TI 2019-065/VIII
Tinbergen Institute Discussion Paper

Productivity effects of an exogenous improvement in transport infrastructure: accessibility and the Great Belt Bridge

Bruno de Borger[1]
Ismir Mulalic[2]
Jan Rouwendal[3]

[1] University of Antwerp
[2] Technical University of Denmark
[3] Vrije Universiteit Amsterdam

Productivity effects of an exogenous improvement in transport infrastructure: accessibility and the Great Belt Bridge

Bruno De Borger[1], Ismir Mulalic[2,3] and Jan Rouwendal[4,5]

Abstract

Most studies of the effects of transport infrastructure on the performance of individual firms have focused on marginal expansions of the rail or highway network over time. In this paper, we study the short-run effects of a large discrete shock in the quality of transport infrastructure, viz. the opening of the Great Belt bridge connecting the Copenhagen area with a neighbouring island and the mainland of Denmark. We analyse the effect of the opening of the bridge on the productivity of firms throughout the country using a two-step approach: we estimate firm- and year-specific productivity for a large panel of individual firms, using the approaches developed by Levinsohn and Petrin (2003) and De Loecker (2011). Then, controlling for firm-fixed effects, we relate productivity to a calculated measure of accessibility that captures the effect of the opening of the bridge. We find large productivity effects for firms located in the regions near the bridge, especially for relatively small firms in the construction and retail industry. Estimation results further suggest statistically significant but small positive wage effects throughout the country, even in regions far from the bridge. Finally, there is some evidence that the bridge has stimulated new activities in the Copenhagen region at the expense of firms disappearing on the neighbouring island Funen.

Keywords: *production functions, productivity, accessibility, agglomeration, transport infrastructure*.

JEL codes: *D2, H54, O18, R4, R12*

Acknowledgement

Earlier versions of the paper have been presented at the ITEA conference in Hong Kong (June 2018), the Workshop on Agglomeration Economies in Copenhagen (January 2019), the 9th European Meeting of the Urban Economics Association (June 2019) and in seminars at the Universities of Antwerp and Valencia. The authors thank Bo Honoré, Jakob Roland Munch, Jan De Loecker, Daniel Graham, Maria Börjesson, Csaba Gabor Pogonyi, Stephan Heblich and Mogens Fosgerau for useful discussions. They are grateful to Statistics Denmark for providing the data. Research support from Kraks Fond – Institute for Urban Economic Research is gratefully acknowledged. The usual disclaimer applies.

[1] Department of Economics, University of Antwerp, Prinsstraat 13, B-2000 Antwerp, Belgium.

[2] DTU Management, Technical University of Denmark, Bygningstorvet building 116, 2800 Kgs. Lyngby, Denmark.

[3] Kraks Fond – Institute for Urban Economic Research, Frederiksholms Kanal 30, 1220 København K, Denmark.

[4] Department of Spatial Economics, Vrije Universiteit, De Boelelaan 1105, 1081 HV Amsterdam, The Netherlands.

[5] Tinbergen Institute, Gustav Mahlerplein 117, 1082 MS Amsterdam, The Netherlands.

1. Introduction

An obvious effect of improvements in transport infrastructure is that it reduces the importance of distance, and this has several implications. At a very basic level, better transportation possibilities make it easier to bring inputs and workers towards firms, and outputs towards customers; this decreases the production and logistic costs per unit (Shirely and Winston (2004), Datta (2012), Li and Li (2013)). To some extent, the quality of transport infrastructure and spatial proximity are substitutes so that, with heterogeneous products and workers, the decreasing friction of distance also opens possibilities for better matches between supply and demand; this is the case on output as well as input markets (see, for example, Helsley and Strange (1990)). Moreover, improved transportation infrastructure provides better opportunities for meeting other economic agents and therefore facilitates knowledge spillovers through formal and informal contacts. The benefits associated with proximity to other actors are generally referred to as agglomeration effects and are the subject of an extensive literature in spatial economics (Duranton and Puga (2004), Rosenthal and Strange (2004), Puga (2010), Gaubert (2018)).

The firm-level effects just mentioned are expected to show up in the productivity of firms. Not surprisingly, a number of studies have used firm-level data to investigate the implications of improved transport infrastructure on the productivity of firms. These studies have typically focused on marginal expansions of the transport infrastructure (such as the highway network) over time; examples include, Graham (2007), Holl (2012, 2016) and Gibbons, Lyytikaïnen, Overman and Sanchis-Guarner (2019). The first objective of this paper is to contribute to this literature by estimating the productivity effects of a large discrete and very localized improvement in transport infrastructure in Denmark, viz., the opening of the Great Belt Bridge connecting Zealand (where Copenhagen, the Danish capital, is located) with the neighboring island of Funen and, indirectly, with mainland Denmark and the rest of Europe. Politically, a major argument in favor of the bridge was the belief that this might shift the focus in the rest of Denmark from Hamburg to Copenhagen. Moreover, it was hoped that the new infrastructure might stimulate development in Funen, now that it would be better connected to the capital region. Arguments against its construction were that it was too expensive, that it would stimulate car driving, and that it generates unemployment among ferry-workers.

Prior to construction of the bridge, which became operational in 1998, the two islands were only connected by a ferry service. Given the geographical setting, the availability of the new infrastructure implied a discrete and substantial reduction in travel costs, not only for connections between the two islands, but also between the Copenhagen area and the rest of the country. The availability of register data allows us to construct a large panel of individual firms, covering the whole country and a large variety of production sectors. As argued below, we estimate productivity while taking into account the demand side of the market. Unlike previous studies, we capture the effect of the transport improvement through its impact on accessibility indices that have been used in studies of agglomeration at the municipal level.

To estimate the impact on firms' productivity, we adopt a two-step approach in which we first estimate total factor productivity for each firm and each year. State-of-the-art techniques for estimating production function that control for correlation between input levels and unobserved firm-specific productivity have been developed by Olley and Pakes (1996) and Levinsohn and Petrin (2003). As physical output figures are often unavailable, studies applying these methodologies (a recent example is Holl (2016)) typically use firm revenues as output indicator. This is somewhat less than desirable, because revenues are affected by price as well as quantity changes. For example, in the case studied in this paper, productivity increases due to the bridge might induce firms to lower their prices so as to increase sales volumes and profits. Using revenues as an indicator for output would then lead to biased estimates of the impact of the bridge. We attempt to avoid this by adopting the more recently developed methodology of De Loecker (2011); it assumes monopolistically competitive markets to take the effect of price setting behavior into account[1].

In a second step, we estimate the effect of the bridge on firm-level productivity. To capture the effect of the bridge we calculate an index of accessibility at the level of individual municipalities prior to and after the opening of the bridge. The index is defined as the weighted sum of employment in surrounding locations, where the weights are a decreasing function of travel time. The recent literature has often used a similar index (often using distance instead of travel time) as an indicator of agglomeration economies (see, for instance, Lucas and Rossi-Hansberg (2002), Hanson (2005), and Redding and Rossi-Hansberg (2017)). We find that the opening of the bridge strongly affects accessibility throughout the country. We then estimate the effect of these changes in accessibility on firms' productivity to identify the productivity effect of the bridge. We provide estimates of these effects at the aggregate level, but also at the regional and sectoral level.

[1] De Loecker (2011) develops a method to integrate demand effects into the estimation of firm-level productivity effects, and he uses the model to study the effect of trade liberalization in the Belgian textile industry. The model allows distinguishing 'revenue' from 'physical' productivity. He finds that trade liberalization has much smaller productivity effects when demand-side effects are incorporated into the analysis.

Of course, on top of the productivity effects, there may be other implications of improved transportation possibilities. They may affect wages and land prices (Donaldson and Hornbeck (2016), Gibbons et al. (2019)). In the long-run, better access to markets exposes firms to fiercer competition, making it more difficult for less efficient firms to survive. Moreover, location patterns of firms and households may change (Baum-Snow (2007), Michaels (2008), Redding and Turner (2015)). Locations that strongly benefit from the transport cost reduction may attract firms from elsewhere (see Coughlin and Segev (2000), Ghani, Goswami and Kerr (2016)), and it may generate a number of startups of new firms Holl ((2004b)). Other locations may become less desirable and lead to firms disappearing or going out of business. Since the pioneering studies of Krugman (1991) and Krugman and Venables (1995) we know that the general equilibrium effects of changes in transportation costs can be large.

Although our data do not allow us to estimate long-run equilibrium effects, a secondary objective of this paper is to study other short-run effects of the opening of the bridge. To the extent that the improved transport infrastructure has raised wages, the effect of the productivity increases on profits may have been partly compensated by higher labor costs; evidence suggests that productivity increases indeed raise input prices (see, for example, Greenstone, Hornbeck and Moretti (2010)). We therefore analyse the effect of the bridge on wages throughout the country. Moreover, we consider the impact of the new infrastructure on firm births and deaths on both sides of the new bridge. Although one of the political reasons for constructing the bridge was to stimulate economic activity in the peripheral region Funen, Krugman's (1991) core-periphery model suggests that transport cost improvements may not benefit the periphery at all.

The contribution of this paper is twofold. First, although the productivity effects of transport infrastructure have been analyzed before, the opening of the Great Belt Bridge is one of the first studies that focuses on the productivity effects of a large and very localized infrastructure project (another recent example is Ahlfeldt and Feddersen (2018)); as such it is ideally suited to identify the economic effects of transportation infrastructure. Most previous studies have estimated the effects of small changes in road infrastructure due to the expansion of the highway network, using various ways to empirically measure how extensions of the transport infrastructure affected 'market access' or firms' 'proximity' to the nearest highway ramp (Holl (2016), Fretz, Parchet and Robert-Nicoud (2017) and Gibbons et al. (2019)). As these improvements of the network are often realized in response to existing bottlenecks, this raises important endogeneity concerns these studies have to deal with. The opening of the Great Belt bridge to some extent avoids this type of endogeneity. The bridge crossing the Great Belt replaces a ferry service that dated back at least to 1624 when the first documented regular "vessel" route was introduced. Since the bridge covers the route followed previously by the ferries, we will argue that its construction can be regarded as a discrete change in travel time (and reliability) that left all other aspects of the network unchanged. We estimate the productivity effects of the bridge while taking into account the demand side of the market, and in line with Holl (2016), we are able to take into account differences in space and across sectors.

Second, although our time window is too narrow to investigate the long-run effects of the Great Belt Bridge on the spatial structure of the Danish economy, we do investigate the reactions of labor markets and the effect on firm births and deaths in the years immediately following the opening of the bridge. We use wage data for almost two million individual workers to study the effect of the opening of the bridge on wages. Implications for firm births and deaths are analyzed at the municipal level.

Results include the following. We find highly asymmetric productivity effects for firms located in the regions directly connected by the bridge. The productivity improvements for firms on Zealand (where Copenhagen is located) due to the bridge are significant but small. The estimated effects for firms on Funen, located on the opposite side of the bridge, are substantial; they amount to more than 1.5% of firms' output for firms in the municipalities close to the bridge. The largest effects are found for relatively small firms in the construction and retail industry, much less so in the manufacturing industries. We further find systematically positive – but small -- wage effects throughout the country, suggesting that the productivity gains have been partly compensated by higher wages. Finally, although one of the motivations for the bridge was to better connect Funen to the Copenhagen area there is some evidence that the bridge has stimulated new activities in the Copenhagen region at the expense of firms disappearing on Funen.

The structure of the paper is as follows. In Section 2 we review the literature dealing with the economic effects of improved transport infrastructure. We discuss the methodology in Section 3. We explain how we estimated productivity, we describe in detail the construction of our accessibility index and how it was used to estimate the effect of the opening of the bridge on productivity. Section 4 reports on the data used in the empirical analysis. The next two sections give the empirical results. In Section 5 we discuss the estimation results capturing the impact of the bridge on productivity at the aggregate, regional and sectoral level. Section 6 focuses on the estimated effects of the bridge on wages, and on firm births and deaths. A final section concludes.

2. Related recent literature

There is a large literature on the economic effects of highway investments. However, much of this literature does not use firm-level data, and it mainly emphasizes local and regional outcomes; relevant references include, among many others, Chandra and Thompson (2000), Faber (2014) and Ghani et al. (2016). A number of papers do use firm-level data and, as we do, they explicitly focus on the productivity effects of extensions of the transport infrastructure. However, the huge majority of these papers study the effect of marginal extensions in the highway network, typically using the changes in area market potential measures to capture the local impact of the highway (for example, see Graham (2007a, 2007b), Holl (2012) and Fretz et al. (2017)).

Closest in spirit to the current paper are Holl (2016) and Gibbons et al. (2019). Holl (2016) studies the effects of freeway accessibility on the productivity of Spanish manufacturing firms, exploiting variation over time related to the construction of the network. She first estimates firm level total factor productivity using the approach suggested by Levinsohn and Petrin (2003). In a second step she estimates the relationship between productivity and access to the highway system using instrumental variable methods to deal with possible endogeneity in the highway access variable. She finds strong productivity effects. Doubling the distance to the nearest highway ramp reduces productivity by 1.3-1.7%. The productivity effect is not just due to agglomeration effects of higher density of economic activity, but a significant direct effect is identified as well. The productivity-enhancing effects are higher in urban than in rural areas, and they appear to be largest in typical manufacturing industries. Finally, highways are found to attract new firms to its vicinity.

Gibbons et al. (2019) considered the effects of incremental improvements in the UK highway network on firms' productivity and employment. They measure exposure to road improvements using changes in a continuous network-based index of accessibility at a detailed small scale, based on the calculation of optimal travel times. They study only treated places, that are areas very close to the changes in the network, identifying their model by changes in the intensity of treatment. The accessibility measure they use is interpreted as a treatment indicator and they note that the effect can realize through better access to output markets, intermediate input markets or workers or through reduced travel times in general. They find that a 1% increase in accessibility raises employment by 0.3-0.4%. Incumbent firms loose employment while the positive effect is generated by new firms. They further find positive effects of accessibility on productivity.

As in Holl (2016), our analysis allows to capture both sectoral and spatial heterogeneity in productivity and in the productivity effects of transport improvements. In line with Gibbons et al. (2019), we use the change in an 'accessibility' measure (see the definition of our index below) defined at the local level to capture the effect of the opening of the bridge. Contrary to both papers, however, we consider a single location-specific but very large infrastructural improvement, not a continuous expansion of the highway network. In this sense, our paper also relates to Ahlfeldt and Feddersen (2018). They study the agglomeration effects of the opening of the high speed rail line between Cologne and Frankfurt. To avoid endogeneity problems they exploit the particular institutional setting that generates variation in transport costs that can be considered exogenous to the level of economic development. Their results show that under some specific conditions peripheral regions benefit from better connections to core regions.

The literature suggests that in the long run improved transportation infrastructure may strongly affect the location of economic activity (Chandra and Thompson (2000), Baum-Snow (2007), Michaels (2008)). Baum-Snow (2007) showed that highways had an important impact on suburbanization; Duranton, Morrow and Turner (2014) demonstrated substantial effects of highways on urban growth, and several studies found a significant impact on trade (Duranton and Turner (2012), Faber (2014), and Storeygard (2016)). Recently, Donaldson (2018) confirmed these findings also for railroads. He estimated the impact of the huge railroad network built in colonial India, and found that the arrival of the railroads in districts reduced trading costs, reduced price differences between regions, and increased trading volumes. Extending the network to the 'average' district is found to increase agricultural production by 16%.

Changes in the density of economic activity generate agglomeration economies in addition to those caused by the improved infrastructure itself (Graham (2007a), Greenstone, Hornbeck and Moretti (2010), and Puga (2010)).[2] Firms located in denser areas are likely to enjoy cheaper and faster delivery of local services and local intermediate goods.[3] Krugman

[2] The empirical relevance of agglomeration economies has been well documented. For example, Ciccone and Hall (1996) found strong evidence for the impact of concentrated activities on productivity, but they did not offer much insight into the importance of different possible theories explaining the link between agglomeration and productivity. Combes, Duranton, Gobillon, Puga and Roux (2012) used French establishment level data to distinguish two reasons why firms are more productive in larger cities: firm selection (only the best firms survive tougher competition) and agglomeration economies. They find that only the latter explains the observed productivity differences. For more empirical evidence, see the meta-analysis of Melo, Graham and Noland (2009) and, more recently, Mare and Graham (2013)).

[3] Transport cost changes are just one of several possible sources of agglomeration economies (Duranton and Puga (2004), Rosenthal and Strange (2004), and Greenstone, Hornbeck and Moretti (2010)). First, concentration of activities may be beneficial because of knowledge spillovers. These generate positive externalities in production and may stimulate faster adoption and penetration of new technologies. Second, workers and firms may be

(1991) and Krugman and Venables (1995) clearly show how transport cost changes affect the spatial equilibrium and can lead to the clustering of economic activities. The interaction between transport costs, scale effects in production and the initial share of manufacturing in total employment can give rise to a core-periphery pattern of firm location. This is more likely to develop when there are important scale economies, low transport costs, and low initial concentration of industrial firms.

Roback (1982) already showed how a local 'amenity' that increases the attractiveness of a particular location affects local wages and land prices.[4] In a similar vein, transport improvements may be capitalized in wages and/or in land prices (Li and Li (2013), Sanchis-Guarner (2012)).[5] The implications of transport infrastructure on input prices have recently also been extensively documented from a historical perspective by Donaldson and Hornbeck (2016). They analyze the impact of US railroad developments on the agricultural sector in 1890. They demonstrate that the presence of the railroad increased a county's market access, calculated using the least-cost freight routes between different counties. It is estimated that improved market access due to the expansion of the railroad network between 1870 and 1890 was capitalized in higher agricultural land values: the absence of railroads would have reduced agricultural land values by 60%.

Finally, the effect of transport improvements on the relocation of firms has been studied by, for example, Coughlin and Segev (2000), Holl (2004a), and Ghani, Goswami and Kerr (2016). The effect on firm births was studied in Holl (2004b). Most recently, Fretz et al. (2017) develop a spatial equilibrium model to study the effects of highway development on the local income distribution and on employment. The model captures trade and commuting patterns, and it has workers with heterogeneous skills and idiosyncratic location preferences. The model

attracted to areas with a large labor market. This facilitates matching workers and firms; it therefore reduces the probability that workers will not find a job as well as the probability that firms will be unable to fill vacancies. Third, the presence of natural advantages (mining resources, oil, soil and climate suited for, for example, wine production) will lead to clustering of firms in particular regions.

[4] Arzaghi and Henderson (2008) focus on the 'proximity' of firms to one another, showing that the spatial decay in the advantages of close neighbors is quite rapid. Contrary to some earlier literature they find that agglomeration benefits are largely capitalized in land prices, much less so in wages.

[5] Evidence for the capitalization of productivity improvements that are unrelated to transport infrastructure in firms' input prices is found by Greenstone, Hornbeck and Moretti (2010). They compare total factor productivity of firms in which a 'million dollar plant' located with that of firms in runner-up counties that narrowly lost the competition. Their main finding is a substantial increase (12 %) in total factor productivity of incumbent firms in the five years following the arrival of the large plant. They also find a large amount of heterogeneity in the effects. Stronger effects are found on plants that are 'close' to the million dollar plant in terms of forward and backward linkages. They interpret their findings with a Roback-type (1992) model in which the positive effects of the productivity shock are partly offset by wage increases, a prediction for which they report empirical support. Profits therefore increase less than productivity.

shows that locations with improved market access (due to highway extensions) become relatively more attractive to high-skilled workers. Using data on the construction of the Swiss highway network between 1960 and 2010 they find strong effects of highway access on the local income distribution: a new highway access within 10km is found to increase the share of high-income taxpayers by 19%; the share of low-income taxpayers declines by 6%.

3. Productivity, accessibility, and the effect of the bridge: empirical strategy

In this section, we describe our empirical strategy to estimate the effect of the opening of the bridge on the productivity of firms. We first discuss how total factor productivity was estimated for individual firms. The we explain in detail the construction of our accessibility index and the role of the bridge in travel time and accessibility changes. Finally, we present the empirical model used to estimate the effect of accessibility and the opening of the bridge on productivity.

3.1. Estimating Total Factor Productivity (TFP)

The current state of the art to estimate firms' total factor productivity has been initiated by Olley and Pakes (1996) and Levinsohn and Petrin (2003). They derive productivity measures from estimated production functions that control for unobserved productivity shocks through investment or intermediate inputs, respectively. Assuming a Cobb-Douglas production function, the Levinson-Petrin approach starts from the following estimation equation:

$$y_{i,t} = \alpha_l l_{i,t} + \alpha_k k_{i,t} + \alpha_m m_{i,t} + \omega_{i,t} + u_{i,t} \quad (1)$$

where $y_{i,t}$ denotes the log of output of firm i in year t, and l, k, m are the logs of the quantities of labor, capital, and intermediate inputs, respectively. The α's are coefficients to be estimated. The model accounts for two types of error. The first of these, $\omega,$ is an unobserved productivity shock that reflects aspects of the production process that are unobserved by the researcher and are potentially correlated with labor or capital. The second error, denoted u, is a standard i.i.d. component.

Capital and the unobserved productivity shock are state variables, while labor and the intermediate inputs are freely variable in each period. The demand for intermediate inputs is a function of the two state variables: $m_{i,t} = m_t(k_{i,t}, \omega_{i,t})$. Levinsohn and Petrin (2003) show that under plausible conditions the demand for intermediate inputs is increasing in the unobserved productivity shock $\left(\frac{\partial m_t}{\partial \omega_{i,t}} > 0\right)$. This function can therefore be inverted, and it follows that the right-hand side of the above equation can be reformulated as the sum of the labor term $\alpha_l l_{i,t}$, an unknown function φ_t of the two state variables, and the second error term:

$$y_{i,t} = \alpha_l l_{i,t} + \varphi_t(k_{i,t}, \omega_{i,t}) + u_{i,t}\,. \tag{2}$$

This equation is estimated by OLS using a third-order polynomial to approximate φ_t. The results are then used to find estimates of α_k and α_m applying the (moment) conditions that capital and the previous period's demand for intermediate inputs are independent of the most recent innovation in productivity. With these results at hand, an estimate of the natural log of total factor productivity can be computed as:

$$\widehat{tfp}_{i,t} \left(= \widehat{\omega}_{i,t}\right) = y_{i,t} - (\hat{\alpha}_l l_{i,t} + \hat{\alpha}_k k_{i,t} + \hat{\alpha}_m m_{i,t}). \tag{3}$$

Although output is the correct dependent variable when estimating the above relation (2), this is usually not reported in the data available to the researcher. In practice only revenues or turnover are known; i.e., the product of the output and the firm-specific price is known, but the individual components are unobserved. In terms of the model presented so far, the firm's output $y_{i,t}$ is unobserved, only its revenue $r_{i,t} = p_{i,t} y_{i,t}$, where $p_{i,t}$ is the price per unit of the firm's output. This price is also not observed: available price information is usually limited to price indices referring to more broadly defined industries to which the firm belongs. Our data set is no exception; we use information about firm's total revenues, deflated by these crude indices, as measure for the firms' outputs. The implication is that price differences occurring at a relatively low level – within the broad sectors for which the price indices are published – are not adequately measured. As noted by De Loecker (2011), this could bias the measurement of productivity. The intuition is clear. For example, we argued above that the bridge over the Great Belt could increase productivity, but it may also lead to more competition from firms in other locations, and this may in turn affect firms' output prices and the demand for their product. Relying on deflated sales using a broad price index will therefore result in productivity estimates that to some extent also reflect price and demand variation.

Recently, De Loecker (2011) observes that one can improve upon using revenues deflated by a broad sectoral price index by taking into account the demand side of the market. His approach requires that broadly defined industries can be divided into a number of industry segments, assumed to be monopolistically competitive[6]. Each firm i is assumed to produce a variety of the product within such an industry segment s. Consumer preferences for varieties of

[6] For example, in his model of the textile industry, he considers segments such as clothing and spinning within the textile industry.

a product within industry s are of the CES-type. The price of firm i is unknown, but at the level of industry s a price and quantity index, denoted as $p_{s,t}$ and $q_{s,t}$, respectively, are available. De Loecker (2011) then shows that the relevant equation to obtain estimates of the production function is:

$$(r_{i,t} - p_{s,t}) = \beta_l l_{i,t} + \beta_k k_{i,t} + \beta_m m_{i,t} + \beta_s q_{s,t} + \omega^*_{i,t} + \xi^*_{i,t} + u_{i,t}\ . \tag{4}$$

The variable on the left-hand side is the firm's revenue deflated by the price index for industry s (note that variables are in logs). The inputs in the production process now appear with a different coefficient, $\beta_h, h = l, k, m$ that can be shown to equals α_h multiplied by the firm's markup. The output of industry s appears as an additional variable and its coefficient β_s can be shown to equal the Lerner index. Similarly, the productivity shock $\omega^*_{i,t}$ equals $\omega_{i,t}$ multiplied by the markup and $\xi^*_{i,t}$ is a demand shock multiplied by the Lerner index. De Loecker (2011) shows that the methodology of Levinsohn and Petrin (2003) can, with appropriate modifications, be applied to obtain estimates of total factor productivity. As mentioned, there are extra data requirements to apply De Loecker's approach. It requires that industries can be subdivided into a number of segments. See below for details.

3.2. Accessibility and the opening of the bridge

As mentioned, we capture the effect of the bridge on productivity indirectly through its effect on travel times and accessibility of locations throughout Denmark. The accessibility index we use captures the proximity of a given location to other locations; it has its roots in the literature on agglomeration economies. Although the literature offers various different indicators (see Rosenthal and Strange (2001, 2004), and Melo et al. (2009)), it has become standard to use the distance-weighted sum of employment in surrounding locations (see Lucas and Rossi-Hansberg (2002), Spiekermann et al. (2015), and Redding and Rossi-Hansberg (2017)). We follow this methodology, but we use travel time rather than distance as weights. More specifically, our indicator A is computed for each municipality as the weighted sum of full time equivalents (FTE's) in all municipalities. The value of A for municipality m is:

$$A_m = \sum_{m'} FTE_{m'}\ e^{-\delta\, d_{m\,m'}} \tag{5}$$

where the summation runs over all municipalities m' and d denotes distance measured in travel time minutes between municipalities. This measure basically captures, for each municipality, the 'proximity' of workers in other municipalities. A similar measure was used in Dekle and

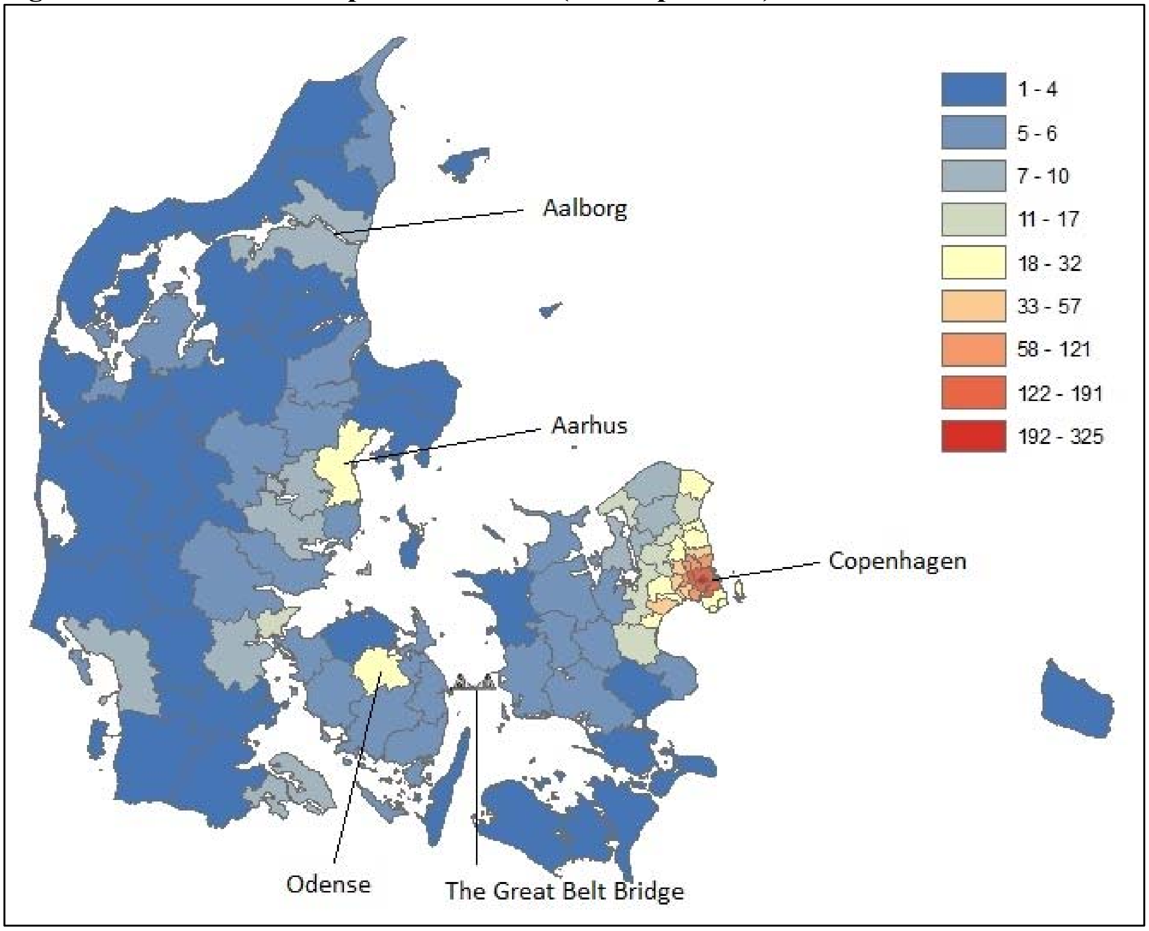
Eaton (1999) (see their equation (1)) and in Lucas and Rossi-Hansberg (2002, p. 1448). Hanson (2005) also uses an analogous index to model locations' proximity to consumer markets.

The geographical distribution of firms is presented in Figure 1[7]. Economic activity is concentrated in a few (relatively) large urban areas around the four largest cities. It turns out that the Great Copenhagen Area accounts for about 19.2 % of all firms in our sample.[8] Other larger cities, i.e., Aarhus, Aalborg and Odense, account for another 10.2 % of the total number of firms. Figure 1 also clearly indicates the location of the new bridge (which, in fact, consists of two bridges plus a railroad tunnel). It replaces the historical ferry route between the islands Zealand and Funen. Zealand is the large island on the right where Copenhagen is located. Funen is clearly visible in the middle of the figure; the main city on the island is Odense.

[7] The register of businesses includes for each firm the municipality where it is located. To protect the identity of the companies for which data exist and to provide sufficient confidentiality protection, Statistics Denmark does not provide the exact workplace addresses for companies, but it does provide the municipality code for each company.

[8] The municipality of Copenhagen in itself accounts for 6.9 % of all firms.

Figure 1. Number of firms per km^2 in 1995 (municipal level)



Combining the information on individual firm location with the available data on FTE's (full time equivalents) from Statistics Denmark and data on travel times between municipalities, we use (5) to compute a municipality-specific agglomeration measure to be used in our empirical analysis. The travel times between all 98 Danish municipalities are available from the Danish National Traffic Model for the year 2002 (Rich et al., 2010). They are derived using the complete road network structure including all minor roads, forbidden turns and one-way restrictions. The average mean travel time between municipality pairs is 137 minutes, with standard deviation 78.8; the minimum is 14.0 minutes and the maximum is almost 6 hours (349.8 minutes).[9]

To specify the 'proximity' weight function, i.e., the parameter δ capturing the decreasing function of travel time, theory does not offer much guidance on how narrowly or

[9] The mean travel time within a municipality is different from zero. This implies that the diagonal in the O-D travel time matrix is not a vector of zeros.

how broadly regional effects should be measured. We initially set δ to 0.03. This implies that FTE's 'around the corner' have a weight 1, while a FTE at the distance of 1 hour has weight 0.17. Figure A.1 in Appendix A shows the computed weights for different values of the decay parameter δ. Given the uncertainty surrounding an appropriate decay parameter, in the empirical analysis we estimate models with alternative decay parameters as robustness checks. As will become clear, different values do not affect the interpretation of the results.

In our empirical work, we exploit the construction of the 18 km long Great Belt Bridge that links the eastern and western parts of Denmark. The Great Belt Bridge opened in June 1998.[10] The bridge is open 24 hours a day, 365 days a year. The new infrastructure obviously affects the travel times between municipalities on opposite sides of the bridge; it does not affect travel times between municipalities on the same side. Moreover, although there is a toll on the new bridge, it is broadly equal to the price of a ferry crossing prior to the opening of the bridge, so that the change in travel time is the only major effect of the bridge on travel costs.

Our data consist of a panel over the period 1995-2002, in other words just before and after the opening of the bridge. As mentioned above, very detailed information on actual travel times is available for 2002, but this is not the case before 2002. We therefore capture the effect of the opening of the Great Belt Bridge in 1998 by adding, for travel times before 1998, 24 minutes for all links between municipalities that cross the Great Belt. This corresponds to the difference between the travel time across the Great Belt by ferry and the free flow travel time for a motor vehicle crossing the bridge.[11] Since using the ferry also implied some waiting time and uncertainty under bad weather conditions, this is a conservative way of dealing with the impact of the bridge on travel times. Importantly, note that we ignore other changes in the road network apart from the opening of the new bridge, because our travel time data refers to one year only (2002). So we proceed as if all travel times are equal to their 2002 values, except when the origin and destination are on different sides of the Great Belt bridge. Changes in our accessibility measure clearly only capture the travel time changes due to the bridge, not changes in travel times due to other adaptations of the highway system. Since the other changes in the road network over the period considered were very small, we do not expect this limitation of our data to have much impact on our results. In our empirical analysis below, as a robustness

[10] The Danish parliament adopted the Construction Act for the Great Belt link in June 1987. Construction work began in August 1990.

[11] The bridge is in general uncongested. It seldom happens, but particularly severe weather can affect traffic on the bridge.

check, we did consider the effect of changes in the distance to the nearest highway ramp as additional information when estimating the effect of the bridge on productivity.

3.3 Estimating the impact of the bridge on productivity

To find the impact of the bridge on firm productivity, we regress the firm- and year-specific estimates of total factor productivity $\widehat{tfp}_{i,t}$ on the log of the accessibility, denoted $a_{m(i),t}$:

$$\widehat{tfp}_{i,t} = \gamma_{i0} + \gamma_1 a_{m(i),t} + \gamma_t + \varepsilon_{i,t}. \tag{6}$$

In this equation $m(i)$ denotes the municipality in which firm i is located. Note that the intercept γ_{i0} is firm-specific. Since we have panel data for firms, we can control for all differences in productivity that remain constant over time using firm-fixed effects. This allows us to deal in a completely general way with the concern that the level of firm productivity may be correlated with the level of accessibility, for instance because firms in Copenhagen tend to be more productive than those in Jutland. Finally, γ_t captures time-fixed effects.

A typical concern in studies analyzing the effect of infrastructural improvements is that these are often realized in response to existing bottlenecks in the network, raising serious concerns about endogeneity. For example, if the timing or the location of highway or rail extensions is selected according to trends and locational patterns in economic development, the improvements are not random, causing correlation between accessibility and the error term. Not surprisingly, therefore, previous studies on the productivity effects of highway or rail extensions have devoted much attention to possible endogeneity issues (Holl (2016), Ahlfeldt and Feddersen (2018), Gibbons et al. (2019), Fretz et al. (2017)). However, by focusing on one localized huge investment in new infrastructure the endogeneity argument is in the setting of the current paper less of a concern. There are good arguments why neither the location nor the timing of the bridge are likely to be endogenous. A brief history of the development of the idea for the bridge suggests that the location was exogenous: it was situated where the distance between the islands it connects was shortest on the exact same location where a ferry service had been operating for several centuries.[12] Moreover, the timing of the opening of the bridge can be considered exogenous as well. It was heavily dependent on the political situation of the

[12] The first documented regular “vessel “route crossing the Great Belt was introduced in 1624. In the 18th century, the connection was improved both for passenger and delivery (post) services, and new vessels were operating the service. In the early 19th century, the link was serviced by steam-operated ships. Note that as early as 1858 there was a proposal to connect the two Danish islands Zealand and Funen. An engineer A.F. Tscherning proposed a tunnel under the Great Belt.

moment; moreover, the scale of the project, the long construction time and the technical challenges involved made it hard to determine the opening date of the bridge in advance[13]. It is very unlikely that it was affected by economic developments on either side of the bridge.

However, given the way we constructed the accessibility index, there is another endogeneity issue that deserves attention. Although in some regions changes in accessibility are dominated by the opening of the bridge, they also depend on the complete distribution of the evolution of local employment, see expression (5) above. If changes in local productivity are associated with changes in local employment and if the latter strongly affect the accessibility index then this may lead to correlation between changes in productivity and in accessibility that are not informative about the impact of the bridge. Alternatively, suppose the bridge was constructed in response to an (expected) increase in employment, then this might lead to reverse causality. To cope with these issues, it has been suggested to remove the employment variations from the accessibility index to 'purify' the measure so that it more precisely captures the effect of the infrastructural improvements only (for an application in another context, see Ahlfeldt and Feddersen (2018)). Although the history of the bridge implies that the decision where and when to construct it was not taken on the basis of considerations with respect to employment growth, in Section 5.4 we also report results when a 'constant employment' accessibility index is used instead of the one described above.

4. The data

To study the effects of the opening of the bridge in 1998, the data used in the empirical analysis are derived from annual register data from Statistics Denmark for the years 1995–2002. Statistics Denmark maintains a register of businesses designed to capture the total population of establishments. The register contains extensive account and balance sheet information. It provides, at the company level, data on sales, investments, inputs, employment and capital stock. Moreover, information is provided on the industrial sector (using a very detailed disaggregation of industries), the ownership structure of the business (for example, plants under common ownership) and its geographical location at the municipality level.

[13] In 1936 the first bridge-idea (a bridge with railway and road) came up, but the project was not realized due to the Second World War. In 1948 an expert group was appointed in order to explore the possibilities for a Great Belt bridge. In 1965 the Danish government offered an award for the best bridge project. It announced 4 winners of the competition in 1967. However, due to political difficulties, the oil crises, and a number of new analyses, the bridge project was postponed again. The Danish parliament finally adopted the Construction Act for the Great Belt link in June 1987. Construction work began in August 1990. The bridge opened in 1998.

We observe the full population of establishments, which we refer to as firms. However, like many similar data sources from other countries, the Danish register of businesses includes accounts and balance sheet data at the company and not at the plant level, so that outputs and inputs cannot be assigned to individual plants in multi-plant companies.[14] This implies that plant-level productivity cannot be estimated for multi-plant companies. We therefore restrict the sample to single-plant firms.[15]

Statistics Denmark has organized the total number of registered industries in Denmark (825) into a number of NACE-standard groupings.[16] We focus on industries belonging to three aggregate sectors at the one-digit level for which we observe balance sheets for the years 1995–2002, i.e., i) manufacturing, ii) construction, and iii) wholesale and retail trade, hotels and restaurants. Our empirical analyses are conducted at the NACE four-digit grouping, in total containing 53 industries. However, for various reasons a number of industries had to be excluded.[17] One implication is that from the sector 'wholesale and retail trade' only 'retail trade and repair work' turned out to be useful. Note that the sample consists of an un-balanced panel of 200,177 observations covering the period 1995–2002.

In Table 1 we provide information on the distribution of firms at the one-digit level by year in the final sample used for estimation. The number of manufacturing firms decreased by approximately 10% during the period considered, while the number of construction and service firms increased by some 18% and 12%, respectively. Table 2 reports the number of observations per industry at the four-digit level. Firms in our sample are mainly concentrated in manufacturing and construction. In the manufacturing sector we find the largest number of firms in the industries 'processing of basic metals', 'paper' and 'machinery and equipment'.

[14] Each plant is assigned a unique identification number and a company identification number corresponding to the firm that owns them (so plants under common ownership share a common company identifier). Accounts and balance sheet information is only available at the company level.

[15] We delete about 22 % of observations that correspond to multi-plant companies.

[16] NACE: Nomenclature générale des Activités économiques dans les Communautes Europeennes.

[17] Some industries had to be excluded because of the small number of firms (examples include 'sale of automotive fuel' and 'wholesale of perfume and cosmetics'. Others were deleted (for example, 'manufacturing of wood and wood products' and 'manufacturing of rubber and plastic products') because for these industries we do not observe segments, as required for the econometric technique used to estimate productivity, see De Loecker (2011) and the discussion above. The number of observations was further reduced by deleting observations with missing values, or zero sales and zero employment. Also note that in Denmark, during the studied period smaller privately owned businesses where not required to report balance sheets.

Table 1. Number of firms by year (one-digit NACE sectors)

Year	Manufacturing	Construction	Wholesale and retail trade	Total
1995	9,364	10,037	4,453	23,854
1996	9,287	10,340	4,655	24,282
1997	9,142	10,773	4,691	24,606
1998	9,099	11,066	4,719	24,884
1999	9,223	11,434	4,865	25,522
2000	9,128	11,957	4,990	26,075
2001	8,828	11,842	4,942	25,612
2002	8,495	11,849	4,998	25,342
Total	72,566	89,298	38,313	200,177

Table 2. Number of observations by sector (four-digit NACE sectors)

NACE one-digit sectors	NACE four-digit sectors	Number of observations
Manufacturing	Mfr. of food, beverages and tobacco	6,395
	Mfr. of textiles and leather	4,943
	Mfr. of paper prod.; printing and publish.	12,200
	Mfr. of chemicals	1,681
	Mfr. of other non-metallic mineral products	2,829
	Mfr. and processing of basic metals	16,026
	Mfr. of machinery and equipment	10,649
	Mfr. of electronic components	8,139
	Mfr. of transport equipment	2,542
	Mfr. of furniture; manufacturing n.e.c.	7,162
Construction	Construction	89,298
Wholesale and retail trade	Other retail sale, repair work	38,313
Total		200,177

Tables 3 and 4 show summary statistics at the firm level. In Table 3 we report, at the one-digit level, the mean of the firms' turnover, the number of full time equivalents and the capital stock over the sample period. The mean turnover is almost constant over time; the slight mean changes in employment and capital are consistent with very modest labor-capital substitution. In all three cases the high standard deviations indicate that we have substantial variation across firms. Table 4 contains similar information at the level of the four-digit NACE sectors. It suggests that both in terms of average turnover and employment levels the largest sectors considered are (i) the chemical industry, (ii) the production of transport equipment and (iii) food, beverages and tobacco.

Table 3. Means and standard deviations for selected variables (1995-2002)

Year	Turnover (1000 DKK)	Full Time job Equivalents	Capital (1000 DKK)
1995	11,763	11.82	2,953
	(55,292)	(46.29)	(20,543)
1996	11,607	11.46	2,834
	(57,283)	(43.99)	(18,448)
1997	11,821	11.54	2,971
	(50,330)	(39.44)	(26,081)
1998	11,881	11.43	2,872
	(51,171)	(40.27)	(18,398)
1999	11,958	11.25	2,981
	(55,238)	(38.19)	(21,762)
2000	11,812	10.99	3,037
	(49,108)	(34.65)	(36,155)
2001	11,940	11.01	3,237
	(53,096)	(35.28)	(37,571)
2002	11,829	10.63	3,261
	(52,177)	(32.79)	(28,934)

Notes: Number of observations is 200,177. Standard deviations are in parentheses. Note that 1 Danish crown (denoted DKK) ≈ 0.13 €.

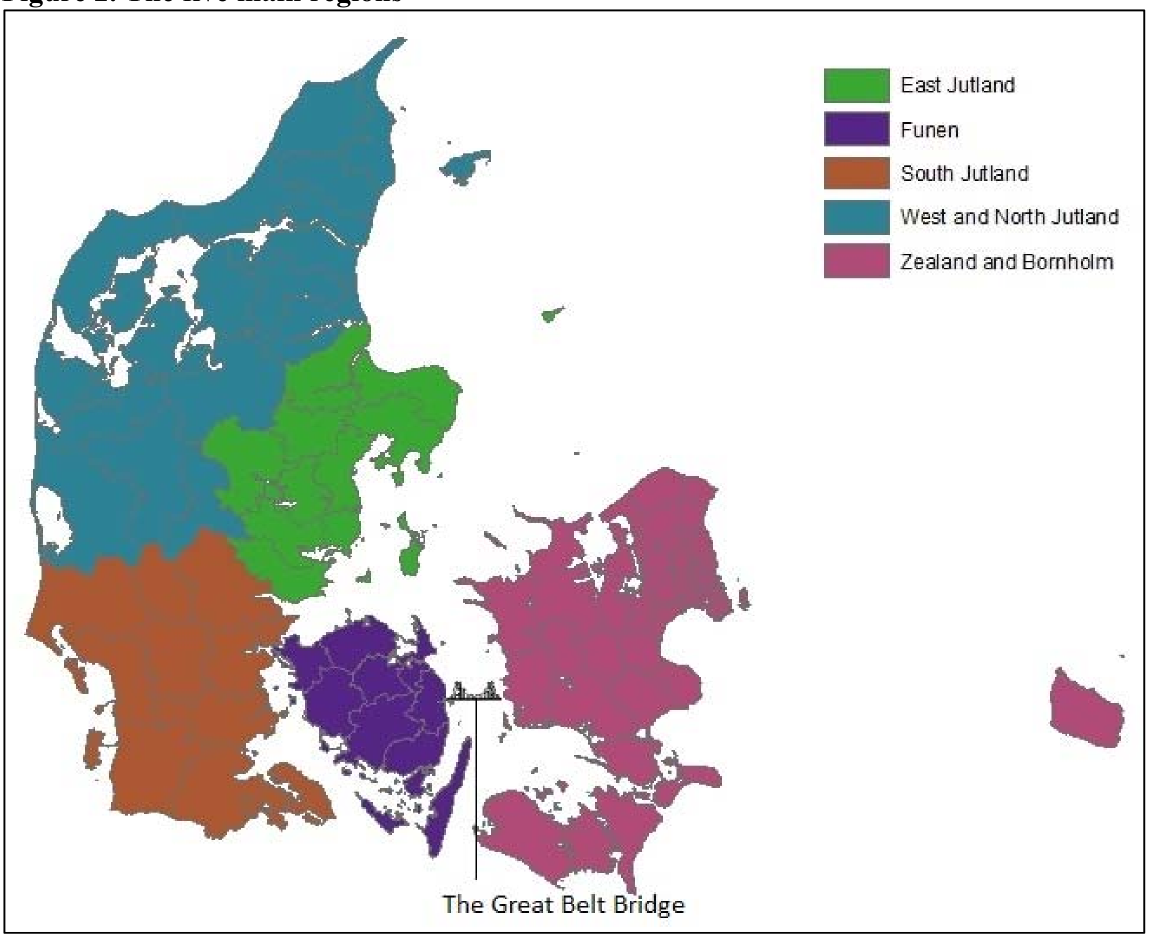
Table 4. Means and standard deviations for selected variables (four-digit NACE sectors)

	Turnover (1000 DKK)	FTE	Capital (1000 DKK)
Mfr. of food, beverages	35,187	20.49	9,412
and tobacco	(99,341)	(56.46)	(69,227)
Mfr. of textiles and	17,589	14.57	5,635
leather	(64,374)	(32.68)	(30,458)
Mfr. of paper prod.;	14,980	12.38	3,757
printing and publish.	(43,298)	(26.30)	(16,304)
Mfr. of chemicals	60,120	35.06	23,770
	(173,219)	(98.24)	(95,865)
Mfr. of other non-	18,897	17.46	6,827
metallic mineral prod.	(50,782)	(45.27)	(26,371)
Mfr. and processing of	14,650	16.77	4,412
basic metals	(47,764)	(43.83)	(31,485)
Mfr. of machinery and	24,646	26.29	7,084
equipment	(70,843)	(70.35)	(41,525)
Mfr. of electronic	23,871	22.78	8,028
components	(85,149)	(58.39)	(60,014)
Mfr. of transport	42,209	38.23	9,350
equipment	(249,823)	(181.95)	(67,311)
Mfr. of furniture;	15,975	17.54	4,281
manufacturing n.e.c.	(82,990)	(60.85)	(20,886)
Construction	6,607	7.65	1,102
	(14,587)	(12.74)	(3,605)
Other retail sale, repair	5,618	3.95	1,231
Work	(11,062)	(5.00)	(15,961)

Notes: Number of observations is 200,177. Std. dev. is in parenthesis. 1 DKK ≈ 0.13 €.

As the bridge may have very different regional effects, it is useful to consider Denmark's regional economic structure. Figure 2 shows the five major regions (Zealand/Bornholm, Funen, South Jutland, East Jutland, and West/North Jutland). Table 5 reports total employment in manufacturing, construction and services in these five regions. Zealand/Bornholm has by far the largest manufacturing and construction sectors in the country. Manufacturing employment in the region declined over the sample period, from about 58,000 to 49,000; the construction industry grew from 33,000 to some 38,000. The Funen economy is markedly smaller, employing some 20,000 people in manufacturing (with a slight decline after 1998), and a rising construction industry (from 6000 to 7800) over the sample period. Note that the three Jutland regions all faced declining employment in the manufacturing industry over the sample period, partly compensated by slightly increasing construction sector employment[18].

Figure 2. The five main regions



.

[18] For completeness sake, in Table A.1 in Appendix A we report sectoral information by region.

Table 5. Total number of full time job equivalents by sector and region

Year		1995	1996	1997	1998	1999	2000	2001	2002
Zealand	Manufacturing	58,147	54,133	53,181	51,846	53,160	52,049	50,145	48,844
And	Construction	33,147	34,107	36,407	36,285	37,284	38,705	38,539	37,558
Bornholm	Services	7,319	7,853	7,852	7,985	8,189	8,550	8,139	8,296
Funen	Manufacturing	20,350	20,448	20,030	20,839	20,187	20,567	20,565	19,629
	Construction	6,121	6,518	7,320	7,406	7,934	8,538	7,897	7,786
	Services	1,348	1,388	1,445	1,465	1,462	1,479	1,494	1,621
South	Manufacturing	33,688	33,793	30,650	31,761	31,383	29,520	29,485	25,689
Jutland	Construction	11,375	11,465	12,162	12,223	12,781	13,989	13,336	12,440
	Services	2,933	2,866	2,744	2,798	2,833	2,767	2,707	2,574
East	Manufacturing	30,762	29,986	30,667	30,168	29,358	28,845	29,383	28,087
Jutland	Construction	9,226	9,753	10,876	11,127	11,852	12,099	12,437	12,208
	Services	2,468	2,629	2,721	2,743	2,789	2,860	2,703	2,829
West and	Manufacturing	46,753	43,883	46,659	46,014	45,024	43,184	41,953	38,483
North	Construction	14,739	15,594	17,329	17,788	18,787	19,270	19,364	19,287
Jutland	Services	3,550	3,878	3,877	4,024	4,083	4,015	3,952	3,974

5. Empirical results: productivity, accessibility and the bridge

In this section, we turn to the empirical results. In a first subsection, we summarize the results when estimating productivity, using both the Levinson-Petrin and De Loecker approaches. A second subsection presents information on the estimated accessibility indices before and after the opening of the bridge. Subsection three reports our findings of estimating the effect of accessibility on firm-level productivity. A final subsection zooms in on the specific role of the bridge.

5.1. Productivity

We estimate separate production functions for each of the four-digit industries listed in Table 4, using the two methods described in section 3.1. We limited the analysis to firms that did not relocate over the period 1995-2002; this reduces the total number of observations to 193,237 or about 96 % of the total number of observations.[19]

To apply De Loecker's (2011) methodology we decomposed four-digit industries into a number of segments. To give an example, for the construction industry we observed seven subsectors: i) general contractors, ii) bricklaying, iii) installing of electrical wiring and fittings, iv) plumbing, v) joinery installation, vi) painting and glazing, and vii) other construction works.

[19] Only 4% of firms in our sample relocate. These firms are not much different from the other firms in our sample, see Table A.2 in Appendix A.

For the manufacturing industries we observed anywhere between three and six segments, with two exceptions: for transport equipment and furniture, we observed only two subsectors. Table A.3 in Appendix A provides more detailed information on the segments we distinguished.

We present detailed results of the estimated production functions in Appendix A, see Table A.4. The main findings can be summarized as follows. First, for the majority of sectors considered (including construction; food, beverages and tobacco; and chemicals), the hypothesis of constant returns to scale cannot be rejected. In cases where it is statistically rejected, scale economies (for example, for paper production) or diseconomies of scale (machinery and equipment; furniture) are very mild. Second, the coefficients of the inputs in production using De Loecker's methodology are almost systematically higher than when using the approach of Levinson and Petrin. As noted by De Loecker (2011, p. 1435-1436) there are two biases in the latter approach that may operate in opposite directions. First, omitted variable bias leads to downward bias in the coefficients of the inputs labor and capital. Second, however, simultaneity bias leads to a lower coefficient for labor and a higher coefficient for capital. The overall effect is therefore theoretically ambiguous; in our data set, the former bias seems to dominate the latter.

Based on the estimated production functions we then derive firm-level productivity estimates, as explained in section 3.1. In Table 6 we present summary statistics for the log of total factor productivity (denoted *tfp*) implied by our production function estimates. It is clear from these figures that there are important qualitative differences between the results of the two approaches. Compared to De Loecker's method which accounts for demand side adjustments, the implied mean productivity is overestimated if we use the Levinsohn-Petrin approach. The latter approach mixes productivity and demand effects, whereas the former attempts to remove the demand effects to get a 'pure' productivity measure.

Table 6. Summary statistics for the log of total factor productivity (tfp)

	Mean	Std. Dev.	Min.	Max.
tfp (Levinsohn-Petrin)	5.638	0.503	1.709	10.174
tfp (De-Loecker)	4.930	0.998	-0.212	13.971

Notes: Number of observations: 193,277.

Table 7 shows the development of productivity over the years. Note that De Loecker's approach yields systematically lower productivity levels. Ignoring the impact of demand and price changes potentially contaminates the productivity estimates resulting from Levinsohn and

Petrin's methodology. The results suggest that these changes muted overall productivity estimates. However, more interesting than the absolute figures are the annual productivity changes they imply. Both approaches suggest that over the period we considered productivity growth was mostly negative, except for 1998 – the year the bridge opened – and, to a lesser extent, in 2000. The figures in Table 7 based on Levinsohn-Petrin imply annual productivity growth ranging between -0.64% and +0.83%; using De Loecker's method the range is from -0.48% to +1.10%. Interestingly, comparing 2002 with 1995, the latter approach suggests productivity growth, the former a productivity decline.

Table 7. Summary statistics for the log of total factor productivity (tfp), by year

	Levinsohn-Petrin		De Loecker	
Year	Mean	Std. Dev.	Mean	Std. Dev.
1995	5.656	0.519	4.916	1.018
1996	5.627	0.515	4.898	1.021
1997	5.619	0.497	4.895	0.994
1998	5.666	0.493	4.949	0.998
1999	5.638	0.482	4.925	0.992
2000	5.656	0.521	4.963	0.997
2001	5.620	0.496	4.951	0.988
2002	5.617	0.501	4.946	0.970

Notes: Number of observations: 193,277.

In Table 8 we decompose productivity by region. The results confirm the different results of the two approaches to estimate productivity. Comparing productivity estimates in 2002 with those in 1995 using De Loecker's method, we see a strong productivity increase in Zealand/Bornholm and to a much lesser extent in Funen and East Jutland. All regions suffered a productivity decline, based on the Levinsohn-Petrin estimates.

Table 8. Summary statistics for the log of total factor productivity (tfp), by year and region

	Zealand and Bornholm	Funen	South Jutland	East Jutland	West and North Jutland
			Levinsohn-Petrin		
1995	5.612	5.657	5.703	5.656	5.705
	(0.533)	(0.502)	(0.508)	(0.508)	(0.506)
1996	5.582	5.626	5.664	5.635	5.679
	(0.522)	(0.494)	(0.512)	(0.516)	(0.507)
1997	5.576	5.621	5.645	5.628	5.672
	(0.500)	(0.484)	(0.487)	(0.502)	(0.490)
1998	5.625	5.667	5.689	5.671	5.719
	(0.500)	(0.487)	(0.487)	(0.489)	(0.486)
1999	5.595	5.637	5.672	5.643	5.690
	(0.487)	(0.472)	(0.481)	(0.480)	(0.473)
2000	5.616	5.670	5.689	5.661	5.699
	(0.532)	(0.507)	(0.496)	(0.524)	(0.516)
2001	5.592	5.620	5.635	5.617	5.666
	(0.502)	(0.494)	(0.474)	(0.498)	(0.495)
2002	5.589	5.620	5.622	5.627	5.657
	(0.502)	(0.510)	(0.491)	(0.515)	(0.486)
			De Loecker		
1995	4.842	4.969	4.994	4.906	4.982
	(1.068)	(0.933)	(0.988)	(1.052)	(0.943)
1996	4.828	4.930	4.957	4.895	4.975
	(1.063)	(0.947)	(0.991)	(1.069)	(0.946)
1997	4.828	4.941	4.938	4.905	4.963
	(1.040)	(0.917)	(0.961)	(1.040)	(0.917)
1998	4.891	4.988	4.986	4.951	5.010
	(1.037)	(0.934)	(0.964)	(1.043)	(0.935)
1999	4.863	4.971	4.977	4.924	4.985
	(1.033)	(0.919)	(0.966)	(1.037)	(0.922)
2000	4.908	5.018	5.010	4.963	5.010
	(1.041)	(0.918)	(0.970)	(1.044)	(0.922)
2001	4.910	4.987	4.980	4.934	5.004
	(1.028)	(0.925)	(0.950)	(1.038)	(0.922)
2002	4.911	4.973	4.958	4.944	4.992
	(1.000)	(0.920)	(0.940)	(1.028)	(0.907)

Note: Number of observations: 193,277. Std. dev. are in parenthesis.

5.2. Accessibility and the effect of the bridge

In Table 9, we report the results of the calculated mean accessibility indices for 1995 and 2002 (before and after the opening of the bridge in 1998), calculated using expression (5) in Section 3.2. We do so for Denmark as a whole and for the five regions defined above. Mean accessibility at the country level increased by 12.24%, but this figure hides large regional variability. By far the largest increase in accessibility is experienced by Funen (some 36%) located across the bridge opposite the Copenhagen region: Funen's 'proximity' to the Copenhagen area is drastically increased by the opening of the bridge. The increase for the other regions is more modest, especially for West and North Jutland, which is a low density region located at a much larger distance from the bridge.

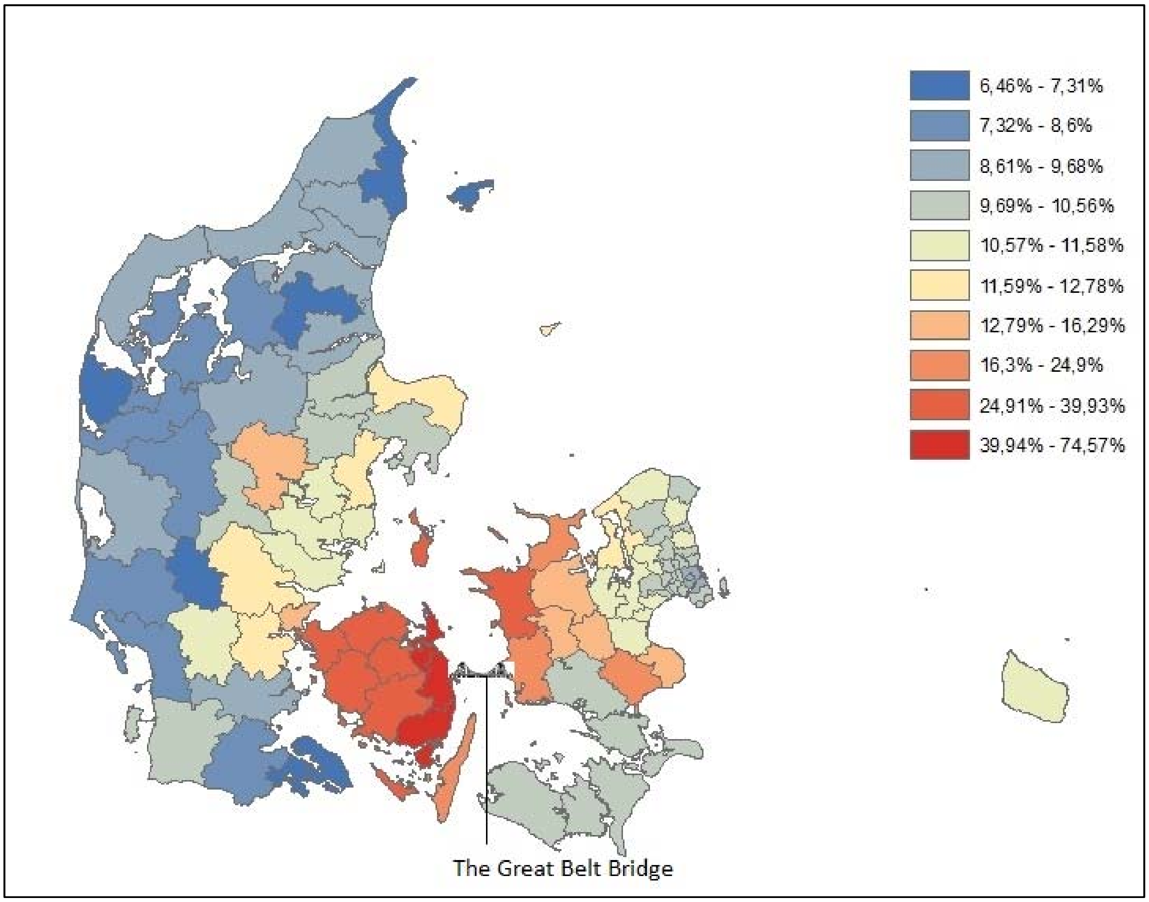
Table 9. Changes in mean for accessibility measure *A* between 1995 and 2002

Regions	A in 1995	A in 2002	Pct. change between 1995 and 2002
Zealand and Bornholm	305	339	11.08%
Funen	96	130	36.00%
South Jutland	123	135	10.54%
East Jutland	141	161	13.67%
West and North Jutland	93	101	8.68%
Total	202	227	12.24%

Note: The accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'}\, e^{-\delta\, d_{m\,m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$. Number of observations for each year equal the number of municipalities (98).

In Figure 3 we give a more detailed view of the increase in the calculated indices between 1995 and 2002 for individual Danish municipalities. Accessibility increased most in municipalities closest to the new bridge; these include several municipalities on Zealand and all those on Funen. Especially on the eastern part of Funen accessibility increases dramatically, by more than 50%.

Figure 3. Percentage changes in accessibility measure *A* between 1995 and 2002



Note: The accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'}\, e^{-\delta\, d_{m\,m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$. Number of observations for each year equal the number of municipalities (98).

5.3. The bridge, accessibility and productivity

In this subsection, we present the results when estimating the effect of accessibility (which includes the effect of the bridge) on firms' productivity, following the methodology explained in Section 3.3.

Table 10 shows a first set of results[20]. They report the effect of accessibility on productivity; all estimated equations included firms- and year- fixed effects. The estimated coefficient associated with the agglomeration measure is positive and significant in both specifications. The elasticity of total factor productivity with respect to agglomeration is

[20] The results reported in Table 10 are based on a distance decay parameter in the accessibility measure that equals 0.03. This value is somewhat arbitrary and we have therefore also estimated the equation for a range of other values. The results are insensitive to the value for the decay parameter. See Table A.5 in Appendix A.

estimated at 0.019 and 0.027, depending on whether demand effects are included in the estimation procedure for productivity. Note that the estimated productivity effect of accessibility is larger using De Loecker's approach than using Levinsohn-Petrin's approach. The former approach removes the effect of price and demand adaptations, so that a given change in accessibility will on average yield a larger impact on estimated productivity.

Table 10. Firm fixed effect models for accessibility impact on firm-level tfp

	Levinsohn-Petrin [1]	De Loecker [2]
log(A)	0.019***	0.027***
	(0.004)	(0.006)
Year-fixed effect	Yes	Yes
R-squared	0.007	0.007
Number of obs.	193,277	193,277

Note: Dependent variable is logarithm of tfp; the accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'}\ e^{-\delta\ d_{m\,m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$. ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively; standard errors clustered at the municipality level are in parentheses.

It could be argued that the estimated effect of accessibility on productivity is small. For example, based on the estimates in Table 9, mean accessibility of municipalities in Denmark went up by 12.24% between 1995 and 2002. Our estimates in Table 10 then suggest that this implies an overall increase in productivity (using De Loecker's approach) of just 0.33%. However, note from Figure 3 and Table 9 that accessibility changes were much larger in some regions than in others. Moreover, as shown below, the estimated effect of accessibility itself varies a lot between regions as well as production sectors. In general, firms that do not require much freight transport in production and that sell on the local market, or firms that are located far from the bridge, may be almost unaffected by the transport cost reductions. Furthermore, sectoral and regional variation may not be independent. For example, it follows from Table 5 above that about 60% of FTE's in manufacturing are located in the more remote areas (South-, East-, West- and North Jutland); construction firms on the other hand seem to be to a larger extent concentrated in the two regions closer to the bridge (Zealand/Bornholm and Funen). Small firms may be operating more on local markets than large ones, and depend less on country-wide accessibility. But if small firms are start-ups, looking for new clients throughout the country, they may benefit more from accessibility improvements (possibly due to the bridge) than their larger counterparts that exploit an existing network.

To explore the accessibility effects further we report the results of decomposing our observations on the basis of sector, region and firm size (as observed in 1995). The implications of accounting for regional variation are reported in Table 11. We learn that the opening of the bridge has affected productivity most for firms in Funen and, to a lesser extent, for firms in Zealand/Bornholm, which includes the greater Copenhagen region. It might be argued that these findings are unsurprising, because these two regions are the ones connected by the new bridge and therefore experiencing the largest shock in accessibility. However, the results mean something stronger, viz. these regions are most strongly affected by a *given* change in accessibility. For example, consider the implications for Funen. Accessibility increased on average by 36% between 1995 and 2002 (see Table 9). Using the estimated coefficient of accessibility changes on firm productivity in Funen then results in an estimated 1.87% average productivity increase for firms located there. Do note that productivity in the regions further away from the bridge is not significantly affected by accessibility changes at all. Also note that Funen is a relatively small part of Denmark, and that the change in accessibility is substantial throughout the island, which makes it difficult to distinguish the impact of the accessibility shock from year-effects. To see why, note that the coefficient for accessibility is estimated on the statistical association between differences in accessibility and differences in productivity. The limited variation in the differences in accessibility in Funen then suggests that the productivity gain may have been partly absorbed in the year-fixed effect.

Table 11. Firm fixed effect models for accessibility impact on firm-level TFP for different regions (total factor productivity based on De Loecker's (2011) method)

	Zealand and Bornholm	Funen	South Jutland	East Jutland	West and North Jutland
	[1]	[2]	[3]	[4]	[5]
log(A)	0.027**	0.052*	-0.007	-0.019	-0.006
	(0.008)	(0.024)	(0.010)	(0.010)	(0.060)
Year-fixed effect	Yes	Yes	Yes	yes	yes
R-squared	0.004	0.009	0.010	0.004	0.004
Number of obs.	76,632	17,261	28,044	29,452	41,888

Note: Dependent variable is logarithm of tfp; the accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'} \, e^{-\delta \, d_{mm'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$. ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels respectively; standard errors clustered at the municipality level are in parentheses.

Table 12 reports estimates separately for the manufacturing industries, the construction industry, and the retail trade industry. Interestingly, we find no significant effect for the manufacturing sector at all. This differs from Holl (2016) who does find significant effects of the proximity to highways on firms' productivity in Spain's manufacturing sector as a whole. Although the difference in results is remarkable, its importance should not be overstated. First, she does report substantial heterogeneity in the impact of highways on firm productivity, with no significant effect estimated for the majority of sectors[21]. The sectors that do yield significant effects are 'mainly traditional manufacturing industries – which tend to have a higher weight-to-value ratio.' (Holl, 2016, p. 132). Such industries are much less important in Denmark, a high wage country where the manufacturing sector emphasizes much more high value-added products. This may be part of the explanation for the difference in results. Second, Holl (2016) uses a different productivity index as well as a different explanatory variable (viz., proximity to highways) to capture the role of improved infrastructure[22]. Do note that her reported elasticities of total factor productivity with respect to distance to the nearest highway are somewhat smaller -- but of the same order of magnitude (they range between 0.013-0.019) -- as our estimated effects of accessibility for Danish firms in general (see Table 8, with estimates ranging between 0.019-0.027).

The estimated impact of the bridge on the productivity of the construction industry is highly significant, see Table 12. Of course, one could argue that many of these firms may have benefited directly or indirectly during the construction stage of the bridge. However, note that our estimates refer to effects realized *after* the opening of the bridge: our accessibility index only strongly increases when the bridge opened in 1998. If the construction itself would have caused a temporary increase in productivity of construction firms before the opening of the bridge, one might in fact expect a negative impact of the bridge becoming operational itself. This provides some support to the interpretation of our estimate as referring to an impact of the bridge that is truly associated with the improved accessibility.

The impact of the opening of accessibility and the bridge on the retail trade industries is significant and quite large as well. These industries are typically located closer to the main population centers, and a relatively larger share is based on Zealand and Funen. For many of

[21] Table E1 in Holl (2016) reports significant effects on productivity with the expected sign in 4 out of 20 manufacturing industries; for one sector the significant coefficient has the unexpected negative sign. When we estimated our model for each of the manufacturing industries separately, accessibility was insignificant in all sectors considered. The results are available from the authors.

[22] Although we do have information on the proximity to the nearest highway ramp, we cannot replicate the specification Holl (2016) uses, because we do not have access to an acceptable instrument to cope with the endogeneity of this variable. We do use it as a robustness check below, to investigate whether it affects our accessibility estimates when included in the productivity regressions.

these firms the bridge may have caused a substantial decrease in transport costs and a sizeable increase in their (potential) market area.

Table 12. Firm fixed effect models for accessibility impact on firm-level De Loecker tfp for considered NACE one-digit sectors

	Manufacturing	Construction	Retail trade
	[1]	[2]	[3]
log(A)	-0.001	0.026***	0.054***
	(0.009)	(0.006)	(0.014)
Year-fixed effect	Yes	Yes	yes
R-squared	0.004	0.022	0.008
Number of obs.	69,642	86,564	37,071

Note: Dependent variable is logarithm of tfp; the accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'} \; e^{-\delta \, d_{m\,m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$. ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels respectively; standard errors clustered at the municipality level are in parentheses.

Finally, Table 13 presents the results of decomposing the sample of firms on the basis of the number of employees. It shows that only the small firms (<50 FTE) are positively affected by the improved accessibility. The aggregate impact on medium-sized and larger firms is not significant.[23]

Table 13. Firm fixed effect models for accessibility impact on firm-level De Loecker tfp for small, medium and large firms

	<50 FTEs	50-250 FTEs	>250 FTEs
	[1]	[2]	[3]
		De Loecker	
log(A)	0.036***	-0.0003	0.032
	(0.007)	(0.012)	(0.030)
Year-fixed effect	Yes	Yes	yes
R-squared	0.006	0.003	0.003
Number of obs.	144,603	41,764	6,910

Note: Dependent variable is logarithm of tfp; the accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'} \; e^{-\delta \, d_{m\,m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$. Small firms have less than 50 FTEs, medium firms between 50 and 250 FTEs, and large firms more than 250 FTEs. ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively; standard errors clustered at the municipality level are in parentheses.

[23] Note that we considered estimating the effect of accessibility on productivity, jointly taking into account firm size as well as regional and sectoral variation. There are at least two approaches for doing this, but they turned out to be too demanding for our data. One approach only requires a single specification but has many coefficients; the other approach would be to have separate regressions for every cell of the 45 cells cross table (5 regions x 3 industries x 3 size classes). Unfortunately, since many of these cells have few observations neither approach produced interesting results on top of those reported in the paper.

5.4. Isolating the productivity effect of the bridge

Given the way we calculated the accessibility index, changes in accessibility are not all due to the bridge, but they also capture changes in the distribution of employment across municipalities. Although some of these employment changes also may have been the result of the opening of the bridge, not all of them are. For example, there was a positive trend in employment throughout Denmark in the period we considered, so that some increases in local employment were likely to be unrelated to the effect of the bridge. Of course, pure trends will be reflected in the year-fixed effects, but our coefficient on accessibility reflects the impact of the bridge as well as those of the remaining changes in the employment distribution across municipalities.

To investigate the relevance of these issues we calculate an alternative accessibility index that artificially eliminates all variability except that which is due to the change in infrastructure (the opening of the bridge). A similar approach was suggested by Ahlfeldt and Feddersen (2018) in a different context. In our model, it implies calculating accessibility, but keeping employment fixed in all municipalities throughout Denmark. Based on straightforward algebra, we show in Appendix B how to disentangle the change in accessibility used earlier in the paper in two components: the effect of the infrastructure (hence, holding employment fixed) and the remaining effect, capturing the effect of changes in the distribution of employment (hence, holding travel times fixed).

The results of this decomposition are in Table 14, both for the country as a whole and for the five regions distinguished. The first component captures changes in accessibility holding employment in all municipalities fixed at their 1995 values. This ensures that the calculated change in accessibility between 1995 and 2002 only reflects the impact of the travel time changes due to the bridge. The second component then keeps travel times constant and captures accessibility changes associated with changes in employment. The results show that the bridge accounts for almost all of the changes in accessibility in Funen, but this is not the case elsewhere. Not surprisingly, in regions very far from the bridge (for example, West and North Jutland) accessibility changes are more due to employment increases in the Danish economy than to the opening of the bridge. Note that there is much more regional variation due to the bridge than due to employment changes. The effect of changes in the distribution of employment is quite uniform across the country.

Table 14. Summary statistics for decomposition of the TFP, by year and region

	Accessibility measure			Accessibility measure FTE's fixed at 1995 level			Accessibility measure travel times fixed at the 2002 level		
	1995	2002	% change	1995	2002	% change	1995	2002	% change
Zealand and Born.	305.38 (127.74)	339.22 (137.69)	11.08%	305.38 (127.74)	312.28 (125.99)	2.26%	312.28 (125.99)	339.22 (137.69)	8.63%
Funen	95.86 (38.09)	130.37 (47.74)	36.00%	95.86 (38.09)	122.79 (44.74)	28.09%	122.79 (44.74)	130.37 (47.74)	6.17%
South Jutland	122.58 (40.20)	135.50 (47.31)	10.54%	122.58 (40.20)	127.55 (43.46)	4.05%	127.55 (43.46)	135.50 (47.31)	6.23%
East Jutland	141.44 (47.52)	160.78 (50.15)	13.67%	141.44 (47.52)	147.61 (45.93)	4.36%	147.61 (45.93)	160.78 (50.15)	8.92%
West and North Jut.	92.70 (36.71)	100.75 (40.59)	8.68%	92.70 (36.71)	93.31 (37.18)	0.66%	93.31 (37.18)	100.75 (40.59)	7.97%
Total	201.98 (134.67)	226.70 (146.34)	12.24%	201.98 (134.67)	209.39 (133.91)	3.67%	209.39 (133.91)	226.70 (146.34)	8.27%

Notes: The accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'} \, e^{-\delta \, d_{m\,m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$; standard deviations are in parentheses.

The 'alternative' accessibility index gives us two crude and mechanical ways to 'isolate' the effect of the bridge on productivity or, stated differently, to 'purify' the accessibility effect on productivity from changes that are potentially unrelated to the opening of the bridge. The first one is to take account of the relative importance of the changes in travel time due to the bridge in the accessibility index. To illustrate the implications, take a few examples. Consider the information in Table 14 for Denmark as a whole. It suggests that the changes in travel time specifically due to the bridge contributed to the increase in accessibility for 30% (note that 3.67/12.24=0.30). The elasticity of productivity with respect to accessibility was estimated earlier as 0.027 (see Table 10). Combining these two pieces of information gives a crude estimate of the elasticity of productivity with respect to bridge-related accessibility; it amounts to 0.008 (=0.027*0.3). This effect is very small indeed, suggesting that on average the bridge raised the productivity of Danish firms only very marginally. Using the percentage increase in accessibility due to the bridge, we find that the total effect of the bridge was to increase productivity by as little as 0.033%. However, looking at individual regions reveals huge differences in the effect of the bridge. For Zealand/Bornholm, a similar exercise suggests an elasticity of productivity with respect to bridge-related accessibility in Zealand/Bornholm of 0.055%. Noting that the bridge raised accessibility by 2.26% the total effect of the bridge on productivity can be calculated at 0.012%. However, consider Funen, on the opposite side of the bridge. Here Table 14 suggests that 78% of the improvement in accessibility (28.09/36=0.78) was directly related to the opening of the bridge. Using the appropriate coefficient of Table 10 (which equals 0.052) this suggests an elasticity of productivity with respect to bridge-related accessibility of 0.041. The total impact of the bridge can therefore be calculated at 1.14% of output. This is a sizeable effect for a single piece of infrastructure. Note also that the effect on municipalities on Funen closest to the bridge is even much larger. For those communities the increase in accessibility is more than 50%, and the contribution to productivity larger than 1.5%.

A second method to isolate the effect of the bridge is to re-estimate the effect of accessibility on productivity, but using the 'fixed employment' accessibility index. The estimation results for the country as a whole are in Table 15 where, for convenience, we also repeat the results when using the standard accessibility index we used before. We limit the analysis to the productivity estimates obtained using De Loecker's method. The results show that accessibility changes that are due to the bridge in this 'narrow' sense again have a positive effect on the productivity of Danish firms: the estimated coefficient is significant at the 1% level. However, the estimates also show that keeping employment fixed has a substantial effect. The estimated coefficient of the accessibility change – which was 0.027 using the measure discussed before -- reduces to 0.009. Note that this elasticity is almost identical to that obtained using the first method described before (equal to 0.008, see above).

The even distribution of employment changes across all regions observed in Table 14 – including regions far from the bridge -- suggests that the bridge is not the main driver of changes in the countrywide distribution of employment. A conservative interpretation would then be to view our estimate of 0.027 (based on the global accessibility index) and the estimate of 0.009 (based on the 'narrow' index) as an absolute upper and lower bound on the effect of the bridge on productivity, respectively.

Table 15. Firm fixed effect models for accessibility impact on firm-level tfp

	[1]	[2]
log[A (FTE's vary over time)]	0.027***	
	(0.006)	
log[A (FTE's fixed at 1995 level)]		0.009***
		(0.003)
Year-fixed effect	Yes	Yes
R-squared	0.007	0.005
Number of obs.	193,277	193,277

Note: Dependent variable is logarithm of tfp; the accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'}\ e^{-\delta\ d_{m\,m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$. ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively; standard errors clustered at the municipality level are in parentheses.

In Appendix B we further explore the effects of using different accessibility indices, distinguishing the impact of the travel time changes due to the bridge and of employment changes in the effect of accessibility on productivity. The results confirm that the bridge only has a significant effect on productivity in Zealand/Bornholm and Funen, and that the effect in Funen is quite a bit larger than in the Copenhagen region. We also estimated relations explaining productivity by the two accessibility indices jointly. We found that employment changes are more important in explaining productivity than travel time changes for the Copenhagen region, whereas the opposite holds for Funen. In that region employment increases have no significant effect on productivity, but changes in travel time due to the bridge do significantly increase productivity. In the Jutland regions neither of the two indices has any effect.

Two remarks conclude this subsection. First, we pointed out before that other studies have used proximity to the nearest highway ramp as an indicator for the changes in infrastructure. For several regions, including Funen, such changes were zero over the period 1995-2002 we studied. Moreover, endogeneity is an obvious problem for this variable and, unlike for example Holl (2016), we do not have appropriate instruments to deal with it. As a robustness check only, we did control for changes in the highway network at the country level. Doing so did not affect the estimated effect of the bridge on productivity at all, see Appendix C.

Second, the bridge could have been constructed in response to an (expected) increase in employment, which would lead to reverse causality. The changes in employment that occur close to the bridge would then be interpreted incorrectly as a causal impact of the bridge, whereas the real causality runs the other way around. Removing the employment changes from the accessibility measure (see above) may reduce biases due to the endogeneity of employment. However, note that removing employment changes from the accessibility index does not *necessarily* result in an improved estimate of the effect of the bridge. If (6) is the correct specification of the relationship between accessibility and total factor productivity, we introduce measurement error by removing the changes in employment from the equation, which would bias the estimated coefficient downwards if the changes in employment were independent of the effect of the bridge on travel times. It is, of course, not clear if these changes are independent. It seems likely that a positive impact of the bridge on productivity has increased employment for those firms that benefitted most from the reduced travel times. This suggests a positive correlation between employment changes and reduced travel times. Under the proviso that (6) is correct, we would find the correct value of γ_1 by taking the employment changes into account when computing the accessibility index, and overestimate this parameter if we leave them out. This is clearly not what our data show.

6. Empirical results: wages, and firm births and deaths

As described in the introduction of the paper, a large shock due to a drastic but localized improvement in transport infrastructure may, especially in some locations close to the new infrastructure, have effects well beyond firms' productivity: it may affect wages and land prices, it may induce firms to move, and it may lead new firms to be established and others to disappear. Due to data limitations, we cannot test the long-run effects of the opening of the bridge for all these dimensions. However, in the remainder of this section we do test for the effect on wages, and we report on the effect of accessibility on firm births and deaths on both sides of the bridge.

6.1. Wages

In this subsection, we report the results of Mincerian wage regressions capturing the possible effect of the bridge on wages. The data used in the table are derived from annual register data from Statistics Denmark for the years 1995–2002. We observe the full population of firms and their workers. For each year, we have information on workers' residence and workplace (both at the municipal level), we have data on hourly wages, and we have a range of explanatory variables for each worker: educational level, age, gender, full-time versus part-time, and the sector of employment. We select workers who have been employed for at least one year. Our Mincerian wage regression is then based on 1,990,619 workers.

In Table 16 we report results, ignoring regional differentiation. The model includes fixed effects for workers, the industrial sector, the municipality where the firm is located, and year-fixed effects. Moreover, we included information on the number of children and cohabitation status[24]. Note that we use worker fixed effects, so that many household characteristics are captured by these fixed effects.

The first column in the table shows that an increase in accessibility significantly raises wages, but that the effect is small; the estimated elasticity is 0.0077. Noting from above that overall accessibility increased by 12.24% this roughly means that accessibility raised wages by 0.1% over the period considered. Of course, this small global effect hides regional variability, see below. Also note that the coefficient on the agglomeration coefficient slightly decreases

[24] Table D.1 in Appendix D reports descriptive statistics for workers. Note that the deleted dummy for cohabitation status refers to married workers.

when we control for worker characteristics such as the number of children, marital or cohabiting status, etc. (see column 2).

There are two endogeneity issues that deserve attention here. First, we must guarantee that accessibility changes are exogenous to workers. We therefore re-estimated the wage equation only for the subsample for which residence and job locations did not change (see column 3). This avoids endogeneity due to the fact that changes in jobs or residence may have been realized *because* of the changes in accessibility that we are analyzing. Restricting the regression to workers who do not change residence and job locations has a significant effect on the estimated wage effect.[25] The elasticity of wages with respect to accessibility is even lower: it reduces to 0.0044. Second, the workings of labor markets suggest that equilibrium wages and employment are jointly determined. As our accessibility index is calculated using employment information, this might introduce correlation with the error term. However, as the accessibility index uses the full distribution of employment changes, both over time and between municipalities, and wages are determined at the level of the worker, we expect the potential bias this might generate to be very small.

[25] In our sample, 9.23 % of workers move residence, 22.86 % move job, 27.29 % move job or residence, and 4.80 % move both job and residence.

Table 16. Mincerian wage regression, worker fixed effects

	[1] All workers	[2] All workers	[3] Job and residence stayers
log(A)	0.0077***	0.0065***	0.0044***
	(0.0001)	(0.0001)	(0.0004)
Dummy variable indicating 1 child		0.0238***	0.0161***
		(0.0002)	(0.0007)
Dummy variable indicating 2 children		0.0377***	0.0252***
		(0.0002)	(0.0011)
Dummy variable indicating 3 children		0.0460***	0.0316***
		(0.0003)	(0.0012)
Dummy variable indicating more than 3 children		0.0508***	0.0360***
		(0.0008)	(0.0016)
Dummy indicating registered partnership		-0.0052**	-0.0025
		(0.0022)	(0.0034)
Dummy indicating couple living in consensual union		-0.0135***	-0.0107***
		(0.0003)	(0.0005)
Dummy indicating cohabiting couples		-0.0092***	-0.0060***
		(0.0002)	(0.0004)
Dummy indicating singles		-0.0077***	-0.0031***
		(0.0002)	(0.0007)
Sector-fixed effect (53 sectors)	No	Yes	No
Municipality fixed effect (workplace)	No	Yes	No
Year fix effect	Yes	Yes	Yes
R squared	0.4900	0.5000	0.5355
Number of obs.	8,610,211	8,610,211	6,648,714

Note: Dependent variable is logarithm of hourly wage, the accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'}\, e^{-\delta\, d_{m\,m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$. ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels respectively; standard errors clustered at the municipality level are in parentheses.

In Table 17 we further explore the regional variation in the effect of accessibility on wages. Interestingly, although we found quite some regional variation in the effects on productivity, the accessibility coefficient has the same order of magnitude throughout the whole of Denmark; one exception is South Jutland, for which we find a small and insignificant coefficient. The estimated coefficients are only very slightly higher for regions closest to the bridge, Zealand/Bornholm and Funen. Based on the estimated coefficients and using the results from Table 11 above, the improved accessibility raised wages most in Funen, but even there the effect was limited to some 0.25%. Finally, note that in Table D.2 in Appendix D we further explore the wage effects across industrial sectors. The results show that an increase in agglomeration raised wages in all sectors to approximately the same extent, although the coefficient for the construction industry is not significant.

Table 17. Mincerian wage regression for different regions for job and residence stayers, worker fixed effect

	[1] Zealand and Bornholm	[2] Funen	[3] South Jutland	[4] East Jutland	[5] West and North Jutland
log(A)	0.0042***	0.0055***	0.0018	0.0044***	0.0033***
	(0.0003)	(0.0016)	(0.0018)	(0.0004)	(0.0007)
Dummy variable indicating 1 child	0.0170***	0.0145***	0.0149***	0.0167***	0.0154***
	(0.0013)	(0.0010)	(0.0010)	(0.0018)	(0.0006)
Dummy variable indicating 2 children	0.0271***	0.0215***	0.0235***	0.0254***	0.0241***
	(0.0021)	(0.0018)	(0.0014)	(0.0028)	(0.0012)
Dummy variable indicating 3 children	0.0336***	0.0276***	0.0301***	0.0316***	0.0309***
	(0.0023)	(0.0019)	(0.0015)	(0.0029)	(0.0016)
Dummy variable indicating more than 3 children	0.0369***	0.0302***	0.0370***	0.0364***	0.0347***
	(0.0035)	(0.0068)	(0.0030)	(0.0038)	(0.0020)
Dummy indicating registered Partnership	-0.0036	0.0160**	-0.0153	-0.0035	-0.0110
	(0.0048)	(0.0070)	(0.0154)	(0.0032)	(0.0086)
Dummy indicating couple living in consensual union	-0.0114***	-0.0086***	-0.0100***	-0.0115***	-0.0102***
	(0.0009)	(0.0015)	(0.0012)	(0.0015)	(0.0009)
Dummy indicating cohabiting Couples	-0.0069***	-0.0035***	-0.0055***	-0.0067***	-0.0051***
	(0.0006)	(0.0008)	(0.0008)	(0.0005)	(0.0007)
Dummy indicating singles	-0.0039***	-0.0005	-0.0025*	-0.0040***	-0.0023***
	(0.0013)	(0.0008)	(0.0012)	(0.0008)	(0.0007)
Year fix effect	Yes	Yes	Yes	Yes	Yes
R squared	0.5210	0.5721	0.5332	0.5432	0.5523
Number of obs.	3,031,573	550,148	921,929	969,331	1,175,733

Note: Dependent variable is logarithm of hourly wage, the accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'}\, e^{-\delta\, d_{m\,m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$. ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels respectively; standard errors clustered at the municipality level are in parentheses.

6.2. Firm births and deaths

Finally, as the literature survey above indicated, transport infrastructure makes some locations more attractive for new activities. We therefore also considered the effect of the bridge on firm births and deaths. We can only do so at the municipal level, which obviously severely limits the number of observations. The results in Table 18 suggest that the improvement in transport infrastructure has also an impact on the process of creative destruction in which less productive plants are replaced by more productive plants. In the aggregate, it suggests that the bridge has attracted new firms while having had no significant effect on the disappearance of firms. A more detailed look at the regional differences leads to two interesting conclusions. First, the bridge has generated a number of firm births in Zealand/Bornholm (the Copenhagen region), but we also find some evidence that, despite the large productivity effects on firms in Funen, it implied the death of a number of firms on the island (mainly firms related with construction activities and support services). Interpreting this from the viewpoint of Krugman's core-periphery model (Krugman (1991), Krugman and Venables (1995)), this seems to indicate that the bridge may well have strengthened the core region at the expense of the periphery. Second, unsurprisingly, the bridge did not affect firm births and deaths in the outer Jutland regions.

Table 18. Fixed effect models for share of firm births and deaths at the municipality level

	All	Zealand and Bornholm	Funen	South Jutland	East Jutland	West and North Jutland
				Births		
	[1]	[2]	[3]	[4]	[5]	[6]
log(A)	0.004***	0.007***	-0.004	0.001	-0.003	-0.004
	(0.001)	(0.003)	(0.008)	(0.003)	(0.006)	(0.004)
Year-fixed effect	Yes	yes	yes	Yes	yes	yes
R-squared	0.094	0.138	0.191	0.095	0.176	0.183
				Deaths		
log(A)	0.005	0.003	0.030*	0.001	0.036	-0.014
	(0.004)	(0.007)	(0.016)	(0.009)	(0.024)	(0.010)
Year-fixed effect	yes	yes	yes	Yes	yes	yes
R-squared	0.158	0.146	0.369	0.201	0.165	0.181
Number of obs.	784	368	80	96	88	152

Note: The accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'}\, e^{-\delta\, d_{m m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$. ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels respectively; standard errors clustered at the municipality level are in parentheses.

7. Conclusion

In this paper we studied the short-run effects of a large discrete shock in transport infrastructure, viz., the opening of the Great Belt bridge (in 1998) connecting the Copenhagen region with the rest of the country. We captured the effect of the opening of the bridge through its effect on accessibility throughout the country, whereby the bridge drastically affected travel times between municipalities located on opposite sides of the bridge. Using the recent methodology developed by De Loecker (2011) to account for demand-side effects, we found significant positive effects of the improved accessibility on the productivity of Danish firms in the construction industry and in the retail industry but, surprisingly, not in the manufacturing sectors. The opening of the bridge has affected productivity most for firms in Funen and, to a lesser extent, for firms in Zealand/Bornholm, which includes the greater Copenhagen region. These findings are unsurprising to the extent that these are the two regions directly connected by the new bridge and therefore experiencing the largest shock in accessibility. What is unexpected, however, is that these regions are most strongly affected by a *given* change in accessibility. The bridge increased productivity by more than 1% of output for firms close to the bridge. The productivity improvements were limited to relatively small firms that are typically active on a local or regional scale. Do note that productivity in the regions further away from the bridge is not significantly affected by accessibility changes at all.

Our estimates of the productivity effects of accessibility changes are consistently larger when using De Loecker's method, which makes an attempt to correct for demand side effects on productivity that are ignored in the Levinsohn-Petrin method. This suggests that the positive effects of accessibility on productivity are associated with lower prices as would be expected when improved accessibility increases competition between firms.

We further studied the impact of the opening of the bridge on wages throughout the country, and on firm births and deaths on both sides of the bridge. We find systematic positive but small elasticities of wages with respect to accessibility throughout the country, even in regions far from the bridge. Moreover, the evidence with respect to firm births and deaths is consistent with Krugman's core-periphery model: the bridge seems to have stimulated new activities in the Copenhagen region at the expense of firms disappearing on the neighbouring island Funen. However, note that the mechanism is different, since Krugman's model has equal productivity for all firms. We find a significant positive effect of improved accessibility on productivity that is partly or completely eaten away by lower prices, that are probably due to increased competition caused by the same change in accessibility, and higher wages.

References

Ahlfeldt, G.M. and A. Feddersen, 2018. From periphery to core: measuring agglomeration effects using high-speed rail, *Journal of Economic Geography 18*, 350-390.

Arzaghi, M. and J.V. Henderson, 2008. Networking off Madison Avenue. *Review of Economic Studies*, 1011–1038.

Baum-Snow, N. 2007. Did highways cause suburbanization? *The Quarterly Journal of Economics*, 122, 775–805.

Chandra, A. and E. Thompson, 2000. Does public infrastructure affect economic activity: evidence from the interstate highway system, *Regional Science and Urban Economics* 30 (4), 457-490.

Ciccone, A. and R. Hall. 1996. Productivity and the Density of Economic Activity. *American Economic Review,* vol. 86, issue 1, 54-70.

Combes, P.-Ph., Duranton, G., Gobillon, L., Puga, D. and S. Roux, 2012. The productivity advantages of large cities: distinguishing agglomeration from firm selection. *Econometrica*, 80 (6), 2543–2594.

Coughlin, C. and E. Segev, 2000. Location determinants of new foreign-owned manufacturing plants, *Jounral of Regional Science* 40 (2), 323-351.

Datta, S, 2012. The impact of improved highways on Indian firms, *Journal of Developments Economics* 99 (1), 46-57.

Dekle, R. and J. Eaton. 1999. Agglomeration and Land Rents: Evidence from the Prefectures. *Journal of Urban Economics* 46, pp. 200-214.

De Loecker, J. 2011. Product differentiation, multiproduct firms and estimating the impact of trade liberalization on productivity. *Econometrica*, 79 (5), 1407–1451.

Donaldson, D., 2018, Railroads of the Raj: estimating the impact of transport infrastructure, *American Economic Review*, vol. 108, no. 4-5, 899-934

Donaldson, D. and R. Hornbeck, 2016, Railroads and American economic growth: a ‘market access’ approach, *Quarterly Journal of Economics* 131 (2), 799-858.

Duranton, G. and M.A. Turner, 2012. Urban growth and transportation. *Review of Economic Studies*, 79 (4), 1407–1440.

Duranton, G., P. Morrow and M.A. Turner, 2014. Roads and trade: Evidence from the US. *Review of Economic Studies*, 81 (2), 681–724.

Duranton, G. and D. Puga, 2004. Micro-foundations of Urban Agglomeration Economies.” In *Handbook of Urban and Regional Economics*, vol. 4, edited by J. Vernon Henderson and Jacques-Francois Thisse. Amsterdam: North-Holland.

Faber, B., 2014. Trade integration, market size, and industrialization, *Review of Economic Studies* 81, 1046-1070.

Fretz, S., Parchet, R. and F. Robert-Nicaud, 2017. Highways, market access and spatial sorting, CESifo working paper 6770.

Ghani, E., Grover Goswarni, A. and W.R. Kerr, 2016. Highway to success: the impact of the golden quadrilateral project for the location and performance of Indian manufacturing, *The Economic Journal* 126, 317-357.

Gaubert, S, 2018. Firm sorting and agglomeration. *American Economic Review*, vol. 108, no. 11, 3117-53.

Gibbons, S., T. Lyytikäinen, H. Overman and R. Sanchis-Guarner, 2019. New road infrastructure: the effects on firms. *Journal of Urban Economics*, vol. 110, pp. 35-50.

Graham, D.J., 2007a. Agglomeration productivity and transport investment, *Journal of Transport Economics and Policy* 41 (3), 317-343.

Graham, D.J., 2007b. Variable returns to agglomeration and the effect of road traffic congestion, *Journal of Urban Economics* 62, 103-120.

Greenstone, M., R. Hornbeck and E. Moretti, 2010. Identifying Agglomeration Spillovers: Evidence from Winners and Losers of Large Plant Openings. *Journal of Political Economy*, Vol. 118, No. 3, pp. 536-598.

Hanson, H. H., 2005. Market potential, increasing returns and geographic concentration. *Journal of International Economics*, 67, pp. 1-24.

Helsley, R.W. and W.C. Strange, 1990. Matching and agglomeration economies in a system of cities. *Regional Science and Urban Economics*, **20**, 189-212.

Holl, A., 2004a. Manufacturing location and impacts of road transport infrastructure: Empirical evidence from Spain. *Regional Science and Urban Economics*, 34, (3), 341–363.

Holl, A. 2004b. Transport infrastructure, agglomeration economies, and firm birth: empirical evidence from Portugal, *Journal of Regional Science* 44 (4), 693-712.

Holl, A., 2012. Market potential and firm level productivity in Spain, *Journal of Economic Geography* 19 (6), 1282-1293.

Holl, A., 2016. Highways and productivity in manufacturing firms. *Journal of Urban Economics*, 93, 131–151

Krugman, P., 1991. Increasing returns and economic geography, *Journal of Political Economy* 99, 483-499.

Krugman, P. and A.J. Venables, 1995. Globalization and the Inequality of Nations. *The Quarterly Journal of Economics*, Vol. 110, No. 4, pp. 857-880.

Levinsohn, J. and J. Petrin. 2003. Estimating production functions using inputs to control for unobservables. *Review of Economic Studies*, 70 (2), 317–341.

Li, H. and Z. Li, 2013. Road investment and inventory reduction: firm-level evidence from China, *Journal of Urban Economics* 76, 43-56.

Lucas, R.E. and Rossi-Hansberg, E. 2002. On the internal structure of cities. *Econometrica*, vol. 70(4), pp. 1445–76.

Mare, D. and D. Graham, 2013. Agglomeration elasticities and firm heterogeneity, *Journal of Urban Economics* 75, 44-56.

Melo, P.C., D.J. Graham and R.B. Noland, 2009. A meta-analysis of estimates of urban agglomeration economies. *Regional Science and Urban Economics*, 39, 332–342.

Michaels, G., 2008, The effect of trade on the demand for skill: evidence from the interstate highway system, *Review of Economics and Statistics* 90 (4), 683-701.

Olley, G. S. and A. Pakes, 1996. The dynamics of productivity in the telecommunications equipment industry. *Econometrica* 64, 1263–1297.

Puga, D., 2010. The Magnitude and Causes of Agglomeration Economies. *Journal of Regional Science*, 50 (1), 203-219.

Redding, S. J. and E. Rossi-Hansberg, 2017. Quantitative Spatial Economics. *Annual Review of Economics*, Vol. 9. 21-58.

Redding, S. J. and Turner, M. A., 2015. Transportation Costs and the Spatial Organization of Economic Activity, in G. Duranton, J. V. Handerson and W. C. Strange (eds), Handbook of Regional and Urban Economics, Elsevier, pp. 1339–1397.

Rich, J., Nielsen O.A., Brems, C. and Hansen, C.O., 2010. Overall design of the Danish National transport model. Annual Transport Conference at Aalborg University 2010.

Roback, J., 1982. Wage, rents and the quality of life. *Journal of Political Economy*, vol. 90, no. 6, 1257-1278.

Rosenthal, S., Strange, W.C., 2001. The determinants of agglomeration. *Journal of Urban Economics* 50 (2), 191–229 .

Rosenthal, S., Strange, W.C., 2004. Evidence on the Nature and Sources of Agglomeration Economies. In: Henderson, J.V., Thisse, J.-F. (Eds.). In: Handbook of Urban and Regional Economics, 4. Elsevier, Amsterdam, pp. 2119–2172. Volume .

Sanchis-Guarner, R., 2012. Driving Up Wages: The Effects of Road Construction in Great Britain, SERC Discussion Paper 120, UK Spatial Economics Research Centre.

Shirely, C. and C. Winston, 2004. Firm inventory behavior and the returns from highway infrastructure investments, *Journal of Urban Economics* 55, 398-415.

Spiekermann, K., Wegener, M., Kveton, V., Marada, M., Schürmann, C., Biosca, O., Ulied Segui, A., Antikainen, H., Kotavaara, O., Rusanen, J., Bielanska, D., Fiorello, D., Komornicki, T., Rosik, P., Stepniak, M. 2015. Transport Accessibility at Regional/Local Scale in Europe TRACC Scientific Report. Luxembourg: ESPON.

Storeygard, A., 2016. Farther on down the Road: Transport Costs, Trade and Urban Growth in Sub-Saharan Africa, *The Review of Economic Stud*ies 83(3): 1263–1295.

Appendix A. Estimating production functions: Supplementary tables and figures

Table A.1. Means and standard deviations for selected variables by region

Year		1995	1996	1997	1998	1999	2000	2001	2002
Zealand and Bornholm	Turnover (1000 DKK)	10,389	9,886	10,035	10,097	10,175	10,079	10,012	9,903
		(42,496)	(35,568)	(36,979)	(36,696)	(38,097)	(37,612)	(41,633)	(35,643)
	Full Time job Equivalents	10.40	9.85	9.91	9.62	9.55	9.35	9.22	9.04
		(34.39)	(28.15)	(28.61)	(26.43)	(26.76)	(23.42)	(23.81)	(24.96)
	Capital (1000 DKK)	2,638	2,431	2,420	2,467	2,580	2,955	3,038	2,750
		(21,039)	(15,845)	(14,423)	(15,350)	(17,480)	(47,200)	(47,081)	(22,691)
Funen	Turnover (1000 DKK)	11,665	12,528	12,516	13,074	13,289	13,653	14,322	14,901
		(67,793)	(96,166)	(82,557)	(82,733)	(96,384)	(82,024)	(97,880)	(111,328)
	Full Time job Equivalents	13.11	13.21	13.16	13.58	13.15	13.04	13.36	13.21
		(73.37)	(74.81)	(72.88)	(72.78)	(65.71)	(62.46)	(66.68)	(65.46)
	Capital (1000 DKK)	3,323	3,259	4,679	3,400	3,277	3,269	3,806	4,672
		(23,298)	(23,378)	(39,443)	(24,420)	(23,611)	(24,197)	(28,252)	(25,936)
South Jutland	Turnover (1000 DKK)	15,005	14,960	14,475	14,487	14,542	13,950	14,069	13,097
		(94,466)	(97,121)	(67,011)	(71,835)	(68,447)	(66,198)	(66,219)	(56,563)
	Full Time job Equivalents	13.62	13.56	12.88	13.14	13.08	12.49	12.50	11.49
		(69.68)	(68.64)	(43.24)	(53.02)	(47.80)	(42.83)	(42.40)	(31.06)
	Capital (1000 DKK)	3,511	3,645	3,473	3,327	3,560	3,075	3,242	3,200
		(23,065)	(24,941)	(21,007)	(19,454)	(23,074)	(18,577)	(20,052)	(17,653)
East Jutland	Turnover (1000 DKK)	11,551	11,554	11,729	11,616	11,604	11,528	12,146	12,671
		(42,388)	(41,476)	(41,980)	(38,677)	(36,943)	(35,115)	(39,219)	(43,622)
	Full Time job Equivalents	11.86	11.70	11.92	11.80	11.37	11.22	11.54	11.30
		(36.62)	(35.82)	(36.77)	(36.12)	(31.13)	(30.62)	(31.02)	(29.74)
	Capital (1000 DKK)	2,897	2,615	2,644	2,733	3,010	3,151	3,358	3,622
		(18,195)	(12,347)	(10,447)	(15,795)	(27,239)	(35,665)	(38,459)	(37,768)
West and North Jutland	Turnover (1000 DKK)	12,264	12,207	13,134	13,161	13,325	13,134	13,122	12,904
		(39,749)	(38,505)	(46,409)	(48,478)	(60,116)	(44,664)	(44,330)	(42,930)
	Full Time job Equivalents	12.64	12.17	12.73	12.52	12.38	12.09	12.15	11.62
		(35.67)	(33.50)	(36.08)	(35.59)	(38.45)	(32.54)	(32.40)	(28.99)
	Capital (1000 DKK)	3,038	3,014	3,181	3,205	3,214	2,990	3,298	3,464
		(17,948)	(18,991)	(20,166)	(21,418)	(22,964)	(22,577)	(27,043)	(29,537)

Notes: Number of observations is 200,177. Std. dev. is in parenthesis. 1 DKK ≈ 0.13 €.

Table A.2. Means and standard deviations for selected variables for stayers and movers

	Turnover (1000 DKK)	FTE	Capital (1000 DKK)	Number of observations
All firms	11,905	11.12	2,935	200,177
	(51,008)	(38.19)	(25,791)	
Stayers	11,862	11.08	2,933	193,277
	(51,609)	(38.66)	(26,076)	
Movers	12,874	12.22	2,977	6,900
	(34,690)	(25.48)	(18,149)	

Notes: Std. dev. is in parenthesis. 1 DKK ≈ 0.13 €.

Table A.3. Means for selected variables by four-digit NACE sectors and their segments

NACE four-digit sectors	Segments	Turnover (1000 DKK)	FTE
Mfr. of food, beverages and tobacco	Production etc. of meat and meat products	47.114	27,06
	Mfr. of dairy products	63.734	24,27
	Baker´s shops	3.677	6,61
	Mfr. of other food products	69.234	36,27
	Mfr. of beverages	85.508	42,57
	Mfr. of tobacco products	63.095	57,86
Mfr. of textiles and leather	Mfr. of textiles	17.710	16,30
	Mfr. of wearing apparel	14.525	11,57
	Mfr. of leather and footwear	31.620	18,08
Mfr. of paper prod.; printing and publish.	Mfr. of pulp, paper and paper products	52.118	31,96
	Publishing of newspapers	42.565	43,86
	Publishing activities, excluding newspapers	13.350	9,66
	Printing activities	9.552	10,09
Mfr. of chemicals	Mfr. of chemical raw materials	98.537	48,40
	Mfr. of paints and soap	47.306	28,73
	Mfr. of pharmaceuticals	60.367	40,58
Mfr. of other non-metallic mineral prod.	Mfr. of glass and ceramic goods	21.459	19,85
	Mfr. of tiles, bricks, cement and concrete	17.646	16,29
Mfr. and processing of basic metals	Mfr. of basic metals	50.187	44,46
	Mfr. of building materials of metal	10.896	13,11
	Mfr. of various metal products	16.850	20,23
Mfr. of machinery and equipment	Mfr. of marine engines and compressors	36.565	40,01
	Mfr. of ovens and cold-storage plants	28.667	29,11
	Mfr. of agricultural machinery	16.359	17,36
	Mfr. of machinery for industries	18.167	20,01
	Mfr. of domestic appliances	65.877	72,93
Mfr. of electronic components	Mfr. of computers and electric motors	18.529	17,60
	Mfr. of radio and communication equipment	54.018	49,94
	Mfr. of medical and optical instruments	21.090	20,81
Mfr. of transport equipment	Building of ships and boats	45.488	40,95
	Mfr. of transport equipment, excl. ships	39.217	35,74
Mfr. of furniture; manufacturing n.e.c.	Mfr. of furniture	17.438	20,05
	Mfr. of toys and jewellery	12.647	11,81
Construction	General contractors	12.932	11,42
	Bricklaying	4.824	6,22
	Install. of electrical wiring and fittings	6.995	9,28
	Plumbing	5.922	7,28
	Joinery installation	5.729	6,59
	Painting and glazing	3.208	6,48
	Other construction works	5.117	5,66
Other retail sale, repair work	Re. sale of furniture and household appliances	7.358	4,93
	Re. sale in other specialized stores	4.905	3,44
	Repair of household goods	3.197	3,52

Notes: 1 DKK ≈ 0.13 €.

Table A.4. Production function estimation: empirical results

	Levinsohn-Petrin			De Loecker (βs)				De Loecker (αs)			Wald test of CRS, De Loecker	No. of obs.
Sector	Labour	Capital	Energy and rent	Labour	Capital	Energy and rent	Output	Labour	Capital	Energy and rent	χ^2	
Mfr. of food, beverages and tobacco	0.326***	0.145***	0.366***	0.330***	0.151***	0.283*	0.211***	0.418***	0.191***	0.359*	0.03	6,395
	(0.020)	(0.017)	(0.188)	(0.018)	(0.020)	(0.159)	(0.011)	(0.024)	(0.025)	(0.202)	(p = 0.8655)	
Mfr. of textiles and leather	0.496***	0.173***	0.189***	0.499***	0.161***	0.199***	0.112***	0.562***	0.182***	0.224***	0.98	4,943
	(0.014)	(0.021)	(0.018)	(0.014)	(0.019)	(0.017)	(0.018)	(0.022)	(0.022)	(0.019)	(p = 0.3220)	
Mfr. of paper prod.; printing and publish.	0.484***	0.143***	0.254***	0.493***	0.140***	0.248***	0.226***	0.638***	0.181***	0.321***	4.27	12,200
	(0.010)	(0.008)	(0.022)	(0.012)	(0.009)	(0.004)	(0.041)	(0.042)	(0.012)	(0.031)	(p = 0.0388)	
Mfr. of chemicals	0.534***	0.151***	0.398***	0.527***	0.156***	0.399***	0.009	0.532***	0.158***	0.403***	0.61	1,681
	(0.034)	(0.041)	(0.124)	(0.035)	(0.053)	(0.019)	(0.010)	(0.035)	(0.054)	(0.120)	(p = 0.4342)	
Mfr. of other non-metallic mineral products	0.608***	0.195***	0.059***	0.622***	0.179***	0.059**	0.089***	0.683***	0.196***	0.065**	2.70	2,829
	(0.022)	(0.028)	(0.024)	(0.024)	(0.030)	(0.024)	(0.016)	(0.031)	(0.032)	(0.027)	(p = 0.1003)	
Mfr. and processing of basic metals	0.540***	0.118***	0.224***	0.539***	0.118***	0.226***	0.118***	0.545***	0.119***	0.228***	29.97	16,026
	(0.010)	(0.009)	(0.021)	(0.010)	(0.004)	(0.017)	(0.004)	(0.010)	(0.009)	(0.017)	(p < 0.0001)	
Mfr. of machinery and equipment	0.511***	0.116***	0.192***	0.504***	0.118***	0.197***	0.058***	0.535***	0.125***	0.209***	33.16	10,649
	(0.012)	(0.011)	(0.021)	(0.012)	(0.011)	(0.021)	(0.005)	(0.013)	(0.012)	(0.022)	(p < 0.0001)	
Mfr. of electronic components	0.480***	0.115***	0.456***	0.477***	0.112***	0.457***	0.046***	0.500***	0.118***	0.479***	2.06	8,139
	(0.015)	(0.018)	(0.070)	(0.014)	(0.019)	(0.072)	(0.008)	(0.014)	(0.020)	(0.076)	(p = 0.1511)	
Mfr. of transport equipment	0.515***	0.155***	0.162***	0.517***	0.151***	0.155***	0.105***	0.577***	0.168***	0.173***	1.78	2,542
	(0.023)	(0.021)	(0.041)	(0.024)	(0.020)	(0.039)	(0.024)	(0.036)	(0.024)	(0.043)	(p = 0.1826)	
Mfr. of furniture; manufacturing n.e.c.	0.460***	0.133***	0.246***	0.459***	0.133***	0.247***	0.002	0.460***	0.133***	0.247***	42.06	7,162
	(0.013)	(0.016)	(0.027)	(0.013)	(0.014)	(0.026)	(0.002)	(0.012)	(0.014)	(0.025)	(p < 0.0001)	
Construction	0.528***	0.106***	0.355***	0.524***	0.110***	0.353***	0.024***	0.537***	0.113***	0.361***	0.04	89,298
	(0.005)	(0.008)	(0.059)	(0.005)	(0.007)	(0.062)	(0.002)	(0.005)	(0.007)	(0.063)	(p = 0.8387)	
Other retail sale, repair work	0.413***	0.146***	0.171***	0.467***	0.102***	0.342***	0.029***	0.481***	0.105***	0.352***	4.07	38,313
	(0.008)	(0.007)	(0.018)	(0.013)	(0.006)	(0.0.027)	(0.005)	(0.014)	(0.007)	(0.028)	(p = 0.0435)	

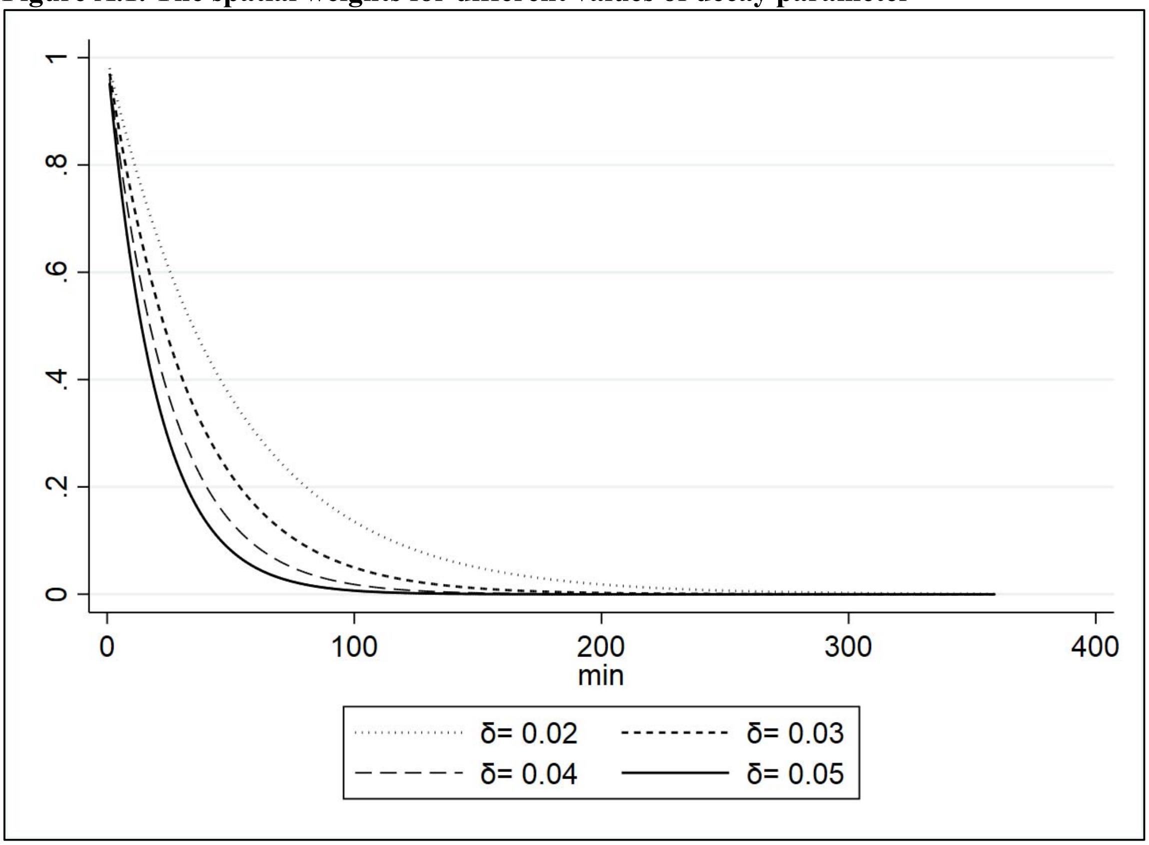
Note: Number of observations is 200,177. Standard errors are in parentheses. ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels respectively.

Table A.5. Firm fixed effect models for accessibility impact on firm-level De Loecker tfp for different decay parameters

	[1]	[2]	[3]	[4]	[5]
	$\delta = 0.01$	$\delta = 0.02$	$\delta = 0.03$	$\delta = 0.04$	$\delta = 0.05$
log(A)	0.029***	0.028***	0.027***	0.026***	0.023***
	(0.007)	(0.006)	(0.006)	(0.008)	(0.006)
Year-fixed effect	yes	Yes	yes	yes	yes
R-squared	0.005	0.005	0.005	0.005	0.005
Number of obs.	193,277	193,277	193,277	193,277	193,277

Note: Dependent variable is logarithm of tfp; the accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'} \, e^{-\delta \, d_{m m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities. ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels respectively; standard errors clustered at the municipality level are in parentheses.

Figure A.1. The spatial weights for different values of decay parameter



Note: the spatial weights are computed as $e^{-\delta \, d_{m m'}}$ where d denotes distance measured in travel time minutes between municipalities.

Appendix B. Decomposing the accessibility index

As mentioned in the main body of the paper, our accessibility index captures both changes in travel times between municipalities and changes in employment. In this appendix we show that the index can be decomposed in two components which each have a clear interpretation. To see this, we start from the definition of our index *A*:

$$A_{m,t} = \sum_{m'} FTE_{m',t}\ e^{-\delta d_{m',t}}$$

Consider the difference of the indicator between two successive periods; we have:

$$A_{m,t+1} - A_{m,t} = \sum_{m'} FTE_{m',t+1}\ e^{-\delta d_{m',t+1}} - \sum_{m'} FTE_{m',t}\ e^{-\delta d_{m',t}}$$

This can be rewritten as:

$$A_{m,t+1} - A_{m,t} = \sum_{m'} \left[e^{-\delta d_{m',t+1}} \left(FTE_{m',t+1} - FTE_{m',t} \right) \right] + \sum_{m'} \left[FTE_{m',t} \left(e^{-\delta d_{m',t+1}} - e^{-\delta d_{m',t}} \right) \right]$$

The first component captures the change in accessibility, holding employment in each municipality fixed at its value in period *t*; the second component holds travel times fixed at their values in period (*t+1*) and considers the changes in employment between periods *t* and (*t+1*). As an illustration, applying this for the change in accessibility between 1995 and 2002 for Denmark as a whole we find:

$$A_{m,2002} - A_{m,1995} = 226.7 - 201.98 = (226.7 - 209.39) + (209.39 - 201.98).$$

Note that the decomposition is additive. We report the results of this decomposition for the country as a whole and for the five regions distinguished in Table 14.

As argued in the text, we further explored the effects of using different accessibility indices, distinguishing the impact (i) of the travel time changes due to the bridge and (ii) of employment changes in the effect of accessibility on productivity. First consider the estimates reported in Table B.1. The results confirm that the bridge only has a significant effect on productivity in Zealand/Bornholm and Funen, and that the effect in Funen is quite a bit larger than in the Copenhagen region. We also report the results of including the two indices separately, see Table B.2. The results suggest that employment changes are at least as important in explaining productivity as travel time changes for the Copenhagen region, whereas the opposite holds for Funen. In that region employment increases have no significant effect on productivity, but changes in travel time due to the bridge do significantly increase productivity. In the other regions neither of the two indices has any effect.

Table B.1. Firm fixed effect models for accessibility impact on firm-level (De Loecker) tfp for different regions

	Zealand and Bornholm	Funen	South Jutland	East Jutland	West and North Jutland
	[1]	[2]	[3]	[4]	[5]
log[A (FTE's fixed at 1995 level)]	0.009**	0.014*	0.012	0.007	0.010
	(0.003)	(0.007)	(0.008)	(0.006)	(0.050)
Year-fixed effect	Yes	Yes	Yes	Yes	Yes
R-squared	0.004	0.008	0.010	0.004	0.005
Number of obs.	76,632	17,261	28,044	29,452	41,888

Note: The accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'} \, e^{-\delta \, d_{m\,m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$. ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels respectively; standard errors clustered at the municipality level are in parentheses.

Table B.2. Firm fixed effect models for accessibility impact on firm-level De Loecker tfp for different regions

	Denmark	Zealand and Bornholm	Funen	South Jutland	East Jutland	West and North Jutland
	[1]	[2]	[3]	[4]	[5]	[6]
Log(accessibility measure)	0.008***	0.005*	0.013*	0.012	0.007	0.001
FTE's fixed at 1995 level	(0.002)	(0.003)	(0.007)	(0.008)	(0.006)	(0.005)
Log(accessibility measure)	0.065***	0.125***	0.210	0.046	-0.091	0.053
travel times fixed at the 2002 level	(0.011)	(0.035)	(0.426)	(0.075)	(0.078)	(0.084)
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.005	0.004	0.009	0.010	0.004	0.005
Number of obs.	193,277	76,632	17,261	28,044	29,452	41,888

Note: Dependent variable is logarithm of tfp; the accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'} \, e^{-\delta \, d_{m\,m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$. ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively; standard errors clustered at the municipality level are in parentheses.

Finally, Table B.3 reports the results of including the two accessibility indices jointly for the three main aggregate sectors, manufacturing, construction and services. Remember that accessibility was significant for construction and services, not for manufacturing. The decomposition now suggests that the accessibility effect on productivity seems to have been driven by employment changes only in the construction industry, the impact of the bridge is significant for manufacturing and services.

Table B.3. Firm fixed effect models for accessibility impact on firm-level De Loecker tfp for considered NACE one-digit sectors

	Manufacturing	Construction	Services
	[1]	[2]	[3]
Log(accessibility measure)	0.007*	-0.0001	0.018**
FTE's fixed at 1995 level	(0.004)	(0.002)	(0.007)
Log(accessibility measure)	-0.014	0.075***	0.160***
travel times fixed at the 2002 level	(0.022)	(0.013)	(0.041)
Year-fixed effect	Yes	Yes	Yes
R-squared	0.004	0.002	0.009
Number of obs.	69,642	86,564	37,071

Note: Dependent variable is logarithm of tfp; the accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'}\ e^{-\delta\ d_{m\,m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$. ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively; standard errors clustered at the municipality level are in parentheses.

Appendix C. Robustness check: control for highway access changes

Although we do have information on access to the nearest highway ramp over the sample period, we can only introduce this extra explanatory variable as a robustness check for our accessibility coefficients. There are two reasons for this. First, unlike previous authors, we do not have appropriate instruments to correct for the possible endogeneity of access to the nearest highway ramp. Second, for several regions, including Funen – a region of particular interest close to the bridge -- we observe zero changes in this variable over the sample period.

When we introduced the change in highway access in the model for the country as a whole, doing so had no effect whatsoever on the coefficient of accessibility, see Table C.1.

Table C.1. Firm fixed effect models for accessibility impact on firm-level De Loecker tfp with control for highways

	[1]
log(A)	0.027***
	(0.006)
log (distance to nearest highway)	0.006**
	(0.003)
Year-fixed effect	Yes
R-squared	0.005
Number of obs.	193,277

Note: Dependent variable is logarithm of tfp; the accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'}\, e^{-\delta\, d_{m\,m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$. ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels, respectively; standard errors clustered at the municipality level are in parentheses.

Appendix D. Wage regressions: supplementary tables

Table D.1. Wage regressions: descriptive statistics for workers

	Mean	Std. Dev.	Min	Max
Hourly wage (DKK/hour)	167.080	55.300	63.000	433.000
One child (share)	0.210	0.407	0.000	1.000
Two children (share)	0.233	0.423	0.000	1.000
Three children (share)	0.053	0.224	0.000	1.000
More than 3 children (share)	0.007	0.087	0.000	1.000
Married couples (share)	0.584	0.493	0.000	1.000
Registered partnership (share)	0.001	0.035	0.000	1.000
Couple living in consensual union (share)	0.069	0.253	0.000	1.000
Cohabiting couples (share)	0.113	0.316	0.000	1.000
Singles (share)	0.234	0.423	0.000	1.000

Notes: Number of observations is 8,610,211. Note that 1 Danish crown (denoted DKK) ≈ 0.13 €.

Table D.2. Mincerian wage regression for different sectors for job and residence stayers, worker fixed effect

	[1] Manufacturing, mining and quarrying, and utility services	[2] Construction	[3] Service
log(A)	0.0020*	0.0027	0.0026***
	(0.0012)	(0.0023)	(0.0005)
Dummy variable indicating 1 child	0.0159***	0.0152***	0.0217***
	(0.0007)	(0.0011)	(0.0008)
Dummy variable indicating 2 children	0.0277***	0.0251***	0.0345***
	(0.0011)	(0.0014)	(0.0016)
Dummy variable indicating 3 children	0.0365***	0.0322***	0.0417***
	(0.0016)	(0.0025)	(0.0024)
Dummy variable indicating more than 3 children	0.0423***	0.0473***	0.0502***
	(0.0027)	(0.0051)	(0.0048)
Dummy indicating registered partnership	-0.0130	-0.0618*	-0.0032
	(0.0133)	(0.0332)	(0.0107)
Dummy indicating couple living in consensual union	-0.0113***	-0.0102***	-0.0134***
	(0.0009)	(0.0020)	(0.0011)
Dummy indicating cohabiting couples	-0.0080***	-0.0074***	-0.0087***
	(0.0007)	(0.0016)	(0.0011)
Dummy indicating singles	-0.0018**	-0.0034*	-0.0114***
	(0.0009)	(0.0018)	(0.0011)
Year fix effect	Yes	Yes	Yes
R squared	0.4570	0.4499	0.4700
Number of obs.	1,410,582	319,337	877,517

Note: Dependent variable is logarithm of hourly wage, the accessibility measure (A) has been computed as a weighted sum of FTEs in all municipalities, $A_m = \sum_{m'} FTE_{m'} \, e^{-\delta \, d_{m\,m'}}$, where the summation runs over all municipalities m', FTE is full time job equivalents, d denotes distance measured in travel time minutes between municipalities, and $\delta = 0.03$. ***, **, * indicate that estimates are significantly different from zero at the 0.01, 0.05 and 0.10 levels respectively; standard errors clustered at the municipality level are in parentheses.