static) pooled model is utilised in both models by including a lagged dependent variable in the regressions. Unfortunately the lagged dependent variable is generally strongly correlated with the error term and so one way to deal with this is to instrument it (Sterner et al. 1992; Sterner 1991).

Model 1: New car sales

Cars are durable goods. Pindyck (1980) models new vehicle sales as a function of the existing vehicle stock lagged by one period, the price of vehicles, fuel price, income, and lagged new vehicle sales\(^8\). Similar specifications are utilized by later researchers in vehicle stock and new car sales models and which also include other socioeconomic variables (Eskeland and Feyzioglu 1997; Johansson and Schipper 1997; Storchmann 2005). Socio-economic factors can be very important in determining the kind of passenger car purchased. Factors such as income can decide whether a person owns a vehicle at all. Also the transport infrastructure and the demographics of a population may influence whether a car is needed for mobility and the type of car used. We model new vehicle sales with the same strategy as others before and incorporate the following variables: prices (\(P\)) including vehicle price index, fuel prices and the ratio of petrol to diesel prices; taxes (\(T\)) including registration and circulation taxes; socio-economic factors (\(X\)) including GNI per capita and population density; vehicle stock (\(S\)); and new car sales from the previous year (Sales).

\[
Sales_t = \gamma_0 + \gamma_1 P_t + \gamma_2 T_t + \gamma_3 X_t + \gamma_4 S_{t-1} + \lambda Sales_{t-1} + \nu_t \quad (1)
\]

While it is interesting to see which variables affect total vehicle sales, it does not provide much insight into the fleet composition or CO\(_2\) emissions intensity per vehicle. Petrol and diesel vehicles are substitutive products to a large extent. Aggregate vehicle sales data do not permit analysis of the effect of switching from petrol to diesel vehicles as a result of, for example, a relative cost increase affecting petrol cars; it only shows an impact when the total number of vehicles changes. It is worthwhile to examine this substitution effect, especially as diesel vehicles on average emit less CO\(_2\) than petrol vehicles. Therefore equation (1) is re-estimated with the ratio of petrol to diesel sales as the dependent variable and the same independent variables.

\(^8\) This is derived from the vehicle stock model, where vehicle stock per capita is dependent on lagged vehicle stock and new car sales.
We include both absolute fuel prices and the relative petrol-to-diesel fuel price in both versions of the model because whereas the absolute fuel price level may determine whether an individual purchases a vehicle, it is expected that the relative price level of petrol and diesel fuel may have an influence on the fuel type of the vehicle bought.

Model 2: CO₂ emissions intensity

The petrol to diesel vehicle sales model gives an indication of some of the factors expected to affect the CO₂ emissions intensity of the passenger car fleet. However, it is necessary to model CO₂ emissions intensity directly, since while it is true that for a given vehicle model diesel vehicles tend to emit less CO₂ per kilometre than petrol vehicles, it is possible that even if people switch from a petrol vehicle to a diesel vehicle, they may purchase a larger, heavier vehicle than before. Similarly the sales models do not capture consumers who remain with a vehicle of the same fuel type but purchase a more or less efficient model.

As stated previously, this study does not examine the effect of policy instruments on the total CO₂ emissions from all passenger cars but rather on the new fleet vehicle carbon emissions intensity. A drawback of using CO₂ emissions intensity as the dependent variable is that neither the vehicle kilometres driven nor driving behaviour are included in the model. CO₂ emissions intensity of a vehicle is largely determined by technical characteristics, such as fuel type, vehicle mass, engine power and size. To examine the influence of other variables, we need to control for these variables.

Our CO₂ emissions intensity model can be directly linked to other work in the literature modelling car fuel efficiency or intensity, since CO₂ emissions are correlated with (fossil) fuel consumption and therefore vehicle fuel efficiency. Pindyck (1980) finds that fuel prices are the most important factor determining the fuel efficiency of the new car fleet. Fuel prices (and therefore taxes) can be an important factor in determining the car people purchase (Sterner 2003). Higher fuel prices can entice people to purchase a more fuel-efficient car. In the limit, they may decide not to purchase a vehicle at all and travel by public transport. However most literature includes other parameters, such as income, vehicle prices, population density, and sometimes road density (Sterner, Dahl et al. 1992; Eskeland and Feyzioglu 1997; Johansson and Schipper 1997; Storchmann 2005). Our model in equation (2) explains CO₂ emissions intensity with prices (P) including vehicle price index, fuel prices and the ratio of petrol to diesel prices, taxes (T), vehicle characteristics (C) including engine size and power and vehicle mass, socio-economic factors (X) including GNI per capita and population density, CO₂ emissions lagged one period, a time trend (t) and a VA-period dummy (V).

\[ CO_{2it} = \beta_0 + \beta_1 P_{it} + \beta_2 T_{it} + \beta_3 C_{it} + \beta_4 X_{it} + \beta_5 t + \beta_6 V_{it} + \lambda CO_{2i(t-1)} + \epsilon_{it}, \]  

(2)
where \( i \) and \( t \) denote country and year, respectively.

The time trend and the VA-period dummy are included to examine two effects: the time trend tests whether there is a reduction in CO\(_2\) emissions intensity year on year, even when we control for all other variables; the VA-period dummy tests whether, in addition, there is a differential impact on CO\(_2\) emissions intensity during the years of operation of the VA\(^9\).

As described above, the dataset employed in this study is a panel dataset. The OLS model of CO\(_2\) emissions intensity of the passenger car fleet does not take account of the country-specific factors which contribute to the CO\(_2\) emissions intensity of each national passenger car fleet and remain constant over time. It is of interest to examine whether these fixed effects are significant and whether the OLS results are robust to their inclusion. The CO\(_2\) emissions intensity model is therefore estimated with both OLS and fixed-effects models.

In both models the \( \gamma \) and \( \beta \) coefficients can be interpreted as the short run coefficients (or elasticities where applicable). If these are divided by \((1-\lambda)\) from the estimated regressions, the long run coefficients are obtained.

### 2.2 Variable definitions and data sources

#### Emissions intensity

Our dependent variable, emissions intensity, is measured in average grams per kilometre per vehicle. This is the metric used in the automobile manufacturers’ VA target. It reflects the amount of CO\(_2\) emissions measured by manufacturers in a standard driving test\(^{10}\) at the time of vehicle certification. Manufacturers are required to report model sales and emissions data to Member State authorities annually, which are collected by the EU Commission as specified under the monitoring decision\(^{11}\). The fleet average CO\(_2\) emissions intensity is published in the monitoring reports for each Member State by car manufacturing association and fuel type.

#### Technical characteristics

The vehicle characteristics included in the model are sales-weighted average engine size and power, and vehicle mass for the new vehicle fleet sold in each Member State from 1995-2003, available from the annual monitoring reports produced by the EU Commission and the automobile industry. In the EU, the values of these characteristics have increased on average over the period 1995-2004, which ceteris paribus should mean that fleet CO\(_2\) emissions increase.

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\(^9\) A third time variable, the interaction term between the year index and VA dummy variable, was also included but found to be insignificant and dropped. This tested whether the slope of the model changed during the period of operation of the VA.  
\(^{10}\) Commission Directive 93/116/EEC  
\(^{11}\) Decision No. 1753/2000/EC of the European Parliament and of the Council of 22 June 2000 establishing a scheme to monitor the average specific emissions of CO\(_2\) from new passenger cars
intensity have also increased. Since this has not been the case, there have clearly been improvements in the technical design of cars.

Vehicle prices and taxes

Vehicle price variables influencing consumer product choice, such as purchase price and operating costs represent the demand-side variables in the model. Circulation, registration and value added taxes (VAT) make up a significant part of the cost of the purchase and the running costs of a new vehicle in many countries within EU15. However, Lehman et al. (2003) show that when buying a new vehicle in the UK, car purchasers consider the most important running cost factors to be (in descending order) fuel consumption, insurance costs, servicing costs, fuel type, road tax and company car tax (if applicable). It is of interest to examine whether vehicle taxes can play any part in reducing the \( \text{CO}_2 \) emissions intensity of the fleet, and which ones are more relevant.

The information on taxes was obtained from the ACEA Tax Guides (ACEA 1996-2005), which are published annually and describe all taxes pertaining to passenger cars in each Member State. As described above, vehicle tax systems vary hugely across EU15 Member States. Circulation and registration taxes are determined based on various vehicle characteristics, fuel economy, or vehicle price. VAT is calculated as a percentage of the pre-tax vehicle price and varies in value between countries also.

In order to estimate the vehicle prices and taxes in many Member States, it was necessary to define representative petrol and diesel vehicle models, which have been on sale for the entire period of analysis. Since Opel led for the longest time and its top-selling model, Opel Astra 1.6L petrol engine, was available on the market for the whole period 1995-2004, this vehicle model was chosen for the purposes of calculating vehicle prices in the model\(^\text{12}\). Price data are available for this model for each EU15 Member State in 2000. These prices were deflated using the Eurostat passenger car consumer price index, to provide a set of individual vehicle prices in constant 2000 Euros for each Member State for the 10-year period. Diesel vehicle prices were not available from the Commission data and thus were not included in the model. Diesel vehicle prices were used only for the purpose of estimating vehicle taxes\(^\text{13}\).

For each Member State, the annual average registration, circulation tax and VAT were estimated based on the representative vehicle price, the sales weighted fuel economy, \( \text{CO}_2 \) emissions intensity or other required vehicle characteristic for the particular Member State.

\(^\text{12}\) Opel was the passenger car brand with largest market share from 1995-1998, subsequently Volkswagen became the leader for 3 years and afterwards Renault went ahead for the last three years of the period.

\(^\text{13}\) Diesel vehicle prices were calculated by increasing the petrol vehicle prices by €2000, the approximate value of the average difference in price between diesel and petrol Opel Astra models. Petrol vehicle price is the variable used to represent vehicle prices. This assumes that the variation in diesel vehicle prices is the same as for petrol vehicle prices.
Average yearly fuel prices including VAT and excise duty are included in constant 2000 Euros for each Member State for each year, as reported by the EU Oil Bulletin.

**Other socio-economic controls**

The socio-economic variables included in the model are population density (number of people per square kilometre) and the gross national income in constant 2000 Euros per capita, from the World Development Indicator database (WDI 2005).

### 3. Regression Results

**Model 1: New car sales**

The results of the estimation of equation (1) are presented in Table 1. The dependent variables in Table 1 are the new car sales per capita (the total new petrol and diesel vehicle registrations per capita) in column 2, and the ratio of petrol to diesel vehicle sales in column 3.

The model for total new car sales was run both as a simple OLS static model and in its dynamic form, which included the lagged dependent variable as specified in Eq. 1. The literature (Pindyck 1980; Eskeland and Feyzioglu 1997) shows that when the variables vehicle stock and new car sales lagged one period are both included in the model, they are not significant simultaneously. We estimated the model with both variables and found the lagged dependent variable, new car sales, to be insignificant.¹⁴ We report the results for a model that does not include this term.

The third column of Table 1 presents the results when the model is run with the ratio of petrol to diesel new passenger car sales as the dependent variable.

-Table 1 here-

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¹⁴ Similar to others we included income up to two lags but did not find either of the income lags to be significant. When we replicated this model with an instrumental variable for lagged new sales, and omitting lagged vehicle stock, we found that the coefficient on the lagged dependent variable remained insignificant. From our results and the literature we interpret this as indicating that investment in new vehicles does not point towards partial adjustment to an optimal level of stock, as originally proposed by Pindyck (1980).
The results in Table 1 are presented as elasticities. The significant coefficients in the regression of total new car sales are those on lagged vehicle stock, fuel price, GNI per capita, diesel circulation tax, petrol and diesel registration taxes, and population density\textsuperscript{15}. GNI per capita is associated with higher vehicle sales. This result agrees with the findings of Mehlin et al. (2004) and Goodwin et al. (2004). It seems reasonable since higher GNI per capita increases purchasing power and therefore a rise in car sales can be expected. The estimated elasticity of new car sales with respect to income (0.88) is higher than estimated by Eskeland and Feyzioglu (0.77) and Pindyck (0.12 in the short run and 0.30 in the long run). Other researchers in this field have modelled vehicle stock rather than new vehicle purchases and therefore the value of the elasticities is not directly comparable.

The positive relationship between population density and vehicle sales is less easily explained. Perhaps in countries with higher average population density, household size is smaller and hence the number of cars per capita increases. Other researchers have found population density to be negatively correlated with vehicle stock (Johansson and Schipper 1997; Storchmann 2005).

Fuel price is negatively associated with vehicle sales, with an elasticity of −0.55. This supports the negative fuel price elasticity of vehicle ownership estimated by Goodwin et al. (2004) from the studies they reviewed.

Vehicle annual circulation (ACT) and registration (RT) taxes appear to have a significant influence on vehicle sales. While the ACT for petrol vehicles is not an important factor determining new car sales, there is a significant negative elasticity of new car sales with respect to diesel ACT and petrol RT. The opposite is true for diesel RT, which may be explained in the second part of this model below. While vehicle model prices might be expected to affect individual new car model sales, in this model the vehicle price index represents an overall level of vehicle prices in each country and it does not appear to be a significant factor determining new car sales.

Based on the analysis of the vehicle sales model, the vehicle sales ratio model is also run as a static OLS regression. The results from this model are reported in column 3 of Table 1. Fuel price is included as an aggregate of petrol and diesel prices and as a ratio of petrol to diesel price. The fit of the model, as indicated by the adjusted $R^2$-value is worse than in the total vehicle sales model. This could be a result of omitted unobserved variables such as cultural preferences.

\textsuperscript{15} Real interest rates were also included but dropped, as its coefficient was not significant and this variable had many missing values.
As expected, there is a high negative elasticity of the ratio of petrol to diesel new car sales with respect to the petrol to diesel fuel price ratio; however sales-weighted fuel price does not have a significant effect. This indicates, as we could expect, that the absolute level of fuel prices does not determine whether a purchaser buys a petrol or diesel vehicle, whereas the relative price difference between petrol and diesel does. Overall, elasticities in the petrol to diesel vehicle sales model are high, which is plausible since petrol and diesel vehicles are *ceteris paribus* strong substitutes.

The coefficients of registration taxes are highly significant in the model. When petrol registration tax increases, the ratio of petrol to diesel car sales drops, while the opposite is true for diesel registration tax. The elasticities of the ratio of petrol to diesel car sales with respect to registration taxes are high while those with respect to annual circulation taxes are insignificant. This suggests that different taxes affect the purchasing behaviour differently and that registration taxes, applied at the moment of purchase, have a more marked influence on the fuel type of the vehicle chosen by a purchaser at the time of purchase than an annual circulation tax which is applied later and continues throughout the life of the vehicle.

GNI also has a significant positive effect on petrol to diesel car sales ratios. The coefficient on GNI per capita is, as we would expect, less significant in this model than in the total sales model.

The vehicle price index represents the price of the average petrol vehicle car in each country and it is, as expected, negatively correlated with the ratio of petrol to diesel car sales.

*Model 2: CO₂ emissions intensity*

In Model 2 the CO₂ emissions intensity of the fleet is regressed against price variables, vehicle technical characteristics, and socio-economic variables according to equation (2).

The values in column 2 of Table 2 are the estimated elasticities for the simple static OLS model of CO₂ emissions intensity of the new passenger car fleet. As in Table 1, the fuel prices in this table are included both as an aggregate fuel price and as a price ratio between petrol and diesel fuel prices. All the coefficients, apart from that on vehicle mass, are found to be significant and most of the signs of the coefficients are as expected. The results suggest that there is a year on year decrease in emissions over the period; an increase in petrol circulation and registration taxes and population density are associated with a reduction in emissions, and vehicle characteristics such as engine power and size have a positive impact in CO₂ emissions. Vehicle taxes appear to cause vehicle fuel switching –as petrol vehicle taxes increase, there is a reduction in CO₂ emissions as consumers switch to more fuel efficient vehicles, however as diesel vehicle taxes increase, CO₂ emissions increase, as consumer switch back to more fuel-consuming petrol vehicles.
The literature indicates that it is preferable to utilise dynamic models when modelling fuel consumption and vehicle efficiency to take account of adaptation delays. Therefore a lagged dependent variable is included in the model and the results are presented in column 3. As it was indicated previously, to deal with the problem of correlation of the lagged term with the error term it is desirable to employ an instrumental variable. Two instrumental variables are tested in table 2 –column 4 (2SLS-A) presents the results when lagged vehicle characteristics are used as the instrumental variable for lagged CO\textsubscript{2} emissions, and column 5 (2SLS-B) presents the results for a two stage process of the same regression but where the lagged dependent variable for the OLS model is predicted from a regression of the independent variables from both time periods and the second lag of CO\textsubscript{2} emissions, as proposed by Johansson and Schipper (1997).

The results for the three dynamic models appear to be quite robust. The significant coefficients are found on the lagged CO\textsubscript{2} variable, the time trend, the vehicle circulation tax (ACT), the vehicle price and the average engine power. As discussed above, the coefficient on the lagged variable provides a multiplier with which the long-term elasticities can be estimated. In these models the value of the multiplier ranges from 2.0 to 2.6. Therefore the long run elasticity of CO\textsubscript{2} emissions intensity of the fleet relative to, for example, ACT is estimated to be between 3 to 7%. Again there appears to be a substitution effect between petrol and diesel vehicle ACT since the coefficients are of opposite signs. The coefficients on RT are lower in magnitude than the ACT coefficients and, except for RT diesel in the third column with the expected sign, they are not significant. The vehicle price index is positively correlated with CO\textsubscript{2} emissions. This may seem surprising, since it would be expected that an increase in vehicle prices might cause consumers to downsize. However, the vehicle price index variable does not represent individual model prices but rather serves as a comparison of vehicle prices between countries. Its coefficient can therefore be explained as an indication that in countries where vehicle prices are higher, CO\textsubscript{2} emissions are also higher. A hypothesis is that since vehicle prices overall are high, there is less relative price difference between luxurious and basic models and therefore customers opt for more luxurious and higher emitting models. Higher engine power produces higher CO\textsubscript{2} emissions intensity as expected. The two dynamic models with instrumental variables produce similar results.

*Impact of time on CO\textsubscript{2} emissions intensity*

The models so far have shown that vehicle taxes may have had an impact on the sales of passenger cars, ratio of petrol to diesel cars sold and the CO\textsubscript{2} emissions intensity of the fleet over the period 1995-2004. It would be interesting to estimate also the direct effect that the
voluntary agreement has had during its time of operation (2000-2004), but it is difficult to find a suitable variable to include in the regressions.

The OLS regressions in Table 2 include a time trend as a regressor. The effect of time on fleet CO$_2$ emissions intensity is highly significant and economically important; as time passes, CO$_2$ emissions are reduced by between 4-9 percent in the short term. We hypothesise that this might be a result of the voluntary agreement, which, although only in operation since 2000, was under negotiation already in 1995. In fact firms had knowledge of impending CO$_2$ emissions reduction requirements since 1992, which could have induced them to begin developing more fuel-efficient cars before the introduction of the VA. The reduction in CO$_2$ emissions year-on-year predicted by the model, which controls for some vehicle characteristics, price and socioeconomic variables, is higher than that observed in Figure 1.

The second time effect is examined in the model by including a VA period dummy variable and an interaction term between the time trend and the VA dummy. This allows us to see whether the period of the voluntary agreement has had a different effect on the CO$_2$ emissions intensity compared with the period 1995-1999. The interaction term was not found to be statistically significant and is dropped in the models presented in Table 2. The effect of the VA dummy coefficient is not robust; it is significant only in the static model and its impact is smaller than the impact of the time trend.

**Fixed effects**

We tested for fixed effects and found that the hypothesis that country-specific error terms are equal to zero cannot be rejected. This may be due to the fact that some explanatory variables included in the models are relatively constant over time and thus highly correlated with the fixed effects. For example, in several countries the vehicle taxes do not change over time. Similarly, variables such as population density do not change significantly with time. Therefore, the fixed-effects results are not reported. An interesting robust result, however, is that the time trend is negative and highly significant in both specifications, with and without fixed effects. It suggests that there is some phenomenon occurring over the sample period, which is causing the fleet CO$_2$ emissions intensity to decrease with time and that is not explained by the sales-weighted average vehicle characteristics, vehicle taxes, fuel prices or socio-economic variables. A reasonable hypothesis is that this is the result of the VA.

**4. Conclusions**

Many of the EU15 countries are facing ‘overshoot’ of their Kyoto-related burden sharing commitments, and the road transport sector is identified in most jurisdictions as the main source of rising CO$_2$ emissions. They are therefore faced with the prospect of buying allowances in order to comply. Any insights that help them identify the potential significance of fiscal policy and/or voluntary agreements in reducing this bill are highly policy-relevant.
This work evaluates the hypothesis that the voluntary agreement and relevant taxes – especially the annual vehicle circulation tax and fuel taxes - influence the carbon intensity of the new car fleet, and gives considerable insight as to how and to what extent this influence is exercised. As such, it provides important analytical support for policy at both Member State and European Union levels. The passenger car VA to reduce CO₂ emissions intensity is an EU level supply-side policy instrument and fiscal measures at the Member-State level can support the achievement of the target and further reductions of CO₂ emissions in the passenger car fleet.

At this time, after five years since the commencement of the VA, it is reasonable to begin to examine these data to investigate the impact of fiscal measures on Member States’ average new car CO₂ emissions intensity and their relationship with the voluntary agreement. Thus this paper has examined the influence of several fiscal measures, technical characteristics and other relevant socio-economic variables on passenger car sales and CO₂ emissions intensity in EU15 over the time period 1995-2004.

Broadly, our results indicate that (i) different taxes (fuel taxes, vehicle registration and circulation taxes) affect individuals’ purchasing behaviour differently; (ii) despite the high correlation between the petrol-to-diesel new car sales with new fleet average CO₂ emissions intensity, fiscal instruments affect them differently; and (iii) new fleet average CO₂ emissions intensity has fallen over the time period 1995-2004 independently of Member-State fiscal measures.

More specifically, with regard to policies that can impact new car sales, fuel price shows the strongest impact on total new passenger car sales, in agreement with the results of Mehlin et al. (2004). The effect of vehicle taxes on new car sales is less clear cut; registration taxes appear to have a more significant impact than annual circulation taxes. If we examine the ratio of petrol to diesel vehicles sales it appears that it is not the level of the fuel price that is important but rather the relative petrol-to-diesel price. Registration taxes are significant and effective in determining the ratio of petrol to diesel vehicle sales and indicate the substitutive nature of petrol and diesel car purchases.

In our model, the fleet average CO₂ emissions intensity is determined by the petrol-to-diesel fuel price ratio, the circulation tax for petrol and diesel cars, the average country price index for a petrol car (which does not include registration and circulation taxes), and engine power. It is notable that the registration tax does not appear to have an important impact on the CO₂ emissions intensity of the new passenger car fleet. This would indicate that while the registration tax influences whether a customer purchases a diesel or petrol vehicle, it is the circulation tax that is more influential in determining the fuel efficiency and hence CO₂
emissions of the vehicle purchased. In principle, this supports the EU Commission proposal to abolish registration taxes in favour of CO₂-differentiated circulation taxes.

A time trend is highly significant across the different models indicating that CO₂ emissions intensity decreases over time, but that this effect is not accounted for by the other variables in the regressions. When the models are reestimated with dummy variables for the period over which the voluntary agreement has been in operation, there does not appear to be a significant difference in CO₂ emissions intensity between the period 1995-1999 and 2000-2004.

Future work will expand the model to include data from countries outside the EU. Since all the car manufacturers involved in the EU CO₂ emissions voluntary agreement operate globally, it would be interesting to include in the model the fleet CO₂ emissions intensities of countries which are not part of the VA, to see whether there is a difference between the CO₂ emissions intensity performance of their passenger car fleets and that observed in EU15. This could provide further insights regarding the impact of the EU VA on passenger car fleet CO₂ emissions intensity.

Acknowledgements
We wish to thank Markus Mehlin of DLR, Gilles Paque of DG Environment, and ACEA for their assistance with tax data collection. We are grateful for the support of the Irish Research Council for Humanities and Social Sciences for this work.
References


Pindyck, R. S. (1980). The Structure of World Energy Demand, MIT Press.


### Table 1: OLS regression of new passenger car sales per capita.

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>New car sales</th>
<th>Petrol/diesel car sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle stock (t-1)</td>
<td>0.418**</td>
<td></td>
</tr>
<tr>
<td>(0.19)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel price</td>
<td>-0.545***</td>
<td>2.769</td>
</tr>
<tr>
<td>(0.142)</td>
<td>(2.580)</td>
<td></td>
</tr>
<tr>
<td>Fuel price ratio</td>
<td>-0.206</td>
<td>-4.394*</td>
</tr>
<tr>
<td>(0.231)</td>
<td>(2.302)</td>
<td></td>
</tr>
<tr>
<td>GNI</td>
<td>0.884***</td>
<td>1.363**</td>
</tr>
<tr>
<td>(0.152)</td>
<td>(0.566)</td>
<td></td>
</tr>
<tr>
<td>ACT petrol</td>
<td>0.028</td>
<td>0.647</td>
</tr>
<tr>
<td>(0.062)</td>
<td>(0.414)</td>
<td></td>
</tr>
<tr>
<td>ACT diesel</td>
<td>-0.102***</td>
<td>-0.356</td>
</tr>
<tr>
<td>(0.029)</td>
<td>(0.362)</td>
<td></td>
</tr>
<tr>
<td>RT petrol</td>
<td>-0.157***</td>
<td>-5.226***</td>
</tr>
<tr>
<td>(0.053)</td>
<td>(1.721)</td>
<td></td>
</tr>
<tr>
<td>RT diesel</td>
<td>0.134**</td>
<td>5.846**</td>
</tr>
<tr>
<td>(0.061)</td>
<td>(2.059)*</td>
<td></td>
</tr>
<tr>
<td>Vehicle price index</td>
<td>0.101</td>
<td>-5.132**</td>
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<tr>
<td>(0.276)</td>
<td>(2.126)</td>
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<tr>
<td>Population density</td>
<td>0.125***</td>
<td>-0.232</td>
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<td>(0.030)</td>
<td>(0.558)</td>
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</tr>
<tr>
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<td>117</td>
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<tr>
<td>n</td>
<td>15</td>
<td>15</td>
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<tr>
<td>R-squared</td>
<td>0.746</td>
<td>0.312</td>
</tr>
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</table>

Notes:
(a) Dependent variable for column 2 = total new petrol and diesel cars sold annually per capita; dependent variable for column 3 = ratio of petrol to diesel car sales. All results given as elasticities estimated at the mean.
(b) *, **, and *** denote significance at the 10%, 5% and 1% levels, respectively.
(c) Standard errors in parenthesis computed using the Huber/White/Sandwich variance-covariance estimator.
(d) 'ACT' and 'RT' signify vehicle annual circulation and registration taxes respectively.
Table 2: Regression results of CO₂ emissions intensity against all other variables.

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>OLS (static)</th>
<th>OLS (dynamic)</th>
<th>2SLS-A (dynamic)</th>
<th>2SLS-B (dynamic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCO₂</td>
<td>--</td>
<td>0.606***</td>
<td>0.490***</td>
<td>0.618***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.089)</td>
<td>(0.164)</td>
<td>(0.147)</td>
</tr>
<tr>
<td>Year</td>
<td>-0.091***</td>
<td>-0.040***</td>
<td>-0.055***</td>
<td>-0.050*</td>
</tr>
<tr>
<td></td>
<td>(0.010)</td>
<td>(0.013)</td>
<td>(0.020)</td>
<td>(0.026)</td>
</tr>
<tr>
<td>VA dummy</td>
<td>-0.010***</td>
<td>-0.004</td>
<td>-0.003</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td>(0.003)</td>
<td>(0.030)</td>
<td>(0.031)</td>
</tr>
<tr>
<td>Fuel price</td>
<td>0.084***</td>
<td>0.015</td>
<td>0.025</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>(0.021)</td>
<td>(0.020)</td>
<td>(0.030)</td>
<td>(0.031)</td>
</tr>
<tr>
<td>Fuel price ratio</td>
<td>-0.196***</td>
<td>-0.035</td>
<td>-0.045*</td>
<td>-0.039</td>
</tr>
<tr>
<td></td>
<td>(0.024)</td>
<td>(0.022)</td>
<td>(0.028)</td>
<td>(0.039)</td>
</tr>
<tr>
<td>ACT petrol</td>
<td>-0.027***</td>
<td>-0.016**</td>
<td>-0.028**</td>
<td>-0.025**</td>
</tr>
<tr>
<td></td>
<td>(0.008)</td>
<td>(0.007)</td>
<td>(0.009)</td>
<td>(0.011)</td>
</tr>
<tr>
<td>ACT diesel</td>
<td>0.034***</td>
<td>0.016***</td>
<td>0.022***</td>
<td>0.018**</td>
</tr>
<tr>
<td></td>
<td>(0.006)</td>
<td>(0.006)</td>
<td>(0.007)</td>
<td>(0.008)</td>
</tr>
<tr>
<td>RT petrol</td>
<td>-0.026***</td>
<td>-0.006</td>
<td>0.005</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td>(0.007)</td>
<td>(0.006)</td>
<td>(0.009)</td>
<td>(0.011)</td>
</tr>
<tr>
<td>RT diesel</td>
<td>0.036***</td>
<td>0.013*</td>
<td>0.003</td>
<td>-0.006</td>
</tr>
<tr>
<td></td>
<td>(0.008)</td>
<td>(0.007)</td>
<td>(0.010)</td>
<td>(0.012)</td>
</tr>
<tr>
<td>Vehicle price</td>
<td>0.097***</td>
<td>0.070**</td>
<td>0.104***</td>
<td>0.088**</td>
</tr>
<tr>
<td></td>
<td>(0.035)</td>
<td>(0.030)</td>
<td>(0.030)</td>
<td>(0.043)</td>
</tr>
<tr>
<td>GNI</td>
<td>0.036***</td>
<td>0.009</td>
<td>0.014</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>(0.011)</td>
<td>(0.010)</td>
<td>(0.011)</td>
<td>(0.012)</td>
</tr>
<tr>
<td>Population density</td>
<td>-0.009**</td>
<td>-0.002</td>
<td>0.001</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td>(0.004)</td>
<td>(0.004)</td>
<td>(0.005)</td>
</tr>
<tr>
<td>Engine power</td>
<td>0.157***</td>
<td>0.080***</td>
<td>0.087**</td>
<td>0.087</td>
</tr>
<tr>
<td></td>
<td>(0.037)</td>
<td>(0.031)</td>
<td>(0.034)</td>
<td>(0.067)</td>
</tr>
<tr>
<td>Engine size</td>
<td>0.137***</td>
<td>0.027</td>
<td>-0.013</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>(0.052)</td>
<td>(0.044)</td>
<td>(0.052)</td>
<td>(0.061)</td>
</tr>
<tr>
<td>Vehicle mass</td>
<td>0.076</td>
<td>0.042</td>
<td>0.119</td>
<td>0.059</td>
</tr>
<tr>
<td></td>
<td>(0.057)</td>
<td>(0.048)</td>
<td>(0.112)</td>
<td>(0.125)</td>
</tr>
<tr>
<td>N</td>
<td>103</td>
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<td>n</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Adj R²</td>
<td>0.910</td>
<td>0.941</td>
<td>0.954</td>
<td>0.942</td>
</tr>
</tbody>
</table>

Notes:
(a) Dependent variable for columns 1-4 = fleet average CO₂ emissions intensity, measured as gCO₂ emissions per kilometre over standard European test cycle.
(b) Column 2 represents a simple static OLS model; column 3 represents an OLS dynamic model including the lagged dependent variable ((t-1) CO₂ emissions); column 4 represents the OLS dynamic model in which the lagged dependent variable is instrumented with lagged vehicle characteristics; and column 5 presents the results of the OLS dynamic model in which a 2SLS is used to predict the lagged dependent variable using all independent variables, their lag, and the second lag of the dependent variable. All results are given as the elasticities estimated at the mean.
(c) *, **, and *** denote coefficients significant at the 10%, 5% and 1% significance levels, respectively. Standard errors are given in parentheses.