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Ex-post analyses of social and economic spatial effects due to changes in transport supply
Approaches and insights

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Ex-Post Analyses of Social and Economic Spatial Effects Due to Changes in Transport Supply: Approaches and Insights

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ABSTRACT
This systematic literature review covers quantitative ex-post analyses of social and economic spatial effects due to changes in transport supply, published within the last decade. Ex-post analyses observe what happened and allow us to understand fundamental principles, to learn for the future, and to use correct values in ex-ante studies, appraisals etc. The focus is on techniques that deal with three tasks: quantification, isolation and causality of such effects. Circa 40 publications by academics, organizations and official authorities are assessed for their technique (e.g. spatial instrumental variable) and theme (e.g. productivity gains), and prototype studies are presented in detail. We conclude that descriptive analyses – frequently done by official authorities – do not suffice for the tasks mentioned. The successful more elaborate techniques on the other hand require several additional statistical tools to be reliable and other data sources that traditionally have not been collected by official authorities.

The purpose of this paper is to report the state of the art in quantitative ex-post analyses of social and economic spatial effects due to changes in transport supply. The reader gains a current overview and a clear picture of such studies and their methods.

Keywords: Ex-post analysis, social and economic spatial effects, quantification, isolation, causality

INTRODUCTION
The content of this paper is the state of the art for quantitative ex-post analyses dealing with spatial effects due to transport supply changes. This section tells why we look at such analyses and which scope we choose.

Motivation
The interplay between transport and activities in space had been investigated by many researchers and found its way into standard textbooks in transport science roughly ten years ago (see for example (1)). In the last decade or so, the interest in this topic has substantially grown in politics as well as national and international organizations. As a consequence thereof, there originated several research initiatives in Europe (SustainCity (2), ESPON1), in North America (3) or with global focus (4), which continued achievements made by the ISGLUTI2 (5) project.

This paper focuses on a specific research branch within this field of research: Ex-post analyses on spatial effects due to transport supply changes. This means, only the effect from transport to space (rather than the influence of spatial activities to transport) is examined. This paper considers only quantitative studies to obtain a clearer picture of the state of the art in such analyses and to answer the following questions:
1. What are the measures to quantify transport-induced spatial effects?
2. What are the measures to isolate transport-induced spatial effects from effects of other origins?
3. How can cause and effect be identified?

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1 European observation network for territorial development and cohesion
2 International Study Group on LandUse/Transport Interaction
Ex-post analyses have the advantage that they observe what happened. On the other hand the researcher has to adapt her or his study design to the given situation in terms of time, of available measurement points, data and so forth. This setting requires special techniques which are assessed in this paper according to the three questions above.

In some countries and regions, spatial effects are already part of their cost-benefit-analysis guidelines, for example in the United Kingdom for so called wider economic benefits (6). In other countries, for example Germany (7) or Switzerland (6 and 7), such ideas are considered. This requires a clear picture of the state of the art in ex-post analyses of spatial effects due to changes in transport supply.

Scope of this paper
This paper assesses literature covering social and economic effects in space rather than environmental ones (see (10) for a recent overview in this field) due to changes in transport supply. Papers have to apply quantitative methods to real data with an ex-post perspective to address at least one of the tasks – quantification, isolation and causality. Authors in academia, organizations and official authorities are included.

Structure of this paper
The remainder is structured as follows. The next section provides an overview on the development of this research and on recent general themes and approaches. The subsequent section reports on the applied guidelines for collection and assessment of the papers. Next, the main part of this paper RESULTS, shows a systematic analysis of all assessed papers as well as a detailed discussion of each main research method. The last section concludes and provides recommendations for researchers and decision-makers.

OVERVIEW AND HISTORY
The first research on transport and land use interaction started roughly 200 years ago and has developed in conjunction with advancements in theory and method of modelling and computation of spatial data.

Historical development
There have been three main developments (11):

1. Land use and urban economics started with von Thünen in 1826 (12): The central idea is that transport is needed for economic success but comes at costs. The economic conditions of producers (goods, services, labour positions etc.) and consumers characterize together how they each respond in terms of spatial decisions to the structure of transport costs.

2. The nature of competition across space started with Hotelling in 1929 (13): Every piece of space can only be used by one agent (firm, person, state). Some of the spots are more desirable than others, for example because they provide better access to customers (company) or friends (household). But these characteristics depend on the decisions of all other agents. This means there is a competition (game) and an equilibrium.

3. New economic geography and the emergence of economic agglomeration started with Krugman in 1991 (14): One important feature is the modelling of dispersion and agglomeration which interacts with the mobility of production factors and the spatial distribution and structure of consumption. Decreasing transport costs even allow agents to
“split” themselves, meaning they figure in one spot as a production factor (for example as a worker) and in the same time figure as consumers in a spatially separated spot.

In addition, the land use and transport interaction (LUTI) models developed in the 1960/70s and 1990s started to distinct between local effects and effects in the export sector. Current LUTIs are able to integrate all four elements presented in this subsection.

**Related themes and relevant policies**

Recently, policy makers and researchers have included these four main research developments in projects that are concerned with demographic change, such as population size or household income, and economic performance, such as sectoral structure, job supply or prosperity growth, on national, regional or municipal level. These themes are detailed further in the after next paragraph based on the reviewed literature.

**METHOD**

This section reports on the way how papers were searched for and provides information about the survey process for papers by organizations and state authorities.

**Criteria for studies to be included in this literature analysis**

Papers have to be quantitative ex-post analyses by authors from academia, organizations or state authorities. They cover social and economic spatial effects due to changes in transport supply and address at least one of the tasks – quantification, isolation and causality. They can be from all over the world and are published in 2006 or later to guarantee current knowledge.

**Survey and search implementation**

The survey is organized twofold. For academic publications, the usual search engines and research repositories were searched. For organizations and state authorities, in addition to the internet search, they were contacted directly and asked to send relevant publications. Whenever possible the specific person in charge was contacted, else the request was sent to the general contact e-mail address. Regarding state authorities, all countries in Western Europe and Northern America were contacted; in large countries such as the USA or regionalized and/or federal countries such as Belgium or Germany, the corresponding lower level – states, regions etc. were contacted too. They usually are governmental offices for transport, economy, environment, planning, statistics, and finance.

**Survey statistics**

March to May 2016 is the time window during which papers were searched and asked for; there was a reminder in early May. In total 36 publication are included in the analysis; 24 of them by academics, 4 by organizations and 8 by official authorities. In total, 109 state authority contacts were contacted and 76 (70%) of them did not react at all. The remaining 33 contacts responded and most of them could provide at least one publication within the scope of this literature analysis. While in some cases the request might have reached the wrong person, one still has to assume that there is not much interest in this topic and/or thus there are very few such studies actually done, the conclusion section picks up the threads to this again.

**RESULTS**

This sections presents the results: A systematic compilation of all assessed literature and a detailed discussion of a prototype study for each technique commonly applied in ex-post analyses.
The assessed literature is systematically categorized along three dimensions. These are the topic they investigate, the technique they apply, and the category of authorship. The categories of the tree dimensions are chosen based on the reviewed literature as well as theory (for example (15) and (16)). Table 1 below follows this classification. On the vertical axis, it features the topics; on the vertical axis, it features the techniques. All topics are grouped into six categories. Population size includes questions about the number of people living in a specific area (density) or sociodemographic composition. Land, property price includes the dynamics of prices for example due to accessibility improvements. Job opportunities includes questions about the number of jobs in a specific area (density) or their accessibility. Structure of economy includes variables such as firm size, sectors or location choice of firms. Productivity includes studies on total factor productivity, trade, or in general efficiency in a regional economy. Poverty level, growth includes questions on household income, prosperity level and growth in a specific area.

In terms of techniques, the following categories are used. Descriptive includes simple computations based on statistics, difference-in-difference approach is included too. Panel analysis includes the modelling of data in a panel structure, various subforms are included. Hedonic pricing includes the use of land or property prices and decomposes them into their different components. Models is a heterogenous category and includes approaches that interweave different rationales into a single mechanism and range from land-use interaction to production function models. Spatial treatment group includes studies that compare two regions which are identical except in the explanatory variable of interest. Spatial instrumental variable includes studies that replace explanatory variables that correlate with the explained variable by variables that highly correlate with that explanatory variable but not with the explained variable; usually one uses historical counterparts of the explanatory variable.

TABLE 1 Systematic compilation of all assessed literature on ex-post analyses
<table>
<thead>
<tr>
<th>Population size</th>
<th>Spatial instrumental variable</th>
<th>Spatial treatment group</th>
<th>Model</th>
<th>Hedonic pricing</th>
<th>Panel analysis</th>
<th>Descriptive</th>
</tr>
</thead>
<tbody>
<tr>
<td>(47), (48), (30)</td>
<td>(44), (31)</td>
<td>(40), (41)&lt;sup&gt;1&lt;/sup&gt;</td>
<td></td>
<td></td>
<td>(30), (31), (32), (33)</td>
<td>(17), (18), (19)&lt;sup&gt;2&lt;/sup&gt;, (20)&lt;sup&gt;2&lt;/sup&gt;, (21)&lt;sup&gt;2&lt;/sup&gt;, (22)&lt;sup&gt;2&lt;/sup&gt;, (23)</td>
</tr>
<tr>
<td>Land, property prices</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(38), (39)</td>
<td>(18)</td>
</tr>
<tr>
<td>Job opportunities</td>
<td>(30)</td>
<td>(44), (45)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>(40)</td>
<td>(39)</td>
<td>(30)</td>
<td>(24), (17), (18), (25)&lt;sup&gt;2&lt;/sup&gt;, (26)&lt;sup&gt;1*&lt;/sup&gt;, (23)</td>
</tr>
<tr>
<td>Structure of economy</td>
<td>(30)</td>
<td>(46)</td>
<td></td>
<td></td>
<td>(34)</td>
<td>(27)&lt;sup&gt;2&lt;/sup&gt;, (18)</td>
</tr>
<tr>
<td>Productivity</td>
<td>(35), (49)</td>
<td>(42), (43), (35)&lt;sup&gt;1&lt;/sup&gt;, (36)</td>
<td></td>
<td></td>
<td>(35), (8), (36)</td>
<td>(28)&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Poverty level, growth</td>
<td>(49)</td>
<td></td>
<td></td>
<td></td>
<td>(29)&lt;sup&gt;1&lt;/sup&gt;</td>
<td>(37)&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Black: Main method or topic; grey: secondary method or topic; superscript refers to author, no: academic, 1: organization, 2: state, *: private
Spatial instrumental variable

The study (47), summarized in Table 2, investigates how the construction of the interstate highway network influenced suburbanization in the United States of America (USA). The development between 1950 and 1990 in population size of 139 metropolitan areas (MSAs) for the core city area and for the suburban area is measured and defined as explained variable. The explanatory variable of interest is the number of rays that end or start in a MSA. The corresponding data is collected from public statistics and data banks. In this setting, there is an endogeneity problem: It is unclear whether highway rays were built because suburbanization led to higher demand or whether suburbanization was caused by highway construction. As a result, regressions for quantification would produce wrong results. To avoid this problem, a spatial instrumental variable (SIV) replaces the original explanatory variable of interest. The author uses a historical map of the planned construction of the national interstate highway network. He shows, that at this time, the underlying reasons for the network design mainly were economic or military ones rather than the development of suburban areas. This SIV thus does not correlate with the explained variable, the population size, but represents well the original variable since the actual construction broadly followed the historical plan. The problem of isolation is solved by using a simulated income distribution control variable. It controls for the potential correlation between income class and suburban living demand. The results obtained through several different regression types show with one third, a very large influence of the interstate highway construction on the spatial distribution of population in the USA. Each highway ray led to a decrease of 18% in the core city within these 40 years while total MSA population grew by 72% in the same time.

TABLE 2 Overview to Prototype Study for Technique Spatial Instrumental Variable (47)

<table>
<thead>
<tr>
<th>Transport</th>
<th>Society</th>
<th>Economy</th>
<th>Area</th>
<th>Resolution</th>
<th>Period</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of rays per MSA</td>
<td>Population size in 139 MSAs</td>
<td>USA</td>
<td>36,250 census tracts</td>
<td>1950-1990</td>
<td>40 years</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Author</th>
<th>Quantification</th>
<th>Isolation</th>
<th>Causality</th>
<th>Result</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>National census Digitized road data (PR-511 data) Official statistics</td>
<td>University</td>
<td>Differences Regressions: ordinary least squares (OLS), instrumented OLS and multilevel regression</td>
<td>Control variable using simulated income</td>
<td>Instrumental variable: 1947 national interstate highway map, tested for endogeneity</td>
<td>The core city of an MSA loses 18% population per ray of highway</td>
<td>Highway construction explains roughly one third in population size variance</td>
</tr>
</tbody>
</table>

Spatial treatment group

This report (44), summarized in Table 3, examines the effects of the Jubilee Line extension in Southeastern London on population size, land and real estate prices as well as employment. It integrates several studies mainly done between 1995 and 2005. The researchers started to collect data very early at the time the project was decided in parliament and used public statistics, surveys and commercial data for real estate. The findings of the studies rely on differences in indicators such as level of motorization, employment rate, tax revenues, etc. These are interpreted with a mix of qualitative (interviews etc.) and quantitative approaches; it was decided not to use hedonic
pricing since the study area seemed too unique and complex. The main technique is instead a system of spatial treatment groups. Rather than choosing a particular reference area as the untreated area, authors identified for every indicator a specific reference area. This approach provides more flexibility and guarantees a higher similarity as it is easier to fulfill this for one indicator separately than for the whole indicator system. An analysis of this spatial treatment group system shapes and isolates the amount of different effects that are purely triggered by the tube extension. The most important ones are that there was no influence on local employment and that many better paid jobs were taken by newcomers or commuters. There was a substantial increase in land prices and population size within the corridor.

TABLE 3 Overview to Prototype Study for Technique Spatial Treatment Group (44)

<table>
<thead>
<tr>
<th>Transport</th>
<th>Society</th>
<th>Economy</th>
<th>Area</th>
<th>Resolution</th>
<th>Period</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station (0/1), travel time on tube network</td>
<td>Development of population size and land price</td>
<td>Development of job opportunities, employment and real estate prices</td>
<td>Southeast of London</td>
<td>Corridor of Jubilee Line extension and buffer of different radii around stations</td>
<td>1989-2001</td>
<td>1989 (parliamentary decision) to 1999 (opening) and 1999 to 2001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Author</th>
<th>Quantification</th>
<th>Isolation</th>
<th>Causality</th>
<th>Result</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surveys Public statistics Private statistics on real estate</td>
<td>University on behalf of a state authority</td>
<td>Differences</td>
<td>Definition of reference areas in London per indicator as treatment group compared to the corridor area</td>
<td>Different qualitative and quantitative approaches</td>
<td>No influence on local employment, better paid jobs occupied by newcomers; increase in land prices; higher growth in population size</td>
<td>Researchers report difficulties in addressing causality questions.</td>
</tr>
</tbody>
</table>

Models (land use, production function etc.)
This study (42), summarized in Table 4, researches the effects of public road investment on total factor productivity (TFP) in Spain using an econometric two-step model. The study is a typical example for the sub-group of productivity models. Another sub-group are transport land use interaction (LUTI) models (40), due to space restrictions, there is no detailed presentation for LUTI. Data is from public statistics and research agencies for regional gross domestic product values, employees, and productive private stock, and also includes a digitized and spatial road statistics. All data comes at a yearly interval, meaning a panel-like structure. The main model however is frontier technique and decomposition of TFP into technological progress and efficiency gains. In a first step, the researchers calculate the gap between the real economic production and the optimum efficient production assuming that the given conditions are used optimal which represents the maximum technically attainable level of production. With these
values, one can in a second step decompose TFP into technological progress – improvement of the optimum production – and efficiency – closing the gap between optimum and actual achieved production level. In this fashion, the transport variable can be related to each part of TFP and TFP as a whole. Within this analysis, the researchers distinguish between internally used and externally exported capital stock for roads. In this setting, the results show that public investment in road infrastructure increases TFP, mainly through efficiency gains. Most of this positive effects of a single expenditure in road infrastructure does not happen within the province of expenditure, but is exported to the rest of the network. In contrast to productivity models in which the interaction laws of (mobile) input factors and efficiency is modeled in several steps, LUTI models frequently model the decision rules of households or firms in several steps such as land prices, generalized travel costs or planning restrictions.

**TABLE 4 Overview to Prototype Study for Technique Models (42)**

<table>
<thead>
<tr>
<th>Transport</th>
<th>Society</th>
<th>Economy</th>
<th>Area</th>
<th>Resolution</th>
<th>Period</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalent value of all roads (€)</td>
<td>-</td>
<td>Total factor productivity</td>
<td>Spain</td>
<td>Provinces</td>
<td>1980-2007</td>
<td>yearly</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Author</th>
<th>Quantification</th>
<th>Isolation</th>
<th>Causality</th>
<th>Result</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public statistics Research agencies Digitized road data</td>
<td>University</td>
<td>Frontier technique: Difference between the real economic production versus optimum efficient production</td>
<td>Regressions with transport variable and all other public expenditures, corrected by the actual traffic flows</td>
<td>Difference allows to decompose total factor productivity into technological progress and efficiency, thus dependent on transport variable. Fixed-effects panel data model</td>
<td>Transport variable positively influences total factor productivity as well as its components technological progress and efficiency, especially the latter one</td>
<td>The effects of the transport variable are weaker within the province where spending happened than in other provinces</td>
</tr>
</tbody>
</table>

**Hedonic prices**

This study (39), summarized in Table 5, reports on a hedonic house pricing approach that captures the effects of a bridge replacing a ferry in a Fjord on the labor market. The researchers look at public and commercial data sources for postcode areas before and after the opening of the bridge. They calculate the changes in car accessibility, accounting for detailed costs elements such as travel time, waiting time (ferry) and money (ferry and toll respectively). They control for potential other effects by using several variables that describe the characteristics of the 1415 single family houses used in the model. There are two main advantages of hedonic pricing models. First, the model converts implicit effects into monetary units. Second, the model itself defines causality, given by the idea of hedonic prices; and inverse causality would not make much sense, meaning that the labor market benefits due to higher house sale prices. The price development is studied.
relative to the distance from the new bridge. The observed regional pattern is uneven. In a distance of 15 minutes from the bridge, on the one side of the bridge the average benefit is 5,000 NOK and on the other side 80,000 NOK (100NOK = 12$). They also investigated the effect of the bridge toll and showed that it diminishes the overall accessibility gains. Rather than introducing a toll with this negative effect one could think of employing a property tax that would capture accessibility benefits without lowering spatial interaction in the job market.

**TABLE 5 Overview to Prototype Study for Technique Hedonic Pricing (39)**

<table>
<thead>
<tr>
<th>Transport</th>
<th>Society</th>
<th>Economy</th>
<th>Area</th>
<th>Resolution</th>
<th>Period</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravity-based accessibility regarding jobs</td>
<td>-</td>
<td>Value of transport infrastructure for the labor market; job pool size</td>
<td>Southwest of Norway</td>
<td>Postcode areas</td>
<td>1992-2009</td>
<td>1992 to 2001 (opening of the bridge) and 2001 to 2009</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Author</th>
<th>Quantification</th>
<th>Isolation</th>
<th>Causality</th>
<th>Result</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public statistics</td>
<td>University</td>
<td>Hedonic pricing model for sale prices of 1415 single family houses</td>
<td>Control variables: characteristic of the house</td>
<td>Hedonic pricing theory</td>
<td>Regional differences: places 15 minutes away of the bridge range between 5,000 and 80,000 NOK values; 100NOK=12$</td>
<td>Tolls might lower accessibility gains. Accessibility beneficiaries rather than bridge users could finance the bridge.</td>
</tr>
</tbody>
</table>

**Panel analysis**

This study (34), summarized in Table 6, details the question how the Tennessee Valley Authority, an economic development program funded by the federal budget, influenced local and national economy by sector in the short and long run. Data used is from public statistics and includes the researchers’ own and published data. It spans from 1900 to 2000 and forms a panel and this panel structure is used in a range of applications to quantify the spatial effects in different sectors of the local and national economy. Control variables and a comparison to the rest of the USA ensures isolation from other effects, which uses the idea of a treatment group or multilevel approaches. However, the focus is on the panel data and causality is partly addressed with placebo regressions, which regress the expected effect backwards on the time 1900-1940. This should not show any effect and can be used as a first step to exclude endogeneity. Applying a range of estimators to the panel data structure, the researchers show that the program was locally successful in terms of rising employment rates in several sectors. After 1960 however, when the program was ended the positive effect was only persistent in the industrial sector. This might be due to lasting agglomeration effects. The question becomes whether such policies are beneficial for a whole economy or if they just rearrange labor without an additional benefit. The authors conclude that in this specific example, this is the case. However in the industrial sector there is an overall national increase in productivity by 0.3% and the profits exceed the cost of the program.
TABLE 6 Overview to Prototype Study for Technique Panel Analysis (34)

<table>
<thead>
<tr>
<th>Transport</th>
<th>Society</th>
<th>Economy</th>
<th>Area</th>
<th>Resolution</th>
<th>Period</th>
<th>Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area that received infrastructure investments (yes or no)</td>
<td>(Income)</td>
<td>Employees for each sector</td>
<td>Tennessee USA</td>
<td>Counties</td>
<td>1900-2000</td>
<td>Decadic: 1900-1940; 1940-1960 (program effective); 1940-2000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Author</th>
<th>Quantification</th>
<th>Isolation</th>
<th>Causality</th>
<th>Result</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public statistics Own and published data</td>
<td>University</td>
<td>Panel analysis</td>
<td>Control variables and comparison of the region to the rest of the USA</td>
<td>(Placebo backward regressions)</td>
<td>0.3% additional national productivity gain in industry sector; local agglomeration benefits; minimal indirect effects</td>
<td>Focus is on long-term and national effects rather than short-term and local ones.</td>
</tr>
</tbody>
</table>

CONCLUSION
This section summarizes and put in context the main findings of the literature assessment according to the research questions in the first section.

Conceptual Findings

Spatial variance

**Instrumental variable**

**Treatment group**

**Hedonic pricing**

**Models**

Panel analysis

Temporal variance
In quantitative terms, the most prominent finding is that two third of the assessed literature is by academic authors. According to the replies by state authorities, this is due to limited resources and the lack of official strategies. One can think of the following further reasons. Ex-ante studies are politically more relevant than ex-post studies as they happen at the time when money has been distributed amongst competing projects. Once a project is completed, the incentive to investigate its spatial effects is lower – except for dedicated authorities, such as an office for spatial development, for statistics, or for financial evaluation. Having said that, often there is no such dedicated authority and the responsibility within administrations for doing ex-post analyses is unclear, being it a classical interdepartmental task that requires exact transport knowledge and spatial-econometric skills. This impression was supported by many replies referring us on to further authorities, which themselves did the same.

In qualitative terms, there is a clear gap between academic literature which mostly includes techniques and literature by state authorities which mostly remains descriptive. In this context, one should mention that the latter study type is hardly able to assess the quantitative claims in ex-ante studies nor to cope with the isolation and causality of spatial effects.

As shown in Figure 1, non-descriptive studies generally are successful in addressing the three tasks – quantification, isolation and causality. Almost all studies exploit temporal variance by using one or several data points before and after the change in transport supply. Panel-data analysis is a very sophisticated variant of this, but requires complete and long-term data. Also, it is not that strong regarding isolation and causality. Thus, most studies exploit spatial variance too. One option is to apply classical techniques like treatment group and instrumental variable in a spatial context.

Treatment group seems to especially be suitable for isolating transport-induced effects from other effects and instrumental variable for disentangle cause and effect. The treatment group is applied in two ways, either a treated place is compared to an as near as possible identical non-treated place or several treated and non-treated places respectively are compared for each variable separately to offset for the problem that one place is usually never identical to another place in all aspects. Instrumental variables are in most cases historical counterparts of the current transport variable. While they help to solve endogeneity problems, they can also be used by applying inversed pseudo-regressions from the current explained variable on the historical instrumental variable. If there is no effect, reverse causality can be excluded.

Models and hedonic pricing have in common that they start with a theory and the corresponding rationale(s) are combined and interwoven into a model that captures the effects. Hedonic pricing has the advantage that causality is implicit as prices react to changes rather than vice-versa. This generally holds too for the vast majority of the rather heterogeneous group of the ‘Model’ category.

Most times, studies apply a combination of several techniques – a main technique and secondary techniques to make sure the main technique’s assumptions are valid. This also allows to address more than one theme. There is no clear pattern between theme and technique. Most prominent themes are population size and job opportunities. These represent the basic indicators of every spatially relevant policy. More recently, studies on productivity have increased.

**Restrictions and limitations**

The quality of and access to data is a general limitation. Techniques that depend on spatial and
temporal variance require comprehensive data sets that come at high generating costs. Using panel
data techniques, a common problem is that the method of measurement has changed over time.
Using spatial treatment group technique, a restriction is that data should be collected in the same
manner in different areas. Using spatial instrumental variables, one depends on the availability of a
suitable data set, for example digitized historical transport data (50). Using hedonic pricing, one
faces privacy issues as many countries do not collect publicly usable real estate data as part of the
official statistics.

Other limitations lie in the techniques themselves. For example, a spatial treatment group needs to
be entirely identical to a non-treated group except for the dependent variable. It is very hard to
establish such a particular setting. A similar problem occurs with spatial instrumental variables:
they need to correlate with the independent variable that causes endogeneity problems but must
not correlate with the dependent variable. To overcome such inherently contradictory conditions,
the researcher is required to apply additional statistical tests to make sure that the use of the chosen
technique produces reliable results. This makes such studies lengthy and complex. This might be
another reason for the observed gap between academic and non-academic publications.

Further research should address, first, solutions to overcome data gaps, such as kriging or
geographically weighted regression and related approaches from the field of landscape modelling
and geography (51). Second, simple decision rules when it is justified to apply one of the presented
techniques.

**Recommendations**

Based on the reviewed literature, researchers are suggested to use a combination of several
techniques and to be aware of the limitations described above. Descriptive studies are not
sufficient to answer the questions related to spatial effects due to changes in transport supply. Such
quantitative ex-post analyses should be done more often and included in official strategies. The
reviewed results show that there are substantial economic and society-related effects. Thus,
cost-benefit-analysis guidelines might need revision.

This means, decision makers need to promote spatially explicit data sets that cover several
decades. This includes to digitize historical data. It is also important to establish a geographic
information system on land and real estate prices, but also localized productivity data as many
countries do not measure this data.

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