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The Right Time for General Road Tax: Evidence from the Czech Republic

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Abstract

Road transport is a source of emissions of which nitrogen oxides (NO_x), particulate matter (PM_{2.5}), and carbon dioxide (CO₂) emissions are most damaging. The economic inefficiency caused by not including the emission externalities of vehicle operation in prices can be improved by using a vehicle use tax. In the Czech Republic, however, a large part of the vehicle fleet is exempt from this tax, which is thus not general. This part of the fleet thus escapes taxation, for which there is no economic justification. To identify the actual ratio of emissions indicators of operating fleet segments in relation to vehicle use tax we use unique dataset composed of national emissions inventories data of the Copert program, road vehicle registry data and vehicle testing stations data. It is also possible to quantify emissions production and determine the external costs of NO_x, PM_{2.5}, and CO₂ generated by road transport segments in the Czech Republic. It was found that half of the production of the emissions in road transport in the Czech Republic representing almost 60% of the environmental costs were not covered by existing tax due to the exclusion of part of the vehicle fleet from this taxation, especially private passenger vehicles.

Keywords

Vehicle Use Tax, Emission, Mileage, Road Transport, Environment

JEL Classification

H21, H23

Introduction

The use of vehicles in road transport creates externalities. A significant externality of road transport, arising mainly from the combustion of conventional fuels, is emissions, which are not included by the market in the prices of vehicle use.

Vehicle users can therefore treat these emissions as free of charge, which causes economic inefficiencies in the form of overuse of vehicles due to the existence of lower than efficient prices. Such inefficiencies can be improved by applying corrective taxes and charges (Pigou, 1920; Baumol, 1972; Sandmo, 1975) imposed on vehicle users in relation to the external costs generated. Moreover, since the price elasticity of demand for vehicle use is non-zero (Marriott & Mortimore, 2017; Rasool et al., 2019) passing emissions costs on to prices through a tax will bring about a desirable reduction in emissions produced by road transport.

The natural evolution of a society's emissions is explained by the concept of the environmental Kuznets curve (EKC), which is based on the Kuznets curve (Kuznets, 1955). This concept has long been accepted as a paradigm in the social sciences (Yandle et al., 2002) and became the basis for the EKC by Grossman & Krueger (1995). The EKC suggests that economic development first brings with it an increase in environmental damage and emissions. From a certain level of the economy onwards, however, these emissions start to fall. That level is determined by the sense of economic security of the population, who then have the potential to reflect on environmental issues (Stern, 2004). Prieur (2009) defines this level as the level of income per capita, based on the value of \$8,000 defined by Grossman & Krueger (1995), from which a reversal occurs in most cases. The validity of the EKC's implications has been the subject of various investigations over time, and although the EKC has been criticized, at least for CO₂ and NO_x purposes, it has not been questioned (Mills & Waite, 2009). Other linkages beyond economic development and emissions have also been explored by Chandran Govindaraju & Tang (2013), Rasool et al. (2019), Solaymani & Kari (2013), and Zhang & Nian (2013).

Because economic growth is desirable and the world population continues to grow, it is essential to use fiscal instruments to control and reduce emissions. A proponent of this view is Santos (2017), who points out that taxes and subsidies can address the high cost of renewable energy compared to non-renewable sources. Rasool et al. (2019) also agree with the effectiveness of environmental taxes on fossil fuel vehicles in reducing transport

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emissions. The effectiveness of fiscal instruments to determine producers and consumers in the transport sector has already been demonstrated in the literature (Marriot & Mortimore, 2017). Parry et al. (2014) argue that a balance needs to be struck between the environmental benefits of taxes and the economic costs, thereby ensuring an optimal level of the greening of economic growth.

Taxes with the potential to be used to internalize the emissions externalities of road transport include the vehicle use tax applied in EU countries under various names, such as the tax on ownership, vehicle tax, road tax.

Vehicle use tax exists in various forms in countries around the world (PwC, 2019). The USA and the People's Republic of China (PRC), which along with the EU have the highest share of the number of vehicles in operation in aggregate (about 15%) (WHO, 2020), impose a generalized form of this tax. No two countries in the European Union (EU) have the same vehicle use tax (ACEA, 2021). The Czech Republic, Poland and Slovakia have a significantly different vehicle use tax from other countries. In these countries, the vehicle use tax was imposed only on commercial vehicles. Private vehicles (P) and foreign registered vehicles (F) were not subject to tax, which appears to be a significant violation of the core tax principle of equity (Le Grand, 1982; Marshall, 1890; Mill, 1910; Rawls, 1971), assuming a conclusive justification for the generality of the tax given the production of externalities produced not only by commercial vehicles (C), but also by private and foreign registered vehicles.

Moreover, in the Czech Republic since July 2022 and retrospectively from January 2022 vehicles under 3.5 tons are not subject to tax, vehicles under 12 tons are burdened by zero rate tax and rates for other vehicles are much lower. The tax here is therefore selective (not general), although it is clear that externalities are created by vehicles regardless of whether they are used by a private individual, a business or a foreign person. What is not clear and can be identified as a gap in the existing research and knowledge in this area, is the specific distribution of emissions in terms of the ownership structure of the vehicle fleet, inter alia in the context of differentiating vehicle categories and establishing a link to the implemented tax policy.

The aim of the study is, based on the national Copert emissions inventory, road vehicle registry data and vehicle testing stations data, to determine what part of the emissions production of the Czech fleet was not burdened by vehicle use tax depending on the type of vehicle use (e.g., private use, commercial use, and foreign registered vehicles). As it is clear that different categories of vehicles will be preferred for different purposes (passenger vehicles (PV), light utility vehicles (LUV), heavy goods vehicles (HGV), tractors (T), Buses (B) and L-Category vehicles (L)), emissions will also be distinguished in this respect. The results of the study will make it possible to compare the static (without taking mileage into account) and the dynamic (taking mileage into account) emission characteristics of parts of the Czech fleet. Furthermore, using existing unit valuations of emissions, the quantification of external costs caused by the operation of vehicles will be carried out, again in relation to the type of vehicle operator and the category of vehicle, with an emphasis on identifying the share of external costs generated by vehicles that were not subject to the vehicle user tax in the Czech Republic.

Literature Review

The transport sector is an important part of economic systems, but in addition to its positive effects, it generates external costs that are passed on to other entities.

Among the fundamental milestones of the theory of externalities, corrective tax, or environmental tax, Pigou (1920) and his proposal for a corrective tax on environmentally harmful activities and externalities determining the neoclassical model of market forces should be mentioned. Sandmo (1975) and Baumol and Oates (1988) further elaborated this concept. Hay and Trinder (1991) summarize equity, fairness, and justice (EFJ) issues into four fundamental questions that need to be addressed in the area of transport and the taxation of their externalities. This includes how decisions are made (process issues), who gets what (provision issues), who pays for transport (burden of costs issues), and who suffers from the use of transport (externalities issues).

The aim of institutional, professional and academic efforts is to ensure the internalization of road transport externalities through the application of an appropriate tax or charge to achieve greater efficiency and sustainable development in this sector. Many authors have articulated the need for the introduction and use of remedial environmental taxes (Leicester, 2005; Nordhaus, 2006; Stern, 2006). These taxes should take into account mainly air pollution and the production of greenhouse gases (Parry et al., 2007; Santos et al., 2010; Sallee, 2011; Johnson et al., 2013), but also the production of noise (Eliou et al., 2016) or other externalities such as traffic congestion, traffic accidents, infrastructure wear and tear, soil pollution, building corrosion, and others (Van Essen et al., 2008). In practice, however, including all the externalities of road transport in taxes and charges would entail significant administrative costs. Therefore, it is advisable to quantify only significant externalities and to disregard less significant ones in tax policy (Cnossen, 2005).

However, environmental taxes are not self-sustaining. Their application brings with them some undesirable effects, as described by Bjertnaes (2019), Bureau (2011), and Callan et al. (2009). Their application also brings tendencies toward cheating, neglecting infrastructure costs, postponing the purchase of a more environmentally friendly new

vehicle, regressive impact, gross domestic product (GDP) reduction, and welfare (Rigot-Müller, 2018) in the uncertainty of the WTP of the population itself.

Parry et al. (2014) cites the continuing challenges of implementing reforms on the ground, educating governments and their constituents about the need for environmental tax reform, and how barriers to reform, such as the aforementioned influences on vulnerable households and firms, can be overcome. Any concerns about the impossibility of identifying the induced effects of reforms are refuted by Alamdarlo (2019). Others also support the need for reforms. Duncan and Graham (2013) point out the inadequacy of the fuel tax. Rigot-Müller (2018) recommends mileage accounting, something which is also supported by Parry et al. (2014).

Of course, it is possible to recommend to the government an optimal solution in the form of a tax on the production of externalities that considers the technical, environmental parameters of the vehicle and the kilometers travelled. However, after experiencing the reluctance of the public sector to apply the optimal solutions identified in science and research academia, it is necessary to proceed at least to evolutionary solutions in the knowledge of the many shortcomings of the current state of road taxes or fuel taxes (Ke and Gkritza, 2018). Unfortunately, as discussed by Gordon (2008), there is still a gap between science and policy that accounts for the continued incompleteness of effective global environmental policy coordination. Santos (2017) recommends that emissions in the transport sector be discussed and addressed at the global level. However, Evans (2012) points out that no international organization has the authority to make and enforce environmental policy.

The issue of emissions in road transport is multi-component. The holistic well to wheel (WTW) approach is composed of the well to tank (WTT) and tank to wheel (TTW) approaches (IFEU et al., 2014). This article will continue to focus only on the TTW component. Road transport emissions below TTW (Fiorito, 2017) include greenhouse gases and pollutants. The greenhouse gases are carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O), collectively referred to as CO₂ equivalent (CO₂e), which is quantified as the sum of CO₂, 25 times CH₄ and 298 times N₂O (Brander, 2012). These gases cause global warming and therefore climate change on Earth with significant irreversible negative impacts on the environment and human society. Pollutants of which particulate matter (PM), nitrogen oxides (NO_x), sulfur dioxide (SO₂), volatile organic compound (VOC), carbon monoxide (CO), hydrocarbons (HC), ozone (O₃) (Van Essen et al., 2008) are considered the most important have negative impacts not only on human health, but also on agricultural and forestry yields, or the occurrence of building defects. Road transport emissions are generated very close to the ground and are therefore contained in the air that people breathe (Schwermer et al., 2014). A higher level of exposure to air pollution increases the percentage of disease development and aggravation (Mostert et al., 2017). In the Czech Republic, air pollution causes more than 6,000 deaths annually (WHO, 2018). Furthermore, there are data showing that only Poland, Romania and Belgium in the European Union are clearly worse off than the Czech Republic in terms of PM_{2.5} (particulate matter with a diameter of 2.5 µm or less) concentrations, with Slovenia possibly being worse off after accounting for uncertainty in the calculation (Friedrich and Kuhn, 2011). NO_x is particularly problematic in urban areas where the contribution of traffic to emissions is significantly higher and where NO_x has significant health impacts due to high concentrations of people.

Transport emissions can be quantified on local, regional, or national level in different ways. It is possible to use Traffic air quality index (TAQI), which is a useful tool for evaluating air quality near roadways (Bagiński, 2015). There are other options for modelling emissions, for example Caline models for quantifying local emissions. The Caline 4 model is also suitable to predict air pollutant concentrations near roadways (Benson, 1992). Vehicle specific power (VSP) and CORINAIR methodology, which represent a bottom-up approach, can be used to determine the air quality determination of the road transport sector (Coelho et al., 2014). A combination of bottom-up and top-down approaches is recommended for some emissions, but not for NO_x and PM_{2.5} emissions (Coelho et al., 2014). To compare empirical concentration values of road network dispersion, the Contaminants in the Air from a Road-Finnish Meteorological Institute (CAR-FMI) model can be used (Kukkonen et al., 2001). The Danish Street Pollution Model (OSPM) is a semi-empirical model suitable for calculating emission concentrations (Berkowicz, 2000). This model was used to determine emission statistics for 12 local stations with the support of emission factors from the COPERT program (Ketzler et al., 2012).

Part of the Norwegian emission model (Sandmo, 2016) includes sub-models for the road transport sector consisting of both the determination of CO₂ emissions using individual fuel consumption and the determination of other emission factors through mileage and emissions per km data. Other models include GM (Chock, 1978), HIWAY-2 (Petersen, 1980), GFLSM (Luhar and Patil, 1989), OMG (Kono and Ito, 1990), and the TDM travel demand model (Wang et al., 2009). An important tool for quantifying emissions at national and local levels is the MOVES model, mostly used in the USA. Motor Vehicle Emission Simulator (MOVES) is a state-of-the-science emission modelling system which brings the possibility to estimate air pollutants, greenhouse gases, and air toxic emissions for mobile sources (USEPA, 2022). The MOVES-Matrix extension model then allows assessing emissions from dynamic large-scale transportation networks. In addition, the model can take into account not only the running exhaust, but also emissions from engine starts, truck idling, brake/tire wear and others (Xu et al., 2018).

These possibilities are also offered by COPERT (EEA, 2019), a software tool for calculation of air pollutant and greenhouse gas emissions from road transport on regional or country scale. COPERT is technologically advanced and transparent model including all main pollutants used by many European countries for reporting official emissions data (Emisia, 2022). Although the COPERT model is sensitive to imperfections in the input data from real traffic, it is very efficient when fleet and mileage data are available and carefully processed (Lozhkina and Lozhkin, 2015). The use of COPERT allows a consistent, transparent and comparable calculation in accordance with all requirements of international conventions and European legislation (Pelikán et al., 2017). The COPERT program has the advantage of classifying pollutants according to the sophistication of the methodology used to determine their emission factors (Pelikán et al., 2018). The pollutants are divided into 4 groups (Ntziachristos and Samaras, 2018; EEA, 2016), with the emission factors CO₂, NO_x and PM_{2.5} included in groups 1 and 2. Group 1 contains pollutants with an elaborate detailed Tier 3 calculation methodology based on specific emission factors depending on the combustion technology (CO, NO_x, nitric oxide NO, nitrogen dioxide NO₂, VOC, CH₄, N₂O, ammonia NH₃, PM) (EEA, 2016). Group 2, with Tier 2 refinement, includes pollutants estimated by means of emission factors related to the fuel type, i.e., dependent on consumption (CO₂, SO₂, heavy metals) (EEA, 2016). Other groups include pollutants with less sophisticated calculation methodologies due to the current lack of data and pollutants derived as a proportion of total non-methane volatile organic compounds (NMVOC) emissions. Copert differentiates road vehicles in terms of several indicators. The basic breakdown by vehicle category is passenger vehicles (PV), light utility vehicles (LUV), heavy goods vehicles (HGV), tractors (T), Buses (B) and L-Category vehicles). Other parameters are fuel, a segment weighing mainly on the size and weight of the vehicle, and the Euro Standard.

Methods

In accordance with the evaluation and the appropriate purpose of using tools for the quantification of aggregate emissions in road transport, the practical application of Copert is used for emissions inventories in the Czech Republic to identify the values of emission factors with a well-developed calculation methodology classified in groups 1 and 2 (Pelikán et al., 2018; IPCC, 2006; Ntziachristos and Samaras, 2018; EEA, 2016; Davies Waldron, 2006). These are specifically CO₂, NO_x and PM_{2.5}; which are at the same time considered to be the most serious emission externalities of road traffic both in terms of air pollution and escalation of the greenhouse effect. Although these data cannot correspond completely to the values achieved in real use of the vehicles, they are very much more reliable than the values given in the vehicles' technical documentation. In the calculation of the PM_{2.5} emission factor, we consider PM_{2.5} Exhaust, PM_{2.5} Road and PM_{2.5} Tire and Brake, in order to cover the widest possible range of PM production from vehicle operation. The production of NO_x emissions depends mainly on combustion conditions, temperature and the use of exhaust gas treatment equipment. The CO₂ emissions determined in Copert depend on calorific value, consumption and fuel composition. Emissions are modelled for road transport at the national level of the Czech Republic. The resulting emissions inventory contains emission factor values based on real fleet data. The more vehicle-specific data is taken into account when assigning emission factor values to a particular vehicle, the more accurate the assigned emission factor value can be, which of course also makes the cumulative values more accurate. The breakdown of the vehicles in this study allows for the differentiation of vehicle emission factor values by category, fuel, segment and Euro Standard, resulting in a total of 373 groups to which each specific vehicle in operation can be assigned.

The calculation of emission factor (EF) values is based on the processing of actual data from the Road Vehicle Register (RVR) of the Czech Republic (RVR, 2021) in 2018, which is the most up-to-date and consistent data at the time of the study. However, this does not appear to be problematic in terms of the transferability of the results to the present. The Czech Republic is very rigid not only in terms of fleet renewal, but also in terms of the use of new technologies in road transport. Between 2019 and 2021, there were only 10,611 BEV (Battery electric vehicle), 4,077 PHEV (Plug in Hybrid Electric Vehicle), and 9 FCEV (Fuel Cell Electric Vehicle) vehicles registered (TRC, 2022). This is cumulatively only 0.23% of the Czech fleet. This study works with RVR data covering passenger vehicle (PV), light utility vehicles (LUV), heavy goods vehicles (HGV), tractors (T), Buses (B) and L-Category vehicles. The processed data includes the real data captured in the RVR in 2018 and the real mileage of these vehicles captured at Vehicle Testing Stations (VTS) over four years, so the data can be considered complete. The mileage data results are always complete only four years before the current calculation year. This is due to the fact that new vehicles in private ownership go to a VTS only after four years, according to § 40 of Act 56/2001, which is valid in the Czech Republic (Czech Republic, 2021a). As a result, the mileage data for 2014, calculated on the basis of the VTS extract for 2018, can be considered complete and unchanged (Pelikán et al., 2017). The source of this non-public data is the national organization Transport Research Centre (TRC, 2021). The mileage data recorded at the VTS are used to determine the average mileage values for all of 373 groups of PV, LUV, HGV, T, B and L vehicle categories.

The records contained in the RVR allow vehicles to be distinguished by the type of owner. These are private vehicles (P), commercial vehicles (C), and foreign registered vehicles (F). Private vehicles are those, whose

operator is a natural person whose birth number is registered in the RVR. Commercial vehicles are those, whose operator is a company or organization with an identification number (ID) registered in the RVR. Foreign registered vehicles are those whose operator is an entity not registered in the Information System of Basic Registers of the Czech Republic. In practice, this may occur, for example, in the case of work stays of foreign persons, foreign leasing, export of a vehicle abroad or inheritance of a vehicle outside the country.

The linking of RVR and VTS data is done through unique vehicle technical characteristic identifiers in each vehicle group. Emissions are then calculated from the transport performance of the 373 vehicle groups listed. In addition, the individual vehicle records in the RVR contain a vehicle owner type identifier, which is necessary for the purpose of segmenting vehicles, their emissions, and emissions damage from this perspective.

The procedures used calculate the following indicators.

$$UEF_{EF}^{Owner} = \sum_{i=1}^n (EF_{Nominal} * N), \quad (1)$$

where

UEF_{EF}^{Owner} is the unit (static - without taking mileage into account) production of the emission factor (EF sequentially NO_x , $PM_{2.5}$, and CO_2) by vehicle owner type ($Owner$ sequentially private vehicles (P), commercial vehicles (C), and foreign registered vehicles (F)) with the possibility of a breakdown by vehicle category,

i is the Copert vehicle group with a total frequency of 373,

$EF_{Nominal}$ is the value of the emission factor (NO_x , $PM_{2.5}$, and CO_2) according to the emission inventory for the Czech Republic in the Copert program in group i reported in g/km,

N is the frequency of vehicles in group i (1 to 373) and of a given vehicle owner (successively P , C , F).

The calculation UEF_{EF}^{Owner} is the input value for determining the share of unit emission factors of P , C , and F in total unit emissions.

$$SUEF_{EF}^{Owner} = UEF_{EF}^{Owner} / (UEF_{EF}^P + UEF_{EF}^C + UEF_{EF}^F), \quad (2)$$

where

$SUEF_{EF}^{Owner}$ is the share of unit production of the emission factors (CO_2 , NO_x , $PM_{2.5}$) of vehicles by vehicle owner ($Owner$ sequentially C , P , F) in total unit emission,

UEF_{EF}^P is the unit emission factor production (EF sequentially NO_x , $PM_{2.5}$, and CO_2) of P ,

UEF_{EF}^C is the unit emission factor production (EF sequentially NO_x , $PM_{2.5}$, and CO_2) of C ,

UEF_{EF}^F is the unit emission factor production (EF sequentially NO_x , $PM_{2.5}$, and CO_2) of F .

By including mileage data, it is possible to calculate the total emission factor production for each type of vehicle owner at a resolution of 373 vehicle groups.

$$TEF_{EF}^{Owner} = \sum_{i=1}^n (EF_{Nominal} * N * ATP), \quad (3)$$

where

TEF_{EF}^{Owner} is the total (dynamic - taking mileage into account) production of the emission factor (EF successively NO_x , $PM_{2.5}$, and CO_2) according to the type of vehicle owner ($Owner$ successively P , C , F) with the possibility of a breakdown by vehicle category,

ATP is the average traffic performance of vehicles in group i (1 to 373) and of a given vehicle owner (successively P , C , F).

Calculation TEF_{EF}^{Owner} is an input value for finding the share of total emission factors of vehicles owned by entrepreneurs, private owners, and foreign persons in the total amount of emission factor produced.

$$STEF_{EF}^{Owner} = TEF_{EF}^{Owner} / (TEF_{EF}^P + TEF_{EF}^C + TEF_{EF}^F), \quad (4)$$

where

$STEF_{EF}^{Owner}$ is the share of the total production of the emission factor (NO_x , $PM_{2.5}$, and CO_2) of vehicles by vehicle owner ($Owner$ in turn C , P , F) on total emissions,

TEF_{EF}^P is the total emission factor production (EF sequentially NO_x , $PM_{2.5}$, and CO_2) of P ,

TEF_{EF}^C is the total emission factor production (EF sequentially NO_x , $PM_{2.5}$, and CO_2) of C ,

TEF_{EF}^F is the total emission factor production (EF sequentially NO_x , $PM_{2.5}$, and CO_2) of F .

By including a unit valuation of the environmental damage caused by the production of emission factors in relation to the quantity of emissions represented by the transport capacity, the vehicle frequency and the unit quantity of the emission factor, the environmental costs of vehicle operation can be calculated.

$$PTEF_{EF}^{Owner} = \sum_{i=1}^n (EF_{Nominal} * N * ATP * UP_{EF}), \quad (5)$$

where

$PTEF_{EF}^{Owner}$ is the total price of the produced quantity of the emission factor (EF sequentially NO_x , $PM_{2.5}$, and CO_2) according to the type of vehicle owner ($Owner$ sequentially P , C , F) with the possibility of a breakdown by vehicle category.

UP_{EF} is the unit price of the emission factor according to (Van Essen et al., 2019) set for the European Commission for 2016 (NO_x : 14.80 €/kg for rural areas, 24.80 €/kg for urban areas; $PM_{2.5}$: 72.00 €/kg for rural areas, 116.00 €/kg for urban areas, 361.00 €/kg for metropolitan areas; CO_2 : 0.1 €/kg) adjusted by the annual average rate of change of harmonized indices of consumer prices (HICP) which was 0.24 for 2017 and 0.20 for 2018 (Eurostat, 2022a) to the 2018 level to be consistent with the input data. This unit price is differentiated in accordance with 30:70 split of exposition to NO_x and $PM_{2.5}$ emissions for urban and rural inhabitants (Schwermer et al., 2014; Van Essen et al., 2019), and the demographic parameters of the Czech Republic for urban, rural, and metropolitan areas to split the 30 % share on urban and metropolitan exposition.

Calculation $PTEF_{EF}^{Owner}$ is an input value to determine the share of the total emission factor cost of vehicles owned by entrepreneurs, private owners, and foreign persons in the total environmental cost of the emission factor produced.

$$SPTEF_{EF}^{Owner} = PTEF_{EF}^{Owner} / (PTEF_{EF}^P + PTEF_{EF}^C + PTEF_{EF}^F), \quad (6)$$

where

$SPTEF_{EF}^{Owner}$ is the share of the environmental cost of the produced amount of emission factors (NO_x , $PM_{2.5}$, and CO_2) of vehicles by vehicle owner ($Owner$ successively P , C , F) on the total calculated environmental costs,

$PTEF_{EF}^P$ is the total cost of producing the emission factor (EF sequentially NO_x , $PM_{2.5}$, and CO_2) of P ,

$PTEF_{EF}^C$ is the total cost of producing the emission factor (EF sequentially NO_x , $PM_{2.5}$, and CO_2) of C ,

$PTEF_{EF}^F$ is the total production cost of the emission factor (EF sequentially NO_x , $PM_{2.5}$, and CO_2) of F .

Resulting values of indicators (i) share of vehicle emission factors by owner in total unit emissions $SUEF_{EF}^{Owner}$, (ii) total emission factor production by vehicle owner type TEF_{EF}^{Owner} and the share of this production by type of vehicle owner $STEF_{EF}^{Owner}$, and (iii) total emission factor output prices by vehicle owner type $PTEF_{EF}^{Owner}$ and the proportion of that price by type of vehicle owner $SPTEF_{EF}^{Owner}$, will make it possible to compare the environmental burden in quantitative and financial units generated by P , C and F including breakdown by vehicle category. This will be an input for assessing the situation in 2018 in the Czech Republic under § 2 of Act 16/1993 (Czech Republic, 2021) and in other countries where no road tax is imposed on the operation of private and foreign persons, unlike vehicles operated in the course of commercial activities.

Results

There was a total of 6,388,192 motor vehicles of the categories PV, LUV, HGV, T, B and L in the RVR of the Czech Republic in 2018. The WHO (2020) publishes the number of registered vehicles in each country in the world. From these statistics, it can be deduced that the number of road vehicles in the Czech Republic accounts for 2.41% of the number of these vehicles within the EU countries.

Table 1 shows the distribution of vehicle frequencies and groups for each vehicle category in the Czech fleet.

Of the total number of vehicles, 99.33% were processed in terms of vehicle owner identification; that is, the loss was 42,937 vehicles and therefore 0.67%. There are 1,143,692 (18%) commercial vehicles (C), 4,826,338 (76%) private vehicles (P), and 375,225 (6%) foreign registered vehicles (F). 89% L vehicles and 81% PV vehicles are private vehicles, on the contrary 69% HGV vehicles, 59% T vehicles and 55% B vehicles are commercial vehicles. For LUV vehicles, the share of commercial vehicles and private vehicles is more balanced. Foreign registered vehicles have the highest frequency shares in categories T and B. 86% of the entire fleet is PV category. In terms

of the number of groups into which the vehicle categories are divided, the most detailed breakdown of vehicles is PV category.

Table 1. Distribution of frequencies of vehicles and categories.

Vehicle category	Number of groups	Σ	Number of vehicles		
			P	Owner C	F
PV	137	5,518,817	4,457,457	718,514	304,493
LUV	54	557,465	244,184	286,171	23,319
HGV	57	149,407	15,763	103,330	30,259
T	42	15,104	790	8,840	5,473
B	47	27,688	1,995	15,339	10,035
L	36	119,711	106,149	11,498	1,646
Σ	373	6,388,192	4,826,338	1,143,692	375,225

The achieved level of coverage of the linkage of vehicle-specific mileage data in the 2014 to 2018 VTS extracts with RVR records in 2018 is 60.30%. Thus, almost 40% of the RVRs could not be linked to the mileage data, which is mainly due to the low quality of the vehicle records in the RVR but also due to some vehicles not having passed their Ministry of Transport (MOT) test for various reasons (e.g., vehicle no longer in service although in RVR; expired vehicle MOT). Data from later periods than 2014 to 2018 achieve even significantly lower coverage of mileage data linkage. The problem of incomplete coverage of mileage data from 2014 to 2018 is solved by substituting the actual kilometers driven by vehicles without this record with the average of vehicles with this record in the corresponding vehicle group according to their classification in one of the 373 vehicle groups in COPERT. This ensures that all vehicles have a mileage record and that this record is either real or is an average of the actual results achieved by vehicles of the same category, size, weight, number of axles, EURO standard and other parameters and thus corresponds to reality as much as possible.

The results of the unit (static) calculation (UEF_{EF}^{Owner}) and comparison ($SUEF_{EF}^{Owner}$) of the production of NO_x, PM_{2.5}, and CO₂ emission factors by type of vehicle owner using Equations (1) and (2) are presented in Table 2. These results are further broken down by vehicle type in Table 3.

Table 2. Production of unit emission factors.

EF	NO _x			Σ
	Owner P	C	F	
UEF (g/km)	2,830,072.12	898,622.43	596,337.53	4,325,032.09
SUEF (%)	65.43	20.78	13.79	100.00
EF	PM _{2.5}			Σ
	Owner P	C	F	
UEF (g/km)	167,575.82	63,596.68	15,062.32	246,234.82
SUEF (%)	68.06	25.83	6.12	100.00
EF	CO ₂			Σ
	Owner P	C	F	
UEF (g/km)	903,983,994.32	246,117,037.11	90,620,372.01	1,240,721,403.44
SUEF (%)	72.86	19.84	7.30	100.00

The results of the UEF_{NOX}^P , UEF_{NOX}^C , and UEF_{NOX}^F calculations show that the vehicle fleet in the Czech Republic produces more than 4 t of NO_x for a hypothetical unit trip of 1 km for each registered vehicle, with private vehicles playing a dominant role in this amount. Indicators $SUEF_{NOX}^P$, $SUEF_{NOX}^C$, and $SUEF_{NOX}^F$ suggest that two-thirds of the unit NO_x emissions are produced by private vehicles. Commercial vehicles and foreign registered vehicles contribute much less to unit emissions, with commercial vehicles contributing only 20% and foreign registered vehicles contributing 14%. 77% of NO_x unit emissions are made up of PV vehicles, with private PV vehicles accounting for 78% of these emissions. The share of private PV vehicles per NO_x unit emissions of the Czech fleet is 60%. The sum of the values of the indicators $UEF_{PM2.5}^P$, $UEF_{PM2.5}^C$, and $UEF_{PM2.5}^F$ identifies the production of the

PM_{2.5} emission factor of the Czech Republic's vehicle fleet at a unit mileage of 1 km for each registered vehicle of almost 0.25 t. As in the case of NO_x, private vehicles play a dominant role in this quantity, as demonstrated by the indicators $SUEF_{PM_{2.5}}^P$, $SUEF_{PM_{2.5}}^C$, and $SUEF_{PM_{2.5}}^F$ by identifying the 2/3 share of these (private) vehicles in the unit production of the emission factor PM_{2.5}. The indicator $SUEF_{PM_{2.5}}^C$ then identifies a share of 1/4 in this production of commercial vehicles and $SUEF_{PM_{2.5}}^F$ the lowest 6% share in the unit production of PM_{2.5} vehicles of foreign persons.

Table 3. Production of unit emission factors UEF (g/km) by vehicle category.

EF	Vehicle category	Owner			Σ
		P	C	F	
NO _x	PV	2,586,086	328,097	422,042	3,336,225
	LUV	172,934	174,884	15,795	363,613
	HGV	43,178	280,229	85,831	409,238
	T	3,921	45,041	25,752	74,714
	B	5,981	68,587	46,644	121,212
	L	17,972	1,784	274	20,031
PM _{2.5}	PV	144,056	28,195	8,001	180,252
	LUV	19,608	19,919	1,737	41,264
	HGV	1,508	11,108	2,799	15,415
	T	174	1,645	985	2,804
	B	323	2,535	1,511	4,369
	L	1,907	194	29	2,131
CO ₂	PV	837,321,567	135,663,718	60,905,153	1,033,890,438
	LUV	46,849,107	48,735,933	4,726,117	100,311,157
	HGV	6,392,045	42,932,303	13,211,566	62,535,914
	T	563,588	5,489,024	3,611,625	9,664,237
	B	1,809,330	12,113,227	7,994,866	21,917,422
	L	11,048,357	1,182,832	171,047	12,402,236

The share of PV vehicles in PM_{2.5} unit emissions is also very high at 73%. Private PV vehicles contributes even 80%, which is 59% of the PM_{2.5} unit emissions of the Czech fleet. Finally, the indicators $UEF_{CO_2}^P$, $UEF_{CO_2}^C$, and $UEF_{CO_2}^F$ quantify the CO₂ unit emissions for the three types of vehicle owners in the Czech vehicle fleet. The total production of the CO₂ emission factor per unit run of 1 km for each registered vehicle is 1.24 t. Calculations $SUEF_{CO_2}^P$, $SUEF_{CO_2}^C$, and $SUEF_{CO_2}^F$ found that private vehicles produce almost 3/4 of the CO₂ unit emissions, while commercial vehicles produce 20% and foreign registered vehicles produce 7% of these unit emissions. Similarly, to NO_x and PM_{2.5}, the highest share of CO₂ unit emissions is recorded for PV vehicles (83%), of which 81% is attributable to private PV vehicles, whose share of CO₂ unit emissions of the Czech fleet is 67%.

The results of the aggregate (dynamic) calculation (TEF_{EF}^{Owner}) and comparison ($STEF_{EF}^{Owner}$) of the total production of NO_x, PM_{2.5}, and CO₂ emission factors by type of vehicle owner are shown in Table 4 after the application of Equations (3) and (4). These results are further broken down by vehicle category in Table 5.

The total NO_x emissions of the Czech Republic's fleet in 2018 are given by the sum of (TEF_{NOx}^{Owner}) emissions of vehicles owned by all types of vehicle owners. The identified NO_x emissions amounts to 60 kt commercial vehicles (TEF_{NOx}^C) account for the largest share, with private vehicles (TEF_{NOx}^P) accounting for 10 percentage points less and foreign registered vehicles (TEF_{NOx}^F) accounting for 16%. Compared to the unit emissions, the higher share of commercial vehicles is particularly noticeable.

46% total NO_x emissions are accounted for by PV vehicles, of which private vehicles accounts for 69% (almost 19 kt). The second highest share of total NO_x emissions was recorded for HGV vehicles with a share of 29%. Of these, 72% are commercial HGV vehicles. The share of private PV vehicles in total NO_x emissions is 31% and commercial HGV vehicles 21%. The shares of other vehicles by owner or vehicle category are already significantly lower.

Table 4. Total production of emission factors.

EF	NO _x			
Owner	P	C	F	Σ
TEF (t)	22,127.15	28,251.59	9,569.23	59,947.97
STEF (%)	36.91	47.13	15.96	100.00
EF	PM _{2.5}			
Owner	P	C	F	Σ
TEF (t)	2,048.71	1,743.42	388.20	4,180.32
STEF (%)	49.01	41.71	9.29	100.00
EF	CO ₂			
Owner	P	C	F	Σ
TEF (t)	8,948,137.57	6,394,426.66	1,564,513.31	16,907,077.54
STEF (%)	52.93	37.82	9.25	100.00

The same impact on the change in the share of emissions as in the case of NO_x can be observed in the case of PM_{2.5} and CO₂ emissions. The total amount of PM_{2.5} emissions given by the sum ($TEF_{PM2.5}^{Owner}$) is higher than 4 kt, and commercial and private vehicles contribute relatively comparably to this amount, with foreign registered vehicles contributing only 9%, as shown by $STEF_{PM2.5}^{Owner}$ indicators. The quantity of CO₂ emissions produced, given by the sum (TEF_{CO2}^{Owner}), amounts to almost 17 Mt. When compared to unit emissions, private vehicles (TEF_{CO2}^P) still account for the largest share of this production, although not by such a large margin compared to commercial vehicles ($STEF_{CO2}^C$) and foreign registered vehicles ($STEF_{CO2}^F$). Yet private vehicles produce more than half of the CO₂ emissions of the Czech fleet.

Table 5. Total production of emission factors TEF (t) by vehicle category.

EF	Vehicle category	Owner			Σ
		P	C	F	
NO _x	PV	18,853	7,185	1,314	27,353
	LUV	2,400	3,240	267	5,907
	HGV	564	12,519	4,260	17,343
	T	117	2,537	1,532	4,186
	B	135	2,766	2,196	5,097
	L	58	5	1	63
PM _{2.5}	PV	1,725	712	80	2,517
	LUV	282	372	30	684
	HGV	25	495	165	685
	T	4	84	51	139
	B	5	81	61	148
	L	6	1	0	7
CO ₂	PV	8,185,083	2,965,351	384,149	11,534,583
	LUV	621,319	874,074	70,676	1,566,069
	HGV	73,399	1,906,192	646,302	2,625,892
	T	11,368	300,356	181,129	492,853
	B	19,400	345,033	281,765	646,198
	L	37,570	3,420	494	41,483

Breaking down the vehicles by category and type of owner, we see that the highest share of total PM_{2.5} emissions in the Czech fleet is accounted for by private PV vehicles (41%, which is almost 2 kt). The second highest share is seen for commercial PV vehicles (17%), followed by commercial HGV vehicles (12%). PV vehicles contributes 60%

of the total PM_{2.5} emissions of the Czech fleet. Also, in the case of CO₂, PV vehicles produce the highest share of total emissions, with 68%. Of this amount, private PV vehicles account for 71%, with a share of 48% of total CO₂ emissions and more than 8 Mt. By comparison, after commercial PV vehicles (17%), commercial HGV vehicles are in third place with a share of 11% of total CO₂ emissions.

The input values for the valuation of the emission factors in accordance with the methodology section are based on previously quantified data (Van Essen et al., 2019). The basis of air pollution costs is an average damage cost of €/kg for transport emissions in 2016 in the Czech Republic. A refining parameter for determining the unit emission damage in the Czech Republic based on the location seems to be suitable for use. The valuation of unit emission factors offers a differentiation of NO_x values for urban and rural areas. In addition to the urban and rural areas, the unit emission factor assessment also offers differentiation of PM_{2.5} values for the metropolitan area, which means cities with more than 0.5 million inhabitants. The CO₂ emission factor will not be differentiated in this way due to its global nature. The central estimate for short-and-medium-run up to 2030 will be used to value CO₂ emissions, a relatively conservative valuation amount.

Nominal amounts of unit emission factors for NO_x, PM_{2.5}, and CO₂ include the NO_x and PM_{2.5} national average emissions damage cost for transport emission (Van Essen et al., 2019), which includes health effects, crop loss, biodiversity loss, and material damage. For CO₂, the value represents the cost of avoiding climate change.

Table 6. Costs of unit emission factors UP_{EF} (€2018/kg).

EF/Area	Rural	Urban	Metropolitan
NO _x	15.4583	25.9031	-
PM _{2.5}	75.2026	121.1597	377.0573
CO ₂		.1044	

UP_{EF} in Table 6 is the unit price of the emission factor (Van Essen et al., 2019; Eurostat, 2022a). The European Commission for 2016 valorized the annual average rate of change of HICP to 2018 levels (Schwermer et al., 2014), so that the data is consistent in time with the input data. For example, the value 15.4583 of rural unit NO_x costs was calculated by multiplying NO_x value 14.80 €/kg for rural areas in 2016 by HICP increase in 2017 (1.024) and 2018 (1.020).

Table 7. Total cost of emission factors (€2018).

EF	NO _x				
	Owner	P	C	F	Σ
PTEF (€2018)		411,382,267.33	525,246,380.64	177,908,634.35	1,114,537,282.32
EF	PM _{2.5}				
	Owner	P	C	F	Σ
PTEF (€2018)		246,273,686.60	209,574,798.61	46,664,983.81	502,513,469.02
EF	CO ₂				
	Owner	P	C	F	Σ
PTEF (€2018)		934,615,072.85	667,885,075.55	163,410,286.36	1,765,910,434.76
EF	Σ (NO _x , PM _{2.5} , CO ₂)				
	Owner	P	C	F	Σ
PTEF (mil. €2018)		1,592.27	1,402.71	387.98	3,382.96
SPTEF (%)		47.07	41.46	11.47	100.00

Table 6 shows that as the concentration of population increases, so does the amount of costs of unit emission factors. For the valuation the data on the production of emissions in the Czech Republic, this article uses (TEF_{NOX}^{Owner}). Further, this article used a 30:70 split of NO_x emissions for urban and rural areas in accordance with the assumption of this split (Schwermer et al., 2014) used for the EU countries. For the purposes of the PM_{2.5} emission factor, only the city of Prague is considered as a metropolitan area in the Czech Republic (CSO, 2018), with a population of 1,294,513 in 2018. In that year, the Czech Republic had a total population of 10,610,055. The proportion of the population exposed to emissions in the metropolitan area is therefore 12.20%. The share of emissions produced in urban areas will be reduced by this proportion. The resulting distribution for the application of the individual unit emissions valuation amounts is 70:17.80:12.20 for PM_{2.5}. For the CO₂ emission factor, due to its global nature, it is not meaningful to distinguish areas.

Including a unit valuation of environmental damage caused by the production of emission factors, the total costs of production of emission factors by vehicle owner type can be calculated in Table 7 using Equations (5) and (6) $PTEF_{EF}^{Owner}$ and the share of the environmental costs of vehicle emission factors produced by vehicle owner $SPTEF_{EF}^{Owner}$. These results can also be further broken down by vehicle category in Table 8.

Table 8. Total cost of emission factors PTEF (€2018) by vehicle category.

EF	Vehicle category	Owner			Σ
		P	C	F	
NO _x	PV	350,513,738	133,588,504	24,431,684	508,533,925
	LUV	44,617,676	60,239,015	4,956,874	109,813,565
	HGV	10,494,948	232,745,827	79,197,187	322,437,962
	T	2,168,684	47,162,293	28,485,215	77,816,192
	B	2,514,880	51,424,044	40,824,122	94,763,047
	L	1,072,342	86,698	13,551	1,172,592
PM _{2.5}	PV	207,344,613	85,598,289	9,647,998	302,590,900
	LUV	33,952,802	44,682,396	3,628,320	82,263,518
	HGV	3,050,456	59,492,865	19,833,924	82,377,245
	T	517,847	10,045,081	6,164,653	16,727,582
	B	657,586	9,692,909	7,380,478	17,730,974
	L	750,381	63,258	9,610	823,250
CO ₂	PV	854,915,534	309,725,009	40,123,586	1,204,764,129
	LUV	64,895,521	91,295,314	7,381,931	163,572,766
	HGV	7,666,362	199,097,909	67,504,904	274,269,174
	T	1,187,333	31,371,617	18,918,516	51,477,466
	B	2,026,261	36,038,054	29,429,753	67,494,068
	L	3,924,063	357,172	51,597	4,332,832

The results of the calculations in Table 7 and Table 8 show the valuation amounts $PTEF_{NOX}^{Owner}$, $PTEF_{PM2.5}^{Owner}$, and $PTEF_{CO2}^{Owner}$ for vehicles by owner type and vehicle category, the total costs of all included emission factors $PTEF_{EF}^{Owner}$ by vehicle owner type and vehicle category, and their shares of the total costs $SPTEF_{EF}^{Owner}$. It is clear that the costliest emission factor is CO₂, with an amount of 1.77 billion €₂₀₁₈. This is followed by the 1.11 billion €₂₀₁₈ of the NO_x emission factor. The lowest cost is generated by PM_{2.5} production at 0.5 billion €₂₀₁₈. PV vehicles accounts for the largest share of the costs of all three pollutants NO_x, PM_{2.5} and CO₂ (60%) and private PV vehicles accounts for 42% of these total costs. HGV vehicles accounts for the second highest share of the costs of all three emission factors. However, this share is only half that of PV vehicles. The shares of the cost of each emission factor, depending on the type of vehicle owner, are the same as in the case of $STEF_{EF}^{Owner}$, i.e., when comparing the total production of NO_x, PM_{2.5}, and CO₂ emission factors depending on the type of vehicle owner when including vehicle passes. Therefore, the shares are not restated.

The total cost $PTEF_{EF}^{Owner}$ amounts to 3.38 billion €₂₀₁₈, representing 1.61% of GDP at Market Prices in 2018 in the Czech Republic (Eurostat, 2022). This amount is mostly accounted for by privately owned vehicles (47%) amounting to €1.60 billion €₂₀₁₈. At 6 p.p. lower (41%), the share of commercial vehicles is 1.40 billion €₂₀₁₈. Significantly lower is the share of vehicles owned by foreign persons (12%) at 0.39 €₂₀₁₈.

The environmental cost of almost two billion €₂₀₁₈ in 2018 is generated by the operation of vehicles not subject to road tax in 2018, i.e., vehicles owned by private and foreign persons. Road tax collection in the Czech Republic in 2018 was €0.2414 billion (Financial Administration, 2022), using a Euro Exchange rate of 25.995 CZK/€ for excise duty tables for 2018 (European Commission, 2018). The road tax collection is therefore 14 times lower than the total calculated environmental damage and six times lower than the environmental damage generated by commercial vehicles alone.

Discussion

The division of the identified unit environmental costs of fleet operation in the Czech Republic into private, commercial, and foreign registered vehicles indicates that the share of private vehicles in these emissions is very significant. At the same time, it is clear that private PV vehicles share plays the biggest role in this.

The distribution of calculated unit NO_x emissions against private vehicles is mainly due to their high frequency and also to their worse emission parameters due to the higher average age of privately owned vehicles. Given the very high frequency, the PV category appears to be particularly problematic within private vehicles.

The interpretation of the results for PM_{2.5} is similar to the NO_x emission factor. The frequency of vehicles and emissions parameters relative to the age of the vehicles also plays a role. Conversely, the tendency toward higher unit emissions for commercial vehicles is due to the higher proportion of multi axle vehicles and higher weights (HGV, T, B, LUV categories) within commercial vehicles. This fact determines PM_{2.5} unit emissions to the disadvantage of commercial vehicles because these emissions include not only PM exhaust but also PM_R generated by road abrasion and PM_{2.5 (T+B)} generated by tire and brake abrasion, where these additional components of total PM_{2.5} are generally higher for multi axle vehicles and higher weights.

In addition to the high frequency of private vehicles, the high contribution to the unit CO₂ emissions of private vehicles can also be attributed to the composition of the fleet in terms of fuel type. Private vehicles are more likely than commercial vehicles and foreign registered vehicles to run on petrol at the expense of diesel, which is especially true for the PV category. As diesel engines are generally more efficient in terms of quantity and CO₂ emissions are directly related to the amount of fuel consumed, the share of private vehicle unit emissions is high.

According to the research, commercial vehicles accounted for 33% of total fleet mileage, private vehicles accounted for 61%, and foreign registered vehicles accounted for 6%. By including a dynamic component in the form of the real-world mileage of the Czech fleet, the ratio of generated emissions changed depending on the type of vehicle owner. Compared to unit emissions, the share of emissions from commercial vehicles, in particular, has increased. The reason for this increase in the share of commercial vehicles in the total emissions of all three emission factors examined is due to the significantly higher average mileage of these vehicles compared to private vehicles. Foreign registered vehicles also have higher mileage than private vehicles.

The share of private PV category in total NO_x emissions fell by almost half due to the inclusion of the dynamic component in the form of mileage data of the Czech fleet compared to the share of private PV category in NO_x unit emissions. A similar effect of including a dynamic component can be seen in the case of PM_{2.5} and CO₂. For both of these emission factors, the reduction in private PV category is about 1/3. Nevertheless, for all three emission factors, it is private PV category that remains the highest.

The factor causing the higher share of CO₂ emissions for commercial vehicles is the approximately 50 g/km higher average unit emissions of commercial vehicles compared to private vehicles. This is due to the composition of the fleet, where commercial vehicles generally include many more HGV and T vehicles, which often make high mileage runs. Therefore, a high number of kilometers with a high CO₂ unit value are included in the calculation of total emissions. Average NO_x unit emissions are more than twice as high for commercial vehicles as for private vehicles. This is due to the composition of the fleet, similar to CO₂, where the commercial fleet includes HGV and T vehicles to a much greater extent. Even in the case of PM_{2.5}, unit emissions are almost twice as high for commercial vehicles as for private vehicles.

In summary, the factor of vehicle frequency and unit emissions thus outweighs the factor of realized mileage runs and unit emissions. With the exception of the NO_x emission factor, i.e., for PM_{2.5} and CO₂, in addition to unit emissions, private vehicles produce the largest quantity of total emissions.

The economic dimension of quantifying emission factors is ensured by the use of the existing unit valuations of emission factors adapted to the needs of this research. Although the CO₂ emission factor is valued at a significantly lower and conservative amount relative to the other emission factors, its high absolute amount results in this emission factor having the highest cost among the three emission factors examined. In terms of distinguishing the type of vehicle owner, private owner vehicles generate the highest costs for the PM_{2.5} and CO₂ emission factors. Only for the NO_x emission factor are the costs highest for commercial vehicles. When distinguishing not only the type of vehicle owner but also the vehicle category, private PV vehicles generates the highest damage for all three emission factors.

The limitation in the research conducted is due to its focus only on a transparent and clearer calculation of environmental costs using the tank-to-wheel approach (IFEU et al., 2014). Simplification also lies in the limited number of emission factors (Fiorito, 2017). This is based on the need to include only the most relevant and at the same time well-developed emission factors in relation to their assessment (EEA, 2019). Actual emissions are not known, so we use modelled emissions based on the emissions of vehicles in each category in real Copert program operation. This provides considerably more accurate and reliable unit emissions values compared to vehicle

technical documentation. Real data on fleet composition and vehicle mileage were used from the Czech Vehicle Register and technical inspection stations.

The article deals with only a slice of possible tax policies, which in turn allows to provide a detailed view of the emission characteristics in relation to the vehicle use tax in the Czech Republic in 2018. In terms of impacts on human health, the extent of exposure to NO_x and PM_{2.5}, i.e., the immission values, is relevant for the emission factors NO_x and PM_{2.5}. In order to reduce or eliminate these impacts, instruments other than taxation are more appropriate, such as restrictions or bans on entry, selective payments for entry to exposed locations, differentiated parking fees, etc. The limits of the predictive power caused by the imperfections in the input data result from the description in the methodological part of the article. The relatively low proportion of linking of mileage data of individual vehicles was solved by substituting the actual kilometers driven by vehicles without this record by the average mileage of vehicles with this record in the corresponding group of vehicles according to their classification in one of the 373 groups used. It should also be noted that the study does not address the one-off and ongoing direct and induced costs of the application of the general road tax, nor does it propose the design of a system for its collection. These are undoubtedly issues that would need to be addressed.

Conclusion

By dynamizing the unit emissions parameters of the Czech Republic's vehicle fleet, it was found that within road transport that private vehicles were the most significant emitters of CO₂ and PM_{2.5}. Only in the case of NO_x were commercial vehicles the most significant emitters. An evaluation of the emission factors produced shows that, overall, private vehicles (especially private PV category) caused the highest costs among the three possible types of vehicle owners.

The research to date (Marriot and Mortimore, 2017; Rasool et al., 2019; Santos, 2017) suggests that external costs need to be incorporated into market prices through fiscal instruments imposed by governments and that these instruments can be more functional (Pui and Othman, 2017). The vehicle use tax can address environmental costs in road transport and is already widespread globally. This tax, however, suffers especially from its selective character in the Czech Republic, Slovakia, and Poland not only in 2018 but up to now. Only commercial vehicles were subject to this tax. In the Czech Republic, this selectivity means that 53% of NO_x, 58% of PM_{2.5}, and 62% of CO₂ emissions generated in road transport by the vehicles of private and foreign owners escaped taxation. From an economic point of view, the overall effect is a tax disregarded of 59% of the environmental costs of the operation of road motor vehicles in the Czech Republic. Similar results can also be expected in Poland and Slovakia, given their common historical development and thus similar fleet composition. In addition, in the Czech Republic, commercial vehicles were also only one-sixth of the environmental costs they generate, which is clear from a simple comparison of these costs and road tax collection.

The above results show that answers related to questions focusing on EFJ of transport externalities formulated by Hay and Trinder (1991), or equitable cost equality in general (Le Grand, 1982), are of great concern. Moreover, if the concept of an EKC (Yandle et al., 2002) and its financial quantification by Prieur (2009) is accepted, then even without indexing the amount to its present value, it is evident that the countries mentioned are nowhere near the tipping point from a natural increase to a natural decrease. Another factor is the socially accepted mantra of continuous economic growth. However, according to evidence from Zhang and Nian (2013) or Chandran Govindaraju and Tang (2013), this mantra leads to an increase in transport emissions.

For these reasons, it is evident that, in line with the need for an easy and quick application of at least an evolutionary solution (Ke and Gkritza, 2018), it is necessary to make the vehicle use tax general without distinction of vehicle use, type or weight. It is also necessary to valorize this tax burden in relation to the amounts of environmental costs generated in road transport. In this way, a reduction of the gap (Gordon, 2008) between the current state of scientific knowledge, sustainable development and applied policy could be achieved and, above all, would mitigate market distortions and inefficiencies in resource allocation leading to inequities. As noted by Bureau (2011) and Callan et al. (2009), the social impacts of this change are relatively easy to address, although they are a common argument for governments' inaction on internalizing externalities beyond transport. Finally, it is necessary to mention the urgent need to find solutions in the Czech Republic to reduce or eliminate the exposure of the population to locally above-limit immissions with negative impact on their health.

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