Evaluation of Externalities of Highway Infrastructures

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Contributor: LEI ZHU

Various externalities caused by highway infrastructures, such as promoting economic development, traffic congestion, and air pollution, are becoming more and more important. Currently, there is no multi-dimensional quantitative evaluation of the externalities of highway infrastructures, hindering the sustainable planning and development of highway infrastructures. A summary of the status of the evaluation of the externalities of highway infrastructures is from four perspectives: social evaluation, economic evaluation, ecological evaluation, and comprehensive evaluation.

highway infrastructures externality evaluation

1. Introduction

Highway infrastructures are very crude instruments of economic development and social changes. During the rapid development, highway infrastructures also produce varying degrees of external effects to the social development [1][2] and ecological environment [3][4][5][6]. For example, the promotion of the economic development of area region and the traffic convenience of the public are the positive external effects; traffic congestion, noise, and air pollution are highly concerned negative external effects. These external effects are usually defined as externalities. Some costs related to highway infrastructures are fully internalized by economic agents, such as construction costs and operation costs. Externality costs of highway infrastructures are not fully internalized and reflected by the economic transaction. However, their influence is real and cannot be ignored.

To cope with these externalities, relevant authorities have taken many response measures. For instance, building new roads, widening the existing highways, and traffic diversion are measures for improving traffic congestion and accidents. Considering the unbalanced economic development, the transportation authority vigorously invests in the construction of highway infrastructure for the undeveloped areas to leverage the advantages of convenient transportation on economic development [7]. In terms of environmental pollution and ecological damage, policies for highway toll [4], motor vehicle emission limits [8], schemes for the shelter forest along the highway [9], and the financing model considering wetlands costs to mitigate highway runoff pollution [10] have been formulated. However, the practical results demonstrate that the effect of the governance or internalization of these externalities is not ideal. One of the possible reasons lies in the lack of a comprehensive quantitative evaluation of economic, social, and ecological externalities. Without such comprehensive evaluation, the influencing factors and the formation mechanism of the externalities of highway infrastructures cannot be accurately quantified, which is not

conducive to the governance or internalization of external effects and the formulation of countermeasures with long-term and sustainable effects [11].

With the deepening of relevant research and the advance in information technology, more and more scholars and policymakers take the externalities of highway infrastructures into their traffic costs function, bringing external or social costs to internal or private costs [12][13]. However, among the economic, social, and ecological dimensions of externalities of highway infrastructures, current research mainly focuses on one or two dimensions. There has been no three-dimensional quantitative evaluation of the externalities of highway infrastructures [2][5][7][14][15][16][17], which hinders the need and possibilities for broadening the scope of highway planning by considering the three-dimensional externalities of highway infrastructures.

2. Evaluation of Social Externalities

From the social aspect, previous studies have shown that highway infrastructures have external effects on social development and sustainability [1][16]. Social sustainability relates to personal characters, which may include employment and income, education, health care, skills, communication, and recreations [16]. From the perspective of welfare economics, Verhoef [18] estimated the external effects and social costs of road transport including congestion, accidents, noise, and air pollution. Using the multiple regression methods, Percoco [7] conducted an empirical study to explore the variation in employment, population, and plants induced by the construction of the highway network by using relevant data from 1951 to 2001. The results indicated that access to a highway for a city has a positive impact on urban development, in terms of employment growth (+4–5%) and firm entry (+2–3%). Abdel-Raheem and Ramsbottom [1] analyzed the performance of highway projects concerning the social dimension of sustainability. Quality of living, diversity with employees, and awareness of social sustainability were identified as three principal contributors of highway infrastructures to social sustainability. Rostamnezhad et al. [16] proposed a new hybrid system dynamic (SD)-fuzzy decision-making trial and evaluation laboratory (DEMATEL) method to analyze the various factors affecting the social sustainability of the highway construction project. Considering the limitations in sample size, the hypotheses of variable independence in statistical methods, and the vagueness and subjectivity of experts' opinions and expressions, system dynamic and fuzzy method rather than structural equation modeling were adopted to assess the complex interactions among critical factors.

3. Evaluation of Economic Externalities

From the economic perspective, previous studies have indicated that externalities of road transport have a significant impact on economic development. Transportation investments affect the economy through increasing accessibility, mobility, safety, and travel reliability [15]. Economic impacts of transportation investments are often studied using the theories of spatial economics and the theoretical framework of production function [15]. Many empirical studies estimate the strong positive influence of transportation investments on economic output at the national, state, or county level by using elasticity estimates. The values of the elasticity range from 0.2 to 0.58, indicating a unit increase in transportation investments is associated with a 0.20 to 0.58 unit increase in economic

outputs [15][19][20]. In terms of highway infrastructures, Duranton et al. [21] proved that highways within cities have a large effect on the weight of city exports with an elasticity of approximately 0.5, indicating a unit increase in highway investments is associated with a 0.5 unit increase in economic outputs.

From the perspective of the externalities of highway infrastructures to its adjacent areas, the improvement of the accessibility of a certain area by the development of highway infrastructures leads to an increase in the price of housing. Hedonic pricing model or difference-in-differences estimators are popularly used methods to estimate the increase in housing prices near highway infrastructures [22][23][24]. With the accumulation of panel data and the improvement of computing power, such estimation become mature and popular and has been considered in policy decision making [11].

4. Evaluation of Ecological Externalities

From the ecological perspective, many studies focus on pollution emissions and noise of highway infrastructures [25], the damage of highway infrastructures to the ecology, and the countermeasures through the natural landscape, highway forest belts [22], and noise barriers [25]. Air pollution caused by the emission of pollutants by vehicles is a direct impact of highway infrastructures on the environment and is a serious problem [17]. Through empirical model and analysis, Yu and Zhou [26] investigated the effect of governmental highway spending on vehicle emissions. The results revealed that improved fuel efficiency and road conditions can cause more traffic. The elasticity of passenger emissions to highway spending is only one-fourth of that in the freight sector. Relying on a bottom-up transportation model, Mangones et al. [27] examined the effect of expanded highway capacity on traffic-related emissions of five pollutant criteria (CO, NO_x, PM10, SO_2, and VOC) in Bogotá, Colombia. The results suggested that adding capacity to the heavily congested road network of Bogotá could reduce traffic-related emissions immediately after the new roads start operating. Sovacool et al. [28] estimated the hidden social and environmental costs of transport externalities which are about $13.018 trillion per year globally.

Major emissions during transport are not only key sources of global climate change, but also harmful for the health of nearby residents [26]. From the perspective of the adjacent areas of highway infrastructures, Hamersma et al. [25] and Hamersma et al. [29] investigated residents' perception of live-ability change caused by negative environmental quality (i.e., noise, air pollution, and barrier effects) and the perception of accessibility change using questionnaire surveys and structural equation modeling.

Highways are not only likely to damage the natural environment, but also cause various ecological problems. Mansuroglu et al. [17] investigated a variety of negative externalities of highways on the natural resources including land consumption, removal of vegetation, and severance of agricultural areas by the road building process. Feng et al. [30] developed a before–during–after control-impact remote sensing (BDACI-RS) approach to quantifying the spatial and temporal changes of the environment during and after the construction of the Wujing Highway in China. The result showed that the impacts of the highway on the environment, which include vegetation and moisture conditions, degradation-recovery trends, land surface temperature, manifested the most in its proximity and faded away with distance. Cai and Lu [31] used remote sensing technology and GIS technology to quantitatively assess

the road ecological effects. The results showed that the process of road construction increases the landscape fragmentation and decreases its contagion which affects animal migration. Ramísio et al. [10] estimated the highway runoff pollution based on a case study on 279-km Portuguese Highway.

5. Evaluation of Multiple Dimensional Externalities

Many studies on externalities of highway infrastructures do not strictly distinguish the dimensions of externalities. Using available data in Mexico and well-established methods, Cravioto et al. [13] calculated six categories of estimates of the externalities in Mexico. The results showed that road transport externalities amounted to at least US $59.42 billion per year or 6.24% of GDP in Mexico. By component, accidents represented the largest share (28%), followed by congestion (22%), greenhouse gases (21%), air pollution (13%), infrastructure (7%), and noise (9%). Moreover, Higgins et al. [32] investigated whether spatial trade-offs occur between the accessibility benefits of transportation and negative externalities from increased levels of harmful emissions and congestions in the single-detached property market around two highways in Hamilton, Canada. Using cross-sectional spatial-temporal hedonic models, the study revealed the evidence of a trade-off between transport advantage and environmental disadvantages in the study area. In addition, Nocker et al. [33] used the European accounting framework to assess and analyze external costs of a wide variety of transportation technologies within the life cycle of the road infrastructure. The European accounting framework allows to quantify and monetize impacts on public health, agriculture, and materials, but could not monetize ecological impacts.

The comprehensive literature review of the externalities of highway infrastructures and a scientometric analysis of infrastructure externalities conducted by Zhu et al. [11] all showed that there are many research on the needs of transport, the impact of transport, and the externalities of transport, providing a solid scientific knowledge base for the evaluation of the externalities of highway infrastructures. However, there are still research gaps in two main perspectives. From a macro and holistic perspective, a human-dominated planet is a kind of social–economic–natural complex ecosystem dominated by human behaviors, sustained by a natural life support system, and vitalized by ecological processes [34]. The development of highway infrastructures comes from the needs of the economy, society, and environment, and conversely, has impacts on these three aspects. The lack of externality evaluation of any dimension will not only bias the view of highway-related externality problems, but also lead to the distortions in the planning and development of highway infrastructures, leading to government failure or market failure for the governance of externalities [11][28][35]. The evaluation indexes in previous research are not comprehensive. On one hand, most of the previous studies only focused on the evaluation of one or two dimensions of the externalities of highway infrastructures. On the other, studies on the evaluation of the social and ecological externalities of highway infrastructures mainly focused on the negative externalities; studies on the evaluation of economic externalities of highway infrastructures mainly focused on the positive externalities. From a micro and technical perspective, due to the different forms of the externalities of highway infrastructures, there are few studies to quantify them with unified dimensional indicators, decreasing the comparability of evaluation results. Even quantifying and monetizing externalities of highway infrastructures, there are a lot of uncertainties and subjective treatments in the evaluation process. The ultimate purpose of the evaluation of the externalities of

highway infrastructures is not only to reveal the impacts of all aspects of externalities, but also to reveal how to balance the impacts of all aspects of externalities, achieving maximum social welfare.

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