METHODS FOR ESTIMATION OF EXTERNAL COSTS OF TRANSPORT

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Summary: *External costs of transport represent the impact on society expressed in monetary units, as a result of transport activities, but not directly accounted for from activities managed by a road agency and/or by users of transport services. Road users require expensive infrastructure, and have various external costs, both in transport (congestion and accidents) and towards the rest of population (accidents, pollution, noise, environmental degradation). Analysis of the external costs of transport is usually, in the area of environmental economics, used to determine and analyze the benefits that are accomplished by investments in the protection and improvement of the environment in the transport area. Externalities are assessed so that they can be, to some extent, connected with assets invested in roads. This paper presents general overview of external costs of transport with particular emphasis on methods for their estimation, necessary inputs and outputs useful for costs internalization.*

Keywords: *Transport, environment, external costs, estimate, internalization*

1. INTRODUCTION

In economics, externalities represent the impacts that are felt by a third party, neither the buyer or the seller, in an economic transaction. These impacts could be positive, where the marginal social benefits outweigh the marginal social costs. Or they can be negative, where the social costs are greater than the benefits. As such, transport externalities occur when society is impacted, for example, by a road.

Roads are considered prime real-life examples of public goods, meaning that the use of a road is available to anyone and non-discriminatory. A pure public good does not allow for rivalry between consumers, and after the first quantity is produced (when Q=1) the marginal cost is zero. In transport however, the externalities represent the costs that arise after a certain quantity (Q=q) where the external costs of transport increase as the number of road users increase. In the sketch diagram below, the external costs of transport are represented by the area under the Marginal Cost (MC) curve after quantity q, which represents the road capacity.

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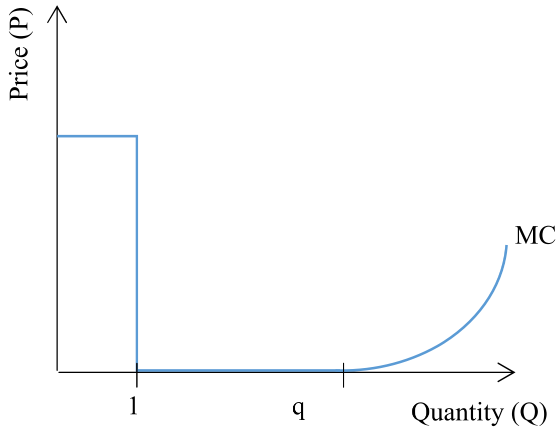

Figure 1. Sketch diagram for external costs of transport

Estimates of external costs of transport may be used for several purposes: (i) as a guide to more economically efficient pricing (given that the optimal price is equal to the private market price plus the estimated marginal external costs), (ii) as a guide to allocating research and development funds to mitigate the largest external costs, (iii) as part of acost-benefit analysis of optimal investment in transportation modes and infrastructure, and (iv) as part of historical or comparative analyses.

Quantification of external costs has served beneficially to many countries as an example on how to begin reform of their transport policies. At the same time, reduction of external costs of transport has been adopted as the main strategic objective in the environmental protection framework.

Wide variations in estimation methods exist among scientific and professional community. The paper presents general overview of these methods and particular elements used for estimates of these costs.

2. EXTERNAL COSTS

Unfortunately, most forms of transport do not only affect society in a positive way but also give rise to side effects. Road vehicles, for example, contribute to congestion, trains and aircrafts to ambient noise levels and ships to air pollution. Such side effects give rise to various resource costs that can be expressed in monetary terms: time costs of delays, health costs caused by air pollution, productivity losses due to lives lost in traffic accidents, abatement costs due to climate impacts of transport, etc. When side effects of a certain activity impose a cost upon society, economists speak of such a cost as an external cost. External costs of transport activities depend strongly on parameters like location (urban, interurban), time of the day (peak, off-peak, night) as well as on vehicle characteristics.

External costs generally fall in one of the following categories [1]:

- Congestion delay costs: Congestion caused by additional travel generates a number of external costs, including opportunities foregone due to travel delay, discomfort of crowding, and impact of travel-time uncertainty on the reliability of arrival and delivery times;

- Accident costs: Estimated costs of accidents include medical costs, property damage, lost productivity, insurance administration, emergency services, and nonmonetary costs of lost quality of life, pain and suffering as a result of death and serious injury. In the case of travel by road, the estimated cost of accidents is greater than every other social cost except travel time. Accident costs and delay costs are inter-related. Accidents usually cause delay, and changes in vehicle speed and density due to congestion can affect the frequency and severity of accidents. External accident costs are also those social costs of traffic accidents, which are not covered by risk oriented insurance premiums. Therefore, the level of external costs does not only depend on the level of accidents, but also on the insurance system (which determines the share of internal costs);
- Air pollution costs: All transportation modes emit significant quantities of air pollutants. Air pollution harms human health, damages materials, reduces visibility, and stresses crops and forests. An extensive epidemiological literature indicates that air pollution causes a variety of effects including premature mortality, chronic illness, and hospital admissions for respiratory and cardiovascular illnesses;
- Climate change costs: All transportation modes emit pollutants that can affect global climate. Climate change induced by worldwide Greenhouse Gas (GHG) emissions is currently one of the key topics of global research output;
- Noise costs: Noise emissions from traffic pose an environmental problem of growing importance. Roadways with large volumes of high-speed traffic, high-speed rail lines, and airports can be very noisy. This noise can disturb sleep and leisure, result in health impairments, disrupt activities, hinder work and impact productivity, impede learning, and cause stress. As a result, homes near major roadways and airports have less value than similar homes further away. The external cost of noise from transport includes the value of damages from excess noise experienced plus the cost of any defensive actions or avoidance behavior, although this second factor (defensive/avoidance behavior) is rarely estimated. The reason the problem is growing is a combined effect from greater urbanization and an increase in traffic volume. Whereas the increase in traffic volume means higher noise levels, the urbanization has led to more individuals being exposed to traffic noise;
- Water pollution: Fuels and chemicals from transportation modes can spill and leak into oceans, rivers, lakes and groundwater. This water pollution can harm human health, injure and kill wildlife, corrode materials, and despoil scenic recreation areas. Transportation modes also can cause water pollution indirectly: emissions of nitrogen oxide from fuel combustion can eventually deposit as nitrate and cause nitrogen pollution in aquatic systems;
- Other costs: Construction and use of transportation modes can create external ornon-market costs beyond those estimated here. For example, all modes create unsightly infrastructure and waste, which presumably have an aesthetic cost. Surveys have found, not unexpectedly, that the general public feels that the world would be prettier without roads, and the unsightliness of scrapped autos and junkyards has been formally condemned by courts. Poorly designed and thoughtlessly placed transportation infrastructure can divide communities, impede circulation, and create barriers to social interaction. Transportation infrastructure can also fragment sensitive

environmental habitat and thereby disturb and possibly even eliminate plants and other (non-human) animals. Valuing these impacts is a complex undertaking.

It has to be noted that external costs are always the result of conflicting interests in the use of a scarce resource: the environment. They arise only when there are competing uses of the scarce resource. If there is rivalry in its use, policy makers are faced with a "tragic" choice: furthering the interests of one group necessarily damages the interests of others. This is known as the reciprocal nature of the problem [2].

3. METHODS

Identifying and defining the external costs of transport are more straightforward than calculating the social and environmental impacts, let alone placing a monetary value for these impacts. However, many countries and multilateral institutions have started to place parameters and formulas for calculating the willingness to pay of individuals in society to reach the expected efficiency levels. This section describes the methods of calculation for each of these costs based on the 2014 update of the European Commission's IMPACT study [3]. The methods described in this study have been utilized by many European cities and public authorities to calculate such costs to substantiate policy changes.

Congestion Costs

Congestion costs are one of the two social costs of transport and are derived based on the willingness of individuals to pay for an estimated value of time. The two models used to calculate these costs are dynamic, meaning that the value of time is dependent on the speed and flow of vehicles on the road. Both the bottleneck model and the network-based system model, calculate the equilibrium where the monetary costs are equal to the inconvenience of waiting for each individual, and the sum of all these costs is equivalent to the net value to society. In order to calculate congestion costs for a road, the data input needed is generally the Origin/Destination (O/D) relevant to the specific road. In some cases aggregate data for a specific country or region can be used to describe larger geographical areas. Disaggregated data by vehicle technology and also occupancy rates are also systematically needed to calculate individual user costs [4].

The bottleneck model, developed by Arnott et al. [5] defines the capacity of the road as the flow, which is equivalent to the number of vehicles that can utilize the road per hour. The model assumes that all users equally dislike arriving early or late to their destinations and therefore optimal road price represents the inconvenience of waiting in traffic. For each flow value, there is a specific equilibrium in which all road users are equally well off. In this equilibrium state, traffic first grows and then gradually declines.

While the bottleneck model creates equilibrium under each toll situation, the network-system model calculates perceived user-cost expectations using real-time data produced by traffic management software, such as Emme/4, Visum and SATURN. The Marginal Cost (MC) is calculated as a function of travel time (t), flow (f) and the average value of time (φ).

$$MC = \varphi \cdot f \cdot \frac{dt(f)}{df} = -\frac{1}{\varepsilon(f{:}v)} \cdot \frac{\varphi}{v'} \qquad (1)$$

This formula illustrates that the marginal costs are derived from the travel time relations as a function of flow and the monetary costs depend on the value of the speed. In other words, the marginal cost can also be calculated based on the elasticity of flow and speed ($\varepsilon(f{:}v)$).

Accident Costs

Accident costs are the second type of social externalities in transport costs. Accident costs are compiled from three components. The first is the expected costs of death and injury for the individual (a). The second component is the expected cost of relatives and friends, including time spent in a hospital, grief and depression (b). The third component is the cost on the rest of society; this includes the output loss as well as police and medical costs (c). To calculate monetary values, the Value of Statistical Life (VSL) is used to quantify the risk of acute mortality, i.e. the willingness to pay [4].

The marginal cost for each vehicle type (v), and road type (i), is a direct function of the accident risk (r) of the three accident components (a, b, and c, respectively) and the traffic risk elasticity (E). E is defined as the percent increase in r with a one percent change in vehicle kilometers (Q). The accident risk is also a function of Q in relation to the number of fatalities/injuries (x) estimated using historical data.

$$MC_i^v = r_i^v \cdot (a + b + c) \cdot (1 + E_i^v) - \theta^v \cdot r_i^v \cdot (a + b) \quad (2)$$

$$r_i^v = \frac{x_i^v}{Q_i^v} \quad (3)$$

$$E_i^v = \frac{\partial r_i^v}{\partial Q_i^v} \cdot \frac{Q_i^v}{r_i^v} \quad (4)$$

When calculating the external costs, it is important to note that insurance companies already internalize some accident costs. This is characterized in the marginal cost formula by the constant θ. The value of θ depends on the extent that the transport user internalizes the risk, which explains why it is only calculated for the first two components. θ can vary from not being covered at all ($\theta=0$), to being fully covered ($\theta=1$).

Air Pollution Costs

Air pollution costs, along with other environmental costs of transport, are quantifying using the Impact Pathway Approach (IPA) to identify and assess the damage costs that emissions have on human health, the environment, economic activity, etc. A key aspect of measuring the impact of pollutants however is the availability of baseline data. The different components of the IPA are illustrated in the diagram below.

Using the IPA to calculate the air pollution costs for a road first identifies the burden based on vehicle emission factors, fleet composition, and traffic flow data. The pollutants identified are both direct products of fuel combustion, primary pollutants, and pollutants that arise through atmospheric chemistry, secondary pollutants. Primary pollutants include sulphur dioxides (SO_2), nitrogen oxides (NO_2), carbon monoxide (CO), polycyclic aromatic hydrocarbons (PAH), heavy metals, volatile organic compounds (VOC) namely benzene and butadiene and other particle matter (PM). Secondary pollutants are ground level ozone (O_3), nitrates and sulphates.

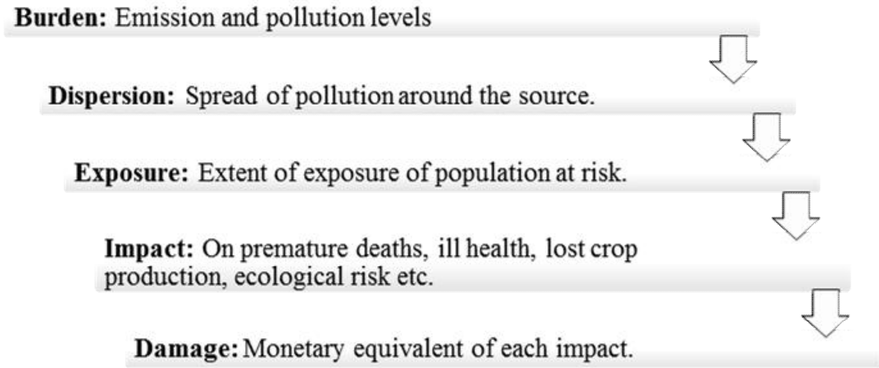

Figure 2. Components of the Impact Pathway Approach

Dispersion is modeled with atmospheric pressure models and meteorological data to define the spread of pollutants over a geographical area. Once this area is identified, the population density and ecosystems that are exposed are included in the damage costs. The extent of the exposure is generally identified using specific ecological and regional studies. These studies are required by many national or multilateral institutions. An example is the Environmental and Social Impact Assessment required under the World Bank Environmental and Social Safeguards. The impact is quantified as a function of the exposure that relates changes in human health and environmental damage to unit changes in ambient concentrations of pollutants. The damage therefore translates the impacts into their respective monetary values, which are derived from the willingness to pay. It is important to note that the health and environmental effects also impact future time periods. Therefore when calculating the costs of air pollution, they should be discounted at the same rate that capital investments are discounted within a social cost-benefit analysis [4].

Noise Pollution Costs

Noise pollution calculations also follow the IPA. The emission of noise is measured as a change in noise levels relative to the time, location, frequency, level and source of noise (measured in decibels, dB). The dispersions is estimated to geographical locations and based on noise level indicators. The dispersion patterns of noise identify separate endpoints, that connected define the boundaries of the exposure radius. The exposure therefore, is the number of susceptible cases within the radius.

The impacts of noise are calculated looking at two different variables. The first is annoyance, which reflects the disturbance individuals experience from exposure to noise traffic. The second are health issues, which are related to long-term exposure including hypertension and myocardial infarction. These impacts are assumed independent and not mutually exclusive. The damage is ultimately the aggregated monetary equivalent of these impacts.

Climate Change Costs

Measuring the costs of GHG emissions as a transport externality is complicated because of global pathways and a long time horizon. GHG emissions can however be quantified

as tons of carbon dioxide (CO_2) equivalent per vehicle km. Once identified, the valuation of climate change costs can be calculated based on data and calculations from global environmental facilities.
There are two different approaches however to address climate change costs in the context of transport externalities. The damage cost approach is more straightforward. This approach evaluates the total costs assuming there are no efforts made to reduce CO_2 equivalent emissions. Using this approach however, the costs of climate change increase in each time period and would directly correlate to the trends in road transport data.
The abatement cost approach on the other hand tries not to account for the overall cost of emissions, but it evaluates the cost of achieving a given amount of emission reductions. The abatement cost approach is beneficial in that it inherently provides incentives for institutions to create policies that target reductions in emissions. For abatement costs to be equal to the externality costs, this approach assumes that the emission reduction targets adequately reflect and capture society's willingness to pay for certain abatement levels.
Currently the World Bank is developing its own GHG model that will be required for project preparation of all future World Bank transport projects globally. The model does not calculate externalities directly, however it looks directly at the impact of policy changes on GHG emission based on the responses of users to available modes of transport services. The model uses behavioral parameters to estimate the socio-economic characteristics of users, prices and travel times, technical characteristics of vehicles and mode composition. These parameters include; income per capita, income elasticity (defined as initial ridership per passenger kilometer traveled for each mode), fuel prices, price elasticity and car speed (calculated based on the average numbers of cars per day as a function of the road capacity). The relationships between these parameters for user responses are calculated based on historical trends.
Once the external costs mentioned above have been calculated, decision makers can then asses the best ways to account for these externalities in their procedures.

4. INTERNALIZATION

In contrast to the benefits, the costs of these effects of transport are generally not borne by the transport users. Without policy intervention, external costs are not taken into account by the transport users when they make a transport decision. Transport users are thus faced with incorrect incentives, leading to welfare losses. The internalization of external costs means making such effects part of the decision making process for transport users. Internalization of external costs of transport has been an important issue for transport research and policy development for many years worldwide.
In very general terms, internalization can be regarded as an intervention that leads to the decision maker facing the full social costs of his actions. This means that costs that would otherwise be external are now taken into account by the decision maker and affect his behavior.
One method of solving the problem of external costs is through direct governmental intervention, i.e. establishment of laws and standards, creation of formal procedures and mechanisms for obtaining production and commercial licenses and product registration, use of economic mechanisms for environmental protection improvement and to

discourage pollution and resource consumption. In order for this approach to be profitable, appropriate policy and effective institutions should exist.
Additional methods of favoring useful techniques and technologies are subsidies, tax exemption or reduction of taxes and environmental taxes and charges for emission or discharge of pollutants. The basic tendency of all these measures is to implement internalisation of external costs of transport according to principle that the causer should borne them ("polluter pays" principle), i.e. must be included in the cost of activities which disturb quality of environment. In addition, internalization should be based on good assessment and to be politically and economically acceptable.
Environmental taxes and charges belong to the group of so-called rigorous or harsh measures to achieve defined objectives [6]. Rigorous measures can change behavior of participants since they change consequences of such behavior. Their effectiveness is consistent with the view that the main determinants of transport behavior are in the environment in which it takes place, and not in the passengers whose behavior needs to be changed. For example, if driving the car becomes tedious, expensive, socially unacceptable or time-consuming, this kind of behavior is changing. Its replacement by another mode of behavior, for example, with bus or train ride, will depend on what is possible and what would be the consequences of using the bus or train. This method of radical internalization is based on the requirements to equilize private and social costs, i.e. that users of transport infrastructure are charged, in such a way as to cover all costs that arise from their activities.
Countries that have implemented environmental taxes and fees have faced a problem where, in most cases, such taxes were not as effective supplement to regulations, as expected, since it was very difficult to determine the exact value of negative impact or damage, and to adjust the amount of the tax to the variable conditions market. Also, since existing monitoring technology has not yet produced a low-cost devices to measure several or all types of contaminants, taxes can even lead to „license or permit for pollution", or their amount may be so low that practically favors pollution.
From an economics point of view, the polluter pays principle is an outdated and limited approach. It is widely agreed in economic circles that its shortcomings have been exposed and its suitability as sound basis for internalization policies soundly superseded by the cheapest cost avoider approach [2]. In the cheapest cost avoider framework, the "polluter pays" is one possible outcome of the analysis, but not a generally applicable principle. The principle requires that the party which can prevent (or abate) the damage at the lowest cost overall should take action. A simplified example would be noise emission: When a truck drives through the open fields the question of noise emissions plays only a minor role. However, when the truck uses a road nearby a house there is a conflict of interests. The house owner wants quiet and the truck needs to emit noise. The question that needs to be answered is: Is it more effective to build a sound barrier to solve the noise-problem or does it make more sense to just charge the truck user?
According to this principle, if there are any preventive measures which cost less than the benefit of the damage that they avoid, then they should be undertaken, whether by the polluter or by the pollutee, and on the condition that they are the least costly means available to accomplish such a reduction. Means to reach this end can be financial charges, taxes, fines, liability or even command and control measures, such as regulated standards or zoning.

The cheapest cost avoider principle is applied in all areas of public decision-making under the heading of “regulatory impact assessment”. It is not currently employed in the context of the regulation of transport related externalities. The mere existence of externalities does not, of itself, provide any reason for governments to induce polluters to take action, because the polluters might well be the highest cost avoiders [2]. Coming back to the example of truck noise, it might be that it is more costly for the overall economy to impose general charges on trucks than to build a sound barrier where there are conflicts of interests. Despite the vast experience, the world has not yet reached a common ground on the most appropriate measures regarding the environmental impacts of transport. The taxes point of view is considered to be a fatal weapon in European surrounding since the transport itself was the primary element of its economic efficiency. Environmentalists and other experts who deal with environmental impacts, are in favor of the standard approach to environmental protection by setting appropriate technical measures, as well as by improvements in vehicle technology. The valid policies in the developed world are a combination of these two types of measures. At the heart of the sustainable transport policy should be a fair, transparent and efficient system of charging for all modes of transport. The current condition, particularly outside congested urban areas, is such that the standard protection methods will maintain primacy for some time, which causes significant effects on physical and financial components of planning, design, maintenance and operation of transport infrastructure.

5. CONCLUSION

Human population demands and expects appropriate mobility for the sake of business, education, health protection, rest and fun. However, transport sector is one of human activities in the closest relation to the quality of environment. Transport system, developed in the world in order to fulfill the needs of population, shows important and growing threat to environment, especially human health, and even endangers its own goals.

The estimation of values for external costs and different traffic situations involves many assumptions, such as valuation of risks, short and long term effects often in the face of scarcity of appropriate data. Thus the questions of required and feasible accuracy are major issues when applying these monetary values for practical ends. This does however not mean that all cost categories are treated at the same level of accuracy, and all modes are covered equally. Each of the externalities requires (a combination of) different design parameters to achieve internalization.

Having in mind the above mentioned, the conclusion is that a number of complex direct and indirect effects of traffic are major challenges to technical and economic experts, both in the domain of theoretical assumptions, as well as in the domain of their quantification. It is necessary to establish a macroeconomic assessment of „consumption“ of the environment as a resource, in order to determine its relative importance in relation to national income, as these resources are not distributed in the market. At the same time, this assessment should allow creation of a basis for defining adequate management policy and pricing in the transport sector. Finally, evaluation of social costs of traffic is also necessary for environmental impact analysis of large investment projects.

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МЕТОДЕ ЗА ПРОЦЕНУ ЕКСТЕРНИХ ТРОШКОВА САОБРАЋАЈА

***Резиме**: Екстерни трошкови саобраћаја представљају утицаје на друштво изражене у новчаним јединицама, као последице саобраћајних активности, али који нису директно настали од активности којима управља агенција за путеве и/или од корисника саобраћајних услуга. Корисници путева захтевају скупу инфраструктуру и остварују различите екстерне трошкове, како у саобраћају (загушења и удеси), тако и према остатку популације (удеси, загађења, бука, деградација животне средине). Анализа екстерних трошкова саобраћаја се најчешће, у области еколошке економије, користи за дефинисање и анализу користи које се остварују улагањима у заштиту и унапређење животне средине у области саобраћаја. Процена екстерних трошкова се обавља како би се исти могли, у одређеној мери, повезати и са средствима уложеним у области путева. Овај рад представља општи преглед екстерних трошкова саобраћаја са посебним нагласком на методе за њихову процену, неопходне улазне и излазне елементе корисне за интернализацију трошкова.*

***Кључне речи**: Саобраћај, животна средина, екстерни трошкови, процена, интернализација*