BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS

DEPARTMENT OF TRANSPORT ECONOMICS

TRANSPORT SCIENCES PHD PROGRAM

Developing the implementation strategies on which the modernisation of road transport pricing schemes are based

overview of Ph.D. thesis

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1. BACKGROUND AND ACTUALITY OF RESEARCH STUDY

In the last few thousand years nature gave humanity a stable base of living and gave almost infinite supply to reserve the biosphere. In early ages humanity made changes to the environment with limited technology, but the rate was infinitesimal compared to the size of the natural environment. Global changes were not detected. In the last two or three hundred years there was an explosion in the development of industrial and technical sector, which gave people a multiplied set of tools to encroach nature. The motorisation has been developed so dynamically that the air, soil, water pollutions are considerable to the amounts of air, soil, water of Earth

The sustainable development is a development, where the pace of technical development, the satiation of increasing supply and the raw materials and resources of Earth are poised so that the rate of living and opportunities of the next generations need not to be worse.

The amounts of emissions from road traffic have enough impact on the environment to be taken seriously. Many traffic emissions come only through the exhaust pipe.

The vehicles used nowadays are polluting. Most of them are converting fossils to mechanical energy and during the conversion 40% of the fossil energy is converted to garbage energy, thereby heating our environment. For this reason transportation systems must be developed and standardized, the effectiveness of transportation service must be increased, while the environmental pollution must be decreased or prevented.

2. OBJECTIVE AND METHOD OF THE RESEARCH

Nowadays there is a common social will to develop and introduce a socially equitable system for reducing the distorsion of market. Externalities according to the EU guideline: „Users should pay the bill" should be internalised and indicated in the cost of transportation. The base of internalised cost is the marginal cost. The aim of this Ph. D. dissertation is to develop the theory of the modernisation of road transport pricing schemes especially focusing on the speciality of central European region. To develop such a strategy it was necessary to take into consideration some other EU guidelines:

- Economically sustainable development

- Form a sustainable transport system

The further steps of the research are determined by the road transport pricing strategy within the strategy of transport sector. For this reason it is requisite to emphasis the conception of EC:

- „polluter pays principle" theory,
- make the financial transparency,
- decoupling the growth of transport demand from economical development

In my dissertation, the main objective was to analyse the possibilities of implementing a new pricing method. In the first step I made analysis about the pricing methods, internalisation and monetarisation.

I analysed the parameters of emission of road passenger transport, and factors that influence motorisation. One part of them comes from economical activity, but realistically based on social development. I dealt also with the complexity of environmental emission caused by the road transportation. My goal was to analyse the influence of road price regimes on modal choice and environmental impact.

Finally, I analysed the possibilities of implementation of road price regimes based on EU guidelines.

3. NEW SCIENTIFIC RESULTS

1. I investigated the connection between economical activity, motorisation and environmental pollution.

There is a strong relation between economical activity and motorisation. Although until now it has been unclear, weather the increase of economical activity affects motorisation or the increase transport demand induces the economical activity. One effect is clear, the increase of motorisation affects our environment, and there is a loop back, our environment has an effect on transportation.

I have analysed the relation between the environment, the economy and motorisation. I have begun with Simon Kuznets' (1901-1985) work (1) with Hungarian dataset 1975-2005:

(1) $$\ln(Y_t) = \delta_0 + \delta_1 \cdot \left(\ln\left(\frac{GDP}{LAK} \right)_t \right)^2 + \delta_2 \cdot \ln\left(\left(\frac{GDP}{LAK} \right)_t \right)$$

where:

Y: environmental pollution [CO_2e kg/person],
t: years,
GDP: Gross Domestic Product [USD/person/year]
LAK: inhabitants [persons],
d_i: weights, assuming that $\delta_1<0$ and $\delta_2>0$
d_0: the environmental impact that can not be explained by economical activity [CO2e kg/person/year]

Before I could add the motorisation factor, I have analysed the correlation of motorisation and economical activity. I have found strong correlation between among them, so when I added the degree of motorisation (2) to provide a link between environmental pollution, economical activity and motorisation I have examined the cross-correlation of motorisation and economical activity:

(2) $$\ln(Y_t) = \alpha_0 + \alpha_1 \left(\ln\left(\frac{GDP}{LAK} \right)_t \right)^2 + \alpha_2 \ln\left(\left(\frac{GDP}{LAK} \right)_t \right) + \alpha_3 \ln\left(\left(\frac{MOT}{LAK} \right)_t \right)$$

where:

Y: environmental pollution [CO_2e kg/person/year],
t: years,
GDP: Gross Domestic Product [USD/person/years],
LAK: inhabitants [person],
MOT: number of private cars,
a_i: weights, assuming that $a_1<0$ and $a_2>0$ and $a_3\geq0$,
a_1: the environmental impact that can not be explained by economical activity nor by the motorisation [CO2e kg/person/year]

I could prove with the extended Kuznets model that the dramatically increasing motorisation is a determining part of environmental pollution. I have compared the results of the extended Kuznets model with a multi-linear model (3):

(3) $$Y_t = \beta_0 + \beta_1 \cdot \left(\frac{GDP}{LAK} \right)_t + \beta_2 \cdot \left(\frac{MOT}{LAK} \right)_t$$

where:

Y: environmental pollution [CO_2e kg/person/years],
t: years,
GDP: Gross Domestic Product [USD/person/year],
LAK: inhabitants,
MOT: number of private cars,
b_i : weights, assuming that $\beta_0\neq0$,

b_0: the environmental impact that can not be explained by economical activity or motorisation [CO_2e kg/person/years].

Having linearised the problem the effect of motorisation on environmental pollution became more significant. When examining the possibility of adaptation of EKC (Environmental Kuznets Curve) the problem arises how effectively GDP reflects the real evolution of society and economy. This problem led me to exchange the GDP to HDI (Human Development Index) and test the modified Kuznets model and the multi-linear model as well.

$$\ln(Y)_t = \alpha'_o + \alpha'_1 \cdot (\ln(HDI)_t)^2 + \alpha'_2 \cdot \ln(HDI_t) + \alpha'_3 \cdot \ln\left(\left(\frac{MOT}{LAK}\right)_t\right) \quad (4)$$

where:

Y: environmental pollution [CO_2 kg/person/year],
t: years,
HDI: Human Development Index,
LAK: inhabitants,
MOT: number of private cars,
a'_i: weights assuming that $a_1<0$ and $a_2>0$ and $a_3\geq 0$,
a'_0: the environmental impact that can not be explained by social development nor by the motorisation [CO2e kg/person/year]

The model that has been extended with motorisation and modified with HDI has remained of an upside-down U shape, as the original one. That means the environmental pollution depends not only on social development, but on the development of motorisation as well.

Finally I have analysed the connection between the development of society, motorisation and environmental pollution with a multi-linear model.

$$Y_t = \beta'_0 + \beta'_1 \cdot (HDI)_t + \beta'_2 \cdot \left(\frac{MOT}{LAK}\right)_t \quad (5)$$

where:

Y: environmental pollution [CO_2 kg/person/year],
t: years,
HDI: Human Development Index,
LAK: inhabitants,
MOT: number of private cars,
b_i : weights, assuming that $\beta'_o \neq 0$,
b'_2: the environmental impact that can not be explained by social development nor by the motorisation [CO_2e kg/person/year].

Having linearised the problem, the effect of motorisation on environmental pollution became more significant where the social development was higher.

Table 1.
Comparism of models

Nr.	Description	Extended with motorisation	Modified with HDI	R^2
1	Original Kuznets	-	-	0,728
2	Extended Kuznets	+	-	0,811
3	Extended linear	+	-	0,753
4	***Extended and modified Kuznets***	+	+	***0,856***
5	Extended and modified linear	+	+	0,782

2a. I designed a model based on the EURO environmental groups that can calculate the cost of local environmental pollution caused by road transportation.

The modern system of transportation should be sustainable from an economical, a social and an environmentally aspect. The dynamically increasing demand of mobility resulted in the increase of environmental pollution.

In this model I have grouped the flow of vehicles by EURO environmental groups.

(6) $\sum_{i=1}^{n} g_{ij} = a_j$ *j=1, …, m* number of vehicles in EURO *j* category

(7) $\sum_{j=1}^{m} g_{ij} = b_i$ *i=1, …,n* $\begin{cases} M_i^{\cdot} & \| i:1..3 \\ N_{i-3}^{\cdot} & \| i:4..6 \end{cases}$ number of vehicles in type

(8) $\underline{\underline{G}} = \begin{vmatrix} g_{11} & g_{1j} & g_{1m} \\ g_{i1} & g_{ij} & g_{im} \\ g_{n1} & g_{nj} & g_{nm} \end{vmatrix}$

where: g_{ij} number of private cars based on (6) and (7).

I used an emission factor to estimate the environmental pollution of road transportation. I have investigated the domestic environmental tests for private cars, for the possibility of adaptation, but I did not find it usable, because of the complexitivity of private car specific data. The emission factors are based on the EURO environmental system, which has become more and more rigorous by the time.

Finally, with the number of vehicles and the emission factors and distance, the emission can be calculated.

(9) $$L_i = \sum_{m=1}^{p} g_m \cdot l_m \cdot d_m$$

g: number of vehicles in the group
l: emission factor of the group
d: distance

2b. I expanded the model with a module that calculates the cost of global pollution of a vehicle flow.

I have designed this module only for petrol and diesel oil driven cars. My idea was to overestimate the produced carbon-dioxide supposing perfect burning. So the carbon-dioxide produced could be estimated chemically. For petrol:

(10) $$C_8H_{18} + \frac{25}{2}O_2 \rightarrow 8CO_2 + 9H_2O$$

For diesel oil:

(11) $$C_{14}H_{30} + \frac{43}{2}O_2 \rightarrow 14CO_2 + 15H_2O$$

From 1 mol, that is 114 g of petrol 8 mol that is 352g of carbon-dioxide is produced, and from 1 mol, that is 198g diesel oil 14 mol, that is 616g carbon-dioxide is produced.

I have supervised the model using the report of the Hungarian Road Transportation Authority from 2004. In this report there the 20 most popular private cars in Hungary are listed. I have analysed the data, and got to the point that the estimation module operates correctly.

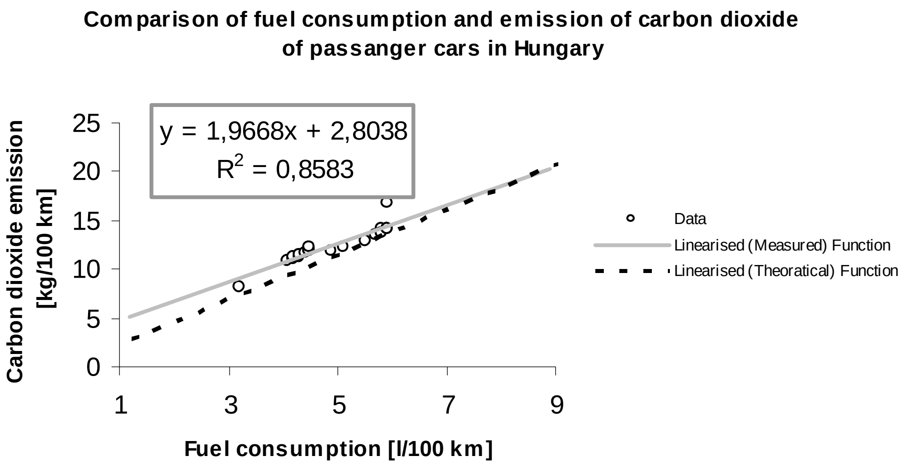

Figure 1. Comparism of fuel consumption and CO_2 emission of 20 most popular private cars in Hungary

3. I analysed the complex conditions of modal choice, particularly the marginal social price method based on environmental centered society.

There are some EU funded researches and development projects that deal with the social cost and with the marginal social cost of transportation.[1]. In the future EU will base its road pricing guideline on the results of these projects. In this field many have tried to properly determine the cost factors.

In the Hungarian literature there are several articles published using different approaches. The aim of my thesis is to get an overview of implementing the cost of environmental pollution into the marginal cost based system. In my PhD dissertation I will only deal with inter urban transportation, based on graph-theory.

To determine the price of a transportation link, we have to determine not just the total cost of transportation but the total marginal cost of society. To determine the marginal cost of society we have to divide it into two parts:

- the time and vehicle operating resource costs directly associated with driving the length of the link in prevailing traffic conditions (the marginal private resource cost), and
- the costs imposed on society, i.e. the change in the total delay caused to all others on the link, and *total* change in vehicle operating resource costs faced by others on the link (the marginal external resource cost) by a marginal vehicle.

The marginal private resource cost represents those costs directly falling to the traveler, measured in terms of the resources consumed. Where different traveler types (user classes) are distinguished to represent different trip purposes or income groups and/or where information on varying vehicle occupancies is available.

The marginal external costs can be broken down into three parts:

- the rise in the time spent travelling by other link users (X(T));
- the change in the vehicle operating costs of other link users (X(C));
- and other changes in external costs such as environmental externalities (X(O));

The marginal external costs associated with environmental / other externalities can be complex to calculate. For the purposes of modeling they could be approximated as an external cost per vehicle kilometre.

International researches found that the air pollution has the worst impact on environment. The real price of transport should be the difference between marginal social cost and perceived private

[1] UNITE **Unification of Accounts and marginal cost for Transport Efficiency - Pilot Accounts for Hungary, Brussels, 2002;**
HEATCO **(Developing** H**armonised** E**uropean** A**pproaches for** T**ransport** CO**sting and Project Assessment) financed by EU 6. Framework (ref. number: SSP8B/502481/2003);**

cost. Nowadays working toll collecting systems are to lower traffic jams on a particulate road or zone, but not to provide the real cost of transportation.

Once a price has been levied, the demand for use of the link will change, as will the private and social costs. Consequently the price calculation problem needs to be solved iteratively. This analysis assumes that fuel duty will continue to be levied as now and thus the resultant equilibrium prices may be positive or negative. In congested conditions, where the marginal external costs are large, prices will be positive. In un-congested conditions, where the marginal external costs are minimal, the prices will be negative.

To summarize from the model of marginal based cost pricing the choice of transportation mode depend on the price, travel time, walking time, waiting time, and comfort, but not depend on environmental pollution. Yet the environmental pollution has not been shown in the price of transportation.

4. I adopted a linear algebrical, discreet binary logit, multicriteria decision making model for decision making in transport modal choice.

The analysis of road transportation has become more and more important in the last 25 years. Model means a similar description of reality, helps to understand the complex, real systems. My aim was to model the human decision making, from the point of view of model choice. Because of the complexity of the system I simplified it. A model works with some assumption, and we have to understand the behavior of the model to be able to use it for predestination, forecasting. To analyse a decision we have to know what has been chosen, and why that has been not chosen. Analyzing the choice of an individual requires the knowledge of what has been chosen, but also of what has not been chosen. Therefore, assumptions must be made about options, or alternatives, that were considered by the individual to perform the choice. The set containing these alternatives, called the choice set, must be characterized.

Here I must add that it would be worth to analyse why one or more modes of transportation were not included in the choice set.

When analysing a problem, we have to identify the attributes that have effects on the decision. All the alternatives must be considered by the attributes. These can be in a transport modal choice model the travel time, the comfort, or the travel price. An attribute is not necessarily a directly observed quantity. It can be any function of available data. For example, instead of considering travel time as an attribute, the logarithm of the travel time may be considered. The out-of-pocket cost may be replaced by the ratio between the out-of-pocket cost and the income of the individual.

The definition of attributes as a function of available data depends on the problem. Several definitions must usually be tested to identify the most appropriate [Kov05].

At this point, we have identified and characterized both the decision-maker and all available alternatives. We will now focus on the assumptions about the rules used by the decision-maker to come up with the actual choice. Different sets of assumptions can be considered, that leads to different family of models. In my dissertation I will focus on the neoclassical economic theory, based on utility. The concept of utility associated with the alternatives plays an important role in the context of discrete choice models. However, the assumptions of neoclassical economic theory present strong limitations for practical applications. Indeed, the complexity of human behavior suggests that a choice model should explicitly capture some level of uncertainty. The neoclassical economic theory fails to do so [Sip06].

In the dissertation I used a utility based modified logit model. The basic idea is that the decision maker will choose from the choice set, to earn the maximal utility. From the model the possibility that the decision maker will choose i. from the alternatives J :

(12) $$P_i = \frac{e^{U_i}}{\sum_{j \in J} e^{U_j}}$$

In this case the disutility is the total cost of transportation. My method only differs by the utility function from the well known logit models. I used some elements that can be hardly monetarised, or cannot be implemented.

My aim was to build a consistent model that describes the local and global air pollution of interurban road transportation and helps to develop a righteous toll system. In international practice there are well developed and multi parametered estimation processes, but because of the domestic situation – lack of information, lack of institutional background [Tan03] – they are not or hardly working. Here Kövesné Dr. Éva Gilicze [Gil75a, Gil75b], Dr. Monigl János [Mon98] worked on modeling the modal choice of passenger transportation, and Szilárd Ajtay [Ajt04] and Dr. Szlávik János worked on the environmental pollution of road transportation in Hungary.

5. I designed an analysis for the modal choice limit-point with partial sensitivity analysis.

Sensitivity analysis is the study of how the variation in the output (deciding of using another mode of transportation) of a model can be apportioned, qualitatively or quantitatively, to different variation of inputs (travel time, and travel cost). The analysis gave me the expected, international results. Those who travel on coach or train are more sensitive to travel cost, and those who travel on car are most sensitive to travel time.

From the point of view of environmental air pollution it is very important to further analyse the critical point of modal choice between coach and private car. Critical modal choice point $U_{szgk} = U_{busz}$

(13) $U_{szgk} - U_{busz} = 0$

(14) $$(w_{13} \cdot \frac{1}{C_{szgk}} + w_{14} \frac{1}{T_{szgk}} \cdot + w_{15} \cdot \frac{1}{L_{szgk}}) - (w_{16} \cdot \frac{1}{C_{busz}} + w_{17} \cdot \frac{1}{T_{busz}} + w_{18} \cdot \frac{1}{L_{busz}}) = 0$$

(15) $$w_{13} \cdot \frac{1}{C_{szgk}}(1 - \frac{w_{16} \cdot C_{szgk}}{w_{13} \cdot C_{busz}}) + w_{14} \cdot \frac{1}{T_{szgk}}(1 - \frac{w_{17} \cdot T_{szgk}}{w_{14} \cdot T_{busz}}) + w_{15} \cdot \frac{1}{L_{szgk}}(1 - \frac{w_{18} \cdot L_{szgk}}{w_{15} \cdot L_{busz}}) = 0$$

From that:

(16) $\frac{w_{16} \cdot C_{szgk}}{w_{13} \cdot C_{busz}}$ weighted travel cost coefficient

(17) $\frac{w_{17} \cdot T_{szgk}}{w_{14} \cdot T_{busz}}$ weighted travel time coefficient

These coefficients are derived from the utility of public and individual road transportation. They are designed to characterise the border point of mode choice.

5. EXPEDIENCE OF NEW SCIENTIFIC RESULTS, POSSIBILITY OF FURTHER RESEARCHES

The models I elaborated can help to understand the effects of internalizing the external costs of climate change and environmental emission of road transport sector. Parallel to internalisation, the share of road transport in modal split will be decreasing – according to the EU directives. In the model I have dealt with utility based mode choice modeling, for modernisation of road transport pricing. In this modernisation I have added to the road price the external cost of local and global environmental impacts.

I have modeled 3 different scenario based on the 2000-2005 Hungarian dataset between Gyor and Budapest. Firstly I have done the do nothing scenario. The result – as I have expected – was the growing share of passenger car transportation against coach and train transport. Secondly I have added an extra fee of average environmental emission. Thirdly I have built up a differential price regime that is based on EURO environmental category and cubic capacity of motor. From the results it can be seen that for EU guideline (user pays the bill / polluter pays) the most adequate model is the third model with differential pricing.

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