TOLL SYSTEM CHARGING NEGATIVE EXTERNALITIES: CASE OF THE CZECH REPUBLIC

Břetislav Andrlík[1], Lucie Zborovská[2]

Abstract

This article deals with the issues of charging negative externalities from transport through a fee based on distance traveled, imposed on road motor traffic. The description of the current state of charging such fees related to road motor traffic in the European Union member states is provided first. The overview focuses on environmental elements which were incorporated into the current toll systems in the EU countries. The article also provides an overview of directives of the European Parliament and of the Council, which cover the issue and stipulate uniform rules to be applied by the EU member states. The construction of the model of fees based on distance traveled in the Czech Republic is based on pre-defined assumptions and is inspired by the systems currently applied in Germany and Austria. Standard methods of scientific work are applicable in the construction of the model. The data sources used in the paper are primary data related to the issue and are obtained from public institutions. The newly constructed model aims at the incorporation of an environmental element in the form of noise into the toll system of the Czech Republic and at increasing total receipts from tolls in line with the plans of the Czech Ministry of Transport. In conclusion, the comparison of the proposed model with the current toll system used in the Czech Republic is made.

Keywords

Road Motor Vehicle, Environmental Element, EURO Standard, Noise

I. Introduction

Road passenger and freight transport is one of the key sectors of modern market economies and construction or renewal of transport infrastructure is necessary for the development of economy as
a whole. The first efforts to determine uniform principles of transport policy were embedded in the Treaties of Rome, namely the Treaty Establishing the European Economic Community (1957), which addressed common rules for international transport, free access to transport services for all member states and prohibition of discrimination of certain transport sectors. The political representations of individual EU member states strive to raise sufficient funds to improve the quality of the transport infrastructure and to cover the negative externalities of environmental and public health impacts. A negative externality originates in the event that a part of the costs generated in connection with motor traffic is transferred to the society, for instance in the form of environmental damage; then the society bears a part of costs of another person's consumption. Such externalities include the risk of traffic accidents and mortality due to the overloaded infrastructure, noise and pollution of the environment (Cnossen, 2005 and Andrlík, 2012, 2014). The costs of negative externalities should be internalized by charging vehicles for the use of infrastructure. The elimination of negative impacts attributed to transport, which include greenhouse gas emissions and other pollutants, but also noise or infrastructure damage, is one of the key points raised in the White Paper (2011), the European Union's strategic document focused on transport (published in 2001, final version in 2011). The entities

[1] Mendel University in Brno, Faculty of Business and Economics, Department of Accounting and Taxes, Zemědělská 1, 613 00 Brno, Czech Republic, E-mail: bretislav.andrlik@mendelu.cz.
[2] Mendel University in Brno, Faculty of Business and Economics, Department of Accounting and Taxes, Zemědělská 1, 613 00 Brno, Czech Republic, E-mail: xzborov@mendelu.cz.

participating in transport should use the infrastructure in better ways and mitigate the negative impacts on the environment and the society. The correct price setting and application of principles "user pays" and "polluter pays", stipulated by Directive 2006/38/EC of the European Parliament and of the Council are ways to cause the infrastructure users realize what impacts their decisions have on their surroundings. The internalization of negative externalities through adequate fees and taxes can be an appropriate means of enforcing these principles. It includes taxes on fuel as a source of greenhouse gases and pollutant emissions, as well as taxes and fees for the infrastructure use and other related externalities (Andrlík, Mísařová and Vrtalová, 2014). Whereas fuel taxes apply to all vehicles, taxes and fees for the infrastructure use are at present firmly set only for heavy goods vehicles in the EU.

The EU member states aim to achieve the above goals through tax policy instruments, where the main measures are the collection of a fee based on time (vignette) or a fee based on the distance (toll) for the use of selected sections of the infrastructure in the country concerned. The tradition of paying a toll dates back to the remote past; the toll was imposed on roads, bridges or ferries. Everyone who wanted to use such sections, had to pay the price which depended on the value of the carried goods. The fee for the use of infrastructure based on the distance depends on the number of kilometers traveled by a road motor vehicle along the charged sections of infrastructure in the EU country concerned. The fee based on the distance traveled may be paid physically at a toll gate or electronically through toll gates or using technologies based e.g. on the GPS.

The Czech Republic at present uses the microwave toll system for vehicles over 3.5 t, similarly to a number of other EU countries. Toll rates are determined according to the distance traveled, EURO emission standard, number of axles, type of road and time of day under Government Regulation No. 240/2014 Coll. (2019). The current system of toll collection uses toll gates which record each passing vehicle that is subject to the fee on the charged section of the road. The Czech Republic plans introducing a satellite system of toll collection that is currently used in Germany and Slovakia. Under Section 20 (4) Act No. 13/1997 Coll., Road Act, the receipts from the electronic tolls and vignettes are revenues of the State Fund of Transport Infrastructure (SFDI) in the Czech Republic.

The introduction of a completely new system provides an opportunity to open discussions about the concurrent increase in rates, which are very low in the Czech Republic in comparison with neighboring countries, see also Table 2. According to Frouzová and Váchal (2019), in April 2019 the Czech Minister of Transport said that the Ministry intended to prepare an amendment to Act No. 13/1997 Coll., Road Act, which would enable an increase in the toll rates by 50 % and would include the costs of noise into the calculation of final rates. At present, the rates cannot be increased due to the high proportion of European subsidies, which are used toward the maintenance of current infrastructure and construction of new roads. The EU also put a cap on the amount of toll rates for the Czech Republic, which is another obstacle to a change of the present rates. In case the toll rates were increased, the Czech Republic would lose part of the subsidies and would be imposed a penalty. The Road Act should be amended by the year 2021 (Frouzová and Váchal, 2019), however it is not clear in what manner the toll rates would change. It is the goal of this article to propose a model of the toll system in the Czech Republic that would emphasize pricing negative externalities caused by the road motor traffic and at the same time respect the plan of the Ministry of Transport to increase the toll rates by 50 % in comparison with the present situation.

II. European legislative framework related to negative externalities from transport

The determination of charges on light vehicles is set out in the Communication from the Commission COM(2012) 199 on the application of national road infrastructure charges levied

on light private vehicles. As stated in the document, the rules of collection of charges for light private vehicles are based on the Treaty on the Functioning of the European Union (2012) and due to the non-existence of a European regulation, the member states are entitled to apply virtually any system of pricing the use of road infrastructure. Such system, however, has to observe two basic principles that are embedded in the Treaty on the Functioning of the European Union (2012). These are the principles of non-discrimination and proportionality in connection with citizenship.

The EU legislation puts greater emphasis on regulating vehicles whose weight exceeds 3.5 t than vehicles below this limit. The main regulation is Directive 1999/62/EC of the European Parliament and of the Council of 17 June 1999 on the charging of heavy goods vehicles for the use of certain infrastructures, the so-called "Eurovignette". The term Eurovignette is used in two senses: it means the above Directive and also refers to the system of charges used in Denmark, Luxembourg, the Netherlands and Sweden. The Directive focuses on tolls and vignettes as well as taxes on vehicles. The Directive states that the charges should not be discriminatory, their rates should be in proportion to the duration of the use made of the infrastructure and the use of road-friendly and less polluting vehicles should be encouraged. The Directive allows the collection of tolls and user charges (vignettes) only on motorways or other multi-lane roads with characteristics similar to motorways, bridges, tunnels and mountain passes. Tolls and user charges may not both be imposed at the same time for the use of a single road section by the same category of vehicles. Toll rates may be differentiated according to the EURO standard, time of day or season, however, without affecting the amount of the weighted average toll, which is the total receipt of the toll in a defined period, divided by the number of kilometers traveled along a certain road. The weighted average toll must correspond to the costs of constructing, operating and developing the infrastructure network concerned (see Article 7 (9) of the Directive). The calculation of weighted average tolls is based on Annex III to Directive 2006/38/EC, which stipulates the basic principles of the allocation of costs and calculation of tolls. The Directive also allows member states to differentiate the toll rates collected for certain purposes such as remedy of environmental damage, tackling congestion, minimizing infrastructure damage, optimizing the use of the infrastructure concerned or promoting road safety, and similarly to the differentiation according to EURO standards, time of day or season, without affecting the weighted average toll. There have been two amendments to the Directive since the year 1999; the first was adopted in 2006 and the second in 2011.

Directive 2006/38/EC, which is a revision of the original Directive 1999/62/EC, adds the principles "user pays" and "polluter pays" to the set of principles of fair tax collection. Transport tax policy should take into account the increasing volume of traffic, infrastructure overload, noise and environmental pollution and encourage such means of transport that are more environmentally friendly. At the same time, it should support a complete internalization of social and environmental costs. Taxpayers should be able to adopt decisions affecting the toll amounts by choosing more environmentally friendly vehicles, times with lower traffic or preferring less burdened roads. Therefore, the EU countries should have the opportunity to differentiate the toll amounts according to the EURO emission standard of the vehicle, according to damage caused by the vehicle on the infrastructure and according to the place, time and degree of congestion. Directive 2006/38/EC also sets the maximum amount of vignettes including administrative costs for heavy goods vehicle based on EURO standards (Annex II to the Directive).

The latest amendment to Directive 1999/62/EC has been Directive 2011/76/EU of the European Parliament and of the Council. It introduces the term of external costs. The member states are newly allowed to incorporate also costs arisen due to environmental pollution and noise. The charges stipulated by the original Directive 1999/62/EC had been imposed on vehicles with the maximum permitted weight exceeding 12 t until the year 2012; after the amendment, such

charges may also be imposed on vehicles exceeding 3.5 t. As mentioned by Kenny (2017), the Eurovignette directive enables the inclusion of external costs into the calculation of charges. Such costs are attributed to air pollution or impacts of noise. The charges reflecting such external costs should be differentiated according to the road type, vehicle category, and time, so that costs caused by the traffic noise could be included. Annex IIIb to Directive 2011/76/EU sets out the parameters to be used to calculate the maximum weighted average charge for external costs.

A proposal for further amendment to Directive 1999/62/EC was presented in 2017, in the document COM(2017) 275. The proposal states that the application of vehicle taxes represents a cost the industry must so far bear in any event, even if tolls were to be levied by member states. Therefore, taxes may present an obstacle to the application of tolls. The EU countries should be allowed to decrease the minimum rates set out in Directive 1999/62/EC. Such decrease should be implemented gradually so that the risk of distortion of competition among transport operators based in different member states was minimized. The first variant of the amendment proposal includes legislative changes that update the original directive and also extend the scope of application to coaches, buses, vans and passenger cars. The second variant assumes gradual discontinuation of time-based charges for heavy goods vehicles, aiming at the issues of CO_2 emissions and pollutants through wider introduction of charges for distance traveled. The third variant presents measures concerning light commercial vehicles, aiming at the mitigation of interurban congestions, reducing emissions of CO_2 and other pollutants from all vehicles. The fourth variant would stipulate mandatory charges for the compensation of external costs generated by heavy goods vehicles and gradually discontinue time-based charges of all vehicles, so that the only pricing method would be contingent on the distance traveled. The proposal is being discussed by the Council of the European Union. The proposal (COM(2017) 275 mentions that Directive 1999/62/EC fails to provide elements leading to substantial reduction of CO_2 emissions generated by transport. Another issue is the condition of infrastructures which rapidly deteriorates, causing increase in operating costs connected with the vehicle, number of accidents, delays and other social and economic problems. The current legislation focuses only on heavy goods vehicles. Other vehicles, in particular passenger cars, lack legal regulation. The proposal of the Directive states that it should cover a wider range of vehicles, such as the above-mentioned buses, cars and vans. It also speaks of reflecting CO_2 emissions into road pricing, creating an Energy Union or canceling the determination of toll rates based on EURO standards.

As early as in 2008, the Opinion COM(2008) 435 defined the strategy for the internalization of external costs of transport. It states that transport generates negative externalities that involve costs to society and economy. These are for instance delays as a result of congestion, health problems caused by noise and air pollution or the effects of CO_2 emissions on climate change. The volumes of such negative externalities should be reflected in the correct and fair prices determined according to the “polluter pays” and “user pays” principles. The goal is to make transport users aware of the generated external costs and encourage them to change their behavior in order to reduce those negative externalities. The main economic instruments for the internalization of external costs of transport are taxes, road charges and emission permits. The instrument of internalization should be adapted to the characteristics of the externality (place, time and impact). The levels of economic instruments should be such so as to avoid market disruptions. The Opinion mentions that considerable funds must be raised to make transport sustainable, and be used for research, innovation, investment in more environmentally friendly infrastructure, development of public transport, etc. Therefore, revenues from the economic instruments should be allocated to the transport sector and used for the reduction of external costs.

III. Situation in the Czech Republic and other EU member states

All member states except Lithuania, Bulgaria, Romania and countries that do not apply tolls or vignettes (Finland, Cyprus, Malta), use toll systems as a form of pricing roads for vehicles over 3.5 t. This means that 22 of the 28 EU countries collect tolls. All the 22 countries except for France, Ireland (excl. M50 section), Italy, Greece and Spain use the electronic toll systems (based on microwave or satellite technology). Satellite systems (combined with microwave) operate in Germany and Slovakia. In general, unlike vignettes, the toll system charges the distance traveled and thus directly reflects the use of infrastructure. Vehicles that use the given road more often spend more money. However, in the "Eurovignette" countries (Denmark, the Netherlands, Sweden, Luxembourg) and the UK, Estonia and Latvia, the toll is based on time and the period of validity of the purchased toll is decisive, regardless of the distance traveled.

Each country is entitled to determine the categories of vehicles that shall be subject to toll and the differences among European countries are significant. As mentioned above, Directive 2011/76/EU allowed these charges to be levied on freight vehicles with the maximum permissible weight exceeding 3.5 t. Before the adoption of this Directive, charges could be levied on vehicles with the maximum weight of over 12 t. In Latvia, toll is mandatory for vehicles over 3 t; in Germany for those exceeding 7.5 t. In countries applying the Eurovignette system, Belgium and the UK, toll is imposed on vehicles over 12 t. In the remaining 14 countries, including the Czech Republic, the toll system is mandatory for vehicles over 3.5 t.

Almost each EU country assesses the resulting rate on the basis of different criteria. This is because Directive 2006/38/EC only stipulates that the rate should be based on the principle of recovery of infrastructure costs. Nevertheless, the Directive also allows member states to differentiate the toll rates collected for certain purposes such as remedy of environmental damage, tackling congestion, minimizing infrastructure damage, optimizing the use of the infrastructure concerned or promoting road safety under the condition that the weighted average toll shall not be affected (see above).

Table 1 lists countries which use the EURO emission standard as one of the principal components in setting rates of non-tax charges related to road motor vehicle operation. The emission standards primarily aim at the reduction of the content of nitrogen oxide, hydrocarbons, carbon monoxide and particulate matter in emissions from petrol and diesel engines. Methane-free hydrocarbons and soot are monitored in heavy goods vehicles. However, the standards do not address the amount of carbon dioxide (CO_2) that significantly contributes to the greenhouse effect and, unlike carbon monoxide (CO), is not toxic (Sajdl, 2019). The individual EURO emission standards set the maximum values of harmful substances in exhaust fumes (CO, HC, NO_x and PM) and thus substitute the ecological element.

Table 1 EU member states considering EURO standards in the pricing of road motor traffic

	Country	Type of charge	Vehicle category
1	Belgium	toll	>12 t
2	Bulgaria	vignettes	>3.5 t
3	Czech Republic	toll	>3.5 t
4	Denmark	toll	>12 t
5	Estonia	toll	>12 t
6	Lithuania	vignettes	buses and coaches of M2 and M3 category, heavy duty vehicles and their combinations of categories N1-N3 and special road vehicles in M2, M3, and N1-N3 categories.
7	Latvia	toll	>3.5 t
8	Luxembourg	toll	>12 t
9	Hungary	toll	>3.5 t
10	Germany	toll	>7.5 t
11	The Netherlands	toll	>12 t
12	Poland	toll	>3.5 t
13	Austria	toll	>3.5 t
14	Slovak Republic	toll	>3.5 t
15	Slovenia	toll	>3.5 t
16	Sweden	toll	>12 t

Source: own work based on ACEA (2019)

It is apparent from data in Table 1 that 16 of the 28 member states of the EU try to combat negative externalities caused by motor vehicles whose weight exceeds 3.5 t. 15 out of the 16 countries do not address environmental issues for vehicles of up to 3.5 t. According to ACEA (2019), an environmental element in the form of EURO standard is only applied by Lithuania, which imposes vignettes, but this measure is limited to buses and coaches of M2 category, heavy duty vehicles and their N1 category combinations and special vehicles in N1 and M2 categories. The above does not apply to motorcycles and passenger cars.

All countries listed in Table 1 (including Lithuania) differentiate the rates of vignettes or tolls on the basis of EURO standards only for vehicles over 3.5 t. In Bulgaria and Lithuania, the environmental element in the form of EURO standard is incorporated into the prices of vignettes; the other countries reflect it in the prices of tolls. In Belgium, the Czech Republic, Denmark, Lithuania, Luxembourg, Hungary, Germany, the Netherlands, Poland, Austria, Slovakia, Slovenia and Sweden, the EURO standard is important in the process of setting rates for all vehicles subject to the charging. In Bulgaria, the EURO standard is used to determine the rate only for vehicles exceeding 3.5 t, in Estonia it is 12 t and Latvia 3.5 t.

The toll system based on microwave technology, which is currently applied in the Czech Republic, favors trucks meeting higher EURO standards. Rates for the trucks were introduced at the time when there were not so many of these vehicles on Czech roads. Whereas vehicles meeting lower emission standards EURO 0-IV were twice imposed an increase by 25 % in 2011 and 2012, vehicles meeting higher emission standards (EURO V and above) were exempt from such increase. The Czech Republic thus loses money that it would have collected if the rates had been raised to include also more environment friendly vehicles (ČTK, 2013). The

association of carriers ČESMAD (2019) states that the condition of lower-class roads is deteriorating, motorways and A roads lack proper maintenance and certain bridges face disaster, which means higher maintenance and repair costs for drivers of vehicles using such roads. This situation has been caused by the long-term underfunding of transport infrastructures. According to Frydryšek (2019), the SFDI financial means are sufficient at present; however, preference has shifted to rail transport due to the poor quality of road construction projects that are being designed. More money than before is allocated to reconstruction and repair. According to Tužín (2014), over 1 trillion Czech crowns are needed for the repair of hitherto neglected roads and motorways and for stopping the deterioration of the present condition of the infrastructure.

The receipts from toll in the Czech Republic amounted to 10.8 billion CZK in 2018. If the toll rates were increased by 50 % as the Ministry of Transport plans, the receipts would amount to 16 billion CZK. Czech transport operators claim that the increase in the rates would increase the prices of goods or certain carriers would close their businesses (Frouzová and Váchal, 2019).

As mentioned by ČTK (2019), the Czech Republic is an ideal transit country for heavy goods vehicles due to very low prices of fuel and tolls. This is also demonstrated by the statistics of the Centre for Economic and Market Analyses (CETA, 2019).

Table 2 Costs of toll and diesel per 100 km for vehicles over 12 t in selected EU countries in 2018

	Costs of toll in EUR	Costs of diesel in EUR	Total costs in EUR
Czech Republic	8.54	37.96	46.50
Austria	14.8	37.48	52.28
Italy	26.6	44.37	70.79
Slovakia	18.5	36.69	55.19
Germany	18.3	39.96	58.26
Belgium	15.5	43.68	59.18
Poland	22.2	36.01	58.21
Croatia	27.84	38.59	66.43

Source: CETA (2019)

Table 2 clearly shows that the costs of toll and diesel are the lowest in the Czech Republic. In Slovakia, the total costs per 100 km are 55.19 EUR, 58.26 EUR in Germany, 58.21 EUR in Poland, 52.28 EUR in Austria and 46.50 EUR in the Czech Republic. This fact accounts for the growing density of transit freight transport. The low costs motivate foreign operators to choose the Czech Republic as the transit country. It is also the significant share of industry in the GDP, which is higher in the Czech Republic than in neighboring countries, that contributes to the increase in the volume of truck traffic (ČTK, 2019).

The ever increasing overload of the transport infrastructure has negative impacts on roads, which become more and more damaged (Dopravní federace, 2014). Noise pollution, volume of pollutants and risk of traffic accidents are increasing. Fuel consumption of trucks is higher than that of cars and this results in higher dependence on the import of raw materials. In 2017, freight transport accounted for 22.9 % of CO emissions and 35.4 % of NO_X emissions of the total volume of emissions generated by transport in the Czech Republic (ISSaR, 2019). The costs of infrastructure repair and maintenance increased by 12 % from 2016 to 2017, from the amount of 16 941.9 million CZK to 18 988.6 million CZK (MD ČR, 2017). All the above facts have resulted in the increase in the volume of truck traffic and related noise, emission of pollutants, road repairs, congestions and many other problems.

IV. The model of toll based on distance traveled

Based on the above-mentioned facts regarding the planned amendment of Act No. 13/1997 Coll., Road Act by the year 2021, the initial assumption of the proposed model is the increase in toll rates and inclusion of environmental elements. The next part of the contribution deals with the construction of the new model of toll based on distance traveled in the Czech Republic. The new environmental element to be added to the existing EURO standard is the negative externality of noise. Another assumption is that the model presumes the inclusion of noise in the toll rates for vehicles with the maximum permissible weight exceeding 3.5 t in accordance with Directive 2011/76 /EU. The proposed model was inspired by the German system, which takes into account not only costs of environmental pollution and infrastructure costs, but also another significant externality, i.e. noise pollution. Another country that considers the external costs of noise in the tolls is Austria. In both the countries, the resulting rate per km of distance traveled is determined by the sum of the chargeable costs. The overview of the costs subject to charge and the feature affecting them are listed in Table 3.

Table 3 Overview of criteria affecting the resulting toll rate in Germany and Austria

	Costs of air pollution	Costs of noise pollution	Costs of infrastructure
Germany	EURO emission standard	lump sum	weight and number of axles
Austria	EURO emission standard	time of day and number of axles	number of axles

Source: Toll collect (2019) and ASFiNAG (2019)

Both countries set the costs of air pollution on the basis of the EURO standard that the vehicle meets. Germany assesses the noise costs by a lump sum under Annex IIIb to Directive 2011/76/EU; Austria differentiates them according to the time of day and number of axles. The infrastructure costs are based on the number of axles in Austria and number of axles plus vehicle weight in Germany. The proposed model of toll system in the Czech Republic uses data from 2018; all the input data from this year are available, which ensures the maximum information value of the model. It will also be possible to calculate the volume of revenues from the proposed model and to compare them with the present state. Another assumption is that the current range of the sections of roads subject to charges will remain the same for the purposes of the construction and evaluation of the model. The proposed model includes all vehicle categories that are subject to the payment of tolls in the Czech Republic nowadays. Such vehicles currently also include the subgroup of M category, i.e. buses, whose toll rates are different. The reduction of tolls for this group of vehicles will not be taken into account in the construction of the present model. The final toll rate per km traveled is constructed as the sum of individual toll rates determined for the respective pre-defined negative externalities caused by freight transport. The resulting rates will be determined through a qualified computation respecting the following parameters and procedures:

- measurement of distance traveled according to the number of axles and EURO standards both in the absolute and the relative values,
- calculation of the percentage representation of distance traveled according to the number of axles and emission class through multiplying their relative values,
- assessment of infrastructure costs through the calculation of the weighted average toll rate on the basis of currently applied rates for motorways and expressways (on Fridays 15:00 – 20:00), using the values obtained in the preceding step,
- the costs of air pollution and noise pollution will be assessed in accordance with Directive 2011/76/EU,

- the resulting toll rate will be calculated as the sum of infrastructure costs and air/noise pollution costs.

Distances traveled according to the number of axles and emission class are listed in Table 4 and Table 5.

Table 4 Distances traveled on sections subject to toll classified according to the number of axles in 2018

Number of axles	Distances traveled classified according to the number of axles (km)	Distances traveled classified according to the number of axles (%)
2	439 909 814	15.6
3	150 677 478	5.34
4	2 230 183 909	79.06
Total	2 820 771 201	100

Source: IODA (2019), own calculation

Table 5 Distances traveled on sections subject to toll classified according to EURO emission standards in 2018

Emission class	Distances traveled classified according to emission class (km)	Distances traveled classified according to the number of axles (%)
EURO 0-II	40 863 434	1.45
EURO III-IV	296 432 183	10.51
EURO V	777 176 932	27.55
EURO VI and EEV	1 706 298 652	60.49
Total	2 820 771 201	100

Source: IODA (2019), own calculation

Table 4 and Table 5 show that the total distances traveled are equal. The data differ in the emission classes and number of axles of the vehicles. This confirms the consistency of the input data concerning the distances traveled; the data may be seen as mutually supportive.

Table 6 provides the percentage representation of distances traveled combining the number of axles and emission classes. The calculation was made by mutual multiplication of the relative values in Tables 4 and 5.

Table 6 Percentage representation of distances traveled according to the number of axles and emission classes in 2018

in %	EURO 0-II	EURO III-IV	EURO V	EURO VI	Total
2 axles	0.23	1.64	4.29	9.44	15.6
3 axles	0.07	0.56	1.47	3.23	5.34
4 plus axles	1.15	8.31	21.78	47.82	79.06
Total	1.45	10.51	27.55	60.49	100

Source: own calculation

It follows from figures in Table 6 that vehicles meeting EURO 0-II with 2 axles form 0.23 % of all distances traveled by all included vehicles on charged roads in the Czech Republic. This value was calculated by multiplying the percentage representation of two-axle vehicles in the total distances traveled 15.6 % and percentage representation of vehicles meeting EURO 0-II standard in the total distances traveled 1.45 %. The results suggest that most distances were traveled by vehicles meeting EURO VI standard which have 4 and more axles, i.e. 47.8 % of all distances traveled by all included vehicles on charged roads in the Czech Republic.

Table 7 Czech toll rates payable on motorways and expressways on Fridays 15:00 – 20:00 in CZK/km

	EURO 0-II			EURO III-IV			EURO V			EURO VI and EEV		
Number of axles	2	3	4+	2	3	4+	2	3	4+	2	3	4+
Rate per km	4.24	8.10	11.76	3.58	6.87	9.94	2.33	4.46	6.46	2.12	4.05	5.88

Source: MYTO.CZ (2019)

For assessing the costs of infrastructure, the weighted average toll rate is calculated for vehicle with 2, 3, a 4 and more axles from the current toll rates listed in Table 7 through cleaning by emission classes. These emission classes are subsequently included into costs of air pollution. Because the proposed model of charging vehicles whose weight exceeds 3.5 t also aims at increasing the toll rates, the calculation of the weighted average toll rate is based on the current rates imposed on motorways and expressways in the time interval 15:00 – 20:00 on Fridays. The toll rates are higher at that time than for the rest of the week. The proposed toll rates will not be differentiated according to time and will remain at the same amounts for 24 hours a day 7 days a week. Calculation of weighted rate of toll for vehicles with the respective number of axles:

$$S_{2axles} = \frac{0.0023 \cdot 4.24 + 0.0164 \cdot 3.58 + 0.0429 \cdot 2.33 + 0.094 \cdot 2.12}{0.0023 + 0.016 + 0.043 + 0.094} = 2.36 \frac{\text{CZK}}{\text{km}} \quad (1)$$

$$S_{3axles} = \frac{0.0007 \cdot 8.10 + 0.0056 \cdot 6.87 + 0.0147 \cdot 4.46 + 0.0323 \cdot 4.05}{0.0007 + 0.0056 + 0.0147 + 0.0323} = 4.51 \ \frac{\text{CZK}}{\text{km}} \quad (2)$$

$$S_{4axles} = \frac{0.0115 \cdot 11.76 + 0.0831 \cdot 9.94 + 0.2178 \cdot 6.46 + 0.4782 \cdot 5.88}{0.0115 + 0.0831 + 0.2178 + 0.4782} = 6.55 \ \frac{\text{CZK}}{\text{km}} \quad (3)$$

Two-axle vehicles are designed for the transport of lower-weight freight and thus their impact on motorways and roads is lower than that of vehicles with 3, 4 and more axles. This fact is also confirmed by the above calculation of the weighted toll rate per km of travel along a charged section of infrastructure.

The determination of charges for air and noise pollution is regulated by Annex IIIb to Directive 2011/76/EU, which stipulates maximum external-cost charges for air and noise pollution. The costs for **noise pollution** are set as a lump sum of 0.2 euro cent in the constructed model. This maximum amount is set for interurban roads including motorways during daytime by Directive 2011/76/EU (at night, the rate is 0.3 euro cent). The model will use the rate of 0.2 euro cent for both day- and nighttime similarly to the German toll system. The amount in euro is converted to Czech crowns by average exchange rate of the year 2018 (1 EUR = 25.643 CZK) to 0.05 hellers (Kurzy.cz, 2019).

Air pollution costs are based on the EURO standard that the vehicle meets. Annex IIIb to Directive 2011/76/EU states the maximum values for each EURO standard separately; certain emission standards are joined together in the proposed model, and therefore the value for the strictest standard in the given category is considered. It means that with standards EURO 0-II, the value of maximum chargeable costs for EURO II is considered and with EURO III-IV, the value for EURO IV is applied. This is the only possible approach due to the fact that the maximum chargeable costs for the stricter EURO standard are lower than for the less strict EURO standard. On the other hand, the maximum chargeable costs for the less strict EURO standard in the given intervals are higher and if their value was chosen, the stricter EURO standard would not correspond to the maximum chargeable toll rate. Such situation would not comply with Directive 2011/76/EU.

Table 8 The amount of maximum chargeable costs of air pollution on interurban infrastructures (including motorways)

Emission class	in euro cents	in hellers *
EURO 0-II	7	1.795
EURO III-IV	3	0.769
EURO V	2	0.051
EURO VI	1	0.026

Source: Directive 2011/76/EU
* average exchange rate of 2018 (1 EUR = 25.643 CZK) (Kurzy.cz, 2019).

The resulting proposed toll rate for 1 km (TR_{1km}) is calculated as the sum of the respective costs of negative externalities, i.e. the sum of infrastructure costs (IC_{1km}), noise pollution costs (NC_{1km}) and air pollution costs (AC_{1km}). The formula (4) for calculating the resulting toll rate in the constructed model:

$$TR_{1km} = IC_{1km} + NC_{1km} + AC_{1km} \quad (4)$$

The resulting rates of the proposed model of toll system in the Czech Republic are calculated in Table 9.

Table 9 Toll rates for vehicles over 3.5 t in CZK

Emission class	Costs of air pollution (A)	Costs of noise pollution (B)	Costs of infrastructure		Total toll rate (A+B+C)	Difference from original rates in %
			Number of axles	C		
EURO 0-II	1.795	0.05	2	2.36	4.205	- 0,8
			3	4.51	6.355	- 21.5
			4+	6.55	8.395	- 28,6
EURO III-IV	0.769	0.05	2	2.36	3.179	- 11,2
			3	4.51	5.329	- 22,4
			4+	6.55	7.369	- 25,9
EURO V	0.051	0.05	2	2.36	2.461	+ 5.6
			3	4.51	4.611	+ 3.4
			4+	6.55	6.651	+ 3.0
EURO VI, EEV	0.026	0.05	2	2.36	2.436	+ 14.9
			3	4.51	4.586	+ 13.2
			4+	6.55	6.626	+ 12.7

Source: own calculation

The proposed model of toll system in the Czech Republic reflects real damage caused by individual types of vehicles and offers fairer distribution of the final financial burden. Inspired by Germany and Austria, this model takes into account the social compensation for costs generated by the negative externality of noise caused by the operation of motor vehicles subject to tolls in the Czech Republic. The model contains an increase in toll rates for vehicles in EURO V, VI and EEV categories, whose numbers using Czech infrastructure is increasing, and on the other hand, a reduction of rates for vehicles meeting EURO 0-IV standards, whose numbers are ever decreasing (see Table 5). The biggest reduction of toll rates in comparison with the present state is apparent in vehicles of EURO 0-II with 3 axles and amounts to 28.6 %. On the other hand, the biggest increase in rates if compared with the original rate is seen in vehicles in EURO VI and EEV category with 2 axles, where the rate has risen by 14.9 %. The following tables show the impact of the proposed model on toll receipts in the Czech Republic.

Table 10 Volume of distances traveled according to the number of axles and emission classes in 2018

Number of axles	EURO 0-II	EURO III-IV	EURO V	EURO VI, EEV
2 axles	6 487 774	46 260 648	121 011 085	266 280 801
3 axles	1 974 540	15 796 319	41 465 337	91 110 910
4 plus axles	32 438 869	234 406 087	614 363 968	1 348 892 788

Source: own calculation

It follows from the results in Table 10 that the biggest volume of distances traveled is attributed to vehicles in the EURO VI and EEV category with 4 and more axles. Values for the respective groups of vehicles according to the number of axles are calculated by multiplication of total distance traveled in 2018 listed in Table 4 or Table 5 and the percentage representation of the respective vehicle groups in the distance traveled according to the number of axles and emission classes calculated in Table 6.

Table 11 Receipts from tolls according to the number of axles and emission classes in CZK

Number of axles	EURO 0-II	EURO III-IV	EURO V	EURO VI, EEV
2 axles	27 281 090	147 062 600	297 808 280	648 660 031
3 axles	12 548 202	84 178 584	191 196 669	417 834 633
4 plus axles	272 324 305	1 727 338 455	4 086 134 751	8 937 763 613

Source: own calculation

Amounts of receipts from tolls based on the proposed model are calculated in Table 11 through the multiplication of the volume of distances listed in Table 10 and rates listed in Table 9. Table 12 provides comparison between the current receipts from tolls in the Czech Republic and receipts based on the constructed model.

Table 12 Comparison of current toll receipts and toll receipts based on the constructed model (in CZK)

Current rates		Proposed rates		Variation
Receipts (in CZK)	10 805 238 568	Receipts (in CZK)	16 850 131 213	+ 55.9 %
Distances subject to toll	2 820 771 201 km			
Weighted average toll rate	3.83	Weighted average toll rate	5.97	+ 55.9 %

Source: own calculation and IODA (2019)

In comparison with the current system, the proposed system of toll generates much higher receipts. The application of toll rates determined through the new model increased the total receipts by 55.9 %, i.e. from the original 10 805 million CZK to the new amount of 16 850

million CZK. The weighted average toll rate increased from 3.83 CZK/km to 5.97 CZK/km although the rates for vehicles in the EURO 0-IV category were reduced by 18.4 % in average.

IV. Conclusion

At present, the Czech Republic imposes toll (a charge based on distance traveled) on vehicles whose weight exceeds 3.5 t, a charge used by another 22 countries of the European Union. Charging vehicles over 3.5 t is regulated on the European level, the principal legal standard being Directive 1999/62/EC of the European Parliament and of the Council, also referred to as "Eurovignette" of 17 June 1999, on the charging of heavy goods vehicles for the use of certain infrastructures. The above Directive has two amendments, Directive 2006/38/EC and Directive 2011/76/EU, which introduced the possibility to incorporate environmental elements into the calculation of the resulting toll rate, and thus enhanced the importance of charges based on distance traveled in obtaining the funds for the elimination of negative externalities caused by transport. Of the 28 EU member states, charges (based on time or distance) on the operation of these vehicles in relation to the environmental element (in the form of the EURO emission standard) are imposed in 16 countries, including the Czech Republic. All member states, except for Lithuania and Bulgaria, have introduced, similarly to the Czech Republic, an environmental element in the form of EURO standards into their toll systems. Tolls are based on the distance traveled by the vehicle, and therefore the final amount of the toll, unlike vignettes, directly reflects the use of the road infrastructure.

In the Czech system, the toll rates for vehicles exceeding 3.5 t are determined on the basis of EURO emission standard, number of axles, type of road and time of day. The proposed toll model, inspired by German and Austrian systems for vehicles over 3.5 t and is based on assessment of toll rates depending on the costs of air pollution, infrastructure costs and noise pollution costs, represents a feasible system that could be introduced in the Czech Republic. According to the statement of the Minister of Transport of April 2019, the Czech Ministry of Transport intends to raise toll rates by 50 % within the framework of amending Act No. 13/1997 Coll., Road Act, and to include the negative externality of noise into the calculation. These changes should account for the increase in the toll receipts up to the amount of 16 billion CZK. The results of the constructed model in Table 12 show that both the total receipts and the weighted average toll rate have increased by more than 50 %, which is attributed to the inclusion of costs of noise pollution as well as change in the toll charge for air pollution and infrastructure construction and maintenance.

The proposed model brings a fundamental change in the distribution of rates among the respective categories of vehicles according to the number of axles. The model also supposes a significant increase in rates for vehicles of EURO V, VI and EEV categories, whose numbers using charged roads is increasing (see Table 5) and whose rates have not increased since the year 2011. There has been a reduction of rates for vehicles meeting EURO 0-II standards in the model, due to the fact that the number of such vehicles is decreasing. Such vehicles participated in the total distance traveled on infrastructures that are subject to toll by only 1.45 % in 2018. The proposed model envisages an increase in receipts from the original 10 805 million CZK to 16 850 million CZK and the weighted average toll rate increase from 3.83 CZK/km to 5.97 CZK/km, i.e. by 55.9 %.

Introduction of the proposed toll system applicable to vehicles over 3.5 t would mean that the Czech Republic alongside Germany and Austria would be one of the three European countries that would incorporate the costs of air and noise pollution and infrastructure costs into the toll system. The resulting toll rate per km traveled is calculated as the sum of toll prices according to the individual external costs of transport (see formula 4), similarly to Germany and Austria. The assessment of costs of air pollution and noise pollution is based on values stated in Annex

IIIb to Directive 2011/76/EU. The costs of infrastructure were assessed according to the number of axles based on the currently applied rates. The amounts of toll rates in the constructed model reflects not only the degree of participation of the respective types of vehicles in external costs of transport, but also the volume of distances traveled.

The proposed model of the toll system to be introduced in the Czech Republic corresponds to the intention of the public sector to implement changes in this area. The calculation of the resulting rates is based on real data concerning the current volumes of traffic on the charged sections of the infrastructure.

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