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THE INTERNALISATION OF EXTERNAL COSTS OF CO_2 AND POLLUTANT EMISSIONS FROM PASSENGER CARS

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Abstract. The paper's goal is to unify practical and theoretical aspects of internalisation of external costs, in line with the "polluter pays" and "user pays" principles. Due to the impossibility of applying an ideal economic solution for internalisation of external costs, alternative solutions have to be developed and implemented. One of the possible solutions for internalisation of external costs of CO_2 and pollutant emissions from passenger cars is presented in this paper. It is a new methodology for calculating annual circulation taxes on passenger cars. This methodology, besides CO_2, also takes into account the pollutants whose emissions are regulated by the Euro standards (CO, HC, NO_x and PM), as well as the vehicle age and kilometres driven. The proposed methodology has been tested on some of the best-selling passenger cars in Europe. The results of analysis show significant differences between our methodology and the methodologies that are used in five European countries (Ireland, the United Kingdom, Malta, Luxembourg and Sweden), which use the CO_2 emissions as a reference value for their calculation. Also, we have proved that the annual circulation tax, calculated using our methodology, provide better internalisation of external costs compared to the fuel tax.

Keywords: external cost, annual circulation tax, passenger cars, emissions, CO_2, pollutants, vehicle age, kilometres driven.

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JEL Classification: H21, H23, R48.

1. Introduction

Due to the negative impacts on the environment and human health, on one hand, and the necessity for sustainable development, on the other, the transport sector today faces a great challenge (Mačiulis *et al.* 2009). Great efforts are made in many countries to create and implement a transport development strategy which will enable better mobility of people and goods, and at the same time provides better environmental conditions. Hence, there is a growing interest in finding and implementing different planning, regulatory and economic instruments which could contribute to achieving this strategy (Štreimikienė, Esekina 2008; Tampère *et al.* 2009; Jakimavičius, Burinskienė 2009; Jović, Đorić 2010).

Although technologically advanced and, in terms of fuel consumption, more efficient than before, motor vehicles still are one of the main sources of CO_2 (carbon dioxide) and pollutant emissions (Tanczos, Torok 2007; Petrović *et al.* 2009). Negative impacts of these emissions can be manifested in the immediate vicinity of the pollution source, as well as regionally and globally.

From an economic point of view, the best solution for internalisation of these externalities would be achieved by applying tax on vehicle emissions in the amount of marginal external damage caused to society. This way, there would be strong economic incentives to reduce CO_2 and pollutant emission levels through an adequate selection of vehicles and optimization of the driven kilometres. This would lead to a lower tax burden and also to improvement of quality of the environment. Unfortunately, the previous solution is still not applicable in practice. Reasons are manifold. Namely, for vehicles in use, the procedure of continuous measurement of emission levels is complicated and expensive, and impossible for some pollutants. Such measurements are usually performed with the purpose of experimental research of the relationship between certain combustion products and the vehicle dynamic characteristics. In addition, the periods in which the experiments are performed are relatively short (Silva *et al.* 2006; Durbin *et al.* 2008). Continuous measurement of damage caused by a given level of emissions represents an even bigger problem, since, except in the case of CO_2, this damage significantly depends on temporal, spatial, atmospheric and many other factors. These are also the reasons for application of different "second-best solutions" for internalisation of external costs of CO_2 and pollutant emissions. One of the possible solutions is provided in this paper. Namely, the objective of this paper is to present a new methodology for calculation of annual circulation taxes on passenger cars which would enable better internalisation of these externalities.

However, there are some gaps in the area of investigation. The first gap was a small number of included pollutants. Vehicle age was not included in most existing methodologies. Driven kilometres were neglected too. We have created a new methodology that provides the solution for all gaps. Also, we have proved that the annual circulation tax, calculated using our methodology, provide better internalisation of external costs compared to the fuel tax.

2. State of the art and problem statement

From literature it can be concluded that only a small number of authors have dealt with identification of such vehicle characteristics that appear to be key determinants of certain pollutant emissions, and therefore, directly or indirectly, with finding such vehicle characteristics that could appear as reference values for determination of annual circulation taxes.

In his study, Khazzoom (1995) formulates a model of determination of the target emission rate of three pollutants (HC – hydrocarbon, CO – carbon monoxide, NO_x – nitrogen oxides) using engine displacement classes, technology of emission control, fuel economy, vehicle weight and horsepower, along with the probability of the EPA (Environmental Protection Agency) inspection, manufacturer recalls and the owner's response to the recall announcement as explanatory variables. According to him, engine displacement and technology of emission control have the greatest impact on these pollutants' emissions, while the engine power significantly affects the HC emissions. On the other hand, he does not find any connection between the fuel economy and the emission of these harmful gases. However, Harrington (1997) finds that fuel economy affects the emissions of HC and CO, and that the effect becomes stronger as vehicles age.

In order to determine whether certain vehicle characteristics (test weight, engine displacement, cylinders, mileage, vehicle age, engine power and model year) affect THC, CO and NO_x emissions, Johnstone and Karousakis (1999) conducted a principle components regression using the data obtained from the US EPA's National Vehicle and Fuels Emissions Laboratory in Ann Arbor, Michigan. The dataset consists of 2850 observations from tests undertaken between the years 1983–1996 using the EPA Federal Test Procedure (FTP) which intended to simulate 'typical' driving conditions. According to them, model-year and the presence of fuel injection have the greatest influence on the emission of all three pollutants. CO and THC emissions are significantly determined by the kilometres driven, as well.

Beydoun and Guldmann (2006) also dealt with the influence of certain vehicle characteristics on emission test failure rates and on the CO, HC and NO_x emissions. Their results indicated that vehicle age, fuel economy, kilometres driven, engine characteristics, weight, general maintenance, and time of year were the most important factors.

Although the CO_2 emission is in direct correlation with fuel consumption (Johnstone, Karousakis 1999; Mickunaitis *et al.* 2007; Vujanović *et al.* 2010), some authors provide evidence of existence of a relationship between this emission and certain vehicle characteristics. Thus, for example, Zervas and Lazarou (2008) defined a linear dependence of CO_2 emission on the weight of the passenger cars. Zervas and Diamandopoulos (2008) analysed the relationships between the exhaust CO_2 of gasoline and diesel passenger cars and four vehicle and engine parameters (vehicle weigh, engine capacity, maximum and specific power). They concluded that weight has the best correlations in the case of diesel passenger cars and displacement in the case of gasoline ones. On the other hand, Washburn *et al.* (2001) used three-stage least squares regression to estimate a simultaneous equations model for CO, CO_2 and HC, and found that vehicle age, vehicle manufacturer, number of engine cylinders, odometer reading and the use (or not) of oxygenated fuels have the largest impact on the I/M (inspection/maintenance) emission test results.

In the world today, there is a wide range of methodologies used for calculating annual circulation taxes and registration taxes on passenger cars. Analyzing passenger car related charges and taxes in twenty-seven European countries (EU25, Switzerland and Norway), Kunert and Kuhfeld (2007) found at least eight different bases for assessing annual circulation taxes and ten different bases for assessing vehicle registration taxes. By conducting a comparative analysis of existing methodologies in the world used to determine annual circulation taxes on passenger cars, it can be concluded that they are, in most cases, based on technical characteristics of vehicles, such as engine capacity, engine power and vehicle weight (Kunert, Kuhfeld 2007; European Automobile Manufacturers' Association... 2010a).

In addition, it is noticeable that an increasing number of countries make certain efforts towards internalization and reduction of external costs of emissions through the introduction of taxes based on CO_2 emission and/or fuel consumption. Moreover, the European Commission itself is trying to set a new foundation for the calculation of annual circulation and registration taxes by introducing CO_2 emission as a reference value. This is indicated by the Proposal for a Council Directive on passenger car related taxes which contains three new measures: the abolition of registration tax, establishment of a registration tax refund system and restructuring the tax base of registration tax, and annual circulation tax to be totally or partially CO_2 based (European Commission 2005). Defining this proposal for a directive was preceded by several studies commissioned by the EU. One of these studies aimed to assess the extent to which annual circulation and registration taxes can represent an effective means of CO_2 emission reduction was carried out by the International Consulting Group COWI A/S. Their research found that purely CO_2 differentiated circulation and registration taxes would provide the largest reductions in average CO_2 emissions from new passenger cars in Denmark and the Netherlands (8.5% and 7% respectively). On the other hand, Portugal has the smallest reduction potentials from fiscal measures, namely 3.3% at the maximum (COWI 2002).

In their research Giblin and McNabola (2009) also found that the introduction of vehicle related taxes based on CO_2 emission in Ireland would result in a reduction of average CO_2 emissions intensity of 3.6 and 3.8% from new diesel and petrol car purchases, respectively. They have also found that annual circulation taxes have a much greater effect on reduction of the intensity of CO_2 emissions with regard to vehicle registration taxes. Ryan *et al.* (2009) concluded that vehicle and fuel fiscal policies affect to a greater extent the reduction of fleet CO_2 emission than voluntary agreements with car manufacturers. They also agree that the proposal of the European Commission on the abolition of car registration taxes is entirely correct.

The annual circulation tax on passenger cars totally based on CO_2 emission currently exists in Ireland, Luxembourg, United Kingdom, Malta and Sweden. In Ireland, this tax ranges from €104 for the greenest cars to €2,100 for cars with the highest emissions ratings (Motor Tax Online... 2009; European Automobile Manufacturers' Association... 2010b). In the UK, the vehicle excise duty (the UK's annual vehicle circulation tax) is split into 13 bands according to the CO_2 emissions of the car. Rates range from £0 to £435 for diesel and petrol cars, and £425 for alternative fuel cars (Directgov... 2010). This is a "standard rate". From April 2010 the so-called "first year rate" of registration has been applied in this country. This rate particularly affects vehicles that emit more than 165 g/km. In Malta, during the first five years, there is also the annual circulation tax totally based on CO_2 emissions. For diesel cars its amount varies depending on the PM (particulate matter) emissions, too. After five years, the amount of annual circulation tax varies depending on the age of the vehicle as well (Transport Malta... 2009). In Sweden, this type of tax is applied for cars meeting at least Euro 4 exhaust emission standards. The tax consists of a basic rate of SEK 360 (SEK – Swedish Kroner) plus SEK 15 for each gram of CO_2 emitted above 100 g/km. This sum is multiplied by 3.15 for diesel cars registered for the first time in 2008 or later and by 3.3 for other diesel cars. For alternative fuel vehicles, the tax is SEK 10 for every gram emitted above 100 g/km (European Automobile Manufacturers' Association... 2010b). In Luxembourg tax rates are calculated by multiplying the CO_2 emissions in g/km with 0.9 for diesel cars and 0.6 for cars using other fuels respectively and with an exponential factor (0.5 below 90 g/km and increased by 0.1 for each additional 10 g of CO_2/km) (European Automobile Manufacturers' Association... 2010b).

However, despite the great number of different methodologies for calculating annual circulation taxes, internalisation of external costs of CO_2 and pollutant emissions is still a challenge. Namely, the existing methodologies based on technical characteristics of vehicles as references for determination of annual circulation taxes, do not provide the most appropriate solution for internalization of external costs, since the correlation between certain characteristics and these emissions is very weak (Mickunaitis *et al.* 2007; Momčilović *et al.* 2009). Also, it is evident the kilometres driven of vehicles are is excluded from calculation. On the other hand, the existing methodologies based on CO_2 emissions as well as the proposal of the European Commission ignore other by-products of combustion that are also harmful to the environment and human health. By doing so, the question is raised whether and to what extent a mistake is made. In addition, these methodologies ignore the age of vehicles, which along with the vehicle kilometres driven significantly affect the observed external costs.

Following the previous observations we can conclude that there is considerable space and need to create a new methodology for calculation of annual circulation taxes on passenger cars that would provide better internalisation of external costs caused by the emission of harmful combustion products. A special feature of the new methodology is reflected in the authors' idea to use, for the first time, the costs of CO_2 and certain pollutants' emissions as reference values for calculating annual circulation taxes.

3. Methodology

The following section proposes one possible methodology for calculating annual circulation taxes on passenger cars. This methodology, besides the CO_2, also takes into account the pollutants whose emissions are regulated by the Euro standards, as well as the vehicle age and kilometres driven.

3.1. The external cost of emissions as a basis for determination of annual circulation taxes

One of the advantages of this methodology is that it takes into account not only the CO_2 but also the pollutants whose emissions are regulated by the EC Regulation 715/2007: NO_x, NMHC (non-methane hydrocarbons), CO and PM (European Commission 2007). Emissions of CO_2 and pollutants have been reduced to a common denominator by expressing them in terms of money, that is, in external costs of emissions.

Annual circulation taxes are calculated for cars whose emission characteristics (emissions of CO_2, HC, NO_x, PM and CO) are taken from the new car catalogue (Kraftstoffverbrauchs… 2002, 2004; Kraftfahrt-Bundesamt 2008). External cost of CO_2, NMHC, NO_x and PM emissions are taken from the Directive 2009/33/EC (European Commission 2009). These data refer to 2007.

As the vehicle catalogue provides data on HC emission, whereas the literature mostly covers the external cost for NMHC emission, the question is whether and to what extent the error is made by equalizing the external costs of HC and NMHC emissions. It is known that hydrocarbon (HC) consists of methane (CH_4) and non-methane hydrocarbon (NMHC). The external cost of NMHC in 2007 is 1 EUR/kg (European Commission 2009), while the external cost of CH_4, considering its global warming potential (GWP) relative to CO_2 is 0.735 EUR/kg. The external cost of CH_4 is calculated by multiplying the external cost of CO_2 by the corresponding GWP of CH_4. The external cost of CO_2 in 2007 is 0.035 EUR/kg (European Commission 2009), while the GWP of CH_4 from the IPCC (Intergovernmental Panel on Climate Change) SAR (Second Assessment Report) on a 100 year time scale is 21 (IPCC 1995).

For the average relationship between CH_4 and NMHC emissions of 0.23, which corresponds to an average relationship between CH_4 and HC of about 0.19 (Nam *et al.* 2004), by applying the previous external costs, it can be concluded that the error of 5.3% is made by equalizing the external costs of NMHC and HC emissions. If we use GWP of 23 (IPCC 2001) or GWP of 25 for CH_4 (IPCC 2007), we make even smaller errors, 3.7% and 2.4% respectively. Considering the previous results, we will hereafter assume that the unit external costs of NMHC and HC emissions are equal.

The external cost of CO emission, found by Mercuri *et al.* (2002), converted in 2007 was 0.01 EUR/kg.

The final values of external costs of CO_2, CO, HC, NO_x and PM emissions for 2007 are given in Table 1.

Table 1. External cost for emissions in road transport, EUR/kg (in 2007 prices)

Pollutant	CO_2	CO	NO_x	HC	PM
EC	0.035	0.01	4.4	1	87

Considering all the above mentioned, the external cost of CO, HC, NO_x, CO_2, PM emissions (hereafter the external cost of emissions) per 1 km for vehicle is determined using the next equation:

$$EC_{km} = ec_{CO} \cdot q_{CO} + ec_{HC} \cdot q_{HC} + ec_{NO_x} \cdot q_{NO_x} + ec_{CO_2} \cdot q_{CO_2} + ec_{PM} \cdot q_{PM}, \text{ EUR/km}, \quad (1)$$

where: ec_{CO}, ec_{HC}, ec_{NO_x}, ec_{CO_2}, ec_{PM}, EUR/kg – external cost of CO, HC, NO_x, CO_2 and PM emissions, respectively, q_{CO}, q_{HC}, q_{NO_x}, q_{CO_2}, q_{PM}, kg/km – CO, HC, NO_x, CO_2 and PM emissions, respectively.

The total external cost of emissions depends on the vehicle kilometres driven. Therefore, we will include the vehicle kilometres driven in the suggested methodology. By using Eq. (1) yearly external cost of emissions and hence annual circulation tax for vehicle can be written as follows:

$$EC_{year} = EC_{km} \cdot S, \text{ EUR/year}, \quad (2)$$

where S (km/year) denotes the yearly vehicle kilometres driven.

3.2. Determination of the annual circulation taxes depending on the vehicle age

Practical application of expression (2) requires the establishment of functional dependency of external costs of emissions on vehicle age. The first problem of this investigation was to find functions (or graph) of dependence of CO, HC, NO_x, CO_2 and PM emissions on the vehicle age. A fleet of vehicles is heterogeneous. Our aim is to include vehicles that have different vehicle characteristics. In the literature, it is possible to find experimental results that allow us to solve the previous problem. Graphs that show the relationship between average CO, HC, NO_x emissions and the vehicle age may be found in Fischer *et al.* (2007). We have taken the numerical values of CO, HC, NO_x emissions for each vehicle age. The maximum vehicle age for previous pollutants was 14 years. Numerical values of average CO_2 emissions, depending on vehicle age, can be found in Vujadinovic (2005) and Vujadinovic *et al.* (2007). Maximum vehicle age for CO_2 was 29 years (petrol vehicles) and 10 years (diesel vehicles). We have accepted the conclusion from Bikas and Zervas (2007), Mazzoleni *et al.* (2010) (Part 5) where the PM remains constant with vehicle age. The next step of the analysis was finding the curve that the experimental data approximate the best.

We used least squares regression to estimate these relationships. Regressions were shown as linear unless nonlinear resulted in better fits. In that case, the nonlinear equation that had the best fit was used. As a measure of goodness of fit of linear regression we used the r^2. On the other hand, as a measure of goodness of fit of nonlinear regressions we used the sum of squares.

The approximation functions of the average CO, HC, NO_x and CO_2 emissions on the vehicle age were approximated by regression calculation:

$$q_{\text{CO, average}} = 1.216 + 0.037 \cdot t^{1.865},\ \text{gCO/km},\quad R^2 = 0.85,\quad SE = 0.711,\quad RSS = 12.643, \tag{3}$$

$$q_{\text{HC, average}} = 0.095 + 0.012 \cdot t^{1.303},\ \text{gHC/km},\quad R^2 = 0.79,\quad SE = 0.06,\quad RSS = 0.09, \tag{4}$$

$$q_{\text{NO}_x\text{, average}} = 0.22 + 0.072 \cdot t,\ \text{gNOx/km},\quad r^2 = 0.92,\quad SE = 0.09,\quad RSS = 0.208, \tag{5}$$

$$q_{\text{CO}_2\text{, average}} = \begin{cases} 171.469 + 3.687 \cdot t & \text{for petrol; } e.d. < 1400 & r^2 = 0.99, & SE = 3.488, & RSS = 72.977 \\ 191.721 + 4.912 \cdot t & \text{for petrol; } 1400 \le e.d. \le 2000 & r^2 = 0.96, & SE = 11.386, & RSS = 777.824 \\ 281.634 + 0.271 \cdot t^2 & \text{for petrol; } 2000 < e.d. & R^2 = 0.97, & SE = 15.815, & RSS = 1500.605 \\ 161.218 + 0.043 \cdot t^3 & \text{for diesel; } e.d. < 2000 & R^2 = 0.99, & SE = 2.694, & RSS = 14.511 \\ 228.766 + 0.066 \cdot t^3 & \text{for diesel; } 2000 \le e.d. & R^2 = 0.95, & SE = 8.773, & RSS = 153.932 \end{cases} \tag{6}$$

$$q_{\text{CO}_2\text{, average}},\ \text{gCO}_2\text{/km};\quad e.d. - \text{engine displacement, cm}^3,$$

where: t – vehicle age; r^2, R^2 – linear and nonlinear coefficient of determinations; SE – standard error; RSS – sum of squared residuals.

Figure 1 shows the experimental data and the approximation function of the average CO_2 emission on the vehicle age for petrol passenger cars whose engine displacement are less than 2000 cm³. Analyzing Figure 1 it can be concluded that shape of the approximation function has the same form as the distribution of experimental data. The some conclusion is available for equations (3), (4), (5) and (6).

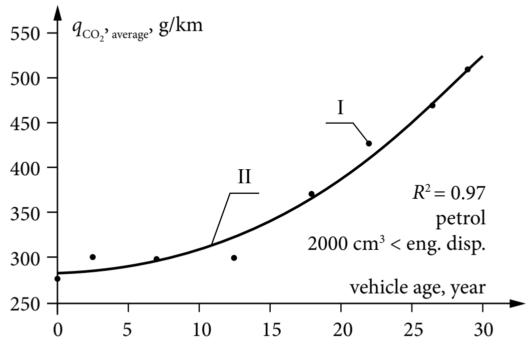

Fig. 1. The relation of the average CO_2 emission to vehicle age – experimental data (I) and approximation function (II)

Numerical value of average CO emission from a new vehicle is determined by substitution of $t = 0$ (vehicle age from new vehicles is zero) into Eq. (3):

$$q^{new}_{CO,\ average} = 1.216\ \text{gCO/km}\ . \tag{7}$$

The ratio of average CO emission of t years old vehicles (3) to average CO emission from new vehicles (7) can be written in the form:

$$\frac{q_{CO,\ average}}{q^{new}_{CO,\ average}} = 1 + 0.0305 \cdot t^{1.865}\ . \tag{8}$$

The next step of the analysis was finding the functions dependence of CO emission on the vehicle age for vehicle. The functions are different than approximation function of an average CO emission on the vehicle age (3). We have introduced assumption that the function of CO emission on the vehicle age for any vehicle depends on the numerical value of CO emission that the vehicle has when new. The numerical value of CO emission for new vehicles (q^{new}) can be found in the vehicle catalogues. It is necessary to formulate the connection between the previous functions. Therefore, our assumption is that the ratio of average CO emission for t years old vehicles to average CO emission from new vehicles is the same as the ratios of CO emission for t years old vehicle to CO emission for new vehicle.

By applying the expression (8) and the previous assumption, the function dependence of CO emission on the vehicle age for any vehicle finally becomes:

$$q_{CO} = q^{new}_{CO} \cdot (1 + 0.0305 \cdot t^{1.865}),\ \text{gCO/km}\ . \tag{9}$$

The functions of HC, NO_x, CO_2 and PM emissions on vehicle age for any vehicle is written in the same way as the function of CO emission on vehicle age for any vehicle (9):

$$q_{HC} = q^{new}_{HC} \cdot (1 + 0.121 \cdot t^{1.303}),\ \text{gHC/km}\ , \tag{10}$$

$$q_{NOx} = q^{new}_{NOx} \cdot (1 + 0.33 \cdot t),\ \text{gNOx/km}\ , \tag{11}$$

$$q_{CO_2} = q_{CO_2}^{new} \cdot \begin{cases} 1+0.0215 \cdot t & \text{for petrol; } e.d. < 1400 \\ 1+0.0256 \cdot t & \text{for petrol; } 1400 \le e.d. \le 2000 \\ 1+0.00096 \cdot t^2 & \text{for petrol; } 2000 < e.d. \\ 1+0.00027 \cdot t^3 & \text{for diesel; } e.d. < 2000 \\ 1+0.00029 \cdot t^3 & \text{for diesel; } 2000 \le e.d. \end{cases} \tag{12}$$

$q_{CO_2,\,average}$, $g\,CO_2/km$; $e.d.$ – engine displacement, cm^3

$$q_{PM} = q_{PM}^{new}, \ g\,PM/km. \tag{13}$$

By applying expressions (9, 10, 11, 12, 13) and values of external costs for emissions (Table 1) the external cost of emissions per 1 km for vehicle (1) obtains its final form:

$$\begin{aligned} EC_{km} = {} & ec_{CO} \cdot q_{CO}^{new} \cdot (1+0.0305 \cdot t^{1.865}) + ec_{HC} \cdot q_{HC}^{new} \cdot (1+0.121 \cdot t^{1.303}) + \\ & + ec_{NO_x} \cdot q_{NOx}^{new} \cdot (1+0.33 \cdot t) + ec_{PM} \cdot q_{PM}^{new} + \\ & + ec_{CO_2} \cdot q_{CO_2}^{new} \cdot \begin{cases} 1+0.0215 \cdot t & \text{for petrol; } e.d. < 1400 \\ 1+0.0256 \cdot t & \text{for petrol; } 1400 \le e.d. \le 2000 \\ 1+0.00096 \cdot t^2 & \text{for petrol; } 2000 < e.d. \\ 1+0.00027 \cdot t^3 & \text{for diesel; } e.d. < 2000 \\ 1+0.00029 \cdot t^3 & \text{for diesel; } 2000 \le e.d. \end{cases} \end{aligned} \tag{14}$$

EC_{km}, EUR/km.

By application of the expression (14) the yearly external cost of emissions and annual circulation tax for vehicle (2) obtains its final form:

$$\begin{aligned} EC_{year} = {} & S \cdot [ec_{CO} \cdot q_{CO}^{new} \cdot (1+0.0305 \cdot t^{1.865}) + ec_{HC} \cdot q_{HC}^{new} \cdot (1+0.121 \cdot t^{1.303}) + \\ & + ec_{NO_x} \cdot q_{NOx}^{new} \cdot (1+0.33 \cdot t) + ec_{PM} \cdot q_{PM}^{new} + \\ & + ec_{CO_2} \cdot q_{CO_2}^{new} \cdot \begin{cases} 1+0.0215 \cdot t & \text{for petrol; } e.d. < 1400 \\ 1+0.0256 \cdot t & \text{for petrol; } 1400 \le e.d. \le 2000 \\ 1+0.00096 \cdot t^2 & \text{for petrol; } 2000 < e.d. \\ 1+0.00027 \cdot t^3 & \text{for diesel; } e.d. < 2000 \\ 1+0.00029 \cdot t^3 & \text{for diesel; } 2000 \le e.d. \end{cases} \end{aligned} \tag{15}$$

EC_{year}, EUR/year.

4. Results

In this section we apply the new methodology that was proposed in our paper to some of the best selling cars in Europe in 2009 (Volkswagen Polo, Volskwagen Golf, Ford Focus, Opel Astra) (Jato 2009), as well as to several cars produced by other major manufacturers (Renault, Peugeot, Audi). At the same time, attention was paid to take into consideration different classes of cars (small, medium and large cars) and different engines (petrol and diesel).

Based on our methodology, the calculated annual circulation taxes for the observed group of vehicles for a ten-year period are presented in Figure 2. In order to obtain these curves, in addition to expression (15), distribution of the average kilometres driven by the vehicle age was utilized (Moghadam, Livernois 2010). Note that this distribution indicates that average annual kilometres driven tend to decrease with vehicle age (S = S(t)).

Annual circulation taxes in five European countries (Ireland, the United Kingdom, Malta, Luxembourg and Sweden), which use CO_2 emissions as a reference value for their calculation, are also presented in Figure 2.

Analyzing Figure 2 it could be concluded that there are significant differences between the taxes. The largest amount of taxes, in most cases, has been recorded in Ireland and Sweden. At the same time, annual circulation taxes in Ireland and Sweden show the largest deviation from the annual circulation taxes calculated using Eq. 15 for S = S(t). On the other hand, the annual circulation taxes in Luxemburg, in most cases, recorded lower or approximately the same values as the annual circulation taxes calculated using the proposed methodology. It is also notable that, beside the new methodology, only the United Kingdom and Malta do not calculate the same taxes during the whole ten years. The United Kingdom makes a distinction between the first and all other years, whereas in Malta, these taxes begin to increase rapidly after the fifth year, when the vehicle age starts to be taken into account. It can also be indicated that there is no tax harmonization in five European countries. The explanation for the previously observed differences between the taxes in five European countries and the taxes calculated using Eq. 15 for S = S(t) lies in the fact that the former taxes are only based on CO_2 emissions. CO_2 emission, which is related directly to fuel consumption, has a generally weak relationship with emissions of CO, HC, NO_x (Johnstone, Karousakis 1999) and consequently with external cost of emissions. This leads to the conclusion that annual circulation taxes in five observed countries are not fully in line with the "polluter pays" principle. This also confirms the fact that two identical vehicles with different kilometres driven have different emissions and consequently different external cost of emissions, but the same tax burden. This is not the case with our methodology which takes kilometres driven into account. Furthermore, by taking into account kilometres driven our methodology gives people more flexibility in the way they respond to taxes. They can buy a nature friendly vehicle and leave their driving behaviour unchanged or they can buy or keep a somewhat environmentally unfriendly vehicle, but reduce their kilometres driven.

Figure 2 also shows that the taxes calculated using the proposed methodology for new vehicles range from €129.8 for the VW Polo (VW – Volkswagen) to €184.5 for the Renault Megane. Lower tax burdens are imposed on vehicles with lower CO_2 and pollution emission levels. Thereby, due to possible tax savings, this tax influences decisions on new car purchases and tend to favours less polluting vehicles. At the same time, Figure 2 reveals that the taxes recorded in the last analyzed year range from €116.3 to €383.7. Petrol vehicles have higher changes of taxes with vehicle age. By using Eq. (15) maximum of yearly external cost of emissions (for S = S(t)) for the VW Golf V is 28.9% higher than minimum of yearly external cost of emissions for the same vehicle. The previous discrepancy for the VW Polo is higher for 7.6%. For diesel vehicles it can be concluded that the yearly external cost of emissions (for S = S(t)) are approximately constant. But, unlike other methodologies, this can be explained by the fact that increase of emissions with increasing vehicle age is compensated by reduction in emissions due to fewer kilometres driven. For most petrol vehicles it can be concluded that the yearly external costs of emissions (for S = S(t)) increase with vehicles age.

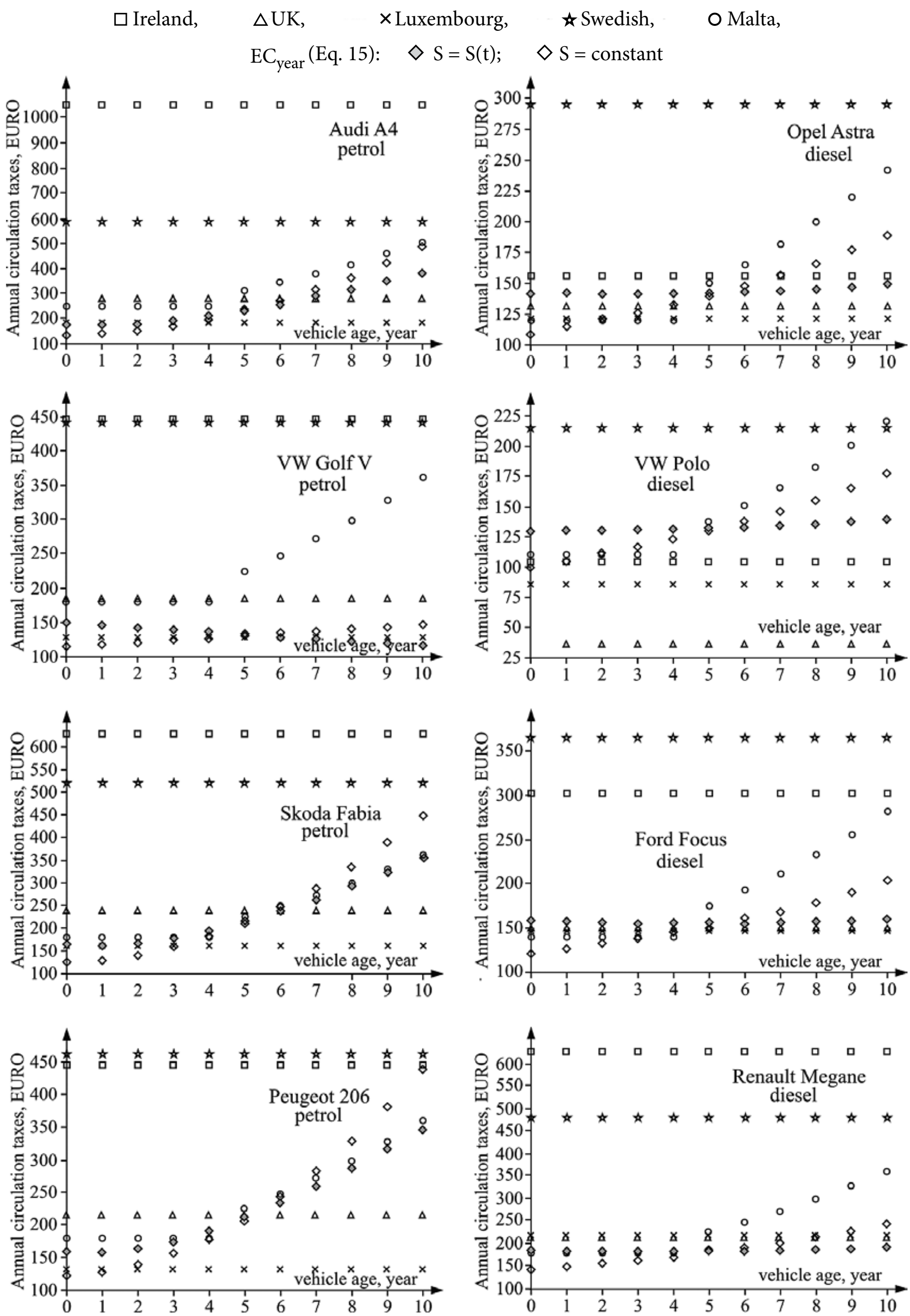

Fig. 2. Annual circulation taxes on passenger cars

We have examined the effect of vehicle age on the tax burden according to our assumption that average annual kilometres driven do not change with vehicle age (S = constant = 19353 km – the average annual kilometres driven were calculated as arithmetic mean for a ten-year period of distribution of average kilometres driven by vehicle age (Moghadam, Livernois 2010)). This way, by using Eq. 15 for S = constant we obtained new curves which clearly show that tax burden increases with vehicle age. Therefore, taking into account the vehicle age, this methodology provides higher annual circulation tax on old and therefore highly polluting vehicles then on the new vehicles with lower external costs. This is just another way to favour nature friendly vehicles.

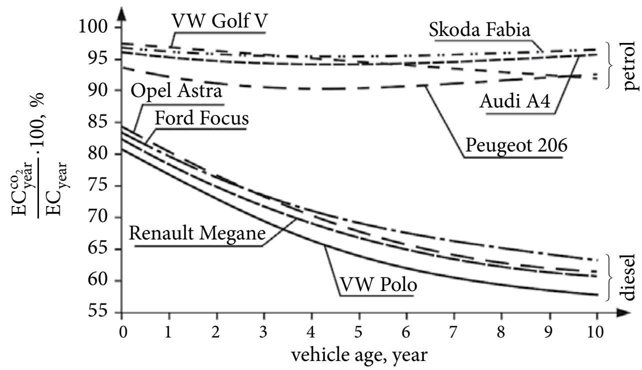

Fig. 3. The percentage of yearly external cost of CO_2 emission in yearly external cost of emissions

Figure 3 presents the percentage of yearly external cost of CO_2 emission in yearly external cost of emissions Eq. (15) for S = S(t) for the observed group of vehicles. Analyzing this figure it is clearly visible that for all the vehicles this percentage is higher than 50%. This, in accordance with proposal for a Council Directive on passenger car related taxes which proposes that at least 50% of the total tax revenue from both the annual circulation tax and the registration tax (pending its abolition) should originate in the CO_2 based element of each of these taxes (European Commission 2005). Therefore, we believe that our methodology can be used for practical implementation of the proposal for a Council Directive on passenger car related taxes. Also, it is evident that petrol vehicles have higher percentage than diesel vehicles. Among the new vehicles, the new VW Golf V has the highest percentage (97.4%), while the new VW Polo has the lowest percentage of yearly external cost of CO_2 emission (81.1%). Also, for diesel vehicles it is evident that the percentage of yearly external cost of CO_2 emissions in yearly external cost of emissions decreases with vehicle age. For petrol vehicles the percentage is approximately constant. Maximum percentage of ten year old vehicles is shown for the Skoda Fabia, while minimum percentage of ten year old vehicles is shown for the VW Polo.

Finally, we have also analyzed advantages of the proposed annual circulation tax compared to the fuel tax. The key question arising: does the fuel tax correspond to the external cost of CO, HC, NO_x, CO_2 and PM emissions? Further analysis will prove that fuel tax does not correspond to the external cost of the emissions.

Relation between CO_2 emission and fuel consumption is linear (Mickunaitis *et al.* 2007; Momčilović *et al.* 2009; Vujanović *et al.* 2010). Functions of CO_2 emissions on the fuel consumptions for petrol and diesel engines are given by (Momčilović *et al.* 2009):

– petrol engines

$$q_{\mathrm{CO_2}} = 0.448 + 23.874 \cdot q_f, \ \mathrm{g\,CO_2/km}, \tag{16}$$

– diesel engines

$$q_{\mathrm{CO_2}} = 2.027 + 26.272 \cdot q_f, \ \mathrm{g\,CO_2/km}, \tag{17}$$

where q_f is the fuel consumption (l/100 km).

We have previously introduced the assumption (Section 3.2) that the ratio of average pollutant emission for t years old vehicles to average pollutant emission from new vehicles are the same as the ratios of pollutant emission for t years old vehicles to pollutant emission which a vehicle has when new, for vehicle. The function of CO_2 emission on the vehicle age for any vehicle is written by equation (12). By applying expressions (12), (16) and (17) the functions of fuel consumptions on the vehicle age obtains its final form:

– petrol engines

$$q_f = \frac{q_{\mathrm{CO_2}} - 0.448}{23.874}, \ l/100 \ \mathrm{km}, \tag{18}$$

– diesel engines

$$q_f = \frac{q_{\mathrm{CO_2}} - 2.027}{26.272}, \ l/100 \ \mathrm{km}. \tag{19}$$

The external cost of emissions per 1 l fuel can be written using expressions (14), (18) and (19) in the form of:

$$EC_l = \frac{100 \cdot EC_{\mathrm{km}}}{q_f}, \ \mathrm{EUR}/l. \tag{20}$$

For diesel vehicles the function EC_l – vehicle age is increasing (Figure 4). Analyzing Figure 4 it can be noticed that there are significant differences between values of external cost of emissions per 1 l fuel from new and ten years old diesel vehicles. The previous discrepancy for the VW Polo is higher – 39.9%. The Ford Fokus has the minimum value of discrepancy – 31.7%. It means that the fuel tax and fuel price should be variable, i.e. they should depend of the type of car and its vehicle age. Therefore, for diesel vehicles, we have concluded that the fuel tax does not internalize external costs of emissions in line with the "polluter pays" and "user pays" principles in the best way. The discrepancies for the petrol vehicles also exist, but they are smaller (from 1.5% for the Skoda Fabia to 5.8% for the VW Golf V). Therefore we have concluded that the fuel tax provides better internalisation of external costs of emissions for petrol than for diesel vehicles.

Numerical data and analysis are available upon request from the authors.

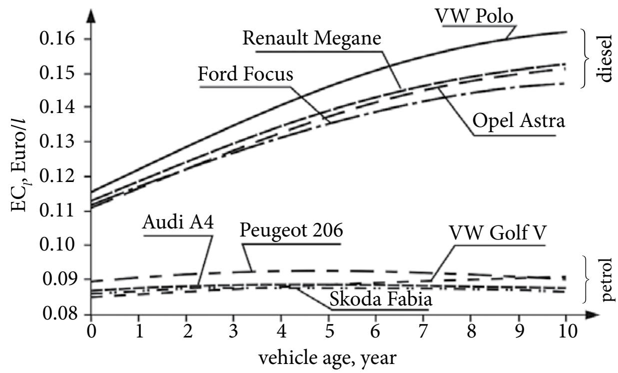

Fig. 4. Dependences of External cost of emissions per 1 *l* fuel – Vehicle age

5. Conclusions

The main conclusions and contributions of our research are as follows:

1. The methodology for calculating annual circulation taxes proposed in this paper, takes into account external cost of CO_2, CO, NMHC, NO_x and PM emissions, as well as kilometres driven and vehicle age. As such, it allows the calculation of annual circulation taxes which are much more in line with "polluter pays" and "user pays" principles then the annual circulation taxes in five European countries (Ireland, the United Kingdom, Malta, Luxembourg and Sweden).
2. The percentage of yearly external cost of CO_2 emission in yearly external cost of emissions is higher than 50%, which is in accordance with the proposal for a Council Directive on passenger car related taxes.
3. Annual circulation tax calculated using the new methodology is directly designed to favour the nature friendly vehicles and penalize the less environmentally friendly vehicles with high CO_2 and pollutant emissions level. This is achieved in two ways, by influencing the new car purchase decisions and favouring newer cars by taking into account the vehicle age.
4. The functions of CO, HC, NO_x, CO_2 and PM emission on the vehicle age are shown in the paper.
5. The proposed methodology also takes into account kilometres driven and leaves people more choice in how they reduce emissions and consequently their tax burden.
6. We have proved that the fuel tax does not internalize external costs of emissions in line with the "polluter pays" and "user pays" principle in the best way. The function of external cost of emissions per 1 *l* fuel on the vehicle age is shown in the paper.
7. Finally, the advantage of this methodology is also its easy and fast applicability. From the economic point of view this means lower implementation costs.

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