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FISCAL IMPACT OF ELECTRONIC FEE COLLECTION SYSTEM ON LONG-RUN EFFICIENCY

Summary. The transport infrastructure is extremely important for economic development and the labour mobility and competitiveness of European economy. However it is becoming increasingly difficult for government to publicly fund transport infrastructures. Therefore the decision to implement toll roads in Europe as a transport-policy instrument is an important shift in the funding of infrastructure. Adoption of appropriate technology has implications on the efficiency of the system. The mathematical model developed upon and simulations were carried out on several scenarios given the different types of technology. The results suggest that DSRC technology employed on motorways to be the most efficient.

BUDŻETOWY WYPŁYW ELEKTRONICZNEGO SYSTEMU POBORU OPŁAT NA EFEKTYWNOŚĆ DŁUGOTERMINOWĄ

Streszczenie. Infrastruktura transportowa jest niezwykle ważna dla rozwoju przemysłowego, mobilności siły roboczej i konkurencyjności gospodarki Europejskiej. Jednakże coraz trudniejsze dla rządu staje się publiczne dofinansowanie infrastruktury transportowej. W związku z tym decyzję o wdrożeniu płatnych dróg w Europie jako instrument polityki transportowej jest znaczącą zmianą w finansowaniu infrastruktury. Przyjęcie odpowiedniego metody dofinansowania ma wpływ na wydajność systemu. Model matematyczny opracowany na jego podstawie i symulacje przeprowadzono na kilka scenariuszy, biorąc pod uwagę różne rodzaje technologii. Wyniki sugerują, że technologia DSRC użyta na autostradach jest najbardziej efektywna.

1. INTRODUCTION

The European transport infrastructure is extremely important for the economic development and the workforce mobility and competitiveness of the European economy [6, 9, 3]. Increased demand for transport infrastructure and increased requirements (environment, traffic safety etc.) call for more financial resources that cannot be gained from the existing resources and funding instruments. No mode of transport can entirely cover all costs incurred (apart from motorway maintenance and toll collection costs this also includes other costs that the society takes on by implementing specific new transport surfaces: the environment, landscape utilisation). The trends for implementing toll roads do not only refer to high-standard inter-city roads – motorways and high-speed roads – but also to congested urban road networks. Whether these objectives will be met or not depends on the degree to which the users are burdened with the costs for infrastructure usage and on the funding possibilities concerning new investments. It is becoming increasingly difficult to depend solely on public funding of transport infrastructures, especially due to the growing budget deficit that many of the EU member states are facing and due to the need for more private investments in the infrastructure projects.

In Slovenia, which is the case country for our research, the state budget envisages less and less budget funds for building motorways. Therefore DARS[1] contracts more and more debts from national and international banks. In the end of year 2009 the projection of debt together with interests amounted approximately to 4,03 billion EUR [13]. The main financial source for covering the debt are toll revenues, which with the present model of road tolling (vignette system), does not provide enough funds for repayment of raised loans.

Therefore road tolls are an important part of road management. Toll revenues are an important source of financing the construction and maintenance of new roads, as well as the pricing policy in this field is an important part of the transport policy of particular countries [17]. In the market economy the construction of up-to-date designed and well placed in physical space motorways presents an effective way of how to better manage the demand for transport services and achieve more effective use of infrastructure. By implementing more efficient payment systems, economic instruments (taxes, fees or emission trading systems) can encourage users of transport services either to use cleaner vehicles or transport modes and use less congested infrastructures, or to travel at different times [11]. To this end, the pricing policy in this area presents an effective way for achieving sustainable mobility.

An optimal road tollsystem is the one that on one hand is acceptable and fair to the users of motorways and on the other hand efficient and economical to the society as a whole. The basic premise when planning toll roads is the so called fair toll system principle [15], i.e. equal burdening of all motorway users based on the driven distance. One needs to take into account that the aim is to maximize potential toll revenues and benefit national economy. Therefore several different technologies can be used. In some cases well known and sophisticated GNSS (Global Navigation Satellite System) technology combined with CN (Cellular Network) telephony is used, while in other is used relatively simple but efficient DSRC (Dedicated Short-Range Communications) technology which some years ago was developed especially for the purpose of road telematics. Although the aim of using each of the technologies is the same (to maximize the potential toll incomes) the systems based on different technologies differ in many aspects.

In the paper we are considering the problem of efficiency among the discussed systems. The efficiency will be defined regarding the objective set, which is in our case financing of the construction and maintenance of new roads without causing negative multiplicative effects on national economy, but at the outmost positive.

The paper is organized as follows. Section 2 outline the problem and input parameters which influence the income. Section 3 introduces the mathematical model of the income, depending on previously defined input parameters. The simulation of different technologies is presented in section 4. Sections 5 and 6 discuss the analysis and concludes.

2. MOTIVATION TO STUDY

Optimal road tolling system introduced in all EU countries has to be in accordance with European directive 2003/58/EC and with the findings of the projects MEDIA, CESARE II in CESARE III Cesare. If we sum up all requirements into a few lines, we can state the following. The final solution has to [4]:

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[1] DARS – Motorway Company in the Republic of Slovenia is a joint-stock company, 100 % owned by the state. In accordance with the decisions of the National Assembly of the Republic of Slovenia (see ReNPIA), DARS d.d. is in charge of financial engineering, preparing, organizing and managing construction and maintenance of the motorway network, and is responsible for the management of motorways as well as for the repayment of raised loans.

- enable toll payments without stopping or slowing down the user,
- enable interoperability and be applicable in all EU member states,
- to a certain degree ensure control over misuse and enable collection of debt.

Considering all above mentioned it is clear that choosing the appropriate technology for establishment of road tolling is not an easy decision and it does not depend only on the character of the technology itself but also on the efficiency of the system. Efficiency of the road tolling can be measured regarding the extent it suits the above mentioned demands and how much funds contributes into the national budget[2]. The factors that influence the efficiency of the system are both, the ones that depend on the selected technology and the ones that do not depend on the selected technology. The toll rate and number of vehicles are not influenced by the technology, while other factors are influenced directly or indirectly. Fixed and variable costs depend on the selected technology and are rising in accordance with increase of length of the road tolling roads.

In continuation of the paper we will present the model for calculation of the road tolling system profit in selected time frame. We will compare the use of different systems, which are based on different technologies while the inputs are the same. Further we will show how the use of different technologies reacts on different input parameters (different lengths of the road tolling roads, different number of vehicles, etc.). We will show the mathematical model build for this purpose and the results.

3. MATHEMATICAL MODEL

3.1. Basic idea of the model

The amount of tolls collected for a specific road section depends on the number of vehicles on that section, toll rates[3] and number of kilometers covered on that section. That can also be expressed as $n_i \cdot T \cdot s_i$ [4] whereas n_i is the number of vehicles on i-th section, T is the rate and s_i the number of kilometers covered on this section. The total revenue on all k section of tolled network is therefore $\sum_{i=1}^{k} n_i \cdot T \cdot s_i$. The net income contributed into the national budget after one year of collection, can be expressed as:

$$\mathrm{Re}v = \sum_{i=1}^{k} n_i \cdot T \cdot s_i - COST, \tag{1}$$

where the term $COST$ means on yearly bases (for the abbreviation $O_{yb} = OPEX$ and $C_{yb} = CAPEX$ on yearly bases). As we are interested in long-run efficiency we define the revenue for each of l years of modelling, which is dependent of traffic growth Tg, inflation Inf and changes of toll rates Ctr each year. Revenue of year l is expressed as:

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[2] Or into the purses of concessionaires when the road is not administered by the state.

[3] Euro/km, it differs regarding the category of vehicle and road.

[4] Revenue from road tolling depends (see table on the number of vehicles that use the road tolling road, number of kilometers covered and the rate defined for the covered kilometer of the road tolling roads. In the detailed calculation it is needed to consider different categories of vehicles as well as different categories of roads and appurtenant rates. In general $\mathrm{Re}w$ in $i-th$ section is calculated through $\mathrm{Re}w_i = n_i \cdot T \cdot s_i + Num \cdot T_{vi} \cdot PT_{vi} \cdot Pen$. The item Pen can be added to the income, only when the toll manager is the penalty fee collector. This kind of regulation is known in Austria where the violator is fined by the manager Asfinag. If the violator does not cover the penalty fee the case is handed over to the police who consider it as the minor offence and the penalty fee is added to the income of state budget. In our case we do not have this kind of regulations and because of that we use only $\mathrm{Re}w_i = n_i \cdot T \cdot s_i$ for calculation of the income.

$$Rev_l = \sum_{i=1}^{k} n_i \cdot \left(1+\frac{Tg}{100}\right)^{l-1} \cdot T \cdot \left(1+\frac{Ctr}{100}\right)^{l-1} \cdot s_i - \left(O_{yb}\left(1+\frac{Tg^{(l-1)}}{100}+\frac{Inf^{(l-1)}}{100}\right)+C_{yb}\right). \tag{2}$$

However as we would like to show the present value $Rev_l(PV)$ of revenue of year l we have to discount it with discount ratex d [8].

$$Rev_l(PV) = Rev_l \cdot \left(1+\frac{d\cdot l}{100}\right). \tag{3}$$

Not with standing the revenue gives an important information about the toll system, it is not the adequate value for measuring the efficiency of the system. Fundamental is a constant comparison between expected benefit and best possible benefit which appears only in ideal conditions (in our case only if $COST = 0$). Hence we define the efficiency rate ρ_l as follows:

$$\rho_l = \frac{\left(\sum_{i=1}^{k} n_i \cdot \left(1+\frac{Tg}{100}\right)^{(l-1)} \cdot T \cdot \left(1+\frac{Ctr}{100}\right)^{(l-1)} \cdot s_i - \left(O_{yb}\left(1+\frac{Tg^{(l-1)}}{100}+\frac{Inf^{(l-1)}}{100}\right)+C_{yb}\right)\right)}{\left(\sum_{i=1}^{k} n_i \cdot \left(1+\frac{Tg}{100}\right)^{(l-1)} \cdot T \cdot \left(1+\frac{Ctr}{100}\right)^{(l-1)} \cdot s_i\right)}, \tag{4}$$

where the fraction numerator is estimated revenue of year l and denominator is ideal revenue. With this we get the value of which relation express the best the efectivenes of the system. The greater the r, more effective the system.

3.2. The structure of COST

Allthough it looks like the ρ_l depends entirely of n_i and T, this is not the case. The biggest influence on ρ_l has the expression $\left(O_{yb}\left(1+\frac{Tg^{(l-1)}}{100}+\frac{Inf^{(l-1)}}{100}\right)+C_{yb}\right)$ which represents the yearly overall cost of the system. O_{yb} and C_{yb} are the quantities which affect the most the total cost of the system and strongly depend on the system scale (see the eqn. 5 and 6). The larger is the system, the bigger are O_{yb} and C_{yb} which increase the overall cost. The ratio between the increase of the cost and the increase of income, caused by the enlargement of the system is not constant and depends on the technology used in the system. Therefore the CAPEX and OPEX are explained more in detail in the following section.

CAPEX

Fixed yearly costs depend on the items presented in the Table 1.
Formally CAPEX can be expressed as:

$$C_{yb} = (TS + ES + CS + PS + OBU + WAN + MM) \tag{5}$$

Costs of building the tolling stations and control stations, costs of WAN network and the points of sale are all in relation with the dimension of the network of tolling roads, in our case with s_i (the relations are explained in Table 2. The costs of setting-up the cartographic system and setting-up the central system are more or less constant for all sizes of the observed system. The cost of providing OBU units are entirely dependent on number of vehicles using road tolling roads. The number of vehicles using road tolling roads is estimated considering the numbers provided by Slovenian Roads Agency. These numbers are collected by occasional vehicle counting and permanent counting stations.

Table 1

Fixed and variable costs of ETC system

	CAPEX
TS	costs of building the tolling stations
ES	costs of building the control stations
CS	costs of setting-up the central system
PS	costs of building the points of sale
OBU	costs of OBU units
WAN	costs of WAN network
MM	costs of setting-up the cartographic system
	OPEX
OOTS	operational costs of the tolling stations
OOES	operational costs of the control stations
OOCS	operational costs of the central system
OPS	operational costs of the points of sale
OOBU	operational costs of OBU units
OWAN	operational costs of WAN network
OMM	operational costs of the cartographic system

OPEX

Similarly as CAPEX also OPEX can be expressed formally:

$$O_{yb} = \left(OTS + OES + OCS + OPS + OOBU + OWAN + OMM\right) \tag{6}$$

From the equation and the Table 1, it is evident that variable costs in the model depend on the operational costs of items defined in CAPEX. Since the OPEX costs are hard to project in advance, they have been estimated on the basis of experience gained from neighbouring countries which are already using the similar system (i.e. Czech Republic, Austria, Slovakia).

4. SIMULATION

The computer simulation is based on the mathematical model presented in previous section. In the mathematical model we will simulate profit regarding different input instances. We named the simulation with the same input instance the scenario. Regarding the input we have 5 different scenarios.

4.1. Hypothesis testing

According to facts presented in previous sections we set the following hypothesis on the test: “the total length of the road tolling roads and the chosen technology affect the effectiveness of the road tolling system”.

Among all possible choices we selected the five scenarios (see Table 2). The length of the road tolling roads were chosen according to the present situation in Slovenia, which has 607 km of motorways, additional 491 km of first category roads which are parallel with motorways and 466 km of second category roads. The input parameters for the first three scenarios were the same, but the parameters for the fourth and fifth scenario were different. We changed the input parameters in order to see how the system reacts to the combination of existing system and the new system. The input parameters for different scenarios are explained in the Table 2.

Table 2

Comparison of input in different scenarios

Model Item	scenario 1	scenario 2	scenario 3	scenario 4	scenario 5
Road tolling for cargo vehicles	√	√	√	√	√
Road tolling for private vehicles	√	√	√	-	-
Vignette system for private vehicles	-	-	-	√	√
Total length of road tolling roads; (s)	$607km$	$1089km$	$1555km$	$1089km$	$607km$
Number of OBU for private vehicles	$3mio$	$3mio$	$3mio$	-	-
Number of OBU for cargo vehicles	300.000	300.000	300.000	300.000	300.000
Number of sold half-year vignettes	-	-	-	$2mio$	$2mio$
Number of sold yearly vignettes	-	-	-	$1mio$	$0{,}75mio$
Yearly traffic growth, $(Tg);[\%]$	7,3	7,3	7,3	7,3	7,3
Number of tolling stations, $\frac{s}{8{,}5}=x$	72	394	890	394	72
Share of control stations; $(\%)$	15	15	15	15	15
rate / covered kilometer, private vehicles; $(T),[EUR/km]$	0.077	0.077	0.077	-	-
rate / covered kilometer, cargo vehicles $3{,}5-7{,}5t$, $(T),[EUR/km]$	0.141	0.141	0.141	0.141	0.141
rate / covered kilometer, cargo vehicles $>7{,}5t$, (T), $[EUR/km]$	0.205	0.205	0.205	0.205	0.205
time of modeling	10 years	10 years	10 years	10 years	10 years

The calculated (according to the equation 1) efficiency rates are shown in the Table 3 and discussed in the following section.

5. RESULTS ANALYSIS

After the analysis of calculation of efficiency upon all five scenarios we gained the results as seen in Table 3 which graphically presents calculated efficiency rates for five different scenarios over ten years of modelling. Bold-faced typed values in scenario 1 DSRC show that DSRC technology is the most efficient. The figure 1 which graphically presents the income for five different scenarios over ten years of modelling shows that the scenario 2 DSRC and 3 DSRC provide higher net income and are therefore more in accordance with the goals to be achieved, as stated in the beginning of the paper. Examining the figure 1 in detail, we can see that the net income gained with the scenario 1 DSRC, 2 DSRC and 3 DSRC is much higher than the annual debt. Also the scenarios 2 GNSS, 3 GNSS, 4 DSRC and 5 DSRC give better results than the present system in the terms of net income.

According to the calculated results we can conclude that the most systems presented in 5 scenarios are better than the present system, but according to the goals set on the beginning of the paper we would suggest the DSRC technology. However when we compare the length of road tolling roads the picture is not as clear anymore.

Table 3

Efficiency rates by years and by scenarios for both used technologies expressed.
The best rates are shaded

Scenario	Technology	2011	2012	2013	2014	2015
No.1	DSRC	0,96	0,96	0,97	0,97	0,97
	GNSS	0,56	0,63	0,69	0,73	0,76
No.2	DSRC	0,95	0,95	0,95	0,96	0,96
	GNSS	0,76	0,79	0,81	0,83	0,85
No.3	DSRC	0,91	0,91	0,92	0,92	0,93
	GNSS	0,74	0,78	0,80	0,82	0,84
No.4	DSRC	0,89	0,90	0,91	0,92	0,92
	GNSS	0,91	0,92	0,93	0,93	0,94
No.5	DSRC	0,94	0,92	0,95	0,96	0,96
	GNSS	0,88	0,96	0,91	0,91	0,92

Scenario	Technology	2016	2017	2018	2019	2020
No.1	DSRC	0,97	0,97	0,97	0,98	0,98
	GNSS	0,79	0,81	0,83	0,85	0,86
No.2	DSRC	0,96	0,96	0,97	0,97	0,97
	GNSS	0,86	0,87	0,88	0,89	0,90
No.3	DSRC	0,93	0,94	0,94	0,95	0,95
	GNSS	0,86	0,87	0,88	0,89	0,90
No.4	DSRC	0,93	0,93	0,94	0,94	0,95
	GNSS	0,94	0,95	0,95	0,95	0,96
No.5	DSRC	0,96	0,96	0,97	0,97	0,97
	GNSS	0,93	0,93	0,94	0,94	0,95

6. CONCLUSION

Various authors have studied different aspects of road tolling system. For instance paper [16] is evaluating the effects of traffic management on fuel efficiency and paper [12] is discussing traffic patterns under various pricing regimes. As well we can find a study about congestion pricing systems and issues surrounding short-run and long-run marginal cost pricing in the paper [14]. Paper [10] is discussing the question whether the tolls regarding the vehicle type, relative to each other, are appropriate and consistent with economic theory. But there is no study which would discuss the impact of the selected technology and selected length of road tolling roads on the long-run efficiency of the system.

As evident from the facts and presumed conditions, presented in the paper, for the purpose of road tolling, the DSRC technology is much more efficient than the GNSS technology. However the technology itself is not disputable for quite some time as all the technologies used for the purpose of road tolling at present are on a very high level of development. More important factors when deciding for the road tolling system are cost efficiency of the system, reliability of the system, capacity of the system and capability of the system to collect as much toll as possible etc. [7,5]. The system founded on the GNSS technology depends on a high degree on the GPS navigation system on which the operators and concessionaires or particular countries where the road tolling is performed, do not influence. Also the transfer of data depends on a high degree on the mobile telephone providers. While the system operation on the basis of the DSRC technology entirely depends on the road tolling manager which also owns the infrastructure and is responsible for collecting the toll.

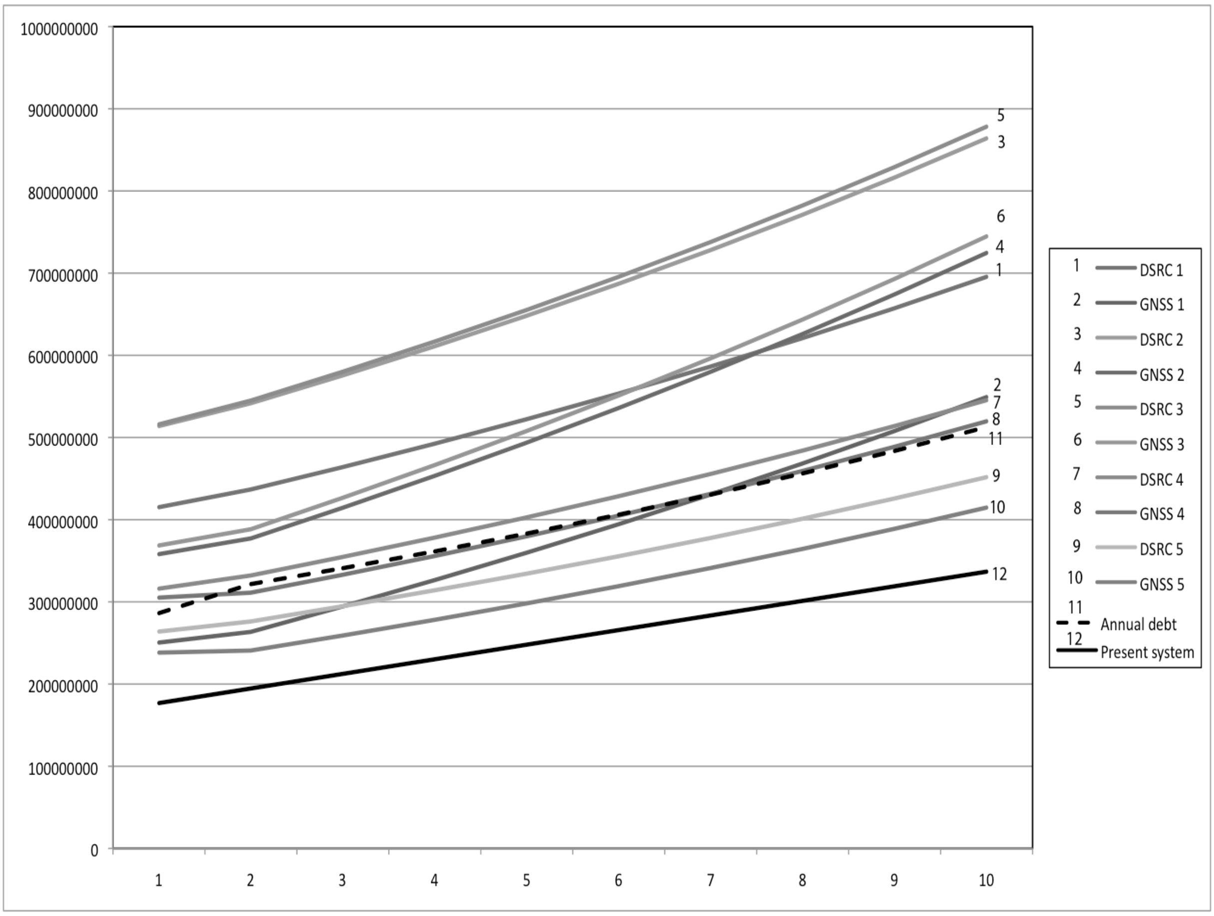

Fig. 1. The net income for five different scenarios using two different technologies compared with present system and the annual debt

Rys. 1. Dochód netto dla pięciu różnych scenariuszy z użyciem dwóch różnych technologii w porównaniu z obecnym systemem i rocznym zadłużeniem

Although cost analysis showed bigger efficiency of the system based on DSRC technology, this sometimes is not sufficient to make a decision. Therefore it is reasonable to choose the system which wills less possible influence the transfer of costs into prices of transport services, which can have negative consequences on the national economy. The experience of countries which already implemented one of the possible forms of electronic road tolling shows that the microwave system offers solutions more cost advantageous for consumers. Therefore also the probability of transfer of the costs into prices of transport is lower and with it the rise of prices of transport less probable.

Regarding the net income the Scenario 1 DSRC is not the most favourable (more favourable are the Scenarios 2 DSRC and 3 DSRC) however it is most efficient regarding the defined Efficiency rate and most close to the realistic expectations of which roads should be included into road tolling. As it corresponds to the traditional comprehension of road tolling in which the road tolling is adaptable only for high standard roads, the solution is highly reliable. Therefore the Scenario 1 needs to be considered as the credible base for realistic solution but the decision for selecting the road tolling system is and will be political.

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