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Review

The two sides of the coin of externality in road transport

Viktória Ötvös[1,2*]

[1]Department of Transport Technology and Economics, Budapest University of Technology and Economics
Műegyetem rkp 3., 1111, Budapest, Hungary
[2]KTI – Hungarian Institute for Transport Sciences and Logistics Ltd.
Than Károly 3-5, 1119, Budapest, Hungary
*e-mail: otvos.viktoria@kti.hu

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Abstract: The development of models of road transport externalities has been driven by the need to capture the broad spectrum of road transport's adverse societal and environmental effects. Externalities, introduced by economist Arthur Pigou in the early 20th century, refer to the unintended side effects of economic activities, such as pollution and congestion, which can be mitigated through taxes and subsidies. Recent models emphasise sustainable transport solutions, such as public transport, electric vehicles, and non-motorised options, aiming to reduce carbon emissions, improve air quality, and enhance urban livability.

Keywords: externality; road transport; emission lowering; economic effect

I. INTRODUCTION

The development of models of road transport externalities has been driven by the necessity of capturing the broad spectrum of road transport's adverse societal and environmental effects. So, what do you refer to when you use the term "externalities"? The idea of externalities originated with the economist Arthur Pigou in the early 20th century. He suggested that negative externalities, like pollution and congestion, could be reduced through taxes and subsidies, called Pigouvian taxes [1]. 1930s-1950s: early road safety measures - traffic signals and speed limits, mechanical turning signals, lap seat belts, and early safety features. During the mid-20th century, economists developed economic tools to contain externalities in the road transport sector [2]. These include command and control policies (regulations) and incentive policies (market-based instruments) [3]. Examples include congestion prices [4], fuel taxes [5], and emission trade systems [6]. Dr William Haddon developed a systematic road safety framework and emphasised the management of motion energy in crashes in the 1960s to 1990s—the introduction of mandatory seatbelt laws and the development of airbags [7]. The 1990s ecological Kuznets curve (EKC) hypothesis indicates that environmental degradation initially increases with economic growth but ultimately decreases as society becomes richer and can afford clean technologies [8]. Since the 1990s, advanced safety features such as anti-lock brake systems (ABS) and electronic stability control (ESC), such as crash test ratings, have been developed [9]. Modern approaches since the 2000s have incorporated several factors, including environmental, social, and economic impacts [10]. These models use advanced data analysis and simulation techniques to better predict and manage external factors. They also consider the long-term sustainability of transport systems. Integrated road safety management (2000s - present) could include adopting a global approach to road safety, integrating infrastructure, vehicle technology, and user behaviour [11], and promoting sustainable and safe transport solutions such as cycling and pedestrian infrastructure [12]. Recent models (since 2010) emphasise sustainable transportation solutions such as public transport [13], electric vehicles, and non-motorised transportation options [14]. These models aim to reduce carbon emissions, improve air quality, and enhance urban livability. In this article, the author wants to investigate the key elements of road transport externalities.

II. METHODOLOGY

The author has identified the key elements of road transport externalities see **Fig. 1**.

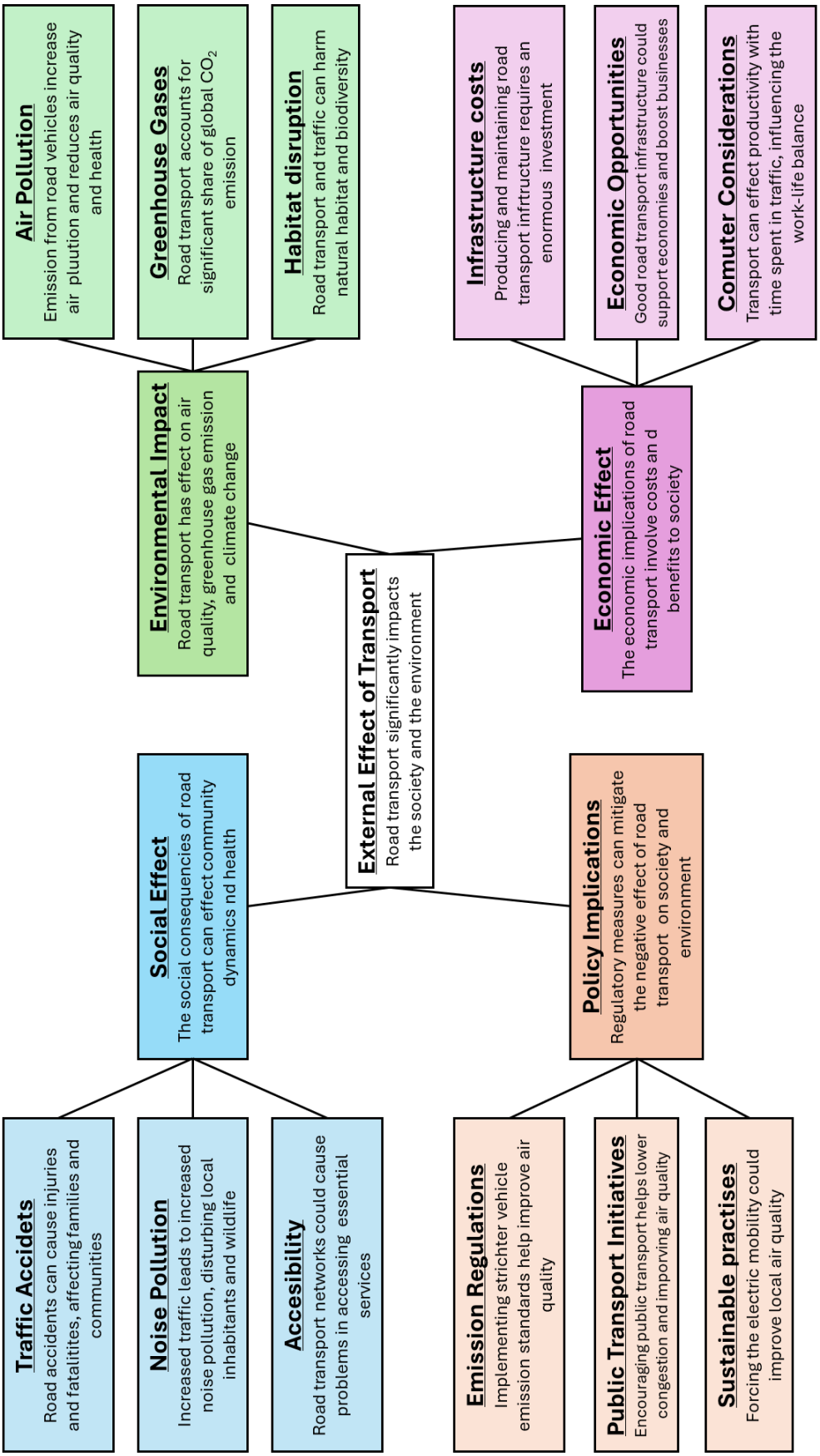

Figure 1. *Key elements of road transport externality*

Based on the map of the key elements, the author has investigated each role in road transport externalities.

III. RESULTS

Significant progress can be achieved by implementing various initiatives to combat air pollution. Adopting more stringent emission standards for vehicles has been identified as a key factor in reducing harmful pollutants such as nitrogen oxides (NO_x) and particulate matter (PM). This approach has enhanced air quality, particularly within urban areas [15]. Reducing air pollution is associated with a decline in respiratory and cardiovascular diseases [16]. This, in turn, leads to improvements in public health and reduced healthcare costs. The improvement in air quality has been demonstrated to be associated with a reduction in health problems, a decrease in healthcare costs, and an increase in productivity among healthy workers [17]. Regulations that promote the use of fuel-efficient vehicles can lead to a reduction in fuel consumption, resulting in cost savings for consumers and businesses [18]. Improving air quality is associated with enhancing the quality of life, making urban areas more attractive places to live and work. Initiatives to combat air pollution often include creating green spaces, which can absorb pollutants and provide recreational areas for residents [19].

In the context of climate change, efforts to mitigate greenhouse gas emissions have become a primary concern. A significant aspect of this mitigation involves the external effects of road transport, which can be substantially reduced through various strategies [20]. A key approach involves the promotion of electric vehicles (EVs) and hybrid cars, as these vehicles reduce the reliance on fossil fuels, leading to a decrease in emissions of pollutants such as nitrogen oxides (NO_x) and particulate matter (PM) [21]. This, in turn, results in improved air quality. Additionally, implementing stricter emission and energy consumption standards and promoting renewable energy sources for transport can substantially reduce carbon dioxide (CO_2) emissions [22]. This contributes to the mitigation of the effects of climate change by reducing the overall greenhouse gas levels in the atmosphere [23].

In the context of environmental concerns, efforts to mitigate the adverse effects of road transportation have garnered significant attention. Establishing wildlife corridors and green bridges has emerged as a primary strategy, enabling animals to trespass on roadways safely, reducing roadkill incidence and preserving biodiversity. This approach conserves ecosystems and sustains their vital functions, including pollination and water purification services. Incorporating green infrastructure, such as vegetated swales and retention ponds, has effectively filtered pollutants from road transport before reaching natural water bodies. This contributes to the maintenance of water quality and the sustenance of aquatic life. Restoring and protecting natural habitats, such as forests and wetlands, enhances their capacity to sequester carbon, thereby mitigating climate change by reducing the overall concentration of greenhouse gases in the atmosphere [24]. Establishing vegetated buffer zones around roads can reduce noise and visual pollution, making the surrounding areas more suitable for wildlife and improving the quality of life for nearby residents [25]. Promoting sustainable land use practices, such as eco-friendly farming and reduced deforestation, minimises habitat disruption. This, in turn, helps to maintain the provision of ecosystem services that benefit both the environment and human populations. Reserving natural habitats can also have positive economic consequences for local communities by promoting eco-tourism and recreational activities [26].

The ongoing struggle against traffic accidents has considerably impacted the external effects of road transport. Implementing road safety measures, including speed limits, seatbelt laws, and advanced vehicle safety technologies, can potentially reduce accident-related costs [27]. This, in turn, could reduce the external costs associated with accidents, such as medical expenses, property damage, and loss of productivity. Enhanced road safety measures have been shown to improve air quality by facilitating smoother traffic flow and reducing congestion. Coordinating traffic signals minimises stop-and-go traffic, reduces vehicle emissions, and enhances air quality. Internalising the external costs of road accidents through cost-benefit analysis (CBA) can ensure economic efficiency, enabling policymakers to make more informed decisions about road safety investments [28]. This approach ensures that resources are allocated efficiently to measures that provide the greatest societal benefit [29]. Road safety initiatives that promote sustainable transport options, such as cycling and walking, are also important. These modes of transport enhance safety and reduce road transport's environmental impact by lowering emissions and decreasing reliance on fossil fuels. Furthermore, reducing traffic accidents can enhance social well-being by decreasing the physical and emotional price for individuals and communities. The interconnected nature of road safety and the broader external effects of road transport is evident in the aforementioned impacts, demonstrating how improvements in one area can lead to positive outcomes in others.

Endeavours to mitigate noise pollution have substantially influenced the external effects of road transport. Implementing measures to reduce noise pollution, such as installing noise barriers and

utilising quieter road surfaces, has been demonstrated to result in a decline in health issues associated with noise exposure. This includes a reduction in stress levels, enhanced sleep quality, and a decrease in the risk of cardiovascular diseases [30]. Furthermore, it has been observed that reducing noise pollution can enhance property values, particularly in areas proximate to major roads and highways. The improvement in property values is particularly evident in areas adjacent to major roads and highways, where noise pollution is reduced, making these areas more attractive for residential and commercial purposes and thus increasing property values. The quality of life is enhanced by mitigating noise pollution, thereby improving overall quality of life. Less noisy environments are conducive to social interactions, outdoor activities, and general well-being. Significant economic benefits can be achieved by reducing the negative externalities associated with noise pollution, such as healthcare costs and lost productivity [31]. These savings can then be reallocated towards other public services and infrastructure improvements. Furthermore, environmental benefits can be realised through noise reduction measures complementary to other environmental initiatives, such as promoting electric vehicles and enhancing green spaces. These combined efforts contribute to creating a more sustainable and liveable urban environment. The aforementioned impacts demonstrate how addressing noise pollution can yield broader positive outcomes for society and the environment.

Enhancing the accessibility of public transport has substantially impacted the external effects of road transport. The reduction in traffic congestion, precipitated by the enhancement of public transport accessibility, has increased individuals' propensity to utilise buses, trains, and other forms of public transit instead of private cars [32]. This transition has led to a decline in vehicles on the road, consequently reducing traffic congestion and facilitating more efficient traffic flow. Reducing private vehicle usage can engender a decline in emissions and improve air quality, owing to a decrease in vehicles on the road. Public transport systems, particularly those utilising electric or low-emission vehicles, contribute to reduced levels of local pollutants. Improved public transport accessibility can also generate economic benefits by reducing the costs associated with traffic congestion, including fuel consumption and time lost in traffic. Furthermore, enhanced accessibility can facilitate access to employment opportunities and services, enhancing economic productivity. Furthermore, promoting social inclusion and equity is a key benefit of accessible public transport systems, ensuring that all population segments, including those without access to private vehicles, can travel conveniently. This, in turn, fosters social inclusion and equity, allowing people to participate more fully in economic and social activities. Moreover, urban livability is enhanced by reducing the reliance on private cars, with cities able to allocate more space for pedestrian areas, parks, and other public amenities. This enhancement in urban livability, in turn, fosters an environment that is more appealing and conducive to health, thereby attracting individuals to live in these areas. The aforementioned impacts underscore the advantages of enhancing public transport accessibility for individual users, society, and the environment.

IV. Analysis

The external effects of road transport have been significantly influenced by efforts to regulate emissions. Air pollutants could be reduced through emission regulations, including stricter vehicle emission standards and fuel quality standards [33]. This has led to improved air quality, particularly in urban areas. Regulations aimed at improving fuel economy and promoting cleaner fuels have contributed to reducing greenhouse gas emissions from the transport sector, which is crucial for mitigating climate change. Furthermore, the health benefits arising from lower levels of air pollution, which have resulted in fewer respiratory and cardiovascular diseases, have improved public health and reduced healthcare costs. The implementation of emission regulations has catalysed advancements in vehicle technology, leading to the development of more efficient and less environment-polluting engines and the adoption of electric and hybrid vehicles. While the initial costs associated with implementing emission regulations can be substantial, they offer long-term economic benefits, including healthcare savings, increased productivity due to enhanced public health, and new employment opportunities in the clean technology sector. Reducing emissions contributes to a more hygienic and aesthetically pleasing urban environment, thereby enhancing residents' overall quality of life [34].

Public transport initiatives have been shown to play a crucial role in lowering the external effects of road transport. Traffic congestion reduction can be achieved by providing efficient and reliable public transport options, resulting in fewer people relying on private vehicles [35]. This shift reduces the number of cars on the road, leading to less traffic congestion and smoother traffic flow. The utilisation of electric or low-emission vehicles by public transport systems has the potential to reduce pollutants, thereby enhancing air quality, particularly in urban areas. Enhancing public transport accessibility can yield economic benefits by mitigating the costs associated with traffic congestion, such as fuel consumption and time lost in traffic. Furthermore, enhanced accessibility to employment and services has increased economic productivity [36]. Accessible public transport

systems ensure that all population segments, including those without access to private vehicles, can travel conveniently, promoting social inclusion and equity and allowing people to participate more fully in economic and social activities.

Sustainable practices can mitigate the external effects of road transport in many significant ways. Reducing greenhouse gas emissions can be achieved by transitioning to electric and alternative fuel vehicles. Adopting electric vehicles (EVs) and using alternative fuels, such as hydrogen and biofuels, can substantially reduce greenhouse gas emissions. These vehicles generate fewer pollutants than traditional internal combustion engine vehicles. The promotion of public transport can contribute to the enhancement of air quality. Enhanced public transport systems lead to a reduction in private vehicle usage, resulting in lower emissions of pollutants. This contributes to improved air quality, particularly in urban areas. Route optimisation can play a significant role by employing advanced route planning and optimisation software to minimise unnecessary travel distances, thereby reducing fuel consumption and emissions [37]. The implementation of congestion charges can effectively alleviate traffic congestion. Implementing congestion charges in high-traffic urban areas has encouraged public transport and off-peak travel, thereby reducing traffic congestion and the associated emissions [38]. Collaborative logistics and transport can be facilitated by sharing logistics and transport resources among companies, leading to optimised vehicle loads and reduced trips required, consequently lowering fuel consumption. The development of green highways and urban green spaces that can absorb pollutants, reduce noise, and enhance the overall urban environment is known as green infrastructure. The promotion of walking and cycling through dedicated infrastructure has the potential to reduce reliance on motor vehicles, thereby lowering emissions and enhancing public health. Implementing systems to track and manage carbon emissions can facilitate the identification of areas for improvement and ensure compliance with environmental regulations.

V. CONCLUSION

Road transport's external effects can be reduced, but this can result in increased infrastructure costs. Implementing green infrastructure, such as bridges, wildlife corridors, and vegetated swales, can be more expensive than traditional road construction methods. Using advanced, more environmentally friendly materials for road construction can also increase initial building costs. The maintenance of green spaces and other environmentally friendly infrastructure requires ongoing investment in landscaping and upkeep. Implementing and enforcing emission standards and other regulations can increase operational costs due to the need for monitoring equipment and personnel. The utilisation of sustainable maintenance practices, including using recycled materials and eco-friendly methods, has been observed to incur costs that are occasionally higher than those of conventional practices. The employment of advanced technologies for infrastructure monitoring and maintenance, such as sensors and predictive analytics, has been found to necessitate initial investments that are often more substantial. The process of retrofitting existing infrastructure to align with novel environmental standards or to incorporate green technologies has been documented to be financially demanding. The development and implementation of innovative solutions, including smart traffic management systems and electric vehicle charging stations, have been shown to contribute to increased costs associated with improvement initiatives [39]. While these measures can increase costs in the short term, they often lead to long-term benefits, such as reduced environmental impact, improved public health, and enhanced urban livability. Additionally, investing in sustainable infrastructure can result in economic savings over time by reducing the need for costly emergency repairs and improving overall efficiency.

The endeavours to mitigate the external effects of road transport can yield economic ramifications, encompassing the potential escalation of infrastructure expenses and the impact on trade and business enterprises. Implementing green infrastructure, advanced materials, and sustainable practices can increase road transport infrastructure construction, operation, maintenance, and enhancement costs. Adherence to more stringent emission and safety standards may necessitate substantial investments in novel technologies and upgrades to existing infrastructure. Imposing more rigorous regulations and increased costs can disrupt logistics and supply chains, leading to elevated transportation costs and delays. The ability of small and medium-sized enterprises (SMEs) to absorb the additional costs associated with compliance may be problematic, potentially leading to reduced competitiveness or business closures.

Indeed, measures implemented to reduce road transport's external effects can affect commuters, productivity and work-life balance. Implementing measures to reduce externalities, such as congestion pricing or higher fuel taxes, can increase commuting costs, which may result in some commuters choosing to forgo private vehicles. This could lead to a shift towards public transport or alternative modes of travel. The imposition of stricter regulations and higher costs could lead to changes in commuting patterns, with some people opting to work remotely or relocate closer to their place of employment to avoid long commutes. While higher costs and stricter regulations might initially seem onerous, they can

lead to reduced traffic congestion and smoother commutes for those who continue to drive, thereby decreasing commuting stress and improving overall productivity. The encouragement of remote work can mitigate the negative impacts of commuting on productivity. Research has indicated that extended commutes increase creativity and productivity, particularly among high-achieving professionals. Strategies to reduce traffic congestion can reduce commuting times, allowing individuals to allocate more time to their families and leisure activities. This, in turn, can enhance work-life balance and overall well-being. The alleviation of stress associated with protracted and unpredictable commutes can have substantial mental health benefits, including reduced anxiety and improved job satisfaction. While the external effects of road transport can be mitigated, resulting in alterations to commuting patterns and potentially higher costs, there are also opportunities to improve productivity and work-life balance. By meticulously designing policies and promoting flexible work arrangements, a balance can be achieved that benefits commuters and the environment.

The Philip-Martin model is a theoretical framework that analyses the interplay between trade, economic growth, and environmental policies. It can be utilised to assess the ramifications of road transport externality measures on economic opportunities. The model facilitates the identification of trade-offs between environmental benefits and economic costs. To illustrate, implementing more stringent emission standards may result in enhanced air quality and improved public health, yet it can concurrently precipitate elevated production costs and impact trade competitiveness. The Philip-Martin model can assist policymakers in optimising regulations, thereby achieving a balance between environmental objectives and economic growth. This is achieved by identifying the appropriate combination of policies that mitigate negative externalities without imposing undue burdens on businesses. The model can illuminate the long-term economic advantages of reducing externalities, including lower healthcare expenditures, enhanced productivity, and the establishment of green employment opportunities. These benefits can offset the initial costs and contribute to sustainable economic growth. While acknowledging the possibility of increased costs and economic challenges in the short term due to efforts to reduce the external effects of road transport, the Philip-Martin model provides a framework for understanding and balancing these impacts. It is therefore concluded that, by carefully designing and implementing policies, it is possible to achieve environmental goals while supporting economic opportunities.

AUTHOR CONTRIBUTIONS

V. Ötvös: Theoretical analysis, Writing, Conceptualisation, Review and editing Supervision.

DISCLOSURE STATEMENT

The author declares that she has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ORCID

V. Ötvös https://orcid.org/0009-0002-3411-018X

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