The peculiarities of travel cost measurement using intelligent technologies: theory and evidence

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Abstract

This paper reviews the theoretical and empirical issues on the measurement of the impacts of the performance generated by improved highway infrastructure. Raising the issues of validity of the intervention of governments into economics in terms of social justice, the concept of public alternative costs is discussed. Stressing that the inadequate usage of public resources for the formation and development of highway infrastructure may have negative consequences on the dynamics and tendencies of the development of other economic sectors, the question of an adequate, socially and economically reasonable assessment of development is raised. Taking into account the complexity of the problem discussed, the present research of the authors is narrowed and concentrates on the improvement of the simplified general equilibrium model which focuses on the price effects of direct changes in transport costs and their measurement. Other aspects are going to be excluded from this initial investigation and presented for the wide public in the nearest future.

In the Introduction, the topic relevance, scientific problem and level of its analysis, object and tasks of the research are presented. The methods of the research, scientific novelty and significance of the work are introduced there as well. The second part is dedicated to the analysis of the methodological framework of the application of general equilibrium models in evaluation of the performance of improved transport systems. The possible extension of the model and its application issues are presented in the third section. The last section is dedicated to the employment of intelligent technologies in evaluating travel cost change as a result of transport infrastructure improvement.

Keywords: highway, infrastructure, costs, consumers, producers, surplus.

1 Introduction

Relevance of the topic: the establishment and management of the strategic rates and priorities of transport sector development relating to the issues of infrastructure upgrowth has become the object of scientific and political discussions in many countries [1]. The development of transport infrastructure is considered to be the means to induce economic prosperity and it earns one of the predominant positions in the headlines of scientific periodicals and broadsheets. However, intensive state investment on large-scale objects must be well substantiated for public resources are limited [2, 3]. Most scientific papers tend to treat transportation (or highways) as a black box, and make no distinctions between different kinds of transportation investment. But measures of investment effectiveness must also include assessments of the equity or fairness, effects on the environment and qualitative experience that users enjoy [4]. Thus, a transparent decision-choice funding of projects or programs must be strictly prioritized seeking to allocate the resources optimally. The state must intervene into the economy only in cases when a market failure cannot be removed by other, less competition distortive measures. Public support should be an appropriate policy tool to align the interests of many groups of interest. So, assuming complexity decisions to be taken in the fields of transport arteries development, the experts-specialists in different areas of knowledge need to be involved [5]. In addition to these aims, the political system is also concerned with fairness and justice which are very difficult to define, while striving to guarantee that public facilities are adequate or that an overall level of service standard is met [4]. Despite the fact that scientists and politicians are often focused on the analysis of interregional and interstate aspects of the interaction, the problem of influence of developed and improved highway infrastructure on separate stockholders and especially measurement of their benefits are still an open ground for scientific discussion. Practice shows that a lot of different methods for the investigation of the phenomenon are employed [6–13]. Usually, the modelling is based on the average parameters as it is difficult to take into account all these varying features. Our approach is to develop an agent based model. Trucks in the model can be simulated by one type of agent, shippers by another agent and receivers by the third kind of agent. Such agent based modelling enables us to vary slightly the features of each individual agent within a given probability distribution. But, on the other hand, simulation is not a straightforward process. Before employing agents in the simulation model, each agent should be assigned concrete realistic numerical features and action rules.

The problem of scientific research: it was determined that there was no structurally coherent base that would allow us to analyze the benefits of highway infrastructure and to assess them in terms of transport cost change employing intelligent technologies.

The object of scientific research: travel cost evaluation.

The aim of scientific research: to propose the methodological framework to assess the benefits of highway infrastructure in terms of transport cost change

presenting how to cope with finding the market equilibrium between demand and supply when due the transportation cost of each agent at the shipper's and receiver's area differs.

Research objectives are as follows:

1. To distinguish the peculiarities of the evaluation of the impacts of highway infrastructure development.
2. To develop the methodological framework of the measurement of the benefits of highway infrastructure in terms of the transport cost change.

Research methods:

1. In order to conceive the analyzed problem, general methods of scientific literature comparative structural analysis and synthesis as well as those of logic analysis were applied.
2. When determining the benefits of highway infrastructure the area method was applied to determine consumer and producer surplus.
3. To model the supply and demand, the market equilibrium condition was employed.

Scientific novelty and significance of the work are specified by the following results: a specified methodological framework that enables to determine the change in consumer and producer surplus (total benefit of consumer and producer when effective quantity of a product is produced) due to transport cost change after highway infrastructure improvement has been specified using intelligent technologies.

2 The effects of highway infrastructure improvements

In their investigation, scientists [14] stress that typical transport infrastructure improvements reduce effective distances between origins and destinations by reducing congestion, thereby lowering travel times [15]. It is believed that travellers gain directly from travel time savings and lowered vehicle-operating costs, despite the fact that some authors argue that the evidence of the research performed in the past is still insufficient [16, 17]. However, the position that companies enjoy direct efficiency gains from cheaper and more reliable freight services and reduced assembly and delivery costs are not under controversy [14, 18]. They also noted that despite the fact that companies compete for customer, revenue and market share with products and services that meet customers' needs, cheaper and better transportation services provide incentives for firms to reorganize and reduce their inventories, sometimes to just-in-time levels. The advantages of scale economies occur as firms consolidate production and distribution sites, increase outputs [15] as well as obtain the possibility to increase the competitive advantage. However, despite large amounts invested on roads, there is still little known about their benefits [19]. In fact, the argument that the improvements of transport infrastructure changes travel costs and benefits the stockholders in the commodity market is not neglected. The analysis of scientific literature allows us to conclude that in this case the benefit to consumers and producers in terms of welfare changes. The increase of the

economy's welfare due to the existence of a market for a particular good is equal to the sum of the consumer's surplus and the producer's surplus [16] measured using partial general or partial equilibrium models.

More recently, the concept of consumer and producer surpluses are defined in a microeconomic course. *Consumer surplus* is a measure of consumer welfare gained by consumers being able to purchase a good or service in the market at a price lower than the maximum that they would be prepared to pay for rather than going without it. *Producer surplus* is the difference between the revenue that the firms would earn from offering a good or service for sale rather than not selling it and the revenue that they are able to achieve by selling it at the market price. The producer surplus arises because the producer can now sell more than before and/or at a higher price. Both of the effects commonly are determined using general or partial equilibrium models [11, 20].

Some authors [11, 20] conclude a general equilibrium analysis which includes a full range of calculations to determine market prices through a set of supply and demand equations. However, the application of the model is rather complicated and hardly functional in developing countries that, firstly, lack an experience in the model application and secondly, are short of the statistical data.

Figure 1: Impact of transport cost change on consumer and producer surpluses (the authors' own representation).

As it was concluded in previous scientific investigation of the authors [14], partial equilibrium models are an alternative to the presented one above. This option is more suitable for economic modelling in developing countries, where each of the related goods and factor markets are not so interrelated compared with the situation demonstrated by the general equilibrium so called "basic" [20] models with several assumptions. Usually, the basic model is a representative consumer model with a quasi-linear utility function. This model is simplified in that no income effects exist. It is sufficiently general that the income share of transportation services is usually low [20]. The partial equilibrium model can be used to analyze how transport costs affect trade and welfare. Taking into account that transport costs in effect drive a wedge in between the price received by a supplier and the price paid by a consumer. As increase or decrease in transport

cost reduces increases or reduces the gains from trade for both stockholders (fig. 1).

A decrease in transport costs [21] and the price of the commodity (the effect is marked by the arrow, fig. 1, *a*) increase the gains from the exchange of the product equal to the areas *vp* (*consumer surplus*) and *gp* (*producer surplus*, *b*) [22]. It is assumed that the commodity is transported from the point *R*, where it is produced, to the point *P*, where it is consumed.

The elasticity μ and γ of the supply function $S = S(p)$ and the demand function $D = D(p)$ and are constant [22]:

$$\frac{S'}{S/p} = \mu, \quad -\frac{D'}{D/p} = \gamma \quad (1)$$

where p – price of commodity.

Assuming these equations to be differential with respect to S and D and solving them, the common form of these functions with free parameters α and β is obtained:

$$S = \alpha p^\mu, \quad D = \beta p^{-\gamma} \quad (2)$$

At a destination point P the transport costs of the commodity unit may increase to a value:

$$q = p(1 + \Delta) = p + \Delta p \quad (3)$$

where the factor Δ describes the increase of price p . Therefore, at the point P the demand for the product is

$$D = \beta (p(1 + \Delta))^{-\gamma} \quad (4)$$

Applying to the eqns. (2), (3) and (4) the supply and demand equilibrium condition, we obtain

$$\alpha p^\mu = \beta (p(1 + \Delta))^{-\gamma} \quad (5)$$

The solution of the equation for the price p is

$$p^{\mu+\gamma} = \frac{\beta}{\alpha} (1 + \Delta)^{-\gamma} \quad (6)$$

Therefore, the producer price, which in this particular case, denoted as p_0 , is:

$$p_0 = \left(\frac{\beta}{\alpha} \right)^{\frac{1}{\mu+\gamma}} (1 + \Delta)^{-\frac{\gamma}{\mu+\gamma}} \quad (7)$$

Substituting p_0 into eqn. (3) we derive the equilibrium price q_0 at the point P :

$$q_0 = p(1 + \Delta) = \left(\frac{\beta}{\alpha} \right)^{\frac{1}{\mu+\gamma}} (1 + \Delta)^{\frac{\mu}{\mu+\gamma}} \quad (8)$$

Since, in the expression of this price q_0 the exponent $\mu / (\mu + \gamma)$ is positive, increase in the transport cost Δ , makes the final price q_0 grow. And conversely, a decrease in transportation costs, declines the price q_0 at the point P.

The consumer and producer surpluses might be calculated using the inverse demand and supply functions: $p = p(S)$, $p = p(D)$ obtained by solving the eqn. (1) for the price p :

$$p = \left(\frac{S}{\alpha} \right)^{1/\mu} \quad (9)$$

$$p = \left(\frac{D}{\beta} \right)^{-1/\gamma} \frac{1}{1 + \Delta} \quad (10)$$

Taking into account that the area under the curve is calculated with a definite integral, the consumer surplus then is

$$vp = \int_0^{D_0} (p(D) - p_0) dD_0 \quad (11)$$

Inserting the inverse demand function D_0 instead $p(D)$ into eqn. (11) and p_0 from eqn. (7) we get the expression of consumer surplus

$$vp = \frac{\beta \left(\frac{\beta}{\alpha} \right)^{\frac{1-\gamma}{\mu+\gamma}} (1 + \Delta)^{\frac{-\gamma(1+\mu)}{\mu+\gamma}}}{\gamma - 1} \quad (12)$$

Analogically, eqn. (2) yields:

$$S_0 = \alpha p_0^\mu \quad (13)$$

Producer surplus gp then is

$$gp = \int_0^{S_0} (p_0 - p(S)) dS_0 \quad (14)$$

Inserting inverse function $p(S)$ into the eqn. (14) as well as the supply function (2), S_0 (13) and p_0 (7) the producer surplus then is

$$gp = \frac{\alpha \left(\frac{\alpha}{\beta} \right)^{\frac{\mu+1}{\mu+\gamma}} (1 + \Delta)^{\frac{-\gamma(1+\mu)}{\mu+\gamma}}}{\mu + 1} \quad (15)$$

Applying these developed dependencies, a numerical simulation was carried out. Results of this simulation and directions for further research are presented in the following sections.

3 Introduction to evaluation of road transport infrastructure development effects

Basing on the theoretical principles presented in the previous section of the paper we do assume, that supply function at the shipper's area is

$$S = \alpha p^u \quad (16)$$

and coefficient $\alpha = 1200$ and the elasticity of supply with respect to goods price p is $u = 1.2$. About the demand function at the receiver's area

$$D = b (p(1 + \Delta))^{-\gamma} \quad (17)$$

assume: $b = 1000000000$, $\gamma = 1.27$ i.e. elasticity of demand with respect to goods price $q = 1 + \Delta$ at receiver's area and Δ is the increase of the price due to hauling the goods from the shipper's to the receiver's area.

This increase of the price can be expressed as $\Delta = \text{cost}/\text{load}$, where $\text{cost} = \text{cost}_0 + d \text{ cost}_1$ load is transportation costs of the loaded truck from the origin point to the destination, load is amount of the goods loaded in the truck, cost_0 is fixed cost of hauling the total amount with the one truck, $d = 250$ km is the average length of the route in Lithuania, and it was assumed $\text{load} = 20$ T, cost_1 is transportation cost of 1 T per 1 km. It was assumed that $\text{cost}_0 = 200$ Lt $\text{cost}_1 = 10$ Lt.

The supply and demand equilibrium condition takes the form of the equation

$$\alpha p^u = b (p + \Delta)^{-\gamma} \quad (18)$$

There have been many approaches to solve this equation for the price p . Our approach is based on the numerical solution by the Newton method applied to equivalent equation

$$\ln(\alpha p^u) = \ln(b (p + \Delta)^{-\gamma}) \quad (19)$$

as all of the parameters in our research had numerical values. Basic calculation results are presented in fig. 2. Fig. 2(a), (b) introduces the demand and supply change in dependence of the variation of truck capacity. It is clear, that growing demand and supply might be satisfied only in the case of growing transportation amounts. The graph presented in fig. 2(c) demonstrates the dependence of product's price at a certain destination on the distance. Fig. 2(d) shows very clearly the growth of transportation costs when the transportation distance increases. The dependences with other distances are presented in fig. 3 (e), (f). Changing the distance of transportation from 250 km/h up to 300 km/h, we tried to analyse the change in producer and consumer surpluses – in other words, to evaluate volatility of the benefit due to the change of the price. For the reason employing actual data would allow testing the hypothesis that final benefits of transport corridors in the sense of consumer and producer surplus change might be questioned.

Figure 2: When distance = 250 km.

Figure 3: When distance = 200 km and 300 km.

4 Conclusions and directions for the further application of intelligent technologies

1. The research revealed that the academic discussions about generalized assessment of benefits of improved highway transport infrastructure are still open for scientific discussion.
2. The fact that strategic solutions in the sphere of transport investments, based on a clear understanding of the needs of the stockholders generated by the infrastructure must be clearly understood.
3. The theoretical analysis of the economic impacts of developed transport infrastructure enables us to state that decreases in expenses of transport users due to infrastructure's development are still not based enough empirically.
4. From the research into the methods used to assess the benefits of highway infrastructure, it was determined that:
 - Modified production function, general equilibrium and land use models as well as the methods of correlation-regression analysis in the change of real estate and hedonic prices are often applied to establish the impact under the investigation. Research has shown that the experience of modelling the impact of highway infrastructure on benefit change of the stockholders is limited: in most cases, demand and supply dependencies are considered only linear. Seeking to eliminate the shortage, the authors improved the method of the partial equilibrium model.
 - It was determined that consumer and producer surpluses might be determined more precisely considering the demand and supply curves to be non-linear. Considering that the modelling is usually based on the average parameters, it is difficult to take into account all these varying features, our suggestion and primary task in the nearest future is to develop an agent based model. Trucks in the model could be simulated by one type of agent, shippers by another agent and receivers by the third kind of agent. Such agent based modelling would enable us to vary slightly the features of each individual agent within a given probability distribution and taking into account the developed supply and demand models.

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