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Transport Infrastructure and Regional Development: A Survey of Literature on Wider Economic and Spatial Impacts

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Abstract: The main purpose of the paper is to provide an overview of methods used to research the relationship between transport infrastructure investments and regional development, with a focus on wider impacts both in the traditional economic context (wider economic impacts or WEIs) and—which is a methodological novelty proposed by this paper—in the spatial context (wider spatial impacts or WSIs). In terms of methodology, research may be conducted using the following methods: cost benefit analysis (CBA) and multi-criteria analysis (MCA), accessibility and potential models, econometric production function estimates, regional modelling, trade and input-output (IO) modelling, Land Use-Transport Interaction (LUTI) or spatial computable general equilibrium (SCGE) models. In the European Union, approaches based on cost-benefit analysis (CBA), or possibly multi-criteria analysis (MCA), continue to prevail. Notwithstanding the availability of a wide range of methods for quantifying socio-economic impacts, the European Union recommends that wider economic impacts at the regional and national levels be assessed by means of qualitative approaches. This being the case, it is recommendable for the European Commission to take broad-ranging action towards ensuring that the effects of transport infrastructure investments are assessed by means of a broader range of approaches.

Keywords: CBA; MCA; potential accessibility; econometric estimations; input-output; general equilibrium models; transport infrastructure; European Union

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1. Introduction

Transport infrastructure investments can have a considerable but varied impact on regional development. Regional development and economic growth theories emphasise the role of transport links in generating income (balanced and unbalanced growth strategies) or in its interregional redistribution (polarisation theories and new economic geography theories) and identify infrastructure investments as a potential source of 'crowding out' private investments (classical theories) or as public expenditure necessary to stimulate economic growth (the Keynesian theory), thus enabling 'externalities' to be achieved (the new growth theory).

The complexity of relationships between infrastructure expansion and regional development and of the transmission of effects requires a separate overview of literary sources. The comprehensive overviews of studies that were produced at the time when research into these topics was 'booming', such as [1,2], do not provide an insight into the most recent research efforts/trends/methods, i.e., those from the last two decades. In addition, to the best of the authors' knowledge, there are no new comprehensive literature surveys which encompass the broad range of methods that look into what is referred to as wider economic impacts (WEIs), which cannot be captured by conventional cost-benefit analysis (CBA). The exceptions include publications by Legaspi et al. [3] and Rothengatter [4], which, however, focus on approaches to measuring WEIs based on GDP and welfare. Moreover, the authors of the present-day publications on the impact of transport infrastructure investments on regional development focus on WEIs and do not adequately address wider spatial impacts (WSIs). This article endeavours to fill the gap in this regard.

A number of authors working on this subject have attempted to depict a variety of effects of transport infrastructure development at the regional level. These effects include: improved accessibility, environmental impacts, sustainable development, location of new private sector investments, numerous effects on inter-regional trade and transport costs and redistribution of regional income. The effects themselves can be [4,5]:

- demand or supply,
- internal or external,
- distributive or generative,
- first round or second round,
- mandatory or discretionary,
- temporary or permanent,
- direct user benefits or indirect and induced (via demand or via supply) wider effects.

On the one hand, the impact of transport infrastructure investments can be direct, measurable and quantifiable, but on the other, it can also be indirect or induced and therefore difficult to measure. In addition, the effects may vary depending on the time perspective. Demand-side effects of infrastructure investments are typically short-term, whereas those on the supply side are medium- and long-term in nature. As regards methodologies, research may be pursued by means of the following methods: cost benefit analysis (CBA) and multi-criteria analysis (MCA), accessibility and potential models, econometric production function estimates, regional modelling, trade and input-output (IO) modelling, Land Use-Transport Interaction (LUTI) or spatial computable general equilibrium (SCGE) models.

The topic of the relationship between transport infrastructure and regional development gained relevance in the 1990s. This is when numerous publications on the subject appeared. The first and most important of these was the publication by Aschauer [6]. Another significant reason for the relationship between transport infrastructure and regional development gaining prominence was the acceleration of the construction of the TEN-T network in Europe. In later years, major transport infrastructure construction initiatives (motorway networks, high-speed railways, seaports and airports) were mainly observed in Asia, as well as in Central and Eastern Europe and on other continents, especially in developing countries. This gave rise to a number of publications in countries previously considered as developing ones, i.e., in Asia [7–13], India [14–16], Pakistan [17], Taiwan [18]; Armenia, Georgia and Turkey [19,20], Russia [21] or in the Middle East [22], as well as in Eastern Europe (in Poland [23–31] and Croatia [32]) and Southern Europe (in Greece [33,34], Spain [35], Portugal [36] and in Italy [37]). The increased interest in this research topic in the countries mentioned above was often linked to the parallel rapid socio-economic development of areas where transport infrastructure was being expanded.

The aim of this article is to present an overview of methods used to research the relationship between transport infrastructure investments and regional development. The emphasis is on wider impacts, both in the traditional economic context (WEIs) and in the spatial context (WSIs), which is a methodological novelty proposed in this paper. These categories of impacts are often disregarded in the regional analyses/reports/evaluations recommended by the European Commission, which follow approaches based on traditional CBA or MCDA methodologies, the four-step travel demand model or environmental impact analysis. Meanwhile, the indirect effects of infrastructure development are difficult to quantify and require more advanced research methods, some of which are presented in articles included in Sustainability's Special Issue "The role of transport infrastructure in regional development" (14(23)/2022).

The article consists of four sections. The first is an introduction. The next section of this paper takes a closer look at traditional methods of evaluating transport infrastructure investments, such as CBA and MCDA. The longest, third section, which is the clue of the article, discusses the latest mechanisms and methods for measuring and analysing the impact of transport infrastructure investments on regional development. This is done by wider economic impacts (WEIs) and in a spatial context (WSIs) of investments. The final, fourth section, concludes the paper.

2. Traditional Methods of Evaluating Infrastructure Investments—CBA and MCDA

The direct effects of transport plans and projects are evaluated ex-post and ex-ante by means of a variety of methodological frameworks [38]. The methods can be grouped into two main categories: single-criterion methods (monetary approach), which include CBA (Cost-Benefit Analysis) or CEA (Cost-Effectiveness Analysis), and multi-criteria methods (non-monetary approach), which include Multi-Criteria Decision Analysis-Aid/Multi-Criteria Decision Making (hereinafter MCDA/MCDM).

The most widely used method for evaluating transport projects is Cost-Benefit Analysis (CBA). It is used to evaluate transport projects and measure their societal value by quantifying their impacts and allowing cost-benefit comparisons in monetary terms [39]. The EU Centre for EU Transport Projects has provided the Guide to Cost Benefit Analysis of Investment Projects: Economic appraisal tool for Cohesion Policy 2014–2020 [40] and Economic Appraisal Vademecum 2021–2027—General Principles and Sector Applications [41], which clearly showed how to carry out CBA for transport infrastructure projects in the 2014–2020 and 2021–2027 programming periods [42]. The Vademecum prepared for the 2021–2027 programming period recommends that transport infrastructure projects use CBA or CEA, alternatively MCA for appraising investments (Table 1).

Table 1. Suggested Effectiveness Analysis methods for transport by investment area.

Investment Area	Project Type	
	Small Projects	**Large/Strategic Projects**
Transport infrastructure (all modes)	(Simplified) CBA	CBA
Transport infrastructure: compliance-driven project (all modes)	CEA/MCA	CEA/MCA
New technology in transport	CEA/MCA	CBA/CEA/MCA

Source: [41].

Due to the complexity of transport investment projects and the shortcomings of standard tools (such as CBA or CEA), more advanced methods such as MCDA/MCDM are increasingly being incorporated into the decision-making process [43,44]. The number of projects using MCDA/MCDM is constantly increasing. MCDA allows two key policy choices to be made: (1) the choice of the criteria against which alternatives will be assessed; and (2) criteria weighting. The choice of criteria is essential in order to capture the major costs and expected impacts of a project, also in relation to the priority development goals for the region or country as a whole. Criteria weighting can be a subjective process, with weights assigned through consultations or with the help of experts who will decide on the importance of the individual decision-making criteria. Alternatively, weights can also be determined using statistical methods such as Principal Component Analysis (PCA) [45]. Owing to the limitations of MCDA/MCDM, Marcelo et al. [46] propose the Infrastructure Prioritisation Framework (IPF), an approach that synthesises financial, economic, social and environmental indicators at the project level into two indexes, namely the Social and Environmental Index (SEI) and the Financial and Economic Index (FEI).

Macharis and Bernardini [43], who have collected 276 titles of publications in their overview, conclude that MCDA/MCDM are widely used in transport projects, inter alia, to assess passenger and freight transport policies [46,47], strategic decision-making [48], siting analyses, e.g., for park and ride facilities [49] and ranking of transport zones [50]. The publication [51] provides an overview of 52 2020–2021 articles regarding, among other topics, the choice of road, air, rail or sea transport investment locations. The authors identify AHP (Analytic Hierarchy Process), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Preference Ranking Organization METHod for Enrichment of Evaluations (PROMETHEE), Fuzzy AHP and data envelopment analysis (DEA) [52] as the most popular methods of multi-criteria decision making. Different methodologies are employed depending on the phase of the infrastructure project (planning, design, maintenance/reconstruction), although AHP remains the most popular method of MCDA/MCDM [53]. Wołek et al. [54] have summarised the pros and cons of the various methods/tools used with regard to public transport investments, which, as they find, include, in addition to CBA, CEA, MCDA/MCDM, also LCA (life-cycle assessment), LCCA (life-cycle cost analysis) and TCO (total cost of ownership).

The table below presents an overview of the full spectrum of effects (impacts) of infrastructure investments, highlighting those identified by the European Commission in the *Vademecum* [41] (Table 2). The European Commission recommends that for wider economic impacts (WEIs) (including agglomeration effects, changes in production in imperfectly competitive markets and the tax effects of a shift to more productive jobs) a qualitative assessment should be applied. The exception is in the case of very large projects for which the potential impacts justify a quantitative approach to evaluation [41].

Table 2. Effects of transport infrastructure investments including those identified by the European Commission.

<table>
<tr><th>Category of Effects</th><th colspan="2">Specification</th><th>EU (COM)</th></tr>
<tr><td rowspan="9">Direct economic and safety effects</td><td rowspan="2">Financial flows</td><td>Costs of construction, maintenance, operation and renovation of infrastructure</td><td rowspan="2">Operating and maintenance (O&M) costs</td></tr>
<tr><td>Proceeds from tolls</td></tr>
<tr><td rowspan="4">Direct benefits for users</td><td colspan="2">Perceived passenger door-to-door time (value of time)</td></tr>
<tr><td colspan="2">Freight time (value of time)</td></tr>
<tr><td colspan="2">Vehicle operating costs</td></tr>
<tr><td colspan="2">Safety (unit values for accident costs)</td></tr>
<tr><td rowspan="3">Direct networking effects</td><td>Induced traffic: new trips (traffic), change of trip purpose and trip re-timing, destination changes</td><td rowspan="3">Demand modelling</td></tr>
<tr><td>Intermodal shift of demand</td></tr>
<tr><td>Quality of transport services (travel comfort and convenience)</td></tr>
<tr><td rowspan="5">Environmental and health effects</td><td colspan="3">Climate change (unit cost of carbon)</td></tr>
<tr><td colspan="3">Environmental greenhouse gas (GHG) emissions (unit external air pollution costs values per mode)</td></tr>
<tr><td colspan="3">Noise (unit external cost values)</td></tr>
<tr><td colspan="2">Other environmental impacts (e.g., impact on Natura 2000, biodiversity)</td><td>Qualitative assessment</td></tr>
<tr><td colspan="3">Local health</td></tr>
<tr><td rowspan="2">Defence, tourism and national heritage effects</td><td colspan="2">Military mobility and accessibility</td><td rowspan="2">No references</td></tr>
<tr><td colspan="2">Tourism and national heritage, i.e., accessibility of sites of historical or archaeological interest</td></tr>
<tr><td rowspan="3">Wider spatial impacts (WSIs)</td><td colspan="2">Accessibility of cities/regions/country</td><td rowspan="3">Described briefly as the ‘German approach’</td></tr>
<tr><td colspan="2">Distributive accessibility effects</td></tr>
<tr><td colspan="2">Spatial planning and urban planning</td></tr>
<tr><td rowspan="5">Wider economic impacts (WEIs)</td><td colspan="2">Productivity of production factors</td><td rowspan="5">Wider economic benefits (qualitative assessment recommended)</td></tr>
<tr><td colspan="2">Labour market (employment)</td></tr>
<tr><td colspan="2">Agglomeration effects</td></tr>
<tr><td colspan="2">Real estate value (residential prices)</td></tr>
<tr><td colspan="2">Trade, interregional and intersectoral flows (input-output), general equilibrium</td></tr>
</table>

Source: own study and [41].

The "Guide to cost benefit analysis of investment projects. Economic appraisal tool for Cohesion Policy 2014–2020" [40] issued in 2014 is supplemented by Jaspers Blue Books for projects in the public transport, road and rail infrastructure sectors (the latest, i.e., 2022, version for the 2021–2027 programming period is an update of the previous 2006, 2008 and 2015 books). They address issues related to demand modelling, socio-economic analysis (for road transport) or economic analysis (for rail transport), financial analysis, assessment of project risks and impact on employment (with the last category pertaining exclusively to road projects). In addition to specific direct economic and safety-related impacts (Table 2), a socio-economic analysis of economic costs/benefits as per Jaspers rules also takes into account costs associated with the emission of pollutants, climate change and noise. As regards the impact of investments on employment, the effects pertain to jobs created both at the project implementation and operation stage. The number of jobs should be determined by reference to the operational or business plan of the infrastructure manager [55–57].

3. Wider Economic and Spatial Impacts

Addressed rather superficially in official European Commission documents, both wider economic impacts (WEIs) and wider spatial impacts (WSIs) are broadly described in the literature on the subject. This article presents below a short overview of literature regarding the various wider spatial impacts (accessibility of cities/regions/country, distributive accessibility effects, spatial and urban planning) and wider economic impacts (productivity of production factors, labour market, agglomeration effects, real estate value or trade, flows (IO) and general equilibrium) as distinguished by the authors.

3.1. Wider Spatial Impacts (WSIs)

In essence, this paper distinguishes wider spatial impacts by reference to the concept of peripherality understood as the inverse of accessibility measured mainly by the potential model. The gravity models used in the four-step travel demand model place emphasis on analysing network flows and forecasting network traffic without exploring thoroughly the direct relationships for individual locations, i.e., network nodes. By contrast, rather than capturing the entirety of the relationships for the transport zones within the research area, trip time shortening, as a measure employed in traditional CBA, investigates individual linkages. In a sense, spatial spillover effects as used in econometric analysis fill this gap in the context of wider economic effects. However, the spillover effects studied are not as comprehensive as the potential model because they do not take into account linkages within the entire area that is being analysed. In addition to being useful in spatial analyses, the thus-defined categories of accessibility effects and distributive accessibility effects can also be used as an explanatory variable for WEIs (as in [58]). Such an approach strengthens the relationships between socio-economic cohesion and territorial cohesion. The wider spatial impacts as identified above are complemented in this article by spatial planning and urban planning effects, which pertain to connectivity and accessibility in particular in intra-agglomeration terms.

3.1.1. Accessibility

Transport and planning studies draw heavily on the concept of the impact of improved transport accessibility on regional development and make use of the evolving potential and gravity models. In Western European countries, this subject has been gaining ever broader attention along with the acceleration of the European integration process. In transport policy, European integration is reflected by the creation of Trans-European Transport Networks (TEN-T), which were being planned from the early eighties. One of the priorities behind the expansion of the network is to ensure the greatest possible level of territorial cohesion. For example, the authors of [59] have assessed the implications of accessibility for regional development in the EU. Their conclusions cast doubt on the ability of Trans-European Networks (TENs) to promote greater convergence in both accessibility and economic development.

Accessibility studies have been associated with the concepts of peripherality and regional cohesion. Pioneering research in this area was conducted by Keeble et al. [60,61] for the European Commission as early as the 1980s to be continued in the following decades by, among others, Spiekermann and Wegener [62] and Bröcker [63] in Germany, Bruinsma and Rietveld [64] in the Netherlands and Gutiérrez et al. [65] in Spain. A number of analyses have been carried out to estimate the impact of changes in potential accessibility on regional development, one outcome of which has been the SASI model (Socio-Economic and Spatial Impacts of Transport Infrastructure Investments and Transport System Improvements) [66,67]. The SASI model has been further developed under the project Integrated Assessment of Spatial Economic and Network Effects of Transport Investments and Policies (IASON) (see SCGE models). The authors of [67] explore the relationship between the level of accessibility and economic performance for European regions. In 2004, Central and Eastern Europe was by far the area where the level of GDP was relatively lower than that of accessibility, whereas Scandinavia was the region which showed a much lower level of accessibility than GDP per capita (relative to the EU average). The authors of [68] continued to explore this topic with the use of the potential quotient method, this time for the entire European continent.

In recent years, changes in accessibility at various spatial levels in Europe have been described as a result of the ESPON TRACC project [69]. In the US, the University of Minnesota runs an accessibility laboratory, headed by Owen, in which accessibility in the US is researched by measuring accessibility to workplaces by various means of transport across the US through constant monitoring [70]. The development of HSR lines in recent years has translated into a number of publications on the relationship between improved accessibility and economic growth, inter alia in Italy [71], as well as in other countries e.g., [72–74].

Accessibility-based models highlight the influence of accessibility on business location or productivity. How changes in potential accessibility influence manufacturing location has been analysed for Spain by Holl [58,75] and for Italy by Gallo et al. [76]. As [76] found, accessibility is mainly relevant for the siting of medium-sized and large companies and is only relevant to a lesser extent for micro and small enterprises. According to [58], motorways affect the spatial distribution of new production facilities by boosting the attractiveness of territorial units that are located close to the new infrastructure. However, the scope of the positive effect varies from one sector to another [75].

Improvement of accessibility through investment in infrastructure may help to solve the housing poverty problem, a resonant issue across Europe [76]. Moreover, research indicates that countries with relevant improvement in infrastructure, mainly in Eastern Europe, have witnessed a clear improvement in poverty status [77], which is an interesting finding in the context of a broader discussion on positive externalities produced by investments in infrastructure. Regions with insufficient infrastructure face traditionally low labour mobility and suffer from higher and longer unemployment [78,79]. Therefore, improving the accessibility of such problem areas through investment in transport infrastructure is conducive to reducing poverty and the resulting social and economic problems.

3.1.2. Distributive Accessibility Effects

Analysing the influence of improved accessibility on spatial and socio-economic inequalities is equally as popular as studying the relationships between infrastructure development and improved accessibility. Cluster 6: Accessibility of the Network on European Communications and Transport Activities Research (NECTAR), which brings together accessibility researchers from various countries, is very active in this area. It has released a series of books and special issues devoted to accessibility modelling, with a focus on exploring the relationship between accessibility, equity and efficiency. One example is a publication by Geurs et al. [80], where the horizontal, vertical, social, spatial or territorial dimensions of equity are investigated. In general, the level of spatial accessibility usually reflects the core-periphery division [81], which does not consider the unequal distribution of accessibility as anything wrong [82].

The key question concerns the threshold beyond which 'natural' spatial differences in accessibility turn into what could be referred to as an 'unfair' or 'dysfunctional' accessibility system. Limited accessibility or inability to access can be seen in normative and relative terms, i.e., measured through absolute and relative values [83]. When the former approach is employed, the results of accessibility analyses are interpreted by reference to a threshold beyond which accessibility is considered to be lacking or limited (e.g., more than 30 min to travel to the nearest pharmacy or nursery), with the inhabitants of the thus-delimited area likely to be exposed to social exclusion. The associated concept is known as sufficientarianism, which assumes that everyone should have a level of access that is at least 'good enough' [82,84]. It means that none of the inhabitants of a study area should live in a place where the level of accessibility is lower than the threshold adopted. In the relative approach, the results of accessibility analyses are interpreted by reference to the so-called equalisandum, which is adopted individually for every study [85]. A detailed overview of the approaches can be found, inter alia, in [81,82,86–88]. According to the egalitarian approach, everyone should be treated equally, so the emphasis is on reducing disparities in accessibility between individual residents, population groups or city areas. In spatial terms, the egalitarian approach will therefore identify the areas with the highest and lowest levels of accessibility and propose transport solutions to shorten the distance between the extreme cases identified [89–93]. By contrast, the utilitarian approach is reflected by CBA. Generally, the Gini, Theil and Atkinson indices are used to estimate the level of equality [84,94]. Often use is also made of the potential accessibility dispersion (PAD) index (e.g., [91,95]), which is based on the potential accessibility index and the coefficient of variation.

3.1.3. Spatial Planning and Urban Planning

In the planning context, the externalities of the development of a system of high-speed railways in the context of land use changes have been analysed by, among others, Willigers and Van Wee [96] in the Netherlands, Ibeas et al. [97] and Moyano et al. [98] in Spain and Cao et al. in China [99]. In Poland, the development of transport infrastructure in planning terms has been analysed by Komornicki and Szejgiec-Kolenda [100]. The Vademecum [41] refers to a German study where, in keeping with the German methodology, two of the four main modules of the long-term national transport infrastructure investment plan concern spatial planning, thus addressing the connectivity and accessibility of agglomerations in terms of distributive equity and urban planning. This addresses the local impacts of transport infrastructure projects that influence the quality of urban areas, inter alia, by relieving them of transit traffic (decongestion).

3.2. Wider Economic Impacts (WEIs)

In our paper, we distinguish several wider economic impacts (WEIs). Among them: productivity of production factors, labour market, agglomeration effects, real estate value or trade and flows. This list is not closed. In addition, feedback between individual categories of effects is frequent. We try to focus on problematic issues related to the application of particular research methods needed to analyse WEIs.

3.2.1. Growth and Productivity

Since the early 1990s, when the topic of the relationship between transport infrastructure and regional development gained prominence [6,101–103], econometric estimates of the impact of public capital on productivity have been the most widely used method of research in this area. Despite the existence of a wide range of analytical tools for forecasting the economic effects of infrastructure investments (such as, for example, MCA, CBA, SCGE, accessibility analysis, input-output analysis), new approaches are being developed by econometrists all the time. A wave of research on the contribution of infrastructure to GDP and productivity growth was also triggered by the new growth theory (NGT), which emphasises increased economies of scale in manufacturing as the main source of economic growth [104]. In the first half of the 1990s, academic researchers and political leaders advocated the need for trade liberalisation. Steps in this direction were taken both in the USA (the 1992 NAFTA agreement) and in Europe (the signing of the Treaty on European Union in 1992), with the creation and development of Trans-European Networks becoming one of the main goals of the unification of Europe. Use is often made of the well-known neoclassical model of the production function, which tends to be extended to include public capital as additional input.

However, the econometric approach raises many questions. Firstly, it is difficult to determine the size of the public capital stock due to, inter alia, the application of an incorrect price deflator, service lives and mortality functions and the particular choice of the public capital depreciation method [105].

Secondly, according to the critics of Aschauer's approach [6], if he had used public capital as an endogenous variable and output as an explanatory one, he would have also obtained a strong correlation. This is an example of how problematic spurious regression and the direction of causality can be in econometric models when high correlation coefficients are observed. It should be noted that when common trends are estimated, correlation does not always imply causality, and therefore the cause-and-effect relationships determined as a result of applying the model may turn out to be 'spurious'. An example of such a false correlation is the story of the "stork and baby" [106]. Models based on Granger causality [107] are a popular tool used by researchers on the impact of transport infrastructure on broadly defined development of regions. Co-integration is usually assessed using the Engle-Granger test or the Johansen method. The advantage of the Engle and Granger approach is its simplicity [108]. Rather than testing whether X causes Y, Granger causality tests whether X predicts Y [109]. For example, models based on Granger causality have been used to determine whether there are causal links between investment in transport infrastructure and economic growth at the national and regional levels in China [7] and in Pakistan [17]. Other methods include vector autoregression procedures (VAR—*Vector Autoregressive Models* and VECM—*Vector Error Correction Model*), which address the problem of the direction of causality (e.g., [14,19,110]). The VAR model departs from the classical distinction between endogenous and exogenous variables and does not apply any limitations to the value of the parameters.

When co-integration of time series is involved, use is made of the VECM model, which helps overcome the problem of the disregard of feedback between model variables that is characteristic of single-equation models. Use is also made of the so-called 'generalised method of moment' or GMM, where the distribution of random variables in the model does not need to be known [111]. By using a GMM procedure, Crescenzi and Rodríguez-Pose [112] attempted answer the question regarding the extent to which motorways contributed to regional growth in the EU over the years 1990–2004. It follows from the results of the study that the stock of infrastructure is a relatively poor predictor of economic growth. Farhadi [113], who has also used GMM modelling, has proved that the return on infrastructure investments in OECD countries in 1870–2009 was weaker than the positive externalities produced by investments in equipment and structural investments. In India, Pradhan and Bagchi [14] have endeavoured to capture the relationship between transport infrastructure and economic growth, assuming the length of roads and railways as the explanatory variables. Based on a VECM model, they identified a two-way relationship between the expansion of road transport infrastructure and economic growth in the years 1970–2010 (road transport generates economic growth and vice versa). The same study identified a unidirectional dependence of economic growth on rail infrastructure, which implies that the deterioration of rail infrastructure within India's transportation network would be detrimental to economic growth.

Thirdly, the results of aggregated time series do not bring to light the actual regional effects of investments in public infrastructure. Transport infrastructure has a networked nature, which means that an appropriate regional model should accommodate the specific features of the area (region) and take into account spatial externalities. Spatial lag (or spatial dependency) occurs when variables regarding 'neighbouring regions' are taken into account as explanatory variables in regression (for an overview of studies see [114]). Whereas some studies have found that the proximity of additional infrastructure in neighbouring regions enhances production or lowers costs, others have proven the opposite. Although most authors point to negative elasticities for neighbours' public capital [115–117], there are also exceptions [118]. It is extremely important, especially for poorer, peripheral areas, whether the investment is part of an interregional or intraregional transportation system, which is emphasized by new economic geography models. According to this approach, if public capital is invested in intraregional infrastructure and lowers the level of transaction costs within such a poor region, it can be expected that this process will attract investors and lead to a reduction of interregional inequalities [119]. In other words, the New Economic Geography (NEG) stresses the role of infrastructure investments for attractiveness of a region for investment, including foreign direct investment (FDI). According to Varahrami and Vajari [120], the effectiveness of foreign direct investment on the growth rate of a region's public consumption significantly relies on public capital efficiency to attract FDI. If investments in infrastructure, including transport infrastructure, are insufficient, and the marginal rate of return on its public capital for attracting FDI is low, public consumption will have a low growth rate in the long-run. Interregional transport networks are an important element in lowering disparities by reducing transaction costs between regions and creating the possibility of expanding the areas of activity of business entities from the connected areas [121].

Fourthly, the problem of missing variables may raise some doubts. As Aschauer's critics [6] point out, his estimates overstate the impact of infrastructure on productivity and also ignore other determinants; in fact, they were supposed to be one of many variables explaining the lower level of productivity in the US after the oil crisis in the 1970s [101]. The production function only reflects technological relations and reduces the role of factor prices in the firm's decision-making process. That is why use is often made of an alternative approach which has some advantages, namely the cost function approach [117,122,123]. For example, Cohen and Morrison Paul [124], who have adapted the cost function and spatial externalities, conclude that better airports in neighbouring regions are just as effective in reducing costs for manufacturing companies in specific regions (US states) as the region's own airport.

Moreover, better access to transport infrastructure can be ensured by means of intelligent traffic systems and proper traffic management [105]. For businesses, the stock of infrastructure is less important than the number of services it provides. The same effects can be achieved through the use of a more flexible pricing system, which is why it is advocated that the public capital series should be adjusted by an appropriate index reflecting the use of public services by the different sectors of the economy [123]. An interesting study of the impact of the development of transport infrastructure on foreign trade, taking into account information and communication technology (ICT) infrastructure as auxiliary to transport networks, has been completed in Turkey [20]. Using an autoregressive distributed lag model (ARDL), the study assesses the short- and long-term relationships between transport infrastructure, exports and imports in 1987–2019. It follows from its results that a network of expressways is a driving force of trade growth, and that investing in railway infrastructure can be beneficial if a well-thought-out, long-term, comprehensive and sustainable transport policy oriented to the development of multimodality is pursued.

Fifthly, it is also worth considering the baseline level of infrastructure investments. According to Fernald [125], retrospective studies are not the optimal way to validate future expenditure on the transport network, because changes in the structure of the economy mean that technical solutions that were sufficient in the past may not be effective nowadays. It is therefore important to bear in mind that the effects of infrastructure investment may vary in the short, medium and long term. Fernald [125] argues that, prior to 1973, vehicle-intensive industries benefited disproportionately from the massive road-building capital of the 1950s and 1960s. However, these same industries seem to have been particularly affected after the oil crisis of the 1970s by a greater slowdown in productivity. In addition, public spending on highways declined during the same period, worsening the crisis of the aforementioned businesses. Canning and Bennathan [126] argue that the greatest productivity of paved roads is seen in middle-income countries, with poorer and richer ones benefiting from lower rates of return on infrastructure development. The authors of [110] have investigated the long- and short-term relationships between the development of infrastructure for the various modes of transport and sustainable economic growth for the EU-28 in 1990–2016. The authors employed a VECM procedure to determine the source of dependence between the variables and the long- and short-term relationships between them. Generally, it can be concluded that the productivity of transport infrastructure differs depending on the level of development of the region/country and the level of development of transport infrastructure.

3.2.2. Employment

Employment-related WEIs are closely linked to GDP impacts. For example, the authors of [3] distinguish the following effects related to GDP impacts: (1) agglomeration economies; (2) business time savings and reliability; (3) more people choose to work due to changes in effective wages; (4) some people choose to work longer hours; (5) a move to more highly productive jobs.

Transport infrastructure investments have both demand-side and supply-side impacts on the labour market, with the former being short-term and the latter more medium- and long-term in nature. The short-term impact of public investment is generally easy to analyse and measure. The Keynesian multiplier [127] shows that increased public spending leads to income and employment gains in the short term, especially on a local scale. Martin [128] maintains that the impact of new investment on jobs will be stronger in regions with high unemployment rates. However, there are as many as three rounds of effects [2]. The first-round effect means 'direct' employment, which occurs when capex on transport infrastructure projects translates directly into new jobs in the construction industry and other sectors of the economy that supply construction materials and equipment. The second-round effect comprises the 'indirect' employment that stems from new job creation also in the finance, insurance, real estate and many other sectors. Finally, the third-round effect encompasses 'induced' employment, which the new employees from the first and second round beneficiary sectors generate by spending their incomes and thus boosting demand.

The long-term supply-side impact of public spending in a poor region may be exactly the opposite of the short-term demand-side effect. As is implied by new economic geography (NEG), reduced transaction costs may lead to the concentration of businesses in rich regions (for agglomeration effects see below) and regional divergence [121]. On the other hand, the lowering of transaction costs through transport investments may stimulate the growth of jobs as a result of increased availability of labour to enterprises and more robust linkages between companies [129]. Improved accessibility translates into a greater number of job seekers willing to commute to work even over longer distances [130]. According to [131], particularly important WEIs are derived from infrastructure investments having a direct effect on densely populated areas and improving accessibility in large cities by increasing the size of functional urban areas (integration of labour markets, interconnection of urban areas, expansion of cities). Moreover, WEIs are even stronger if areas integrated through transport investments are characterised by large pay gaps.

3.2.3. Agglomeration Effects

A key analytical area of New Economic Geography deals with assessing the nature and magnitude of impacts of transport infrastructure on the economy [132]. The economic mechanisms described by the NEG theory are prevalent in large cities, since they benefit from spatial agglomeration, i.e., productivity benefits derived from proximity of location [3]. The reduction of trip times as a result of infrastructure investments increases the number of interactions. Agglomeration effects may take two forms, namely intensified connectivity between firms and between firms and households, on the one hand, and spatial densification in the vicinity of network nodes, on the other, which leads to new location choices by firms (enterprise location) and households (residential relocation) among those who seek to benefit from shortened travel times [133]. Insight into the relationships between spatial organization and transport infrastructure investments is provided by LUTI (Land Use-Transport Interaction) modelling (for an overview of the models used and theoretical and methodological implications see: [134]). LUTI models encompass the following sub-models: (1) land-use sub-models, (2) socio-demographic sub-models, (3) travel demand sub-models. LUTI modelling is mainly useful for predicting job and residence relocation for various traffic scenarios, including scenarios for new transport investments. LUTI models consist of static and quasi-dynamic models, with the latter further divisible into entropy-based, spatial economics and activity-based models.

In recent years, research on changes in accessibility, conducted on the basis of ABA (activity-based accessibility) measures, has been gaining importance [135]. ABA is generated with a model based on a day activity schedule (DAS), where rather than being looked at independently, every trip is analysed in the framework of an activity system/schedule. For an overview of ABA models see [136]. Ref. [135] demonstrates how to use activity-based accessibility (ABA) measures to determine the importance of daily accessibility as a variable in residence selection, such accessibility being an intermediate link between short-term daily activities, including work and school commuting decisions, etc., and long-term residence decisions (see below for the impact of transport investments on housing prices).

It is worth comparing LUTI modelling with alternative approaches, in particular with spatial computable general equilibrium (SCGE) models [137]. SCGE modelling (for more see under *trade*, *interregional flows*, *input-output*, *general equilibrium*) tests the impacts of transport investments on the economy as a whole with much lesser emphasis on the spatial distribution of impacts, whereas LUTI models are more microeconomic in nature and are mainly used in urban, agglomeration and sometimes regional planning [4]. LUTI models are more eclectic than SCGE modelling because they draw on theoretical and conceptual propositions from a range of disciplines, including economics, geography, psychology and complexity science [134]. As the authors of [137] point out, it is LUTI and SCGE models that are the two leading approaches to assessing the economic impacts of transport policies.

3.2.4. Real Estate Value (Residential Prices)

The influence of transport infrastructure investments on development is also measured through the investigation of real estate market developments, mainly in terms of the impact on property prices. Such an approach is exemplified by a study of Radzimski and Gadziński [25] on the impact of the Poznań Fast Tram on the housing market (transaction prices). Based on the results of geographically weighted regression, the study has shown that the importance of the Poznań Fast Tram in terms of satisfaction with the place of residence is high, whereas the impact on home prices is relatively small. Another study, also in Poznań [26], has not revealed a statistically significant relationship between distance from bus stops and the price of housing. Similarly, the authors of [18] have proved that the Taiwan High Speed Rail has a negligible impact on house prices.

Kim and Lahr [138] have come to different conclusions in their research into the impact of the Hudson-Bergen Light Rail in New Jersey, US on residential property prices. Their results show that properties near the two commuting stations farthest from the central business district experienced high appreciation. Additionally, studies in Naples [37] show a rise in the value of real estate in the catchment areas of newly built metro and city rail stations. In the Yangtze River Delta, there is also a high spatial correlation between property prices in the region and the level of infrastructure development [11].

The expansion of transport infrastructure may also have an adverse effect on housing prices due to exposure to noise, pollution, shrinkage of green areas or deteriorated security [139]. Dubé, Thériault and Des Rosiers [140] have noted a negative impact of public transport infrastructure on property prices in as many as 7 out of 24 North American cities. Studies in Athens [34] have found that the ISAP (i.e., the old city railway in Attica) and large national railway stations, airports and ports have also been detrimental to property prices.

Ylmaz [141] attempted to predict the impact of the London Crossrail 2 project. The study found that rental prices would increase significantly in certain boroughs at a distance from the city centre in which the project would improve the public transport accessibility, and that the number of households would increase in those boroughs. Meanwhile, some, especially central boroughs, would see a decline in prices and the number of households. Ylmaz's forecast is based on the modelling framework that integrates three sub-models: a household choice model, a travel model and a macroeconomic urban-CGE model. In methodological terms, hedonic pricing models [18,26,34,138,140] are also methods frequently used in research.

LUTI modelling has important implications in relation to the property market. A key focus of LUTI research is on understanding the long-term behaviour and choices of households with respect to residential (re)location and job (re)location, as well as on the interdependence between these decisions. The choice of one's place of residence is considered to be a long-term decision that directly influences spatial structure and determines the set of activities and travels available to a household or an individual [142]. Combined with the location of employment, these two locations provide sets of choices in the form of spatial anchors that influence commuting opportunities and their changes over time [143].

3.2.5. Trade, Interregional Flows, Input-Output, General Equilibrium

In the light of new economic geography models, reduced travel times/costs and improved service quality produced by transport infrastructure investments expand markets for economic operators. Market expansion benefits the development of areas by driving exports and imports and increasing the specialisation of individual cities/regions [132]. Increases of exports drive up production levels, which translate into higher sales, and make it easier for economic operators to recover their fixed costs. By contrast, increases of imports put competitive pressure on local prices. Both of these phenomena lead to improved efficiency and economic growth, also as a result of increasing economies of scale [132,144,145].

Research on the impact of transport infrastructure on growth, including that based on the CGE and SCGE models, makes use of intersectoral flows (input-output analysis) [138]. Input-output tables are based on statistical data on the flow of goods and services between different industries and provide detailed information on the economy of a region or country in a given year [146]. An input-output model consists of three elements: (1) an input matrix, i.e., a table showing the costs of inputs (goods and services, labour and capital) engaged by each industry in the production process; (2) an output matrix, i.e., a table with goods and services produced by each industry; and (3) a final demand matrix, i.e., a table of goods and services available to end consumers. Sugimori et al. [16] have used input-output modelling to estimate the economic impacts of investments in the Mumbai-Ahmedabad High Speed Rail (MAHSR) in India. The researchers assess the interregional variations in the economic impact of the investment. Han et al. [147] have used an IO method to analyse the impact of the Japanese Shinkansen high-speed line on the location of industrial plants in Japan. The approach presented in their study is based on an analysis of the correlation between industrial linkages and changes in workforce figures in the individual industries before and after the opening of the Nagano Shinkansen line in 1997.

As already mentioned, computable general equilibrium (CGE) models are one of the methodological options for measuring the impact of the expansion of transport infrastructure on regional development. They are based on the interaction of supply and demand in multiple markets at the same time. Contrary to econometric models, which isolate the fragment of reality analysed from the rest of the economy, CGE models recognise the fact that all markets are interconnected by supply-demand mechanisms. CGE modelling requires that the markets under investigation be in equilibrium; by comparing two states of equilibrium, the effects of specific actions, e.g., infrastructure investments, can be determined [148]. Computable general equilibrium models take into account the supply side and changeability of prices, which is one of the main features that distinguish them from input-output models. What distinguishes them from macroeconometric models is that they rely more on theoretical foundations and take into account detailed data on the structure of industry [149]. General equilibrium models take into account long cause-effect chains and feedbacks present in the economy [148].

CGE modelling is widely used by a range of institutions to evaluate policies, including macroeconomic ones, inter alia, in regional transport [24,149,150]. Employing a CGE model, Rokicki et al. [24] have analysed the relationships between the general level of accessibility ensured by investments in transport infrastructure and regional economic development in Poland over the years 2004–2014. Their study concludes that improved accessibility was weakly but positively correlated with a rise in regional employment, but its beneficial effect on regional production was not statistically significant. Rokicki et al. [23] have used data on both capital expenditure and on improvement in accessibility to identify possible short-term and long-term effects. They have found that there are significant differences in impacts between regions with a high proportion of large private road infrastructure investments and those relying entirely on public funding. For the former, lack of investment would lead to a relatively large decline in real GDP. For the latter, the impact of transport infrastructure investments would be negligible.

The European Commission’s preferred SCGE model is RHOMOLO. RHOMOLO is intended to support EU policy makers by providing sectoral, regional and temporal simulations of investment policy and structural reforms [151]. The model was developed by the Directorate General Joint Research Centre (DG JRC) in cooperation with the Directorate General for Regional and Urban Policy (DG REGIO). RHOMOLO is a traditional CGE model that takes into account spatial relations (trade, services, capital, FDI, knowledge) between the 267 regions in Europe [141]. The asymmetric transport cost matrix has been derived from the European Commission’s transport model TRANSTOOLS [152]. In the RHOMOLO model and transport infrastructure investments, including investments in the TEN-T network, are modelled as a reduction of trade costs (as opposed to other infrastructure investments which are implemented in the model as changes in the stock of public capital) [153]. The RHOMOLO model has been used, inter alia, by DG REGIO to assess the impact of the cohesion policy and structural reforms and by the European Investment Bank to evaluate the effects of the EU’s investment support policy [151]. Use has also been made of other general equilibrium models, one of which is CGEurope, developed in the framework of the IASON project [154]. IASON was designed to integrate already existing national models into one universal spatial general equilibrium model for Europe. One of the national models was the Dutch RAEM (Regional Applied General Equilibrium) tool, which is considered to be one of the most ambitious SCGE models to date, as it takes into account migration and interregional commuting. The RAEM model has been used, e.g., to assess the impact of the different variants of rail connections between Groningen and Schiphol airport [155]. SCGE modelling has also been employed in a Norwegian study of various transport projects in terms of wider economic impacts (WEIs) [131]. The results show that the WEIs of a transport investment depend on the type of project: (1) investments where a large proportion of the benefits to users derive from changed leisure trip behaviour induce relatively lower WEIs; and (2) investments where a large share of the benefits to users come from changed commuting patterns produce a relatively larger number of WEIs.

4. Conclusions

There are many possible mechanisms through which infrastructure investments translate into wide-ranging socio-economic and spatial impacts. These include the following effects, as identified in this article:

– Wider spatial impacts:
    - accessibility of cities/regions/country,
    - distributive accessibility effects,
    - spatial planning and urban planning,
– Wider economic impacts:
    - productivity of production factors,
    - labour market (employment),
    - agglomeration effects,
    - real estate value (residential prices)
    - trade, interregional and intersectoral flows (input-output), general equilibrium.

However, it is important to note that the list presented above may be longer, which is due to the literature limitations. In the future, one of the possible extensions of the presented research is the analysis of the impact of transport investments on other areas of human activity, also in the context of changes in mobility taking place in modern society, both for short and long trips.

In the European Union, approaches based on CBA, or possibly MCA, continue to prevail. Notwithstanding the availability of a wide range of methods for quantifying socio-economic impacts, such as accessibility analysis using a potential model, econometric estimations, input-output, and general equilibrium models, the European Union recommends that wider economic impacts at the regional and national levels be assessed by means of qualitative approaches. This being the case, it is recommendable for the European Commission to take broad-ranging action towards ensuring that the effects of transport infrastructure investments are assessed by means of a broader range of approaches. Currently, activities in this respect are highly fragmented and differ depending on the level of analysis, e.g., the SCGE RHOMOLO [152] model is used for the Union as a whole and classic CBA modelling and is deployed to appraise investments in individual regions. Meanwhile, as Rothengatter [4] points out, the British Department of Transport recommends analysing WEIs in addition to conducting CBA for major transportation projects. This implies that the above recommendation should also be followed at the level of individual EU countries.

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