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The effect of agglomeration and transport on labour productivity in Saint Petersburg metropolitan area¹

Abstract. In this paper, we assess the extent of agglomeration externalities that mirror on labour productivity gains while accounting for the direct and indirect effects of transportation exposure. To this end we combine data on the local average wage and employment with comprehensive information on the public transportation and road networks of the Saint Petersburg Metropolitan Area, one of the most populous agglomerations in Europe. According to our findings, there is a considerable and noteworthy impact of only transit exposure measures on local labour productivity, whereas the effect of agglomeration economies on labour productivity evaporates after the instrumentation technique is applied. Additionally, we reveal that the inclusion of public transportation exposure measures into estimation results in stealing the positive effect on labour productivity from private modes in favour of public transit.

Keywords: *agglomeration economies, transport exposure, employment density, public transport, road network.*

JEL Classification: C23, C26, R10, R40.

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1. Introduction

The existence of agglomeration externalities implies that the concentration of resources provides productivity gains, and their allocation to cities instead of scattering can be beneficial to foster economic growth on the level of the country. Agglomeration effects can be broken down into scale and network effects. Scale economies increase when the cost of producing or distributing an additional unit of a good or service decreases as the volume increases. They result from the spreading of fixed costs. Network economies, occurring on the demand side, correspond to scale economies on the supply side. The former arise from synergy between economic processes. As a result, the value of a product to an individual goes up as more people use it.

The topic of agglomeration effects is widely investigated; however, little is known about them in Russian settlements. Do the latter have their specificity in terms of magnitude and spatial gradient? Or do they fit the patterns characteristic of North American and European cities? Our research tries to answer some of the major questions of agglomeration economics with regard to the Saint Petersburg area, which is the second most important agglomeration in Russia by its size, human capital, and concentration of business activities. It is also the location of the former capital of Russia in times of the Empire and the second most important destination for work, study, and travel in Russia. The above-mentioned facts make Saint Petersburg area an ideal

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setting for exploring the agglomeration effects and associated with them productivity gains. In particular, we shed light on the relationship between employment density and labour productivity and the role that transportation improvements play in generating productivity gains. Despite the fact that there were a few substantial changes in the transport networks of the Saint Petersburg area over the period under consideration (2017–2022)², it is believed that they improved connectivity and broadened employment opportunities for residents via accessibility augmentation.

This paper combines two branches of economic literature: literature on agglomeration economics and literature showing the effects of transport on various employment-related outcomes. To date, a number of papers have accumulated evidence of a positive interaction of productivity and agglomeration effects when using cross-city variation (see (Combes, Gobillon, 2015) for a survey). There are fewer publications using within-city variation (Arzaghi, Henderson, 2008); and only a few studies include transport-induced agglomeration measures (Holl, 2012; Gibbons et al., 2019). In relation to the second branch, a lot of publications examine how transportation infrastructure and the geographic distribution of economic activity are related. Many such papers investigate the impact of transportation networks on the spatial economy in historical (Duranton, Turner, 2012; Hornung, 2015; Berger, Enflo, 2017; Baum-Snow, 2020) or developing country contexts (Ghani et al., 2016; Wang, Dong, 2022; Ma, Liu, 2022); however, little is known about the micro-level consequences of additions to well-developed transport networks. It is uncommon to find direct evidence of causal impacts when evaluating road network enhancements *ex post*. Additionally, theory provides little clarity on this issue. Given this, determining the magnitude and direction of the effects is mostly an empirical issue. The primary focus of the above-mentioned second branch of economic literature is the impact of roads and railroads on population and employment-related outcomes (Duranton, Turner, 2012; Mayer, Trevien, 2017). As far as we are aware, the only research papers on the impact of roads on labour productivity are (Gibbons et al., 2019; Quinet, Ruiz-Mejia, 2022).

The two main channels of the influence of urban transport on within-city urban productivity can be put forward. First, by lowering the cost of interaction between economic agents situated in various areas, transportation may widen the scope of agglomeration externalities. Second, transportation may make some locations preferable as compared to others and thus affect placement of business and labour force. Additionally, enhanced transport facilities might attract highly trained workers and businesses with high added value because they have a comparative advantage in choosing locations with better infrastructure. This leads to local productivity gains in two ways, i.e. increased quantity and increased quality of the workforce. Because of these effects of transportation on productivity, the goal of this paper is to estimate the size of agglomeration externalities at the urban level.

To do so, we have at our disposal data on the productivity of municipalities of the Saint Petersburg agglomeration and the local structure of the economy provided by Rosstat as part of the Database of municipal indicators. In addition, Saint Petersburg Open Data contains information about the georeferenced routes of public transport (tram, trolleybus, and bus). Transport data is updated monthly; previous data sets are

² Saint Petersburg metro network has been expanded only by 5 stations for the 2017–2022 period. Their openings were accompanied by incessant postponements of the commission date. Flagrant violations of construction technologies have led to repeated flooding of these stations that has not been rectified to date. The Saint Petersburg tram network has been expanded due to the launch of the Chizhik network in 2018 and 2019, a 4-route tram network commissioned on terms of concession. Among the largest projects in road construction, the opening of the whole Western High-Speed Diameter for traffic in December 2016 should be highlighted.

available. Due to the accessibility of these data, we create an econometric technique that is based on (Quinet, Ruiz-Mejia, 2022)'s interpretation of (Combes et al., 2008)'s wage equations in order to unravel the intricate relationships between agglomeration effects, transportation options, and productivity. This tries to give an urban planner a more precise tool to optimise city wealth by identifying the productivity impact of transportation infrastructure on a disaggregated basis.

Our econometric strategy involves using a model of two stages for determining wages. The first step enables us to weigh the significance of differences in local sectoral structure against the factors that highlight actual productivity disparities between municipalities. Formally, we regress the local average of the logarithm of individual wages on the municipality-year fixed effects and a set of variables related to the local economic structure in this first stage to account for localisation economies. The vector of municipality-year fixed effects calculated in the first stage is used as the dependent variable in the second stage. This vector is regarded as a local wage index after accounting for local sectoral peculiarities. Formally, we use a set of time dummies, a number of agglomeration measures that take into account the economics of urbanisation, and then a number of transport exposure measures to regress the predicted municipality-year fixed effects. Additionally, in order to fully portray the effects of transportation, we look into how local employment density is affected by the latter. This is because different levels of exposure to transportation may influence where businesses and people choose to locate their operations by making some locations more desirable than others.

We quantify transportation exposure using two accessibility indices determined on a local geographical scale. The first assesses employment accessibility from a given origin to all prospective destinations via the road and public transportation network, while the second measures the degree of reachability of a specific location. Both indices project transportation improvements through changes in commuting times, and they measure each location's local and global exposure to transportation. Access to employment is specifically quantified by the weighted sum of inverse optimal travel times, where the weights are measurements of job density at the destination. The underlying assumption is that transportation exposure expands the geographic reach of agglomeration externalities on productivity by lowering the interaction cost between economic actors located in various locations. Similarly, reachability levels are determined by averaging optimal travel times from all possible starting points along the road and public transportation network. The index is calculated in such a way that when it decreases, it reflects a decrease in the average of ideal travel times to get to a specific destination. Reachability levels can have two implications for productivity. On the one hand, they may increase productivity by attracting more and higher-skilled employment activity locally. On the other hand, improvements in reachability may have a negative impact on productivity when measured by average earnings because employers may compensate employees for longer commuting.

The fundamental issue is the endogeneity of agglomeration and transport exposure measurements. When firms' productivity and/or employees' talents are ordered by unobserved local traits that are connected with observed local factors, there is an omitted variable bias. Differences in local amenities, for example, may influence the placement of both enterprises and people; areas with more amenities may attract a disproportionately skilled workforce and higher value-added firms that rely on skilled

labour. When those facilities also influence agglomeration measurements and transportation supply, the estimates for both are skewed upwards. Second, identification is jeopardised by the reverse causality between productivity and agglomeration, as well as between productivity and transportation exposure. On the one hand, employees are drawn to denser locations due to better earnings. However, the decision to allocate transportation infrastructure is not made randomly. Indeed, the planner may choose to connect dynamic (deficient) areas on purpose, shifting the estimations higher (downwards). Recent papers have addressed this problem using various identification strategies, including: (a) using historical variables as instruments, assuming that they are unrelated to current conditions (Herzog, 2021; Garcia-López et al., 2023; Rocha et al., 2024; Frye, 2024); (b) using physical geography as an instrument, assuming that physical geography is unrelated to current conditions (Jedwab, Moradi, 2016; Jiao et al., 2020; Gao et al., 2020); or (c) assuming that some places are incidental beneficiaries of new links, e.g., metropolitan margins (Holl, 2004; Melo et al., 2010; Padeiro, 2013).

To address the endogeneity problem, we combine district fixed effects with an oblast' fixed effects. Specifically, districts are higher-level units of the administrative division for Saint Petersburg municipalities (the federal city of Saint Petersburg is divided into eighteen districts), whereas such analogues are absent for Leningrad oblast' municipalities. Thus, they can all belong to a single category. Through this strategy, we are able to independently identify agglomeration and transport exposure effects on local productivity apart from potential employee sorting at the district level within Saint Petersburg, and at oblast' level for the rest of the metropolitan area.

The reverse-causality bias can be solved via usage of the IV approach. We use past levels of agglomeration and transport exposure measures as instruments. Furthermore, we add to the list of instruments physical-distance-based measures of reachability and access to employment. We also employ one distance indicators for historical infrastructure, such as the distance to the 1916 tramway network. We address the non-randomness of infrastructure location even further by controlling for infrastructure-type measures in our regressions. This allows us to assess the accessibility and reachability effects that are orthogonal to the endogenous presence of infrastructure. In other words, we use the continuous geographical variation of our transport exposure measurements, which is partly unrelated to the local availability of infrastructure, to identify the effects of transportation on productivity. This allows us to discover the transportation exposure effects, regardless of the benefits or drawbacks of certain places.

2. Context and data

2.1. Saint Petersburg metropolitan area

We assess the agglomeration and transport effects within the metropolitan area of Saint Petersburg. The core of the Saint Petersburg agglomeration, the federal city of Saint Petersburg, is the second largest city in Russia (after Moscow). Saint Petersburg is the fourth-most populous city in Europe (after Istanbul, Moscow, and London), the most populous city on the Baltic Sea, and the world's northernmost city of more than 1 million residents. The city has experienced a series of tragic events that have seriously affected its development and the growth of its population. Specifically, the October Revolution in 1917 and the following Red Terror and Civil War led to a significant

decrease in the number of Saint Petersburg residents, many of them were forced to emigrate, and the Saint Petersburg population plummeted by 70%, from 2415 700 in 1916 to 740 000 in 1920. In 1918, when the Bolsheviks moved their government to Moscow, Saint Petersburg lost its capital status. The pre-revolutionary level of the city's population was regained by 1933, soon after Saint Petersburg fell under a blockade that lasted 872 days, during which about 1 million people died. In 1944, the city's population was 18% of the pre-war level. Further, Saint Petersburg experienced a significant population growth until 1991. The subsequent collapse of the USSR and economic degradation led to the depopulation of Saint Petersburg, which lasted until 2009, when the decline in numbers was replaced by a long period of growth. Finally, as of January 1, 2023, Saint Petersburg had a population of 5.6 million residents.

Following population growth, road and public transport networks have experienced radical extensions. By present, the Saint Petersburg public transport system includes tram, metro, trolleybus, city-funded and private-funded buses. Trams in Saint Petersburg used to be the main means of transport (partly, extensive tramway system compensated for underdeveloped metro network that does not keep pace with population growth and urban sprawl). In the 1980s, this was the largest tram network globally, but many tracks were dismantled in the 2000s. As of 2023, 43 tramway routes (including two temporarily closed due to track repairs) currently operate in Saint Petersburg. The Saint Petersburg trolleybus was opened on October 21, 1936. As of September 2023, there are 46 trolleybus routes, of which 11 are served daily by trolleybuses with increased autonomous running (also known as electric buses with recharging in motion). Bus routes are divided into social and commercial. In 2022, during the implementation of the “New Model of Transport Services”, commercial bus routes (minibuses) were eliminated. At present, bus passenger transportation is carried out by one state transport company (Saint Petersburg State Unitary Enterprise “Passagiravtotrans”) and four private ones. As of 2023, there are 447 urban routes, and the number of rolling stock is more than 4600 buses (mainly large and especially large capacity). The largest share of intercity transportation in Saint Petersburg is carried out by the metro, which has been operating since November 15, 1955. Transportation is carried out on five lines, on which 72 stations are located. There are 7 transfer hubs – 6 two-station and one three-station. 12 stations have transfers to railway infrastructure facilities (train stations, stations, and platforms). The operational length of all lines is 124.8 km.

2.2. Data sources

Our main data sources are the Federal State Statistics Service (“Rosstat”), Open Street Maps, Open Data of Saint Petersburg³, and “Pitertransport”. First, the database of municipalities provided by “Rosstat” contains information about wages, employment, and its structure at the local level from 2017 to 2022. Some time series are available from 2010, but the 2010–2016 and the 2017–2022 datasets are not comparable because of a change in the all-Russian classifier of economic activities. Second, data on road networks and the exact location of buildings were scraped from Open Street Maps, including historical versions of those maps. Third, data on the public transport network was obtained from Open Data of Saint Petersburg. They contain the exact location of every stop that corresponds to every route of tram, bus, and trolleybus in both directions.

³ Open Data of Saint Petersburg is an open data platform developed on the initiative of the Government of Saint Petersburg. It is aimed at providing open access to the data of the state executive authorities of Saint Petersburg, located in various information systems and databases.

Additionally, routes were validated using information provided by “Pitertransport”, a collaborative website where data on changes in the routes of Saint Petersburg public transport is collected. The routes of the Saint Petersburg tramway as of 1916, were elaborated using a historical city plan (appendix to the address and reference book “The Whole Petrograd in 1916”), were validated and clarified by means of the above website.

3. Econometric methodology

The econometric technique presented below is based on (Quinet, Ruiz-Mejia, 2022)’s interpretation of (Combes et al., 2008)’s wage equations.

The specification of the first step is given by:

$$w_{z,k,t} = \delta_{z,t} + \delta_k + \tilde{X}_{z,k,t} \beta_k + \tilde{I}_{z,k,t} \alpha + \zeta_{z,k,t}, \quad (1)$$

where $w_{z,k,t}$ is the average wage in municipality z in industry k at time t , $\delta_{z,t}$ is a municipality-year fixed effect, δ_k is an industry fixed effect, $\tilde{X}_{z,k,t}$ is the centered vector of local characteristics of industry k at time t and $\tilde{I}_{z,k,t}$ is the centered vector of local average time-varying individual characteristics of employees working in industry k at time t .

However, we are not able to select relevant regressors. Thus, we aggregate wages by industries that leads us to $w_{z,t} = \delta_{z,t} + \tilde{X}_{z,t} \beta + \tilde{I}_{z,t} \alpha + \zeta_{z,t}$, where $\zeta_{z,t} = (1 / M_{z,t}) \sum_{k \in (z,t)} \zeta_{z,k,t}$ is the new error term, $M_{z,t}$ denotes the number of industries located in municipality z at time t .

The objective of the second stage is to assess the relative importance of agglomeration externalities, which shape urbanisation economies, and transport endowments or amenities, on our measure for local productivity – i.e. the estimation of the location-specific term of the wage equation (see Equation (1)). The econometric specification of the second stage is

$$\hat{\delta}_{z,t} = \lambda_t + \lambda_c + E_{z,t} \pi_1 + X_{z,t} \pi_2 + Controls_{z,t} + \varepsilon_{z,t}, \quad (2)$$

where λ_t are time fixed effects, λ_c are oblast’/district fixed effects⁴, $E_{z,t}$ is the vector of transport exposure measures, $X_{z,t}$ represents the vector of location specific variables defining agglomeration characteristics, $Controls_{z,t}$ is a vector of productivity-related control variables that are associated with our regressors of interest, and finally $\varepsilon_{z,t}$ is the error term reflecting local shocks assumed to be i.i.d. across spatial units and periods.

We introduce two agglomeration measures: employment density and building density. The first one is the log of employment/area ratio. The latter quantifies the area that the building sits on as a percentage of the total land area.

Our transport exposure measures are reachability index and accessibility to employment. Both are calculated for the two transport modes available – public transport and private vehicle. The former is the average time travel from location z to all others,

$$Reachability\ Index_{z,m,t} = \left(\sum_{j \neq z} d_{jz}(m) \right) / J,$$

where J is the number of municipalities except municipality z , and $d_{jz}(m)$ is the travel time from municipality j to municipality z by mode m at time t . The second measure shows local concentration of jobs taking into account commuting time. It follows the following formula:

$$Accessibility\ to\ Employment_{z,m,t} = \sum_{j \neq z} \left(dens_j / d_{jz}(m) \right),$$

⁴ The municipalities of the federal city of St. Petersburg form city districts, whereas in the case of the Leningrad region there is no such intermediate level of administrative division. Therefore, λ_c denotes the fixed effect of the corresponding district for the municipalities of St. Petersburg, whereas for the municipalities of the Leningrad region λ_c denotes the oblast’ fixed effect.

where $dens_j$ is the employment density in municipality j . This index has been called an index of accessibility (Vickerman et al., 1999), population or market potential (Harris, 1954), effective density (Graham, 2007), or market access (Donaldson, Hornbeck, 2016). The interpretation of this index as measuring market access can be theoretically grounded in trade theory (Donaldson, Hornbeck, 2016; Baum-Snow et al., 2016).

The bulk of literature has opted for infrastructure-type transport exposure measures (e.g. distance to the nearest station, number of stations/lines). For example, publications analyzing road-based transportation improvements have used the local length of roads (Melo et al., 2010; Möller, Zierer, 2018; Rocha et al., 2023), road density (Iacono, Levinson, 2016), whether a spatial unit is crossed by a highway (Chandra, Thompson, 2000; Faber, 2014), the distance to the nearest highway (Ciani et al., 2022), the presence of highway exit in the surroundings (Percoco, 2016), the number of radial roads from a city center (Baum-Snow et al., 2016), or the local public investment on roads (Zhang, Yan, 2022). In publications on public transportation improvements, they use distance to infrastructure (García-López, Holl, Viladecans-Marsal, 2015) or the number of public transportation stations and lines in the local area (García-López, Hémet, Viladecans-Marsal, 2017).

However, in our case, infrastructure-type measures are not applicable due to the short time range during which our data are available, due to the fact that Saint Petersburg transport network is already well-developed, and due to small variations in infrastructure-type measures from one year to the next. Additionally, our choice in favour of accessibility-type measures is motivated by the endogeneity of infrastructure location, whereas its control in the study enables us to compute the accessibility and reachability effects orthogonal to the endogenous presence of infrastructure. Specifically, we control for the distance to the closest station and the distance to the closest highway from each municipality centroid.

A group of controls represented by $Controls_{z,t}$ includes road density, and travel time to the Central Business District (CBD) of Saint Petersburg.

Due to the fact that the true value of the dependent variable of the second stage, $\delta_{z,t}$, is unknown, we use the estimators $\hat{\delta}_{z,t}$ obtained in the first stage. However, if there is any association between our local features of interest, i.e. agglomeration ($X_{z,t}$) and transport exposure measures ($E_{z,t}$), and the average of local skills, which is included in the first stage's error term, these estimators will be biased and inconsistent. Certainly, the larger the spatial aggregation of the data, the more relevant this issue becomes. For example, when cities are used as spatial units, entire cities are confined to a single, unique unit of observation. This raises concerns about unobserved variable bias because variables such as transportation and agglomeration affect the quality of the urban workforce in a consistent and simultaneous manner.

Even if the skill-sorting situation is less troublesome, it can nonetheless occur at the infra-city level. Particularly in large cities, which have a diverse mix of neighborhoods with varying levels of local amenities. As a result, we include oblast' effects for Leningrad oblast' municipalities and district effects for Saint Petersburg municipalities in the estimation of the second stage. We are able to uncover agglomeration and transport exposure effects on local productivity independently of potential employees' sorting at the district level inside Saint Petersburg and at oblast' level for the rest of the metropolitan area using this technique.

We are also aware of the reverse causality between observed transport exposure, agglomeration metrics, and local productivity rates. Employees, particularly those with higher talents, are drawn to denser locations due to better production. Furthermore, transportation infrastructure allocation is not random; the planner may seek to connect dynamic (deficient) areas, biasing the estimates higher (downwards). Because the bias's direction is uncertain, endogeneity becomes a severe problem.

To address this issue, we use the instrumental variables method. We employ instruments popular in the literature: historical levels of agglomeration and transportation exposure, as well as physical-distance-based counterparts of our accessibility and reachability indexes. We use 2013 levels of employment density, 2013 predicted levels of accessibility to employment and local reachability, and the distance from each municipality centroid to the closest 1916 tramway line. In terms of the second set of instruments, we calculate our accessibility to employment and reachability indices using basic straight-line lengths in kilometers. The reasoning is as follows: geographical closeness should not have an independent impact on production since physical proximity does not affect productivity independently; rather, productivity increases are generated by the interaction of economic agents. As a result, without a network connecting the nodes, this interaction would be impossible. We adopt thus as instruments synthetic measures of employment accessibility and reachability that replace trip times with basic physical distances between each pair of nodes.

Our instruments are appropriate because historical levels of agglomeration and transportation exposure are highly correlated with their current counterparts. In addition, the same relations can be observed regarding physical-distance-based measures of accessibility and reachability indexes on the one hand and their transport-based analogues, on the other hand. Moreover, the employed instruments have causal effect on wages only through corresponding endogenous independent variables.

We conduct a density analysis in which we estimate the effects of transport exposure on local employment density in order to obtain a complete picture of transport effects on labour productivity. Certain locations may be more desirable than others due to their exposure to transportation, which could influence job placement selections. Workers might prefer being employed in more connected places where commutings are shorter. Thus, it would be worthwhile to look at how our reachability index affects where jobs are located. We recoup the indirect impact of transportation on productivity through agglomeration and job location by interacting the density coefficient from the productivity analysis with the reachability index coefficient from the density analysis.

Undoubtedly, endogeneity problems occur when estimating the effects of transportation exposure on job density. Because the location of the transportation system is not random, there exists a reverse causality between employment density and transportation exposure, which could skew the estimates either upward or downward. The estimate of transport exposure on density is biased downward if the planner chooses to invest in transportation inside less developed and impoverished areas in order to spur their growth. The estimate is biased higher if the planner chooses to connect dense and dynamic areas more effectively. We use the same approach as in the productivity study to account for this bias. First, we incorporate variables that gauge the existence of actual transportation infrastructure in the area. In this way, the endogeneity of the installation of local infrastructure is controlled. Second, we use an instrumental varia-

bles approach, using a subset of the instruments suggested in the productivity analysis: the physical-distance equivalent of this index, degrees of prior reachability, and other indicators of proximity to historical infrastructure.

4. Results

The results correspond to the estimation of the two-stage econometric specification presented in the previous section, i.e. the estimation of Equations (1) and (2).

Firstly, Table 1 presents the estimation results for Equation (1), i.e. the first stage. The dependent variable is the local average of log wages. The estimated coefficients for the first stage of the estimation have the expected sign, but two of them (out of three) are statistically insignificant, and regression as a whole is statistically significant only at 10%-level. The log manufacture share has a negative but insignificant effect, -0.004 . The log of the proportion in high services is positive but insignificant, with an average effect of 0.004 . The log of the proportion in low services is negative and significant, with an average effect of -0.016 .

The results of the second stage are presented in Table 2. The dependent variable is the estimated municipality-year fixed effect from the first stage. The instrumental variables (IV) estimations in columns (8)–(11) apply the six instruments proposed in this paper, i.e., both past predicted levels of transport exposure measures, the synthetic index for reachability and accessibility to employment, the distance to the closest tramway line in 1916, and road density. In even columns, transport exposure measures for both modes of transport are used, whereas in odd columns (except for column (1), where the only regressor is employment density), only transport exposure measures for private vehicles are used. The motivation behind this is that data on public transportation is available only for three years (2017, 2021, and 2022) out of six in the 2017–2022 period. That fact explains why the number of observations in odd columns is almost halved in comparison with that in even columns. Table 2 also displays the over-identification tests computed by the Sargan method. Their values of between 0.659 and 0.214 allow us to reject the null hypothesis of having at least one endogenous instrument. Therefore, our instruments are valid. The size of the first stage F-statistics displayed

Table 1.
Stage I results: Average local wage (Dependent variable: Local average of log wages)

Variable	Coefficient	St. Deviation
log(manuf share)	-0.004	(0.020)
log(high serv)	0.004	(0.004)
log(low serv)	-0.016^*	(0.007)
Time Effects	Yes	
Municipality Effects	Yes	
Observations	570	
Adjusted R^2	0.201	
F-statistic	2.283	

Note. The constant is included but is not shown, * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 2.

Productivity analysis results

Variable	OLS							IV			
	1	2	3	4	5	6	7	8	9	10	11
Dependent variable: log(municipality year)											
log(emp dens)	0.006*** (0.0003)	0.003** (0.001)	0.003 (0.002)	0.003*** (0.001)	0.003** (0.001)	0.004*** (0.001)	0.004*** (0.001)	-0.002 (0.001)	0.0002 (0.002)	-0.002 (0.001)	0.003 (0.003)
log(access priv)		0.010*** (0.003)	0.013** (0.005)	0.014*** (0.004)	0.019*** (0.006)	-0.004 (0.005)	-0.008 (0.008)	0.031*** (0.005)	0.026*** (0.007)	0.014** (0.006)	0.002 (0.012)
log(duration priv)		0.004 (0.004)	0.001 (0.008)	0.013** (0.005)	0.012 (0.008)	-0.015** (0.007)	-0.022** (0.011)	0.019*** (0.006)	0.015 (0.010)	-0.005 (0.009)	-0.024 (0.016)
log(access pub)			-0.001 (0.002)		-0.0002 (0.001)		-0.0001 (0.001)		-0.006 (0.005)		-0.016* (0.009)
log(duration pub)			0.018** (0.007)		0.008 (0.005)		0.009 (0.006)		-0.009 (0.012)		-0.064** (0.030)
Time effects	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District effects	No	No	No	No	No	Yes	Yes	No	No	Yes	Yes
Observations	570	570	279	570	279	570	279	570	279	570	279
Adjusted R ²	0.368	0.379	0.343	0.610	0.647	0.699	0.717	0.577	0.598	0.667	0.409
Over-identification p-value								0.659	0.521	0.214	0.232
First Stage Statistics for:											
log(emp dens)								517.52	1064.81	153.69	387.21
log(access priv)								805.84	1812.05	818.76	484.93
log(duration priv)								1660.01	1951.32	1886.24	702.01
log(access pub)									19.97		13.70
log(duration pub)									37.94		30.71

Note. The constant is included but is not shown; “*” – $p < 0.1$; “**” – $p < 0.05$; “***” – $p < 0.01$.

in Table 2 allows us to conclude that the instruments are relevant for all endogenous regressors.

From Table 2, we draw several important findings. First, the effect of employment density on local productivity becomes insignificant, and it decreases after instrumenting, which reveals the importance of controlling by the skills-sorting and the reverse causality issues. In general, the agglomeration effect does not directly boost labour productivity in the context of Saint Petersburg, and any positive influence of the former on the latter can be explained by the correlation of firms' quality and/or employees' skills with observed local factors and/or the possible attractiveness of denser areas for highly paid employees.

Second, the statistical significance, sign, and magnitude of transport exposure measures markedly vary across different specifications; we obtain the expected signs of transport exposure measure coefficients in one of our preferred specifications in column 10, but only accessibility to employment by private vehicle is significant. When accessibility to employment by the road network increases by 10%, local productivity

increases by 0.14%. In our second preferred specification in column 11, both transport exposure measures by private vehicles are statistically insignificant at any convenient level, whereas accessibility to employment by the public transport network and reachability by public transport are both significant and have a negative sign. However, it is expected that the sign of the coefficient for accessibility levels should be positive. The soothing aspect is that the reachability effect of public transport is significant only at 10% level.

Third, the absolute magnitude of transport exposure measure by the road network is getting greater after instrumenting. However, the inclusion of district fixed effects leads to a decrease in those coefficients to the level obtained during OLS estimation without district fixed effects. Moreover, the effect of private transportation on labour productivity is getting insignificant with the inclusion of both district fixed effects and public transport exposure measures along with using the IV approach (see column 11 in Table 2) whereas in other specifications, at least one coefficient of private transport exposure measures is statistically significant. It indicates that in the case of exploiting the variation in accessibility within each district, public transportation takes over the positive effect of accessibility by road network on labour productivity, and the latter is of no importance when municipalities with similar unobserved characteristics are compared with each other. Said differently, when exploiting variation in the average accessibility from one municipality to the next along with paying attention only to private transportation, we find a positive effect of the latter on labour productivity. While the introduction of distinct fixed effects together with public transport exposure measures into estimation results in stealing the effect in favour of public transit.

The results from the density analysis are presented in Table 3⁵. The OLS results are displayed in the first six columns, while the IV results are presented in columns 7–11. The same instrumental variables proposed for productivity analysis are used for density analysis, specifically, past predicted levels of transport exposure measures, the synthetic index for reachability and accessibility to employment, the distance to the closest tramway line in 1916, and road density. Additionally, the over-identification p-value calculated using the Sargan approach is shown in Table 3. The p-values are large and the null hypothesis that the overidentifying restrictions are valid cannot be rejected. We may also conclude that the instruments are relevant for all endogenous regressors based on the size of the first stage F-statistics shown in Table 3.

Inspecting the results displayed in Table 3, we find that the magnitude of coefficients for transport exposure measures is getting greater in absolute values when instrumentation techniques are applied and measures for both transport modes are considered (for example, column 4 vs. column 8 or column 6 vs. column 10), while the opposite is true when the effect of private vehicles on employment density is examined in isolation from the one of public transport (for example, column 3 vs. column 7 or column 5 vs. column 9). As in the case of productivity analysis, we observe that public transportation steals the positive effect of accessibility/reachability by private vehicles on the outcome variable. Now it is more pronounced: after instrumenting and the introduction of public transport exposure measures into the estimation, private ones are getting statistically insignificant, despite the fact that their absolute values are increasing. In contrast to productivity analysis, we obtain the expected signs of coeffi-

⁵ The density analysis repeats the productivity analysis, with the exception that in the latter case, at the first stage, the local employment density is used as the left-hand-side variable, not the local wage level.

Table 2.

Density analysis results

Variable	OLS						IV			
	1	2	3	4	5	6	7	8	9	10
Dependent variable: log(municipality year)										
log(duration priv)	0.255 (0.294)	0.082 (0.404)	-0.550* (0.317)	-0.425 (0.441)	-3.155*** (0.754)	-3.332*** (1.089)	-0.475 (0.323)	-2.412 (1.640)	-2.763*** (0.792)	-8.455 (5.316)
log(access priv)	0.778*** (0.067)	0.371*** (0.104)	0.255** (0.114)	0.083 (0.155)	0.313* (0.184)	0.353 (0.261)	0.278** (0.116)	0.127 (0.289)	0.222 (0.194)	1.257 (0.990)
log(duration pub)		-0.553*** (0.164)		-0.499*** (0.165)		-0.383** (0.160)		-3.862* (2.017)		-3.402 (3.224)
log(access pub)		0.331*** (0.046)		0.290*** (0.047)		0.251*** (0.050)		0.706*** (0.185)		0.435*** (0.144)
Time effects	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
District effects	No	No	No	No	Yes	Yes	No	No	Yes	Yes
Observations	570	279	570	279	570	279	570	279	570	279
Adjusted R ²	0.514	0.600	0.552	0.612	0.699	0.714	0.552	0.433	0.699	0.455
Over-identification p-value							0.477	0.445	0.293	0.268
First stage statistics for:										
log(access priv)							3785.54	1578.43	1734.23	683.17
log(duration priv)							5100.81	2029.21	2596.64	1253.90
log(access pub)								30.29		14.15
log(duration pub)								10.19		6.55

Note. The constant is included but is not shown; “*” – $p < 0.1$; “**” – $p < 0.05$; “***” – $p < 0.01$.

coefficients for transport exposure measures (except for reachability levels by private vehicles in columns 1 and 2, but in that case the coefficients are statistically insignificant).

In our preferred specifications (column 9 and column 10), a 10% decrease in the average of optimal travel times by the road network to a particular destination is associated with a 27.6% increase in local employment density (see column 9), while doubling reachability by public transit is coupled with a 43.5% increase in local job density (see column 10). These findings imply that a greater degree of local connectedness has a favourable effect on local employment density. Consequently, employment is lower in more remote places. Since reachability/accessibility levels affect employment density, which in turn affects productivity, these results show that exposure to private vehicles and public transportation has an indirect impact on productivity through employment and its impact on the distribution of employment. We obtain the whole indirect effect of reachability levels on production through the interaction of both effects. But in our case, the effect of employment density on labour productivity is statistically insignificant after the instrumentation technique is applied.

5. Conclusions

In this study, a framework for examining the causes of differences in labour productivity among small-scale geographic units in the Saint Petersburg metropolitan region is developed. Transport exposure measures and agglomeration economies are the two issues we concentrate on. On the one hand, we investigate the positive spatial externalities on productivity caused by economic activity concentration. Conversely, we look into the mechanisms via which transportation affects labour productivity. First, by lowering the interaction cost between economic agents positioned in disparate places, transportation broadens the geographic reach of agglomeration externalities. Additionally, transportation raises the skills and quantity of the local labour force. Indeed, the greater connection of locations with higher levels of education attracts businesses, employees, and more skilled workers and generates greater added value. Indeed, the greater connectivity of locations with higher degrees of transportation exposure attracts businesses and personnel, particularly those with higher skills and added value. Therefore, we consider the effects of transportation exposure on local employment and productivity while estimating the magnitude of agglomeration externalities at the urban scale in this work.

Two continuous accessibility-type indices – the reachability and the employment accessibility index – are used to quantify the exposure to transportation. The reachability index is calculated by averaging the optimal travel times from all possible municipality centroids along the road and public transportation network, while the accessibility to employment index is determined by the weighted sum of inverse optimal travel times, where the weights are measures of employment density at the destination. Both indexes quantify the local and global levels of transport exposure for each area and project improvements in transportation through changes in commuting time.

By implementing and estimating a wage determination model in two stages, we are able to recover the productivity effects of agglomeration and transport initiatives. In the first step, the significance of personnel characteristics and industrial concentration is evaluated in relation to actual productivity disparities between municipalities based on the average local wage. Local agglomeration and local transportation measures are our main variables of interest in the second stage; they explain local productivity variations. Finally, by first estimating the relationship between local employment density and transport exposure measures and then interacting these estimates with those relating to employment density and productivity, we are able to recover the size of the indirect effect of transport exposure on productivity.

We address the reverse causality between agglomeration and transport measures and productivity, as well as the endogeneity of agglomeration and transport exposure measures caused by the exclusion of unobserved local factors. First, we utilise the panel character of our data to address the bias caused by missing variables by including district fixed effects in the productivity effects of agglomeration and transit exposure measures. Second, in order to compensate for the reverse-causality issues, we apply an IV approach, where the instruments are historical levels of agglomeration and transport exposure, the physical distance equivalents of the accessibility and reachability indices, road density, as well as the distance to historical infrastructure, specifically, the distance to the closest tramway line in 1916.

Noteworthy, after applying the instrumentation technique, the agglomeration effect on labour productivity is getting statistically insignificant. Moreover, the IV approach leads to higher coefficient estimates of transport exposure measures; however, in several specifications, their sign and statistical significance are doubtful. We also find that when both measures are considered together, the effect of private transport loses its statistical significance, while the effect of public transport remains significant. The shrinkage of agglomeration effects indicates that the problem of skills-sorting is still a significant issue at the metropolitan level, where highly skilled workers and high-value businesses may be relocating to more accessible and densely populated areas of Saint Petersburg or its surrounding municipalities. Additionally, the underestimation of transport effects indicates that the non-random nature of transport sites is a significant issue, and the findings are consistent with a planner who favours placing transportation infrastructure in more remote places in order to foster its expansion.

In our preferred specification, halving the average of optimal travel times by the public transport is associated with 6.4% increase in labour productivity. Disregarding the effect of public transportation, we find that a 10% increase in accessibility to employment is coupled with a 0.14% increase in labour productivity. Inspecting the results of the density analysis, we reveal that the takeover effect of public transit with regard to accessibility/reachability by road network is more pronounced. The inclusion of public transport exposure measures into estimation leads to higher magnitudes in the absolute values of coefficients for private transport exposure measures, but they are getting statistically insignificant. In our preferred specification, doubling the accessibility to employment by public transit is associated with a 43.5% increase in job density. Being considered in isolation, halving the average of optimal travel times by the road network increases employment density by a factor of 4 (by 276.3%).

In contrast to (Quinet, Ruiz-Mejia, 2022), we find that agglomeration economies are not directly responsible for local productivity disparities, at least in the context of Saint Petersburg agglomeration.

Our paper proposes a general framework to investigate the sources of wage differences across local labour markets. It shows that agglomeration economies and development of transportation infrastructure are intertwined and affect local productivity, while this effect is difficult to be disentangled. As for policy implications of our results, they can be used as a basis for decision-making in the field of urban planning, development of transport infrastructure, motivated by improved transport accessibility and territorial development. Our paper can provide predictions on the potential effect of these factors on local labour productivity. At the same time, the findings can be used outside the Saint Petersburg agglomeration. However, this issue requires further study.

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Влияние агломерации и транспорта на производительность труда в агломерации Санкт-Петербурга⁶

Аннотация. В статье оцениваются масштабы внешних эффектов агломерации, которые отражаются на повышении производительности труда, и учитывается прямое и косвенное воздействие транспортных факторов. Для достижения этой цели мы объединяем данные о средней заработной плате и занятости в регионе с исчерпывающей информацией об общественном транспорте и дорожной сети Санкт-Петербурга, одной из самых густонаселенных агломераций в Европе. Согласно нашим выводам, только транзитные меры воздействия значительно влияют на производительность труда на местном уровне, в то время как влияние экономики агломераций на производительность труда исчезает после применения инструментальных переменных. Кроме того, мы выявили, что включение в оценку показателей воздействия общественного транспорта приводит к тому, что положительное влияние на производительность труда снижается за счет использования частных видов транспорта в пользу общественного транспорта.

Ключевые слова: экономика агломераций, транспортная доступность, плотность рабочих мест, общественный транспорт, дорожная сеть.

Классификация JEL: C23, C26, R10, R40.

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