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On track towards improved regional development? – Impacts of the Svealand rail line on labour earnings in the Mälaren region

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This paper studies the impacts on productivity following an investment in regional high-speed rail in the Mälaren region in Sweden. It uses wage earnings as a measure of productivity and proposes to capture agglomeration effects by measuring changes in effective labour force density induced by the transport improvement across municipalities in the region. This change in effective labour force density is then used as a continuous measure of treatment, in order to estimate the effect of the Svealand line introduction on labour earnings. While the transport improvement had a large impact on the connectivity and commuting patterns in affected municipalities, we find estimates of wage elasticities with respect to agglomeration that are in line with or smaller than average values from previous literature. The productivity effects, estimated over a ten-year time period, are shown to be rather modest and concentrated to the regions whose connectivity to the greater Stockholm area was directly affected. We also find that the main results do not materialize when a much shorter time period is used for analysis, indicating that a rather long adjustment time needs to occur before any effects can be seen.

Keywords: *Agglomeration, Ex-post appraisal, High-speed rail, Infrastructure, Investment, Regional Development.*

1. Introduction

An increased standard of living is pursued by the majority of the world's economies and despite some dispute as to the suitability of GDP as a welfare indicator, economic growth in terms of the percentage change in GDP (or GDP per capita) has become the universal measure of how strong and successful an economy is. In times of economic challenges including high unemployment (especially in some groups and regions) and reduced growth in Europe, it is not surprising that policy makers and academics have increased their interest in the causes of long-term economic development. The question of the causes of economic growth has been a part of economic research all since the days of Adam Smith (1976 [1776]) but experienced a surge after the influential work of Robert Solow (1956) and T.W. Swan (1956), who explained differences in GDP per capita with differences in capital per unit of labour. Early work on economic growth treated factor productivity as exogenously determined; its development over time, sometimes referred to as technological

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development, was seen as a black box. Since increases in productivity must be the cause of long-term increases in production capacity of an economy, such as approach is unsatisfactory for policy purposes as well as from a theoretical perspective.

It is often argued that investments in transport infrastructure, alongside investments in R&D and human capital, are a crucial prerequisite for, and cause of, economic growth. Although not a new claim (see e.g. Fogel, 1964), the period of heightened focus on the role of public capital, of which transport infrastructure is a substantial part, as a generator of economic growth was triggered by the work of Aschauer (1989), which found that the elasticity of production with respect to public capital (including transport infrastructure, public buildings such as schools, and sewer systems) was 0.24. This is to say that a one percent increase in public capital would cause production (i.e. GDP) to increase by 0.24 percent. Although this and subsequent similar work was criticized for the methods employed and for the results being unrealistically high, it unquestionably gave rise to a huge interest in macro oriented studies of the connections between investments in public capital and economic growth (see Melo et al. (2013), Elburz et al. (2017) and Holmgren and Merkel (2017) for an overview of previous studies). An issue with macro-level studies on high aggregates is that they have typically paid insufficient attention to the question of causality. It is quite possible that increased economic activity gives rise to increased demands on the transport system, resulting in new investments to address capacity problems. Countries and regions with higher production and income are better able to afford a higher level of infrastructure, which is likely to result in high correlations between GDP and the level of infrastructure (Berechman, 2002; Jansson, 1993).

A modern strand of infrastructure appraisal literature has tended to focus on agglomeration as a causal channel for induced growth impacts following transport improvements (Venables, 2007; Graham, 2007). It is generally seen as an established fact that urban agglomeration positively affects productivity, although the magnitude of reported elasticities (productivity with respect to city population size) varies (Melo et al., 2009). Given the existence of positive agglomeration externalities, transport investments can potentially bring about external benefits through inducing changes in the effective density of labour markets, meaning the number of workers accessible to firms in an industry. An increasing number of studies try to link accessibility to increased production and/or productivity, but in many cases this is done by studying differences in productivity between areas with different degrees of agglomeration (e.g. city size, labour force density). Since differences in agglomeration imply differences in accessibility, results from such studies are then used to infer effects of improved infrastructure without explicitly studying effects of infrastructure improvements. Results from such studies might be misleading when it comes to understanding the effects of infrastructure improvements and it is therefore promising to see an increasing number of empirical studies attempting to exploit actual variation in accessibility through changes in transport networks (Ahlfeldt and Feddersen, 2018; Holl, 2011; Chen and Hall, 2012; Graham and Van Dender, 2011; Tveter, 2017). Several such studies look to estimate the effects of investments in high-speed rail specifically (Ahlfeldt and Feddersen, 2018; Chen and Hall, 2012; Graham and Melo 2011). Due to the relative lack of empirical research using actual changes in the transport network to investigate the effects of improved infrastructure on productivity, this is an issue that would benefit from further attention and empirical evidence. In addition, it is also likely that contextual factors, such as geography, demography and the affected transport mode, will affect the outcome of an investment. The purpose of this paper is to study the effects on productivity of an investment in regional railway infrastructure. We focus specifically on the Svealand line in Sweden.

Providing a natural experiment of labour market widening through connectivity improvements, the study aims to add to our understanding of the effects of investing in transport infrastructure. The construction of the rail line in question had the expressed purpose to strengthen the economy of the municipalities along its path and to spread economic growth in the Stockholm region into neighbouring areas in the Mälaren valley (Fröidh, 2003). It is therefore interesting to see to what extent these hopes have been realized. The question of ex-post effects is also interesting in the wake of current debates in Sweden regarding whether or not a high-speed rail network connecting the three major cities Stockholm – Gothenburg – Malmö at speeds of up to 320 km/h should be constructed. The project has been estimated to be socio-economically unprofitable, with a ratio of net present benefits to investment cost of -0.6 (Swedish Transport Administration, 2016), yet claims are frequently being made that the standard cost-benefit methodology excludes important benefits. Despite there being differences between a regional high-speed line primarily intended for commuting and an inter-city high-speed line, this paper adds to the understanding of the issue, and finds that, to the extent that such benefits exist, they are most likely very limited in magnitude.

The paper is structured as follows. Section 2 provides details about the Svealand rail line, which is our empirical case. Section 3 briefly reviews the theoretical underpinnings of our research, as well as the relevant previous literature. Section 4 outlines the empirical strategy of the paper and section 5 provides and explains our estimation results. Finally, section 6 summarizes the conclusions of the paper.

2. The empirical case

The Svealand line is a 115-kilometre-long railway running from Valskog to Södertälje, connecting six municipalities. At the time of construction, these municipalities together comprised some roughly 180 000 residents. Most of the line is single-track, though it has some double-track sections. At its western end it connects to the track between Örebro and Västerås and one of the main purposes of the investment was to reduce travel time to Stockholm (the capital city of Sweden) to which Södertälje, at the other end, is connected through the main line. Figure 1 shows a map of the area and the track.

Figure 1. Location of the Svealand rail line (solid). Plotted localities (from left: Arboga, Kungsör, Eskilstuna, Strängnäs, Åkers styckbruk, Nykvarn, Södertälje, Stockholm) scaled by natural log of population size. Dashed line shows connecting transit line to Stockholm. Source: Own elaboration.

The Svealand line is interesting because it constitutes an example of a regional high-speed rail service specifically designed to serve regional markets, contrasted with dedicated inter-city connections that can also be used for regional travel (Fröidh, 2005). An objective of the service was to improve the possibilities for frequent commuting in the Stockholm – Mälaren region, effectively extending and evening out imbalances in labour and housing markets.

The decision to build the Svealand line was made in September 1991 and the project was financed by the state and a company owned by the municipalities Eskilstuna, Kungsör, Strängnäs, Södertälje, the County of Södermanland as well as the public transport authority in Södermanland. It replaced a late 19th century railway system in the region and the construction meant a considerable reduction in travel time to the capital as well as between the municipalities. Table 1 shows the reduction of total (walking, waiting and in-vehicle) travel times to Stockholm for the two most populous municipalities whose travel time was affected. These estimates were made by Fröidh (2003) and represent the travel time for 'typical' journeys between Eskilstuna/Strängnäs and central areas in Stockholm, assuming 5 minutes walking time to a transit station and 5 minutes waiting time at the station. The travel times for driving between Eskilstuna and Stockholm are calculated without the inclusion of the motorway section of the E20, which was opened after services on the Svealand line began and would have shortened driving times by around 5 minutes. It is notable that the total rail transit time between Eskilstuna/Stockholm and Strängnäs/Stockholm are identical, even though the in-vehicle commute is shorter for Strängnäs commuters. This is because slightly different end points in Stockholm were assumed. For a fixed end point, Strängäs is 'closer' in terms of travel time. Estimated driving times include only in-vehicle time and were computed by Fröidh (2003) to take account of possible traffic jams.

Table 1. Travel times (city to city) before and after Svealand line introduction

Station	Transit time to Stockholm before (Fröidh, 2003)	Transit time to Stockholm after (Fröidh, 2003)	Travel time to Stockholm by car (Fröidh, 2003)
Eskilstuna	2h 30min	1h 20min	1h 40min
Strängnäs	2h 00min	1h 20min	1h 25min

The line opened for service in June 1997 and had a large impact on regional commuting. Four years after introduction, in 2001, the number of trips made on the new tracks was four times higher than it had been during 1994-1997, and seven times higher than prior to 1994. The market share of trips to Stockholm by rail increased from 6 to 30 percent (Fröidh, 2003). Despite high monthly ticket prices compared to other regional rail systems elsewhere in the country, the travelling time reductions enabled by the Svealand line led to high passenger volumes and a profitable operation (Fröidh, 2005).

The effect of the line introduction can also be seen from the growth in the number of residents living in one of the aforementioned municipalities but working elsewhere, i.e. the number of outbound commuters. This is shown in Figure 2, which shows the rapid increase in outbound commuters during the years following the line's introduction. There is a clearly noticeable increase in the number of outbound commuters starting at the time of the opening. This strong growth of commuter travel persisted for the entire ten-year period following opening. Figure 2 also shows the number of commuters in the years prior to the opening of the Svealand line, illustrating that the rapid growth of outbound commuter travel did not start until 1997.

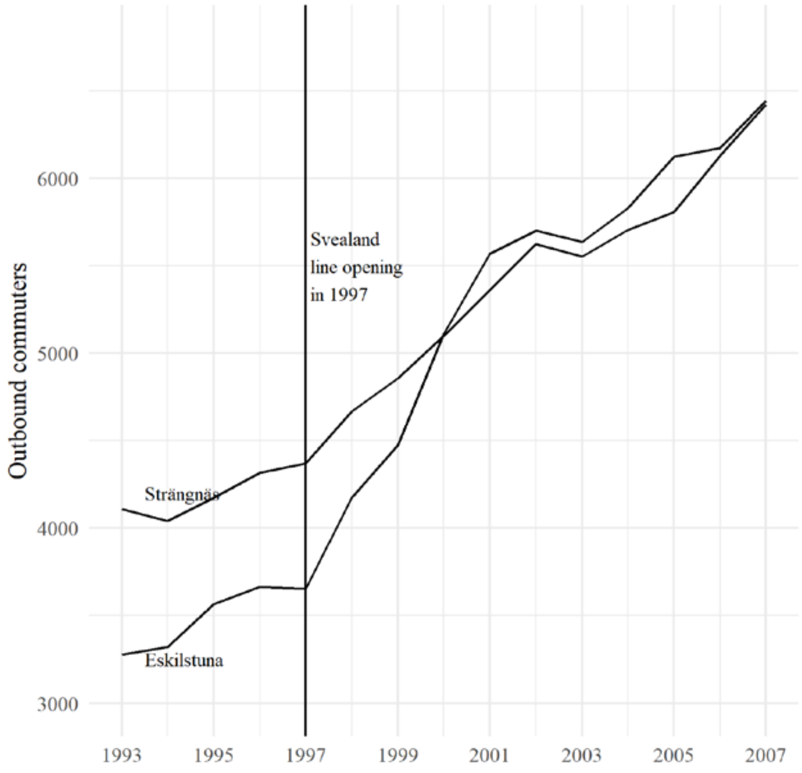

Figure 2. Number of outbound commuters (defined as residents working in another municipality) in Eskilstuna and Strängnäs, before and after the introduction of the Svealand line. Source: Own elaboration of Statistics Sweden (2018).

Evaluating the labour market impacts of the opening of the Svealand line is not a trivial task. We present our methodology for doing this in section 4. In order to first get a sense of the development in the region, Table 2 details the development of median wages (converted to 2018 prices using CPI) for the municipalities located along the Svealand line.

Table 2. Median wages (for population aged 20-64) in municipalities along the Svealand line. (Statistics Sweden, 2018)

Municipality	Median wage 1996 (2018 SEK)	Median wage 2006 (2018 SEK)	Change in percent
Nykvarn	236 205	309 350	30.97
Södertälje	212 318	260 353	22.62
Eskilstuna	200 002	257 696	28.85
Strängnäs	211 035	275 954	30.76
Kungsör	212 318	269 714	27.03
Arboga	209 785	261 625	24.71
Södermanland / Västmanland average	**207 763**	**261 393**	**25.81**

The final row shows the average development in the two counties where the municipalities are located. It is clear that some regions, including those which could be hypothesized to be most affected by the development of the regional high-speed rail line (Nykvarn, Eskilstuna and Strängnäs) have outperformed the region overall in terms of median wage growth. Others (Södertälje and Arboga) have underperformed in terms of median wage growth. While this information is contextually important for the rest of the paper, it is not possible to draw any conclusions since in order to determine what wage growth can be attributed to the improved accessibility caused by the Svealand line, a proper analysis must be conducted wherein other factors affecting wage rate development are controlled. This is the focus of the remainder of the paper.

3. Theoretical underpinnings and previous research

An investment in transport infrastructure will potentially have several different socio-economic impacts. If we assume that the investment reduces the generalized cost of traveling between two places (A and B) for at least some people without increasing the generalized cost of travel for anyone else such that the cost reduction is offset, we can call it an improvement of the transport network. Whether or not this improvement of the transport network brings about socio-economic net benefits is ultimately a matter of weighing the value of generalized cost reductions against the total cost of the improvement. Using our example of an improvement of an existing railway, the first and most obvious effect is that the people using the railway, regularly (mostly commuters) or irregularly, before the improvement will be better off after the improvement is made (though they might experience discomfort and problems during the construction phase). In addition, some people who before the investment were using other modes of transport to travel between A and B will find that using the railway will now lower their travel costs and therefore switch to train. Some of these individuals will use this reduction in generalized cost to increase their leisure time and some might use (at least part of) it to work more resulting in increased production. Furthermore, some people that previously were not working at all or working close to home might now find it profitable to commute by train and take a job further from home. In the longer run, firms and households might relocate as they realize that size of the market and/or labour market has changed (Nash and Laird, 2009). All of these effects can be observed as changes in traffic volumes in the primary market (the rail market in our example) and if all (relevant) other markets are well functioning, the value of the improvement can be easily estimated (Mohring and Williamson, 1969; Jara-Diaz, 1986; Mohring, 1993). Under such an assumption, cost-benefit analysis of a transport improvement is a relatively simple task, though the presence of distorted secondary markets potentially makes appraisal more difficult. While the term 'wider impacts' in principle refers to any welfare change not captured by the conventional consumer surplus, the vast majority of recent literature on additional impacts has focused on effects arising from labour market distortions.

Duranton and Puga (2004) classify the microeconomic mechanisms connecting improved transport infrastructure and increased productivity as sharing, matching and learning. Sharing effects occur when firms to a greater extent are able to utilize existing facilities and thereby spread fixed costs over a larger production volume. Matching effects can be seen when the labour market increases in size so that firms can employ labour that are better qualified for the job they are hired to do and people find it easier to find jobs suitable for their skills. Learning effects refer to the situation where proximity, physical or through low transport costs, makes it possible to share information, and knowledge as well as transfer skills between workers. These effects are often referred to as agglomeration effects. Previous empirical studies of productivity effects induced by transport improvements find estimates of agglomeration (or similarly defined measures of density) elasticities range from 0.007 (Isacsson et al., 2015) to 0.2 (Montolio and Solé-Ollé, 2009), with other contributions falling somewhere in between (e.g. Graham et al., 2009; Ahlfeldt and Feddersen, 2018; Holl, 2011; Börjesson et al., 2019). The interpretation of an agglomeration elasticity is the percentage change in productivity following a 1 percent increase in labour force density or city size. A recent large study of Norwegian transport improvements, a context reasonably similar to that of this paper, finds effect sizes in the region of 0.03 (Tveter, 2018). In a large review, Melo et al. (2009) find that the empirical elasticities reported in 34 studies (though these do not necessarily study changes to transport networks directly) exhibit a 5:th and 95:th percentile range of [-0.09 – 0.292], with an average of 0.058. Several of the aforementioned studies use a wage earnings model derived from a production function to estimate effects of agglomeration on productivity. The justification for this approach is that when the labour market is competitive, the input factor price (wage rate) represents the value of the marginal product. It is, however, likely problematic to assume that there should be a one-to-one relationship between wages and productivity. The approach used in this paper regresses changes in wage rates on changes in travel time accessibility, holding constant a series of regressors that also influence the structure and changes of local wage rates. This is in order to isolate wage rate changes attributable to better transport connections, and to give a plausible identification of agglomeration effects.

The relationship between agglomeration effects and the conventional consumer surplus is not entirely straightforward. As shown by Eliasson and Fosgerau (2019), a transport improvement that leads to improved workers-to-jobs accessibility and a denser labour market will tend to give rise to agglomeration benefits, though not all of these are external to workers' decision of whether or not to take a commuting job. In particular, the matching effect is partly internal; the (after-tax) wage increase earned by a worker who chooses to commute to a job for which she is better matched has already been taken into account. The implication is that adding the entire change in output arising from agglomeration effects leads to double-counting, since part of the matching effect is already captured by the consumer surplus. For different simulated transport cost reductions of 10 percent, Eliasson and Fosgerau (2019) find that the ratio of wider benefits attributable to a matching effect to the value of the change in consumer surplus ranges from 1 percent to 27 percent. Graham and Gibbons (2019) interestingly disagree with the proposition made by Eliasson and Fosgerau (2019) that all (after-tax) matching effects are internal to workers and thereby captured by the standard consumer surplus. Their argument is that the increased quality of matching that goes along with an effective increase of city size involves an externality. In any case, in this and most similar studies, it is not possible to disentangle effects of matching from sharing and learning (pure spillovers), and it is therefore important to stress that this paper cannot and does not aim to provide policy makers with 'wider impacts' parameters to be used in appraisal. Instead, we are interested in whether and to what extent the introduction of the regional high-speed rail line in question led to any effects of agglomeration, which could have implications for regional economic policy.

4. Empirical strategy

The objective is to estimate the effect of a new regional high-speed rail line, which was completed in 1997, on municipality wage levels (used as a measure of productivity). Our approach to measuring effects of the transport improvement is through changes in the effective densities of municipalities. We begin from a baseline empirical model:

$$ln\, W_{it} = \delta_0 + \delta_1 ln\, D_{it} + \boldsymbol{g}_t\boldsymbol{\theta} + c_i + \varepsilon_{it} \quad (1)$$

Here, W_{it} represents the average wage rate in municipality i at time t. The conditional average wage rate of all municipalities in the dataset is captured by δ_0. D_{it} is a measure of density, $\boldsymbol{g_t}$ is a vector of time-specific dummies, c_i are unobserved time-invariant municipality (fixed) effects and ε_{it} is a random error term. There are a number of problems that need to be addressed, the most important of which is the potential endogeneity of effective density. Changes in effective density are typically composed of a variety of sources: settlement patterns, industry localization as well as actual changes to accessibility. In evaluating the effect on productivity of transport infrastructure improvements, it is crucial to adopt a measure that isolates the effect of accessibility changes (Graham & Van Dender, 2010).

The empirical strategy employed in this paper exploits variation in commuting times enabled through the new rail line by constructing an effective density measure expressed as market potential, a method originating from Harris (1954) and frequently employed in similar contexts (Ahlfeldt and Feddersen, 2018; Hanson, 2005; Isacsson et al., 2015). Expressed in this way, effective density is a metric of a site's access to markets using a distance or transport cost weighted sum of other areas' purchasing power or labour supply. Crucial to the construction of such a measure is the function by which weights decline with distance (see e.g. Graham et al. (2009) for an extensive treatment of the issue). This study considers three different variants: a simple inverse weighting scheme in which the decay parameter is set to 1 (Eq. 2), as well as an exponential (Eq. 3) and a logistic (Eq. 4) distance decay function with parameters to be estimated:

$$D_{it} = \sum_j L_{jt} E_{ij,t}^{-1} \quad (2)$$

$$D_{it} = \sum_j L_{jt} e^{-\alpha E_{ij,t}} \quad (3)$$

$$D_{it} = \sum_j \frac{L_{jt}}{\left[1+e^{-\alpha E_{ij,t}}\right]} \quad (4)$$

The effective density (D) of municipality i at time t is a sum of j adjacent regions' labour supply (L) weighted by the effective distance (E) between the municipalities. The parameter α indicates the rate of spatial decay.

In order to approximate effective distance, the simplifying assumption is made that commuter times are a valid representation of transport costs, and that commuters choose time-minimizing routes. For each municipality pair, the shortest attainable commuting time using either car or public transport was recorded in two least-time commuting matrices, including all municipalities as origins and destinations within the counties Stockholm, Södermanland, Uppland, Västmanland, Östergötland and Örebro.[3] Rather than assuming costless transport within municipalities, the own-pair effective distances (*ji*=*ii*) are measured by internal driving distances, calculated as the radius of a municipality. Municipalities are assumed circular, for ease of computation. Data extracted from Google Maps was used to determine driving and public transport travel times between every pair of municipality main bus/railway stations during the hours of morning commute for a fixed day.

Pre- and post-treatment transport time matrices were computed, where the pre-treatment time values ignored any time-minimizing public transport route solutions using the rail line in question:

$$PreTreatmentTT_{ij} = \min\left(CarTT_{ij}, PublicTT_{ij}^{1996}\right) \quad (5)$$

$$PostTreatmentTT_{ij} = \min\left(CarTT_{ij}, PublicTT_{ij}^{2006}\right) \quad (6)$$

[3] The rail line runs through stops located in only Stockholm, Södermanland and Västmanland. Uppland is included because it is usually classified to belong to the same larger region, the Mälaren valley. In addition, it provides a number of municipalities with desirable control group properties, as they are at a similar commuting distance from Stockholm compared to the treated municipalities. Örebro and Östergötland are adjacent to the regional and provide additions to the control group.

Using these empirical values of effective distance, the impact of effective density changes due to improved access through the new rail line was estimated by employing a differenced form of Eq. 1, where effective density change takes the form of a continuous treatment variable. We use long differences and estimate the effect over a 10-year time span where the first period is the year prior to intervention (alternative end years are investigated in the following section). The exponentially weighted variant of the differenced equation is:

$$\ln\left(W_{i,t=2006}\right) - \ln\left(W_{i,t=1996}\right) = \beta_0 + \beta_1\left[\ln \sum_j L_{j,t=1996} e^{\left[-\beta_2 PostTreatmentTT_{ij}\right]} - \ln \sum_j L_{j,t=1996} e^{\left[-\beta_2 PreTreatmentTT_{ij}\right]}\right] + \beta_3 X_1 + \beta_4 X_2 + \mathbf{X_3}\boldsymbol{\beta} + \Delta\varepsilon_{i,t} \quad (7)$$

Where $W_{i,t}$ again represents the average wage rate in municipality *i* at time *t*. β_0 captures the overall increase in wages during the period. Since only two time periods are included and the model is estimated in first-differenced form, the time-specific dummy variables ($\boldsymbol{g}_t$ in eq. 1) fall out of the equation and are replaced by a common intercept term. The term c_i is dropped from the equation since first-differencing the equation nets out any time-invariant municipality effects. The average difference between the two time periods is instead captured by the intercept parameter. Note that the labour supply variable *L*, approximated as the number of residents between the ages of 20 and 64, is held fixed at the pre-treatment period level. Such an approach gives an estimate of the impact of changes in effective density on wages that is purely driven by travel time reductions contained in the effective distance matrices. In effect, changes in effective density arising from changes in employment levels are filtered out. In addition, three control variables (X_1-X_3) are added to the estimating equation. These are described in the following paragraph. Equation (7) and the logistically weighted variant of the same model are estimated in two steps: first using non-linear least squares (NLS) in order to determine the distance decay parameter β_2. Next, the estimated decay parameter is held fixed and the equation is estimated by OLS in order to obtain robust standard errors.

A potential issue in estimation is heterogeneity in the composition of worker skills among municipalities, and changes in the composition of worker skills within municipalities over the observed period. The first part of the issue is met by taking differences, removing time-invariant unobserved differences from the equation (Wooldridge, 2010). The second part is potentially more serious. When measuring actual productivity change, one would ideally like to observe constant-skill workers in pre- and post-treatment periods (Hanson, 2005). To control for changes in the composition of skills affecting the average municipality wage rate, the proportion of residents with a (3+ years) university degree is included as a control (X_1 in eq. 7). An additional issue is the possibility that unobserved regional factors, rather than any effect of treatment, is the cause of differential wage growth in treated and untreated municipalities. If not properly investigated, it is possible that such a scenario leads to confounding the effects of treatment with wage growth persistence. This is especially relevant if treatment cannot be considered randomly assigned with respect to potential outcomes. In order to deal with this, we introduce a pre-trend variable as a second control (X_2 in eq. 7). This variable is the log difference in average wages per municipality between 1991 and 1995. Finally, in order to control for the varying industrial structure of municipalities, a set of control variables corresponding to the share of employment working in different categories of industry are included (represented by the matrix $\boldsymbol{X_3}$ in eq. 7). These variables correspond to the 1996 share of labour in manufacturing, communications, financial services, research and education and health care for each municipality, as well as the changes in each category between the pre- and post-treatment period.

Another issue that needs to be mentioned is that while the analysis focuses solely on the travel time improvement caused by the opening of the Svealand line, several other changes to the transport system happened during the period of analysis. This includes the construction of a motorway section of the E20 connecting Strängnäs and Eskilstuna, which was opened in 2004. Another example is the improvement of the Mälar rail line north of lake Mälaren, connecting Arboga to Stockholm via Västerås. The Mälar line was improved around the same time as the construction of the Svealand line. Clearly, these changes improved accessibility in the region and there is a risk that the observed effects of improved access through the Svealand line could be confounded with the effects of other investments. We deal with this problem by studying the isolated impact of the Svealand line, meaning that we model the transport system *as it currently operates* (i.e. including these additional improvements) with and without the availability of the Svealand line. This means that we compute the shortest travel time (using either car or public transit) between any pair of municipalities using data extracted from Google Maps and manually censor any shortest travel time achieved by using the Svealand line in order to construct the pre-treatment time-minimizing transport network. This method is not impervious to bias: if there have been changes to the transport system during the same period that disproportionately improved the accessibility of the municipalities whose accessibility was also improved by the Svealand line, there is a risk that our method slightly overestimates the productivity effects attributable to the Svealand line. We return to this issue in the discussion of our results.

5. Results

A visualization of the difference in overall accessibility for treated municipalities is shown in Figure 3. The municipalities that are categorized as treated in the graph are those whose main railway station is serviced by the constructed rail line: Eskilstuna, Strängnäs, Kungsör, Arboga, Nykvarn and Södertälje. Strictly speaking, there are other municipalities that are also subject to treatment, in the sense that they experience a small change in effective density due to these principally treated regions coming 'closer'. The size of the effect is however considerably larger for the municipalities located along the rail line. Figure 3 shows that the average minimized travel time to all destinations within the Mälaren valley region from these municipalities decreased only slightly, from 74.5 to 73.5 minutes. This unweighted average does however not reflect the commuting patterns of the treated municipalities. The average travel time reduction from treated municipalities to Stockholm, which is effectively the region's central business district, was roughly 7.5 minutes. The most sizeable reductions in Stockholm commuting times were to/from Strängnäs and Eskilstuna, which were respectively shortened by 11 and 18 minutes.

Estimation of Eq. (7) in the ways detailed in the previous section yielded the results presented in Table 3. The NLS estimates of spatial decay are 0.055 for the exponentially weighted effective density function and 0.062 for the logistic function. Despite this slight difference, the estimated wage elasticity with respect to effective density is very similar for both models: roughly 0.06. The inversely weighted effective density elasticity is significantly larger, with an estimate of 0.173. The estimated elasticities with respect to effective density are all significant at the 1 % threshold, with heteroskedasticy-robust standard errors corrected for sample size (MacKinnon & White, 1985).

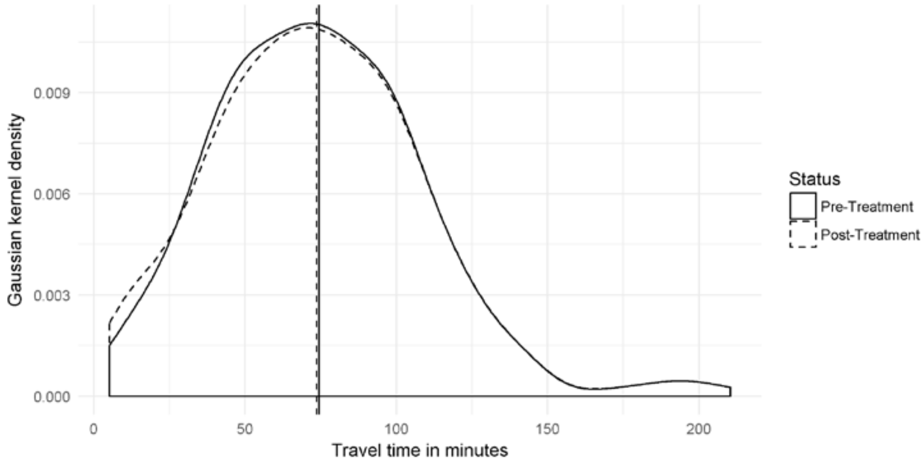

Figure 3. Minimized travel time distributions within the Mälaren valley region for treated municipalities. Vertical line: unweighted averages pre- and post opening. Source: Own elaboration.

The elasticity of effective density with respect to wage levels is not directly comparable with estimates of labour force density's effect on wages (since a percentage point's increase in effective density is equivalent to a larger increase in 'regular' density, the elasticity of market size is usually larger than the expected elasticity of agglomeration). Ahlfeldt and Feddersen (2018) suggest that this estimate can be made comparable by scaling the coefficient by the log ratio of standard deviations (effective density over actual labour force density). Normalized accordingly, the elasticity of density from model 1 is 0.0523 and the elasticities from models 2 and 3 are 0.0126 and 0.0128 respectively. It is notable that fixing the decay parameter to 1 and using inverse weights yields a result (5.2 %) very close to most derived elasticities of productivity with regard to labour market density found in the relevant literature (Ciccone, 2002; Melo and Graham, 2009). Using empirical estimates of spatial decay however yields parameters that are significantly smaller, in the region of 1 %. It can also be noted that the R-squared values from all three model specifications are almost identical. This is because most of the variation in municipality wage growth rates is explained by growth in previous years (pre-trend control), proportion of residents with a degree (skills control) and sector-wise employment (industrial structure control). While effective density demonstrably affects expected wage growth rates, the differences in how density is weighted only contribute very marginally to the coefficient of determination.

Table 3. Results of effective density parameter estimation for the time period 1996-2006. Spatial decay parameters estimated with NLS and robust standard errors obtained from OLS regressions, holding spatial decay fixed.

	Inverse	Exponential	Logistic
Effective density (β_1)	0.173***	0.064***	0.063***
	(0.063)	(0.021)	(0.022)
Spatial decay (β_2)		0.055	0.062*
		(0.036)	(0.035)
Estimation method	OLS	NLS	NLS
Skills control	√	√	√
Pre-trend control	√	√	√
Industry structure controls	√	√	√
R^2	0.704	0.705	0.704
Adj. R^2	0.641	0.642	0.641
Num. obs.	75	75	75

Note: ***,**,* represent statistical significance at the 1, 5 and 10 % levels.

Table 4 illustrates results from estimating the exact same model but with differing end years. The estimated wage elasticities with respect to market size exhibit a range of [0.036 – 0.173], implying a normalized density parameter range of [0.0071 – 0.0523]. While all parameters have the expected sign and are within a rather close range, the estimates from end years 2003 and 2004 are not statistically significant. This means that no effect of the transport improvement on 7 or 8-year wage growth can be robustly discerned.

Table 4. Exploration of effective density parameter estimates for different end years

End year	Inverse	Exponential	Logistic
2003	0.085	0.037	0.036
	(0.069)	(0.028)	(0.027)
2004	0.1	0.041	0.040
	(0.073)	(0.027)	(0.026)
2005	0.124*	0.048**	0.047**
	(0.069)	(0.023)	(0.023)
2006	0.173***	0.064***	0.063***
	(0.063)	(0.021)	(0.022)
2007	0.156**	0.058**	0.058**
	(0.073)	(0.025)	(0.026)

Note: ***,**,* represent statistical significance at the 1, 5 and 10 % levels.

Figure 4 shows a visualization of the empirical spatial decay functions from Table 3. The most conservative wage elasticity with respect to effective density, 0.063, implies that a doubling of a municipality's effective density yields an increase in wages of 6.5 %.[4] For the exponential decay function, the strength of regional spillover effects decreases by 6.4 % for every extra minute of commuting time separating the regions. The implied half-life travel times are roughly 12 minutes for the exponential function and 17 minutes for the logistic function. After 60 minutes, the spillover effects are very close to zero.

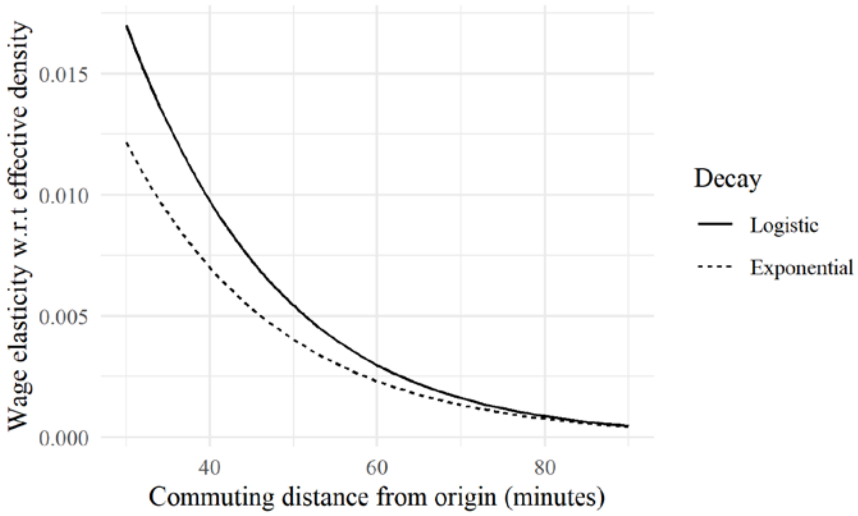

Figure 4: Estimated spatial decay functions in the interval 30-90 minutes of commuting time. Source: Own elaboration.

[4] $0.065 = e^{0.063} - 1$

From the empirical models estimated, it is possible to trace the predicted effects for each individual municipality whose effective density was improved by the opening of the Svealand line. These figures are shown in Table 5 for the directly affected municipalities along the rail line. It should be stressed that the predicted effects are based on fitted values obtained from the exponentially weighted empirical model and are subject to uncertainty. The point of illustrating them is to highlight the modelled distribution of expected effects rather than to report precise evidence of wage effects at the municipality level. It is interesting to see that the largest modelled effect is found not for the largest municipality, which is Eskilstuna, but for its neighbour Strängnäs. The reason is simply that Strängnäs benefited from shorted travel times not only to Södertälje and the greater Stockholm area, but also to Eskilstuna. Figure 1 shows how the introduction of the line would give Strängnäs improved accessibility to larger labour markets in both directions. Predicted effects on wage levels in indirectly affected municipalities range from 0.01 % (Stockholm) to 0.03 % (Huddinge), but the effects are so small that they are very unlikely to be significantly different from zero. The overall predicted effect on wages for all the municipalities located along the Svealand line was 0.98 % over the ten-year time period measured. Since not all municipalities were affected in the same way, and there could be argued to be a set of 'core' stations along the Svealand line whose commuting access was particularly improved, we also calculate a predicted wage increase for the collection of municipalities (Eskilstuna, Strängnäs and Nykvarn) whose effective density was most increased by the Svealand line. This shows that the predicted wage effect for these municipalities was 1.63 percent, highlighting some important differences in how the various municipalities along the line were affected.

To put the overall predicted effect into perspective, the construction cost (in 1997 SEK) of the line was 2.3 billion SEK (Fröidh, 2003). A rough calculation shows that the estimated benefits in the form of increased wage earnings in directly affected municipalities amounts to some 6.2 % of this investment cost. This figure is found by first calculating the net present value of wage increases, which is done in the following way. The population aged 20 to 64 in each municipality is multiplied by the labour force participation rate in each municipalities' respective county (0.764 for Södermanlands län, which includes Södertälje, Nykvarn, Strängnäs and Eskilstuna, and 0.761 for Västmanlands län, which includes Kungsör and Arboga).[5] The resulting number of labour force participants is shown in the second column of Table 6. This, multiplied by the median wage and the percentual predicted wage increase (shown in the final column of Table 5) over a ten-year period, gives the total value of wage increases attributable to improved accessibility, shown in column 3 of Table 6. This figure is 210 million SEK, when all municipalities in Table 5 are added together. Note that this reflects the total value of the wage increase that is measured over a period of ten years (1996-2006, the main period of analysis presented in Table 2) and not an annual benefit.[6] Assuming for simplicity that timing of the wage increase were to be evenly spread out across the years 1997-2006, the present value of the total wage increase in 2018 can then be calculated as:

$$PV_W = \sum_{t=1997}^{2006} \frac{\Delta W}{10} * (1+r)^{2018-t} \quad (8)$$

[5] While it proved difficult to find labour force participation data at the municipality level, for the correct age intervals and for the year of investment, we used the closest relevant published labour force participation figures, which reflect the percentage of people in the age group 16-64 that is classified as belonging to the labour force in each county for the year 2001 (Statistics Sweden, 2001).

[6] It is possible that the improved accessibility provides positive agglomeration effects further into the future, which should then also be considered. That question is however outside of the scope of this study.

Where ΔW is the modelled 10-year wage increase for all workers (Table 6, third row) and r is the social discount rate. Applying the rate recommended in Swedish transport appraisal guidelines, 3.5 percent, the present value (in 2018 SEK) is 372.2 million. The value of 372.2 million SEK can be compared to the investment cost, which discounted to the present and expressed in 2018 prices is 6.04 billion SEK. This shows that the benefits in form of increased wages due to improved accessibility accounts for roughly 6.2 percent of the investment cost. It is important, however, to again stress that there is an unknown degree of overlap between the productivity effects measured in this paper and the traditional consumer surplus. When including productivity effects in appraisal, one must be cautious to avoid double-counting.

Table 5. Predicted ten-year wage effects of Svealand line opening in directly affected municipalities

Municipality	Population aged 20-64 (in 1996)	Median annual income for ages 20-64 (1996 in 2018 SEK)	Calculated effective density change (%)	Predicted effect on wages for population aged 20-64 (%)
Nykvarn	4 752	236 205	21.98	1.40
Södertälje	49 971	212 318	1.72	0.11
Eskilstuna	51 427	200 002	21.23	1.36
Strängnäs	16 197	211 035	39.83	2.55
Kungsör	4 918	212 318	18.52	1.18
Arboga	8 230	209 785	7.77	0.49
All	**135 495**		**15.39**	**0.98**
Core stations (Eskilstuna, Strängäs, Nykvarn)	**72 376**		**25.49**	**1.63**

The normalized agglomeration parameters (wage with respect to effective labour force density) estimated in this paper range from roughly 1 to 5 percent. This is in line with similar empirical studies such as Börjesson et al. (2019), who find estimates ranging from 2.8 to 3.5 percent, or Ahlfeldt and Feddersen (2018), who find that the elasticity of worker output with respect to economic density is 3.8 percent. Overall, the results confirm that there may be small but non-negligible impacts of improved accessibility arising from transport infrastructure improvements on productivity. Still, it should be stressed that the significance of our results is not robust to all varying end years specified in Table 4. This indicates that such benefits cannot be taken for granted and might materialize only after a rather long period of adjustment. Another aspect of the method that should be highlighted is the fact that we model the isolated transport network change that occurred as a result of the construction of the Svealand line. In practice, we model the transport system as it is currently structured with and without the Svealand line. During the modelled period, there have naturally been other investments which have improved the accessibility of both the 'treated' and 'control' municipalities in the dataset. Simply put, if there were changes which disproportionately improved the accessibility of *control* regions, we run the risk of underestimating the size of the agglomeration elasticity parameters since we could then be overstating the relative travel time impact of the Svealand line in terms of accessibility. If, on the other hand, there were changes besides the Svealand line which disproportionately improved the accessibility of the *treated* regions, we run the risk of overestimating the size of the agglomeration elasticity parameters, since the productivity gains observed could in part be due to other accessibility-improving interventions. As with any modelling task, simplifying assumptions have to be made and in absence of complete travel time matrices between Swedish municipalities before and after the Svealand line, we have constructed a method that allows for plausibly robust estimation of the wage impacts attributable to the investment in question.

Table 6. Present value of predicted ten-year wage effects

	Population aged 20-64	Labour force participants	Modelled 10-year wage increase for all workers	Present value of 10-year wage increase
Södertälje	49 971	38 178	8 886 429	15 752 920
Nykvarn	4 752	3 631	12 031 045	21 327 361
Strängnäs	16 197	12 375	66 494 161	117 873 803
Eskilstuna	51 427	39 290	106 744 216	189 224 837
Kungsör	4 918	3 743	9 392 089	16 649 299
Arboga	8 230	6 263	6 440 084	11 416 298
All	**135 495**	**103 479**	**209 988 023**	**372 244 519**

6. Conclusions

The introduction of the Svealand rail line had a sizeable effect on commuting in and around the region. Drastically improved public transport commuting times between Stockholm and a number of municipalities connected along the line resulted in a larger number of commuters and a higher market share for rail transport services. Did workers in the region become more productive due to the effective widening of the labour market? Our estimates, which are broadly in line with the existing empirical literature, indicate that there may indeed have been such an effect, but it appears to have been relatively small and unlikely to plausibly have made a difference in ex-ante appraisal. The higher end of empirical elasticity parameters of agglomeration implied by the models are in line with average values from previous research, though some are significantly smaller. Despite this, the actual changes in connectivity (as calculated through the change in least-time commuting networks) were sizeable in many of the directly affected regions, yielding predicted wage impacts as high as 1.6 % in the three municipalities whose commuting access was best improved by the line. Overall, our evaluation of the Svealand case demonstrates that improved opportunities for labour market mobility within a region can have modest but nonetheless significant effects on productivity.

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