AGGLOMERATION DECAY IN RURAL AREAS[*]

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Abstract. Spatial proximity to other economic activities – occasionally labeled as 'market access' and 'economic density' – is associated with good economic performance. How the impulses from economic activities diminish over space is known as 'agglomeration decay' or 'distance decay'. Although market access functions and the associated agglomeration decay constitute an important topic within spatial economic research, the phenomenon is seldom studies in a rural setting or addressed by non-linear estimation techniques. In this paper, we estimate the market access function in the relatively rural regions of Southern parts of Norway. We approximate market access in the national road network by alternative market access functions with power and exponential distance decay, applying ordinary non-linear least squares (NLS) and non-linear mixed effects (NLME). We apply labor productivity as the outcome variable, employment and population as alternative measures for potential market connections and traveling time as distance measure. In the regression, we control for capital intensity, industry structure and annual growth trend, as well as mixed effect in case of the NLME model. Compared to previous findings in the literature, we find evidence of relative sharp agglomeration decay in a rural setting, involving power and exponential distance decay parameters of about 2.3 and 0.07 respectively. Comparisons of the log likelihood from the estimation of market access functions suggest that exponential distance decay involve a slightly better fit than power distance decay. In addition, employment involves slightly more explanatory power than population as a measure for potential market connections.

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1. Introduction

The positive correlation between density of economic activities and economic performance have attracted the attention of researchers in spatial economics for more than a century. Since the turn of the millennium, there has been a growing consensus in the literature that there may be causal impulses from economic density to productivity (see for instance Graham et al. 2010, Melo, Graham and Brage-Ardao 2013 and Behrens, Duranton and Robert-Nicoud 2014). Theoretical rationales for such linkages include direct transportation costs savings, production agglomeration and competition effects.[†] For an economic actor, decreased transportation costs to surrounding areas imply more potential profitable economic transactions with other actors, in addition to improved access to public goods and fiercer competition. Nevertheless, the occurrence of such impulses in rural areas are more uncertain (e.g. Holmen 2022b).

As traveling speed constitutes a direct substitute for physical proximity in context mobility that changes more rapidly, authors have in recent years argued that studies of road constructions may shed light on the relationship between productivity and economic density (e.g. Rice, Venables and Patacchini 2006 and Graham et al. 2010). Moreover, new major road constructions could potentially increase local value creation by growing the market access for local economic actors and strengthen the local competition.

How the economic impulses from economic density – and thereby so-called 'market access' – evolves over geographic space can be measured by so-called 'market access functions.'[‡] Market access measures explicitly assesses traveling time to surrounding areas and the magnitudes of these areas. They capture that higher reach to neighboring areas may provide positive impulses on productivity (or other economic outcomes) for an actor, due to more potential profitable economic interactions, lower transportation costs for existing shipments and fiercer competition. The impulses of increased market access for an economic actor depend on several conditions, among them the magnitude of the relative increase, and how the importance of proximity evolves with the traveling time from the source. Other important factors include availability of other infrastructures, industry composition and the absolute magnitudes of the market enlargement and the initial markets.

Market access functions typically involve summation of fractions over adjacent regions. In the fractions, the numerators are subfunctions of variables capturing potential market connections (e.g. population, employment or production) and the denominators are subfunctions of variables capturing how the market potential diminish as the potential market connections become more remote (e.g. with traveling time, traveling distance or generalized traveling costs). The diminishing of impulses from economic activities over traveling time and traveling distance from each source of interaction is known as 'agglomeration decay' or 'distance decay'. Several studies analyze and estimate market access functions in various applications, but the spatial settings are mainly relatively urban.
In this study, we estimate market access functions in the relatively rural setting of the most Southern parts of Norway. We approximate market access in the national road network by alternative market access functions with

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[†] Direct transportation costs savings involve cost reductions associated with actual transportation processes (e.g. Shirley and Winston 2004 and Venables 2007). Production agglomeration involves production synergies for firms and individuals being near each other. Potential production agglomeration impulses include sharing of product markets, factor markets and common goods; more efficient matching of factor inputs and learning in terms of knowledge exchange (confer Duranton and Puga 2004 and Rosenthal and Strange 2004 for overviews, both building on Marshall 1890). Potential competition effects are firm selection, disciplinary competition effects and impacts on market power exploitation (e.g. Fujita 1988, Melitz and Ottaviano 2008 and Behrens, Duranton and Robert-Nicoud 2014). A general review of impacts of transportation measures is provided by Holmen and Hansen (2020).

[‡] Note that while authors within the international trade literature commonly refer to this sort of functions as 'market access functions' (e.g. Fujita, Krugman and Venables 1999 and Redding 2010), others use terms such as 'gravity functions' (e.g. Hansen 1959 and Sevtsuk and Mekonnen 2012), 'market potential' (e.g. Harris 1954), 'effective density' (e.g. Graham 2007), 'distance decay of agglomeration benefits' (e.g. Graham et al. 2010) and 'index of accessibility' (e.g. Vickerman, Spiekermann and Wegener 1999 and El-Geneidy and Levinson 2006).

power and exponential distance decay. The estimation is carried out by ordinary non-linear least squares (NLS) and non-linear mixed effects (NLME) with labor productivity as the outcome, and employment and population as alternative measures for potential market connections. As distance measure, we apply traveling time, while we use capital intensity, industry structure and annual growth trend as controls. Our study distinguishes itself from earlier studies by addressing a relative rural area and by applying nonlinear estimation techniques. The estimation is conducted at regional level, such that local composition effects also will be considered.

A wide range of market access measures have been applied to address how market access decreases with traveling frictions. In particular, various specifications have been used for the nominator in this regard. Common specifications include summation of proportional subfunctions (e.g. Harris 1954, Hansen 1959, Dicken and Lloyd 1990, Graham 2007, Graham, Gibbons and Martin 2010 and Gibbons et al. 2019) and power functions (e.g. Huff 1963, El-Geneidy and Levinson 2006 and Graham et al. 2010), which is a straight forward extension of the former. Another common approach is to model agglomeration decay by exponential functions (e.g. Handy and Niemeier 1997, Fujita, Krugman and Venables 1999, Vickerman, Spiekermann and Wegener 1999, Waddell and Ulfarsson 2003, El-Geneidy and Levinson 2006, and Sevtsuk and Mekonnen 2012). Other specifications do of course also exist, including distance bands (e.g. Hanson 2005, and Graham et al. 2010) and ratios based on traveling costs in general equilibrium models as their market access measure (e.g. Redding and Venables 2004, Redding 2010, Donaldson and Hornbeck 2016, and Redding and Rossi-Hansberg 2017).

Much of the attention in the literature on market access has been devoted to agglomeration elasticities, which indicates how much increased agglomeration affect an economic measure (typically productivity). Estimates for agglomeration elasticities with regard to productivity differ substantially with regard to sector, geography, method of measurement, inclusion of controls for unobserved cross-sectional heterogeneity, differences in time-variant labor quality and handling of potential reverse causality. In their review of empirical findings on the elasticity of productivity with respect to the magnitude of the functional city area, Melo, Graham and Noland (2009) find an average elasticity around 0.058 and that service industries generally are subject to larger agglomeration elasticities than manufacturing industries. In line with these findings, Rosenthal and Strange (2003) conclude in their survey that the average elasticities of productivity with respect to city size lies between 0.03 and 0.08. Other more recent studies also approximate the agglomeration elasticity to around five percent (e.g. Behrens, Duranton and Robert-Nicoud 2014, Graham, Gibbons and Martin 2010; confer Graham and Gibbons 2019 for a brief and more recent review).

Agglomeration elasticities will however depend on how market access is measured and thereby the agglomeration decay pattern. Some studies also explore how market access is of different importance in different industries, and how it diminishes with traveling costs (i.e. agglomeration decay). Rice, Venables and Patacchini (2006) find that the agglomeration impact on productivity declines steeply with traveling time, ceasing to be important beyond approximately 80 minutes. Similarly, Duranton and Overman (2005) find positive effects from collocation within 50 kilometers. Estimating market access functions in the United Kingdom with linear methods, Graham et al. (2010) estimate sector-specific point estimates for the power distance decay parameter ranging from 1.06 to 1.48. They establish that the effects of agglomeration impulses on productivity diminish more rapidly over traveling distances to surrounding economic activities for service firms than for manufacturing firms. Similarly, Rosenthal and Strange (2003) find that the gains from agglomeration economies arising from spatial concentration diminish rapidly over traveling distances for most industries, before diminishing more slowly. We refer to Graham et al. (2010), Redding (2010) and Sevtsuk and Mekonnen (2012) for overviews over different areas of research addressing market access and agglomeration decay.

This paper is structured as follows: After this introduction in section 1, we present our empirical strategy in section 2 and the data applied in our empirical investigations in section 3. The empirical analyses are provided in section 4. We discuss our results and draw our conclusions in section 5.

2. Empirical Strategy

We will now introduce a framework suited for estimating market access measures that capture the agglomeration decay over space, controlling for differences in capital intensity, industry composition and economic growth trend. We start by some conceptual considerations, before we move on to our formal framework and how we carry out the estimation in practice.

2.1 Conceptual Considerations

In order to study how productivity depends on geographic configuration over space, we need to apply a market access measure that accounts for proximity to and the magnitude of places with economic activity nearby. Based on theory and earlier empirical findings, one should expect positive impulses on productivity from economic density of activities nearby and declining impact as the traveling time to surrounding economic areas increases.

The theoretical foundations for market access functions are clear, concerning economic benefits for local economic activities of proximity to other economic agents such as agglomeration synergies, competition effects and savings in direct transportation costs. Higher economic performance at macro level can both be caused by improved firm performance and composition effects. Accordingly, the market access measure captures how economic gains in a broader sense of economic activities nearby diminish over space, where the adjacent economic activities may be related to both the product and factor markets.

It is not obvious how agglomeration decay evolves over space. In our empirical investigations, we are interested in how market access affects local economic performance and utilization of local factor inputs. As mentioned in section 1, a standard approach in the literature is to assume that the market access function for a location follows a summation function over the ratio between a proxy for economic activity (e.g. employment) and proxy for transportation frictions to surrounding locations (e.g. traveling distances). We will estimate a generalization of this function, where the proxy for economic activity is raised to power of a decay coefficient, which no longer is restricted to one.[§]

Yet, functional form implies that proportional distance decay decreases as traveling time increases, whereas our preliminary empirical investigations on our data suggest that this assumption is unreasonable for how economic performance is affected by surrounding economic activities in our case. Accordingly, we have also made use of the common alternative approach from the literature, where the subfunction concerning traveling distances is formulated as an exponential function. This functional form suggests that distance decay remains proportional over traveling time.

2.2 Formal Framework

We will denote the functional forms of the market access functions by $f \in \{pow, exp\}$, indicating whether the subfunction in the denominator is a power function or an exponential function. The agglomeration decay patterns of the market access specifications can be referred to as 'power distance decay' and 'exponential distance decay'.

[§] A disadvantage in abandoning the simple specification involving summation of the ratios between employment and traveling time is that activities within regions cannot be aggregated by weighted summation without creating aggregation biases. Yet, sticking with a misspecification to avoid aggregation issues appears as a misjudgment.

We let $\mathcal{D}_{r,t}$ denote the matrix consisting of traveling times between region r and all regions s at time t and $\mathcal{N}_t$ be a vector of labor stock in all municipalities at time t. The applied market access functions are:

$$(1) \quad G_{r,t}^{pow}\left(\mathcal{N}_t, \mathcal{D}_{r,t}\right) = \sum_{s=1}^{S} \frac{N_{s,t}}{d_{r,s,t}^{\delta^{pow}}}, \quad G_{r,t}^{exp}\left(\mathcal{N}_t, \mathcal{D}_{r,t}\right) = \sum_{s=1}^{S} \frac{N_{s,t}}{\exp\left(d_{r,s,t}\delta^{exp}\right)}$$

where $N_{s,t}$ is the magnitude of the labor stock in municipality s, $d_{r,s,t}$ is the minimum traveling time between municipality r and municipality s at time t. More generally, $N_{s,t}$ could be considered as a proxy for potential market connections at given locations, while $d_{r,s,t}$ could be considered as a proxy for frictions in connectivity. δ^{pow} and δ^{exp} are parameters that describe how the market access decreases with traveling time (i.e. distance decay parameters).

Before applying the gravity function, we want to estimate δ^{pow} and δ^{exp}. For this purpose, we introduce a function for aggregate productivity, $A_{r,t}$ for municipality r at time t, suited for empirical estimation, which depends on $G_{r,t}^{f}$ and other factors:

$$(2) \quad A_{r,t} = \exp\left(\alpha_0^f\right) G_{r,t}^f\left(\mathcal{N}_t, \mathcal{D}_{r,t}\right)^{\alpha_1^f} \exp\left(\sum_{j=2}^{J} \alpha_j^f z_{j,r,t}\right) \exp\left(\psi_{r,t}^f\right)$$

where $z_{j,r,t}$ is expected relative productivity differences due to contextual factors other than market access captured by control j for with corresponding parameters α_j^f for functional form f. Furthermore, α_1^f is an elasticity for how the market access of functional form f varies with congestion in the labor market, which in its raw form could be considered as an agglomeration elasticity that is not adjusted for selection patterns. α_0^f are constants capturing the persistent productivity level. $\psi_{r,t}^f$ are the error terms for municipality r at time t.

Taking natural logarithms to assess our market access functions, we obtain:

$$(3) \quad a_{r,t} \equiv \ln A_{r,t} = \alpha_0^f + \alpha_1^f \ln\left(\sum_{s=1}^{S} G_{z,t}^f\left(\mathcal{N}_t, \mathcal{D}_{r,t}\right)\right) + \sum_{j=2}^{J} \alpha_j^f z_{i,r,t} + \psi_{r,t}^f$$

where $g_{r,t}$ is the log impact measure for municipality r at time t.

Inserting our chosen market access function from equations (1) into equation (3) gives us the equations to be estimated, in order to obtain the distance decay parameters:

$$(4) \quad \begin{aligned} a_{r,t} &= \alpha_0^{pow} + \alpha_1^{pow} \ln\left(\sum_{s=1}^{S} \frac{N_{s,t}}{d_{r,s,t}^{\delta^{pow}}}\right) + \sum_{j=2}^{J=4} \alpha_j^{pow} z_{i,r,t} + \psi_{r,t}^{pow} \\ a_{r,t} &= \alpha_0^{exp} + \alpha_1^{exp} \ln\left(\sum_{s=1}^{S} \frac{N_{s,t}}{\exp\left(d_{r,s,t}\delta^{exp}\right)}\right) + \sum_{j=2}^{J=4} \alpha_j^{exp} z_{i,r,t} + \psi_{r,t}^{exp} \end{aligned}$$

In our empirical estimation of equation (4), we apply net value added volumes per person engaged in the production (i.e. employees and self-employed) as our productivity measure ($a_{r,t}$). Thus, we both capture changes in technical productivity (i.e. productivity regardless of technology specification) and changes in capital intensity. Furthermore, we utilize three controls – overall economic development patterns (i.e. a year trend, marked by $z_{2,r,t}$), capital intensity (i.e. fixed capital services in fixed prices per person employed, marked by $z_{3,r,t}$) and industry composition (marked by $z_{4,r,t}$). In addition, we apply mixed effects (a combination of random and fixed effects) in estimation in some of the regressions, which we will return to soon. While the two first mentioned controls do not need further explanations, the industry composition control will be explained in the following. Within relatively homogenous developed countries like Norway, the main decisive factors for regional productivity disparities beyond differences in degree of urbanization are captured by differences in industry structure. Accordingly, we design our contextual control to address the productivity disparities caused by industry composition:

$$(5) \quad z_{4,r,t} = \sum_{i=1}^{N} \frac{a_{i,b,t}}{a_{b,t}} \frac{n_{r,i,t_0}}{n_{r,t_0}} - 1$$

where $a_{i,b,t}$ is labor productivity in industry i in benchmark region b at time t and $a_{b,t}$ is the same, but for all industries. Furthermore, $n_{r,i,t}$ is industry i's employment in region r at the initial period t_0 and $n_{r,t}$ is the total employment in region r at the initial period t_0. Thus, the ratio between the two variables corresponds to industry i's share of total employment in region r at the initial period t_0. This share is calculated with basis in the initial period to allow for changes in industry composition caused by market access over the study period.

The denominator of the fraction can be interpreted as the labor productivity in the industry reflection in region r. It captures what the aggregate labor productivity in the benchmark region would have been, if the industry composition was the same as in region r, and industry-specific labor productivities remained the same. Measured against the actual national labor productivity, the fraction gives a number below 1, if the industry composition suggests that the labor productivity should be expected to be lower than the national labor productivity. Analogously, it gives a number above 1, if the industry composition suggests that the labor productivity should be expected to be higher than the national labor productivity.

2.3 Estimation in Practice
Estimation of market access function in large datasets like ours constitutes a complex matter subject to computational limitations, so application of more advanced estimation procedures may limit the amount of possible regression controls. We estimate the market access function in equation (3) by ordinary non-linear least squares (NLS) and non-linear mixed effects (NLME) regressions (confer Davidian and Giltinan 2003 for an overview). NLME is an extension of NLS, where the coefficients incorporate mixed effects with fixed and independently distributed random components. The huge set of variables and parameters (although restricted) in the regression makes us unable to apply a general unstructured covariance matrix for the error term.

In our implementation of NLME, we thus use an exchangeable covariance structure, where the between-subjects and within-subject variances are assumed to be constant. Robustness checks where surrounding municipalities beyond some traveling distance were taken out from the dataset indicate that this assumption on covariance matrix structure only has minor impact on our results. We include estimates of NLS as a base of comparison, where the error terms across units are assumed independent from each other. In our applications of both methods, we let the error terms follow the normal distribution. In our practical implementation, we utilize the Stata commands '*menl*' and '*nl*' for NLME and NLS respectively.

3. Data Sources
In the following, we account for the firm and spatial data made use of in our empirical investigation.

3.1 Firm Data
We collect economic data for our study from the Norwegian Register of Business Enterprises at the Brønnøysund Register Centre (Norwegian Register of Business Enterprises in short) from 2004 to 2014. This data source covers roughly 95 percent of the Norwegian business sector employment including public firms.[**] We only include firms

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[**] We approximate the ratio by a comparison between the Norwegian Register of Business Enterprises and the Enterprise Register of Statistics Norway. Note that the Norwegian Register of Business Enterprises involves stock companies and larger companies of all kinds, while the Enterprise Register of Statistics Norway also covers small firms with unlimited liability and small business-oriented firms with a public enterprise form. Furthermore, small firms that are either organized as unlimited liability corporate form or with a self-owned corporate form do not have a duty to report to the Norwegian Register of Business

with registered employees for each year. In case of reporting in foreign currency, we convert the monetary values to NOK using the Norwegian Central Bank's statistics over historical exchange rates. In a few cases where firm's zip codes are missing, we approximate their locations within the reported municipalities' bases on our own mapping of historical zip codes, time series of reported zip codes, correspondence between postal box codes and physical zip codes, and other reported geographical information to determine geographical location by zip code.
As other European enterprise register data, our data involves a branch challenge in the sense that the geographic distribution of economic activities beyond employment in firms with branches at multiple geographic locations is unidentified. To prevent potential biases related to firms switching status from single-branch firms to multi-branch firms and vice versa, we remove all firms that have several branches at least once during our study period. We make use of the most detailed industry division in the national accounts at the time of our study, A64 second revision. Due to of measurement and identification concerns, we do not consider resource industries (NACE 1 to 9 and 35 to 39), construction (NACE 41 to 43), finance and insurance (NACE 64 to 66) and real estate (NACE 68) and non-market-oriented industries (NACE 84 to 99). These industries are either relatively volatile, not profit-driven, strongly driven by international prices and local natural resources, strongly regulated, requiring alternative measurement of value added, directly affected by road construction processes or poorly captured by the data.

We also omit oil and gas suppliers, since they have had a relative strong, heterogenous and volatile productivity development during our study period, which could be seen relation to quality competition and a global upturn in the associated markets during our study period (e.g. Grünfeld et al. 2013). These firms cut across the NACE classification system. Instead, they are identified by the firm population of Norwegian firms that mainly deliver goods to the petroleum extractors' value chain, developed by International Research Institute of Stavanger, Menon Economics and their regional collaborators[††] (Blomgren et al. 2015).

We apply figures for fixed capital services in fixed prices, obtained from Holmen (2022a).[‡‡] Furthermore, we operate with two forms of intermediates – 'commodity purchases' and 'service purchases' (including electricity purchases, but not financial costs). Commodity and service deflators are also obtained from Holmen (2020), which are based on the Norwegian national accounts' gross production and intermediate deflators and industry input-output matrixes. Note that regional price developments are accounted for in the capital deflators for buildings and land area and the service purchase deflators (which is affected at a rate proportional to share of services purchases related to real estate).[§§] Gross production deflators are collected from Statistics Norway.

3.2 Spatial Data
In our study, we make use of annual traveling time data between all Norwegian zip codes (represented by post offices) from 2004 and 2014. The data are constructed by the Institute of Transport Economics and Menon Economics based on Geographic Information Systems data, containing periodical shapefiles of the Norwegian

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Enterprises. Some industries such as for instance agriculture and forestry are also subject to less strict reporting obligations. Overall, primary industries and nonprofit industries are poorly captured by the Norwegian Register of Business Enterprises, but these industries are not in our study in any case.

[††] The regional collaborators include Bodø Science Park, Center for Economic Research at Norwegian University of Science and Technology, Eastern Norway Research Institute and Impello Management.

[‡‡] Holmen (2022a) make use of firm data from Norwegian Register of Business Enterprises and Norwegian National Accounts data to estimate fixed capital figures by the perpetual inventory methods with industry-specific capital deflators and depreciation rates, the. In case of assets without capital depreciation, the author estimates the capital by direct measurement based on book values. We utilize fixed capital services as our capital measure, which adjusts the capital utilization for capital composition by weighting each type of asset in accordance to their stock volume and annual required return (confer Jorgenson and Griliches 1967 and Christensen and Jorgenson 1969 for details on the concept). We refer to Holmen (2022a) for details on the practical implementation of the fixed capital services concept.

[§§] In the fixed capital and deflator data applied, it is distinguished between regional price differences related to real estate capital and real estate purchases, based on processed price data from Statistics Norway and Eiendomsverdi (confer Holmen 2020 for details). The other price deflators are national, implying that we will not be able to adjust for local price variations for other economic components beyond what follows from differences in industry composition and differences in the relative strengths of the ground components.

route network from the Norwegian Mapping Authority (known as '*Elvegdata*'). The calculations are conducted, applying the Dijkstra's (1959) algorithm and the application 'Network Analyst' in ArcGis.

Traveling time does not account for congestion, variations waiting time at ferry crossings, road tolls, logistical optimization or other cost or quality aspects beyond the speed limits or traveling distances. Moreover, such factors tend to be more likely to suffer for endogeneity issues in studies of local economic outcomes. For ferry transitions, we assume a traveling speed of 15 kilometers per hour and a boarding time of five minutes.

The traveling data involves snap shots of the road network at different points in time, but we have recalculated them into annual averages. Here, we have adjusted for what time of the year major road construction projects (defined as projects inducing traveling time reductions of at least five minutes within thirty minutes' traveling time) have been opened. In the related quality assurance exercise, we have utilized the Norwegian Public Road Administration's project database. In this regard, a few data breaches in the road network related to winter closed roads and ferry crossings were identified in the corrected. In a few instances, data from Gule Sider and Google Maps have been used to connect geographical destinations to the road network.

We have received statistics for the built-up areas of each zip code based on maps over buildings and population in Norway from the division for population statistics at Statistics Norway. Based on the spatial distribution of the built-up areas, we have approximated internal traveling distances weighted for population, assuming that the average traveling time equals half of the radius of a circle with similar area. On the advice from the division for population statistics at Statistics Norway, we assume a speed limit of 60 kilometers per hour within zip codes. We further assume that the internal traveling times within zip codes are time-invariant and equal to their value in the initial year of our study (i.e. 2004).

In addition to domestic traveling time data for Norway, the Institute of Transport Economics has by the help of Open Street Map gathered traveling times to all municipalities in Sweden. This data includes all foreign municipalities within six hours' reach from Norway including travel by ferry. From this, we have calculated the traveling distances and traveling time between Norwegian zip codes and Swedish municipalities. We refer to the acknowledgement section in the end of this paper for credits to people that have contributed in processing of the applied traveling time data.

We have received employment and population figures at zip code level and municipal level from Statistics Norway's divisions for population statistics and labor market and wage statistics. In this data, the geographical location information of between 1.5 to 3 percent of the employment figures at municipal level is not identified at zip code level. The municipal employment figures without known zip code location are distributed proportionately to the annual employment shares within each municipality. Employment and population figures for Swedish municipalities are collected from Statistics Sweden.

4. Empirical Analyses

In this section, we conduct empirical analyses on the market access function in line with the framework and procedure outlined in section 2, before we provide some recommendations.

4.1 Estimation

We estimate the distance decay parameters in equations (4) by NLME with exchangeable covariance structure and by ordinary NLS. This involves parameter δ^{pow} in the market access specification, where the distance decay follows a power function, and parameter δ^{exp} in the market access specification, where the distance decay follows an exponential function.

We explore three alternative potential source of market access – employment by workplace, employment by residence and population. We have not used value added, as it fluctuates relatively much compared to labor over time (particularly in Norway where labor rights stand strong). We do this under two alternative assumptions – one where the potential market connections are allowed to vary over time and one where they are held constant to their initial levels (of 2004) to control for the most severe endogeneity challenges related to urbanization.

Due to computational limitations and challenges in convergence, we are not able to estimate market access for all of Norway in a single operation. Instead, we limit ourselves to southern parts of Norway, which also ensures somewhat more comparable municipalities with more homogenous industry structure and degree of urbanization. In practice, wee delimit the region for which we estimate market access parameters to the two counties of Southern Norway (i.e. Aust-Agder and Vest-Agder), their bordering counties (i.e. Rogaland and Telemark) and their bordering counties again (i.e. Buskerud, Hordaland and Vestfold). In our estimation, we also face a computational need for limiting the number of geographical units that are source for market access.

In context of sources for market access, we also include municipalities in the closest Norwegian counties beyond our estimation region (i.e. municipalities in Akershus, Hedmark, Oppland, Oslo and Østfold) and county observations for the closest Swedish counties (i.e. Halland, Värmland and Västra Götaland in Sweden). Combined, the region which gives source to market access covers all areas within four hours' reach from our estimation region.[***] Altogether, our selection enables us to investigate how market access in 142 municipalities is affected by proximity to 260 regions (including themselves) over 11 years. We have not operated with industry-specific decay parameters in our study, as we also want to capture factor usage and composition effects.

Our results under the assumption of power distance decay are reported in Table 1, while our results under the assumption of exponential distance decay are reported in Table 2.

[***]Although omission of regions far away may involve small selection biases, our estimated decay parameters suggest that the impact of regions many hours away is negligible. While the impact of potential market connections approaches zero for this traveling time in case of exponential distance decay, it will be nearly constant for moderate traveling time changes in case of power distance decay. Market access to regions beyond the ones included in our regressions is so far away that the proximity becomes roughly constant for the municipalities investigated, such that it mostly will be captured by the constant and potentially changes in traveling time to areas in the outskirts of our estimation region. The correlation patterns between economic performance and concentrations of economic activity beyond two hours' reach are weak, underpinning this point. Moreover, other biases such as to omission of other modes of transportation infrastructure are likely to be considerably more severe. Since the agglomeration decay parameter turns out to be above one, aggregation of regions can be expected to underestimate market access. Yet, robustness checks in region composition indicate that the aggregated municipalities are so far away that they have very limited impact on regression results.

Table 1. Impact of increased marked access through expansions in the road network on net value added per employee in fixed prices from 2004 to 2014, estimated by NLS and NLME with time-invariant and time-varying market connections

Labor productivity (*logarithm*)	Employment by workplace				Employment by residence				Population			
Market connections	Time-invariant		Time-varying		Time-invariant		Time-varying		Time-invariant		Time-varying	
Est. procedure	NLS	NLME	NLS	NLME	NLS	NLME	NLS	NLME	NLS	NLME	NLS	NLME
Constant (α_0)	4.897***	4.967***	4.903***	4.980***	4.860***	4.932***	4.856***	4.914***	4.798***	4.869***	4.801***	4.865***
	(0.104)	(0.190)	(0.103)	(0.184)	(0.104)	(0.188)	(0.105)	(0.194)	(0.109)	(0.200)	(0.109)	(0.202)
Market access (α_1) (*logarithm*)	0.072***	0.072***	0.072***	0.072***	0.077***	0.077***	0.077***	0.078***	0.077***	0.077***	0.077***	0.077***
	(0.007)	(0.014)	(0.007)	(0.014)	(0.007)	(0.014)	(0.007)	(0.015)	(0.007)	(0.015)	(0.007)	(0.015)
Year trend (α_2)	0.005	0.006**	0.005	0.005*	0.005	0.006**	0.005	0.005	0.006	0.006**	0.005	0.005*
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Capital intensity (α_3) (*logarithm*)	0.135***	0.115***	0.135***	0.115***	0.134***	0.115***	0.134***	0.115***	0.134***	0.115***	0.135***	0.115***
	(0.016)	(0.022)	(0.016)	(0.022)	(0.016)	(0.022)	(0.016)	(0.022)	(0.016)	(0.022)	(0.016)	(0.022)
Industry composition (α_4)	0.773***	0.765***	0.787***	0.778***	0.773***	0.765***	0.787***	0.778***	0.773***	0.765***	0.773***	0.764***
	(0.160)	(0.135)	(0.160)	(0.135)	(0.160)	(0.135)	(0.160)	(0.135)	(0.160)	(0.135)	(0.160)	(0.135)
Agglomeration decay (δ)	2.376***	2.341***	2.408***	2.396***	2.325***	2.297***	2.320***	2.258***	2.300***	2.270***	2.305***	2.260***
	(0.215)	(0.427)	(0.215)	(0.424)	(0.196)	(0.389)	(0.198)	(0.394)	(0.197)	(0.392)	(0.199)	(0.395)
Within-group error variance		-0.957***		-0.958***		-0.958***		-0.958***		-0.957***		-0.957***
		(0.024)		(0.024)		(0.024)		(0.024)		(0.024)		(0.024)
Between-group covariance		0.302***		0.301***		0.301***		0.301***		0.302***		0.302***
		(0.034)		(0.034)		(0.034)		(0.034)		(0.034)		(0.034)
No. of observations	1,562	1,562	1,562	1,562	1,562	1,562	1,562	1,562	1,562	1,562	1,562	1,562
Log likelihood	-720.7	-572.3	-719.1	-571.4	-719.5	-572.0	-719.1	-571.7	-720.7	-572.3	-720.1	-571.9

Note: The agglomeration decay pattern is assumed to follow an exponential function. Estimated by ordinary NLS and NLME with exchangeable covariance matrix. Potential market connections are held constant to their initial value or allowed to vary. (* for $p < 0.1$, ** for $p < 0.05$ and *** for $p < 0.01$)

We see that all parameters are significant with signs and magnitudes in accordance with what one could expect. The choice between our two estimation procedures and measures for potential market connections has only limited impact on the estimation results. The productivity growth during the period (reflected by α_2^f) is estimated to 0.5 to 0.6 percent annually, although the coefficients' p-values are only around ten percent. The impact of capital intensity (reflected by α_3^f) is estimated to be around 10 to 13 percent, which also seems reasonable considering the net operational profit's share of net value added. Industry composition that enhances labor productivity (reflected by α_4^f) somewhat less than aggregate productivity differences between industries suggest, which is partly related to collinearity with the other explanatory variables. Although not reported, it could also be noted that omission of any of the controls or adding of controls do not change our agglomeration decay estimate considerably.

Our point estimates for the raw agglomeration elasticity is also relatively high, confer our discussion in section 1. As we have not controlled for location selection and find evidence of relatively sharp distance decay, this is also as expected. We estimate the distance decay parameter in the power function specification, δ^{pow} lies around 2.2 to 2.4 (point estimates), being significantly different from 1, which often is assumed in empirical studies. We estimate δ^{exp} to be around 0.07, which also indicates much faster distance decay than the standard assumption.

Our estimates also imply sharper distance decay than the ones found by Graham et al. (2010), as mentioned in section 1. Compared to the United Kingdom, our study region is considerably more rural. In addition, we carry out our estimates on municipality level, while Graham et al. conduct their investigation on firm level, indicating that our measure accounts for composition effects, while their study focuses on firm performance. Another important difference, which we will return to in a moment, is that much smaller geographical distances are observed on disaggregated than aggregated geographical levels. As empirical investigations suggest that changes in traveling time within the immediate vicinity are of limited importance for economic performance, while the distance decay assumed in the market access functions suggests the opposite, inclusion of such short traveling times in the regressions on market access functions are likely to produce lower distance decay parameters.

We estimate the distance decay parameters to be barely higher under NLME with exchangeable covariance structure than under NLS, and for employment after workplace than employment after residence and population. The number of observations in the regressions is somewhat lower in the specifications with the exponential distance decay than the specification with power distance decay, since the estimation algorithms throw out some observations with peculiar characteristics under the first-mentioned specification (i.e. remote islands with relatively low internal traveling time and relatively high external traveling time). Yet, if we take these municipalities out from the regressions on market access with power distance decay, the log likelihoods are still lower (in absolute value) for the specification with exponential distance decay. This indicates that the exponential distance decay is barely closer to the true distance decay pattern than the power distance decay. For given model specification and estimation procedure, the explanatory power of each estimation model is slightly lower when population is applied as potential market connection measure rather than an employment measure (again indicated by lower log likelihood), but again the differences are small.

Population is less connected to the business sector than employment, although it may capture firm-to-consumer linkages better and may fluctuate less over business cycles. Yet, in further empirical investigations, one may in any case keep potential market connections constant to the initial level to limit potential endogeneity challenges.
From a theoretical point of view, it is not obvious whether employment by workplace or employment by residence should be applied to measure potential market connections in market access functions. While employment by workplace is likely to capture business-business interactions most precisely, employment by residence could be expected to better capture linkages in the local labor supply and business-to-consumer markets. A possible challenge with employment by workplace is that regional integration could seemingly decrease, when potential market connections are measured by employment by workplace, due to higher commuting (i.e. the same challenge as with value added, although somewhat less severe). Moreover, we do not see any strong general reason to choose one of the employment measures over the other, as their relevance depend on the markets under investigation. A possibility in generic applications of market access functions (without pre-estimation) could be to simply apply the average of them.

Table 2. Impact of increased marked access through expansions in the road network on net value added per employee in fixed prices of industry composition in the initial year and market access from 2004 to 2014.

Labor productivity (*logarithm*)	Employment by workplace				Employment by residence				Population			
Market connections	Time-invariant		Time-varying		Time-invariant		Time-varying		Time-invariant		Time-invariant	
Est. procedure	NLS	NLME	NLS	NLME	NLS	NLME	NLS	NLME	NLS	NLME	NLS	NLME
Constant (α_0)	4.699***	4.712***	4.709***	4.731***	4.685***	4.699***	4.686***	4.694***	4.638***	4.652***	4.645***	4.652***
	(0.113)	(0.195)	(0.111)	(0.188)	(0.113)	(0.197)	(0.113)	(0.199)	(0.116)	(0.206)	(0.116)	(0.206)
Market access (α_1) (*logarithm*)	0.067***	0.067***	0.066***	0.066***	0.069***	0.069***	0.068***	0.069***	0.069***	0.069***	0.068***	0.069***
	(0.006)	(0.012)	(0.006)	(0.011)	(0.006)	(0.012)	(0.006)	(0.012)	(0.006)	(0.012)	(0.006)	(0.012)
Year trend (α_2)	0.006	0.006*	0.005	0.005*	0.006	0.006*	0.005	0.005	0.006	0.006*	0.005	0.005*
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Capital intensity (α_3) (*logarithm*)	0.107***	0.100***	0.107***	0.100***	0.107***	0.100***	0.107***	0.100***	0.107***	0.100***	0.107***	0.100***
	(0.018)	(0.024)	(0.018)	(0.024)	(0.018)	(0.024)	(0.018)	(0.024)	(0.018)	(0.024)	(0.018)	(0.024)
Industry composition (α_4)	0.784***	0.781***	0.797***	0.795***	0.784***	0.781***	0.797***	0.794***	0.784***	0.782***	0.783***	0.780***
	(0.162)	(0.138)	(0.162)	(0.138)	(0.162)	(0.138)	(0.162)	(0.138)	(0.162)	(0.138)	(0.162)	(0.138)
Agglomeration decay (δ)	0.071***	0.067***	0.073***	0.071***	0.071***	0.067***	0.071***	0.066***	0.071***	0.067***	0.071***	0.066***
	(0.014)	(0.025)	(0.014)	(0.026)	(0.014)	(0.026)	(0.014)	(0.025)	(0.014)	(0.026)	(0.014)	(0.026)
Within-group error variance		-0.959***		-0.959***		-0.958***		-0.958***		-0.958***		-0.958***
		(0.024)		(0.024)		(0.024)		(0.024)		(0.024)		(0.024)
Between-group covariance		0.286***		0.286***		0.287***		0.287***		0.288***		0.288***
		(0.034)		(0.034)		(0.034)		(0.034)		(0.034)		(0.034)
No. of observations	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,518	1,518
Log likelihood	-699.1	-565.0	-698.1	-564.6	-699.1	-565.2	-699.0	-565.1	-699.9	-565.4	-699.6	-565.2

Note: The agglomeration decay pattern is assumed to follow an exponential function. Estimated by ordinary NLS and NLME with exchangeable covariance matrix. Potential market connections are held constant to their initial value or allowed to vary. (* for $p < 0.1$, ** for $p < 0.05$ and *** for $p < 0.01$)

4.2 Recommendations

Based on our, we approximate the distance decay parameters in rural areas to $\delta^{pow} = 2.3$ for the market access specification with power distance decay and $\delta^{exp} = 0.07$ for the market access function with exponential distance decay. Admittedly, the estimated distance decay parameters may not only reflect causal influences of increased market access, but also location effects. Nevertheless, our estimated parameter values change little when we omit firms moving in or out of our sample or fix the traveling times to the initial period (as in our reported regressions). This indicates that they are not too far from the true ones, adjusted for location selection.

In empirical investigations based on pre-calculated market access function, low traveling time may constitute a challenge, both due to measurement errors and missing theoretical justifications for why changes in low traveling time should matter as much as the assumed functional forms typically suggest. A simple possible solution could be to add a fixed number to all traveling times (which could be interpreted as the time used to begin and end a journey). Our robustness checks suggest that operating with a minimum traveling time of ten minutes has limited impact on the distance decay parameter estimates. Ten minutes seems like a reasonable choice for the minimum

traveling time threshold, as it passes the robustness check, and ten minutes is of about the same magnitude as the typical internal traveling times within municipalities. Persistent differences in traveling time below this limit may still be captured by fixed effects in estimation models that applies pre-estimated measures for market access.

An alternative solution to the challenge with low traveling time would be to add a constant to the actual traveling time, which could be interpreted as a fixed traveling time mark-up regardless of actual transportation process. Yet, this alternative assumption did provide less robust results in our empirical estimations of the market access function, so we have abandoned it.

The estimated market access functions and the corresponding marginal distance decay functions are illustrated in Fig. 1 with straight lines, where we have operated with the suggested minimum traveling time of ten minutes. As benchmark, we have illustrated the market access-decay curves for proportional distance decay with a dotted line – a standard assumption applied in much of the literature (corresponding to $\delta^{pow} = 1$ in the power distance decay function). Analogously, we have also illustrated a benchmark with flatter exponential decay (with $\delta^{exp} = 0.03$, also marked with dotted lines).
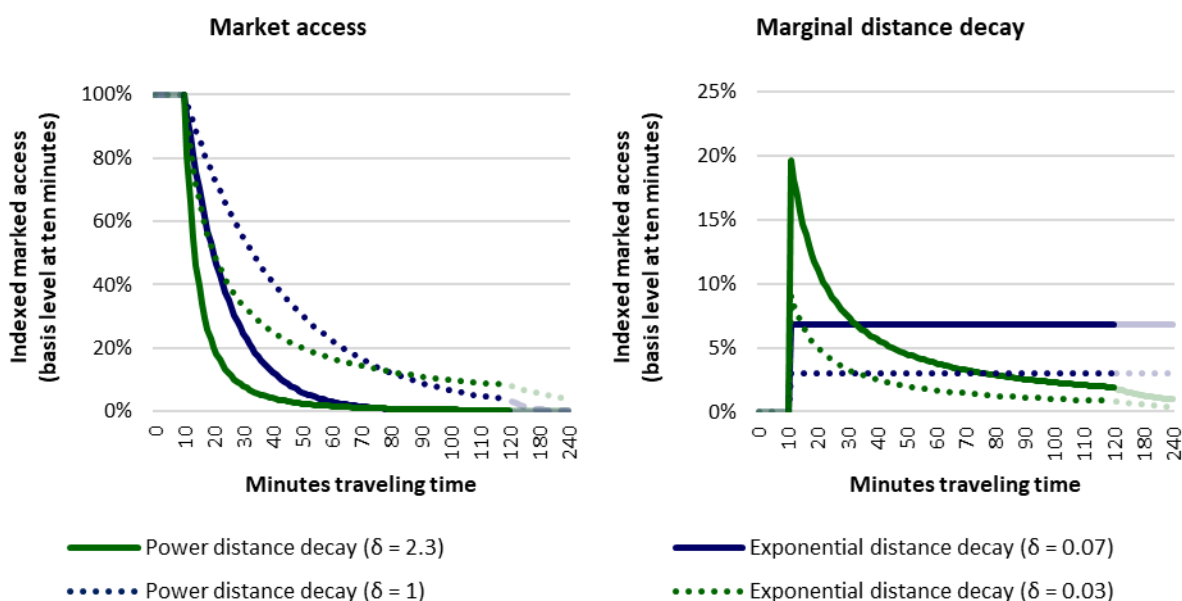
Fig. 1. Comparison of development in a) market access (l.h.s.) and b) marginal decay (r.h.s.) over minutes of traveling time under the assumption of exponential distance decay (with $\delta^{exp} = \{0.03, 0.07\}$) and power distance decay (with $\delta^{pow} = \{1.0, 2.3\}$)

5. Conclusions

For economic actors, spatial proximity to other economic activities – so called 'market access' and 'economic density' – is often associated better economic performance. How the impulses from economic activities diminish over space is known as 'agglomeration decay' or 'distance decay'. Market access functions and the associated agglomeration decay constitute an important topic within spatial economic research. Yet, the phenomenon has mostly been studied in urban settings. Furthermore, market access functions are seldom estimated by non-linear estimation techniques.

In this paper, we investigate how market access develop in rural areas. We estimate market access measures for the Southern parts of Norway by nonlinear estimation techniques, namely ordinary non-linear least squares (NLS) and non-linear mixed effects (NLME) with exchangeable covariance structure. Here, we utilize labor productivity as the outcome variable, traveling time as distance measure, and employment and population as alternative measures for potential market connections. We control for capital intensity, annual growth trend and industry composition with the help of an 'industry reflection' control. This control reflects what the labor productivity can be expected to be given the local industry composition and each industry's performance in the rest of the country. In addition, we operate with mixed effects in our application of the NLME model.

Our results support sharper agglomeration decay in rural areas than what is usually assumed in the literature, involving power and exponential distance decay parameters of about 2.3 and 0.07 respectively. This suggest that the agglomeration decay is stronger in rural areas than in urban areas. Comparisons of the log likelihood from the estimation of market access functions with power and exponential distance decay suggest that later function constitute a slightly better fit than the former. In addition, employment involves slightly more explanatory power as a measure for potential market connections than population. To cope with the market access functions' sensibility to traveling frictions near zero, operating with a minimum traveling friction involve more robust results than adding a constant to all traveling frictions.

We see many fruitful avenues for future research. In particular, alternative choices of estimation techniques and the form of the market access function can be explored further. We also hope to see further investigations on how market access function depends on spatial configuration and industry composition.

References

Behrens, K., Duranton, G., & Robert-Nicoud, F. 2014. Productive Cities: Sorting, Selection and Agglomeration. *Journal of Political Economy*, 122(3), 507-553. https://doi.org/10.1086/675534

Blomgren, A., Quale, C., Austnes-Underhaug, R., Harstad, A. M., Fjose, S., Wifstad, K., Mellbye, C., Amble, I. B., Nyvold, C. E., Steffensen, T., Viggen, J. R., Inglebæk, F., Arnesen, T., & Hagen, S. E. 2015. A survey of employees in Norwegian petroleum-related businesses, with a particular focus on supplier firms' employees related to exports (in *Norwegian*), ordered by The Norwegian Oil and Gas Association, report IRIS 2015/031. URL: https://norceresearch.brage.unit.no/norceresearch-xmlui/handle/11250/2631778

Christensen, L. R., & Jorgenson, D. W. 1969. The measurement of US real capital input, 1929–1967. *Review of Income and Wealth*, 15(4), 293-320. https://doi.org/10.1111/j.1475-4991.1969.tb00814.x

Davidian, M., & Giltinan, D. M. 2003. Nonlinear models for repeated measurement data: An overview and update. *Journal of Agricultural, Biological, and Environmental Statistics,* 8(4), 387. https://doi.org/10.1198/1085711032697

Davis, M. A., Fisher, J. D., & Whited, T. M. 2014. Macroeconomic implications of agglomeration. *Econometrica*, 82(2), 731-764. https://doi.org/10.3982/ECTA9029

Dicken, P., & Lloyd, P. E. 1990. Location in space: Theoretical perspectives in economic geography. Prentice Hall. Available for purchase: https://www.amazon.com/Location-Space-Theoretical-Perspectives-Geography/dp/0060416777

Dijkstra, E. W. 1959. A note on two problems in connexion with graphs. *Numerische Mathematik*, 1(1), 269-271. https://doi.org/10.1007/BF01386390

Donaldson, D., & Hornbeck, R. 2016. Railroads and American economic growth: A 'market access' approach. *The Quarterly Journal of Economics*, 131(2), 799-858. https://doi.org/10.1093/qje/qjw002

Duranton, G., & Overman, H. G. 2005. Testing for localization using micro-geographic data. *The Review of Economic Studies*, 72(4), 1077-1106. https://doi.org/10.1111/0034-6527.00362

Duranton, G., & Puga, D. 2004. Micro-foundations of urban agglomeration economies. *Handbook of Regional and Urban Economics*, 4, 2063-2117. https://doi.org/10.1016/S1574-0080(04)80005-1

Duranton, G., Morrow, P. M., & Turner, M. A. 2014. Roads and Trade: Evidence from the US. *The Review of Economic Studies*, 81(2), 681-724. https://doi.org/10.1093/restud/rdt039

El-Geneidy, A. M., & Levinson, D. M. 2006. Access to destinations: Development of accessibility measures. URL: https://conservancy.umn.edu/handle/11299/638

Fujita, M. 1988. A monopolistic competition model of spatial agglomeration: Differentiated product approach. *Regional Science and Urban Economics*, 18(1), 87-124. https://doi.org/10.1016/0166-0462(88)90007-5

Fujita M., Krugman P., & Venables, A. J. 1999. The spatial economy: Cities, regions and international trade, MIT Press, Cambridge MA. https://doi.org/10.7551/mitpress/6389.001.0001

Gibbons, S., Lyytikäinen, T., Overman, H. G., & Sanchis-Guarner, R. 2019. New road infrastructure: The effects on firms. *Journal of Urban Economics*, 110, 35-50. https://doi.org/10.1016/j.jue.2019.01.002

Graham, D. J. 2007. Agglomeration, productivity and transport investment. Journal of transport economics and policy, 41(3), 317-343. URL: https://www.ingentaconnect.com/content/lse/jtep/2007/00000041/00000003/art00003

Graham, D. J., & Gibbons, S. 2019. Quantifying Wider Economic Impacts of Agglomeration for Transport Appraisal: Existing Evidence and Future Directions. *Economics of Transportation*, 19, 100121. https://doi.org/10.1016/j.ecotra.2019.100121

Graham, D. J., Gibbons, S., & Martin, R. 2010. The spatial decay of agglomeration economies: Estimates for use in transport appraisal. Department for Transport. URL: http://eprints.lse.ac.uk/id/eprint/44666

Graham, D. J., Melo, P. S., Jiwattanakulpaisarn, P., & Noland, R. B. 2010. Testing for causality between productivity and agglomeration economies. *Journal of Regional Science*, 50(5), 935-951. https://doi.org/10.1111/j.1467-9787.2010.00676.x

Griliches, Z., & Jorgenson, D. W. 1966. Sources of measured productivity change: Capital input. *The American Economic Review*, 56(1/2), 50-61. URL: https://www.jstor.org/stable/1821267

Grünfeld, L. A., Holmen, R. B., Gulbrandsen, M. U., & Wifstad, K. 2013. Competitiveness and wage growth: Some updated indicators and perspectives (in *Norwegian*), topical comment, Samfunnsøkonomen No. 2014/9. URL: https://docplayer.me/462808-Samfunnsokonomen-nr-1-2014-128-argang-holden-grunfeld-mfl-bjerkholt-hauge-hawkins.html

Handy, S. L., & Niemeier, D. A. 1997. Measuring accessibility: an exploration of issues and alternatives. *Environment and planning A*, 29(7), 1175-1194. https://doi.org/10.1068/a291175

Hansen, W. G. 1959. How accessibility shapes land use. *Journal of the American Institute of Planners*, 25(2), 73-76. https://doi.org/10.1080/01944365908978307

Hanson, G. H. (2005). Market potential, increasing returns and geographic concentration. *Journal of International Economics*, 67(1), 1-24. https://doi.org/10.1016/j.jinteco.2004.09.008

Harris, C. D. 1954. The Market as a Factor in the Localization of Industry in the United States. *Annals of the Association of American Geographers*, 44(4), 315-348. https://doi.org/10.1080/00045605409352140

Holmen, R. B. 2020. Heterogeneity in Fixed Capital Estimation: Implications for Productivity Estimation. Chapter 4 in Productivity and Mobility in Holmen, R. B. (2020). A dissertation submitted to BI Norwegian Business School for the degree of PhD. PhD specialization: Economics. Series of Dissertations 7/2020. Contact information for access: rbh@toi.no

Holmen, R. B. 2022a. Fixed Capital Estimation: Utilization of Macro Data to Account for Capital Heterogeneity at Firm Level. *Beta Scandinavian Journal of Business Research*. Forthcoming. URL: https://www.idunn.no/journal/beta

Holmen, R. B. 2022b. Productivity Impulses from Regional Integration: Lessons from Road Openings. *Insights into Regional Development*. 2022 Volume 4 Number 4 (December). Forthcoming. URL: https://jssidoi.org/ird/

Holmen, R. B. & Hansen, W. 2020. The Scientific Foundation for Impacts Estimation in Transportation Appraisal: A Literature Review. Chapter 2 in Productivity and Mobility in Holmen, R. B. (2020). A dissertation submitted to BI Norwegian Business School for the degree of PhD. PhD specialization: Economics. Series of Dissertations 7/2020. Contact information for access: rbh@toi.no

Jorgenson, D. W., & Griliches, Z. 1967. The explanation of productivity change. *The Review of Economic Studies*, 34(3), 249-283. https://doi.org/10.2307/2296675

Marshall, A. 1890. Principles of economics, revised 1920. London: Mac-Millan. Available for purchase: https://www.amazon.com/Principles-Economics-Great-Alfred-Marshall/dp/1573921408

McCann, P. 2005. Transport costs and new economic geography. *Journal of Economic Geography*, 5(3), 305-318. https://doi.org/10.1093/jnlecg/lbh050

Melitz, M. J., & Ottaviano, G. I. 2008. Market size, trade, and productivity. *The Review of Economic Studies*, 75(1), 295-316. https://doi.org/10.1111/j.1467-937X.2008.00505.x

Melo, P. C., Graham, D. J., & Noland, R. B. 2009. A meta-analysis of estimates of urban agglomeration economies. *Regional Science and Urban Economics*, 39(3), 332-342. https://doi.org/10.1016/j.regsciurbeco.2008.12.002

Melo, P. C., Graham, D. J., & Brage-Ardao, R. 2013. The productivity of transport infrastructure investment: A meta-analysis of empirical evidence. *Regional Science and Urban Economics*, 43(5), 695-706. https://doi.org/10.1016/j.regsciurbeco.2013.05.002

Redding, S. J. 2010. The empirics of new economic geography. *Journal of Regional Science*, 50(1), 297-311. https://doi.org/10.1111/j.1467-9787.2009.00646.x

Redding, S. J., & Rossi-Hansberg, E. (2017). Quantitative spatial economics. *Annual Review of Economics*, 9, 21-58. https://doi.org/10.1146/annurev-economics-063016-103713

Redding, S., & Venables, A. (2004). Geography and export performance: external market access and internal supply capacity. In Challenges to globalization: Analyzing the economics (pp. 95-130). University of Chicago Press. URL: https://www.nber.org/system/files/chapters/c9535/c9535.pdf

Rice, P., Venables, A. J., & Patacchini, E. 2006. Spatial determinants of productivity: analysis for the regions of Great Britain. *Regional Science and Urban Economics*, 36(6), 727-752. https://doi.org/10.1016/j.regsciurbeco.2006.03.006

Rigby, D. L., & Brown, W. M. (2015). Who benefits from agglomeration?. *Regional Studies*, 49(1), 28-43. https://doi.org/10.1080/00343404.2012.753141

Rosenthal, S. S., & Strange, W. C. 2003. Geography, industrial organization, and agglomeration. *Review of Economics and Statistics*, 85(2), 377-393. https://doi.org/10.1162/003465303765299882

Rosenthal, S. S., & Strange, W. C. 2004. Evidence on the nature and sources of agglomeration economies. *Handbook of Regional and Urban Economics*, 4, 2119-2171. https://doi.org/10.1016/S1574-0080(04)80006-3

Sevtsuk, A., & Mekonnen, M. 2012. Urban network analysis. Revue internationale de géomatique–n, p. 287-305. https://doi.org/10.3166/rig.22.287-305

Shirley, C., & Winston, C. 2004. Firm inventory behavior and the returns from highway infrastructure investments. *Journal of Urban Economics*, 55(2), 398-415. https://doi.org/10.1016/j.jue.2003.11.001

Venables, A. J. 2007. Evaluating Urban Transport Improvements: Cost-Benefit Analysis in the Presence of Agglomeration and Income Taxation. *Journal of Transport Economics and Policy*, 41, 173-188. URL: https://www.ingentaconnect.com/content/lse/jtep/2007/00000041/00000002/art00002

Vickerman, R., Spiekermann, K., & Wegener, M. 1999. Accessibility and economic development in Europe. *Regional Studies*, 33(1), 1-15. https://doi.org/10.1080/00343409950118878

Waddell, P., & Ulfarsson, G. F. (2003). Accessibility and agglomeration: Discrete-choice models of employment location by industry sector. In 82nd annual meeting of the Transportation Research Board, Washington, DC (Vol. 63) URL: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.202.5658&rep=rep1&type=pdf

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