Investigating the effects of transport safety- and infrastructure- development with the use of SCGE models in the material flows

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Abstract—Spatial general equilibrium models are worldwidely used for investigating the effects of transport investments. SCGE models can improve the weak points of CBA analysis and quantitative measurement tools. Useability of SCGE models are proven in dozens of case studies. The research aims to introduce the possibilities in reference to involving road safety decision making processes related to companies.

I. INTRODUCTION

The development of information technologies and the demand for continuous economic growing generated more efficient and detailed modelling tools for a long while. So the basics of the economic equilibrium approach are rooted back in the 18th century [1].

The concept of general equilibrium – according to the statement of János Kornai – plays similar role in the economics as the absolute-zero in the physics. This state cannot be obtained in the real life, but is well defined in theory. Equilibrium point is an abstract reference point. Real economic systems can be characterized by their distance from this theoretical equilibrium point [2].

Equilibrium theories are became more and more popular by the time, since compared to traditional CBA methodology - it can result a wider set of econometric parameters. These models can be applied together with the commonly used cost-benefit and multi-criteria analyses, and so can eliminate their greatest disadvantages. [3] [4]

Spatiality has been integrated into the CGE models in the 20th century. Krugman’s theory on New Economic
Geography has to be emphasized here as an important pioneer of this scientific field. [5]

In his concept spatiality has been represented through transport cost. Our study is based on the main elements of the Fujita Krugman model [6].

II. THE BASIC MODEL

The definition of the applied model is based on the authors’ own work; however it does not include any revolutionary scientific innovation. The basic model development is based on the above mentioned traditional methodologies.

The environment is spatially divided to zones. The zones are linked with each other. Assume that each link includes all the possible routes between two locations (e.g. average distance). Production functions of the companies are expressed based on the volume of utilized resources and their production coefficients.

Accordingly, in our study the manufactured goods are represented by the traditional Cobb-Douglas [7] function (1):

\[ X = B \cdot M^\delta K^{1-\delta} \]  

where

\[ X = \text{The amount of manufactured goods [piece(s)],} \]
\[ B = \text{Scale factor [-],} \]
\[ M = \text{Labour resource [piece(s)],} \]
\[ K = \text{Other resources (e.g. capital) [piece(s)],} \]
\[ \delta = \text{Cobb-Douglas parameter [-].} \]

Considering firms as profit orientated organizations, and state that all their profit has to be spent on production, the (2) constraint of the production function can be defined by the budget function.

\[ p \cdot X = w \cdot M + c \cdot K \]  

where

\[ p = \text{Unit price [EUR/Piece],} \]
\[ w = \text{cost of Labour resource (wages) [EUR/Piece],} \]
\[ c = \text{cost of other resources [EUR/Piece].} \]

The authors applied Lagrange theorem to solve the introduced constrained optimization problem. Therefore following context can be deducted (3) [8].

\[ w = \frac{\delta}{1-\delta} \cdot \frac{K}{M} \]

(1), (2) and (3) equations represent the production side of the model. This part will be in the scope of the further discussion.

The demand side of the model can be represented with the following contexts:

Consumers are used to maximize their utility considering their budget constraints.

III. EXTENSION OF THE SUPPLY FUNCTIONS.

The extension of the model below is based on the own work of the researchers and it represents a completely new scientific approach aiming to involve road safety aspects in an equilibrium model.

According to the basic idea there are two main parameters which should be investigated in a road safety related transport model: velocity (depending
upon distance and time), number of daily (haulage) rounds. These factors will influence the costs, the accident risk and indirectly the whole system (and decisions).

Modelling road safety makes it necessary to involve safety related cost elements. Assets allocated on safety are defined as a share of the companies' incomes.

Considering transport from the companies’ point of view, transporting goods can be defined as a value-added service. The quality of transportation influences directly the customers’ complacency and so the rate of consumption.

A simplified transport decision can be characterized with (4). Firms can decide if they want to satisfy the consumers’ demand with faster transportation - increasing the velocity leading to more transportable goods in a given time period - or with increasing the number of applied trucks - that can also lead to more transported goods.

$$X^* = \frac{v}{s} \cdot Q \cdot N_{truck} \quad (4),$$

where

\(X^*\) = The amount of transported goods in a unit of time [piece(s)/h],

\(v\) = velocity [km/h],

\(s\) = distance [km],

\(Q\) = capacity of the transport unit [piece(s)/truck],

\(N_{truck}\) = number of trucks [truck].

This new equation (4) will be an additional constraint of the optimization problem.

Commonly it can be said that the costs of a single truck consists of time and distance dependent costs (including e.g. fuel, maintenance and all the additional costs too).

The cost of the applied trucks during the transportation can be described by the equation (5).

$$C_{truck} = N_{truck} \cdot \left( C_s \cdot s + C_d \cdot \frac{v}{s} + C_{leasing} \right) \quad (5),$$

where

\(C_{truck}\) = Sum cost of the applied trucks [EUR],

\(C_s\) = Distance based transport cost of a truck [EUR/km/truck],

\(C_d\) = Time cost of a trucks [EUR/h/truck],

\(C_{leasing}\) = Usage costs of a truck [EUR/truck].

According to the above introduced equation time and distant dependent factors of freight transportation have been taken into account.

In the model increasing velocity also affects the equilibrium, and leads to increased fuel consumption (6).

$$C_{grossfuel} = N_{truck} \cdot C_{fuel} \cdot (a \cdot v^2 + b \cdot v + c) \quad (6),$$

where

\(C_{grossfuel}\) = Sum cost of fuel have been used for transportation [EUR],

\(C_{fuel}\) = Cost of fuel per litre [EUR/litre],

\(a\) = fuel consumption coefficient [litre* h²/km³]

\(b\) = fuel consumption coefficient [litre* h/km²]
c = fuel consumption coefficient [litre/km].

In the model increasing velocity also affects accidents’ probability also aggregates extra (accidents’) costs (7).

\[ C_{\text{gross acc}} = N_{\text{truck}} \cdot a_{\text{accident}} \cdot P_{\text{acc}}(v) \cdot s \cdot C_{\text{acc}} \] (7),

where

\[ C_{\text{gross acc}} = \text{Sum cost of accidents [EUR]}, \]
\[ C_{\text{acc}} = \text{Accident’s average unit cost [EUR/accident]}, \]
\[ a_{\text{accident}} = \text{Accident density coefficient [accident/km/truck]}. \]

\[ P_{\text{acc}}(v) = \text{probability of accident’s in the function of velocity [-]} \]

Based on the newly developed road safety module a new profit function (8) should be set up, which includes the introduced cost factors.

\[ p \cdot X = w \cdot M + c \cdot K + N_{\text{truck}} \cdot \left( C_s \cdot s + C_d \cdot \frac{v}{s} + C_{\text{leasing}} + s \cdot C_{\text{fuel}} \cdot (a \cdot v^2 + b \cdot v + c) + a_{\text{accident}} \cdot P_{\text{acc}}(v) \cdot s \cdot C_{\text{acc}} \right) \] (8),

where

\[ p = \text{unit price [EUR/piece]}, \]
\[ X = \text{amount of produced goods [piece(s)]}, \]
\[ w = \text{wages (the cost of “M” reasource) [EUR/piece (Labour)]}, \]
\[ M = \text{amount of workers [piece(s) (labour)]}, \]
\[ c = \text{cost of alternative resources [EUR/piece (capital)]}, \]
\[ K = \text{amount of alternative resources [piece(s) (capital)]}, \]
\[ N_{\text{truck}} = \text{number of used trucks [truck(s)]}, \]
\[ C_s = \text{Distance based transport cost of a truck [EUR/km/truck]}, \]
\[ C_d = \text{time cost of a truck [EUR/h/truck]}, \]
\[ C_{\text{leasing}} = \text{cost of hiring a truck [EUR/truck]}, \]
\[ C_{\text{fuel}} = \text{fuel cost [EUR/litre]}, \]
\[ C_{\text{acc}} = \text{Accident’s average unit cost [EUR/accident]}, \]
\[ a_{\text{accident}} = \text{Accident density coefficient [accident/km/truck]}, \]
\[ P_{\text{acc}}(v) = \text{probability of accident’s in the function of velocity [-]} \]
\[ a = \text{fuel consumption coefficient [litre* h/ km³]}, \]
\[ b = \text{fuel consumption coefficient [litre* h/ km²]}, \]
\[ c = \text{fuel consumption coefficient [litre/km]}, \]
\[ v = \text{velocity [km/h]}, \]
\[ s = \text{distance [km]}, \]

The sense of the above presented constrained optimization problem is to maximize the profit function (8) considering the given conditions (1), (4). This problem can be easily solved by the well-known Lagrange method.

**CONCLUSION**

The development of infrastructure affects our whole environment. However it directly influences our everyday life too. Our needs for
transportation, with all the quality standards, speed and comfort, and through the supply chains and all other logistical costs with their externalities are connected with the level of infrastructure. SCGE models can give a utility-based, computable and easily analysable view of transport investments.

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