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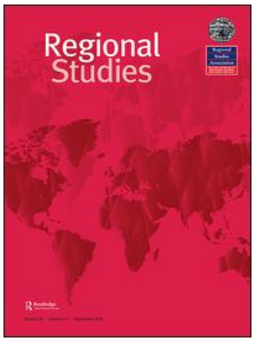

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Does broadband internet allow cities to 'borrow size'? Evidence from the Swedish labour market

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ABSTRACT

Borrowed size refers to the idea that small cities near larger metropolitan centres can reap the advantages of large agglomerations, but without the costs of agglomeration. The study explores whether broadband internet helps such smaller cities to enjoy the labour market benefits of a larger city. Using Swedish micro-data from 2007 to 2015, together with unique data on broadband, suggestive evidence is found that broadband indeed allows smaller cities to reap such benefits. Borrowed size is primarily driven by the overall penetration of broadband in the place of residence, rather than by broadband availability at the residence.

KEYWORD

broadband internet; agglomeration economies; borrowed size; commuting; employment

JEL L96, O3, O18, R11

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INTRODUCTION

In 1973, William Alonso coined the concept of 'borrowed size', referring to the situation 'whereby a small city or metropolitan area exhibits some of the characteristics of a larger one if it is near other population concentrations' (Alonso, 1973, p. 200). He argued that to reap the benefits of agglomeration in large cities, it is often not necessary to locate in these cities themselves, but it suffices to be within reasonable proximity. Recently, this concept has been used to explain why medium-sized cities in Europe do not perform worse than the largest cities, contrary to the theory of agglomeration economies (Dijkstra, Garcilazo, & McCann, 2013; Meijers & Burger, 2017). Even while large cities are increasingly perceived as engines of economic growth, it is argued that Europe's medium-sized cities can continue to flourish, provided they are within reasonable proximity of larger urban areas (Dijkstra et al., 2013).

In the original conceptualization of borrowed size (Alonso, 1973), not much attention is paid to the mechanisms that allow borrowed size to occur – just proximity is stressed. Yet, there is evidence for integration and interaction between cities more generally playing a key role (e.g., Meijers, Hoogerbrugge, & Cardoso, 2018; Phelps, Fallon, & Williams, 2001) and a particular emphasis has also been put on data infrastructure allowing the transfer of information. For instance, Phelps (1992, p. 44) notes that 'information costs … have played an increasing role in constraining the geographical availability of external economies over time'; Dijkstra et al. (2013, p. 334) argue that in Europe, 'improvements in the access to services, including broadband, outside large cities may have facilitated the higher growth rates of smaller centres and rural regions'; and Hesse (2016, p. 617) even contends that 'borrowing size or significance no longer relies on physical proximity between the cities, but on embeddedness in overarching networks between and within polycentric city-regions, via corporate relations, market pervasion and, last but not least, information and communication networks'. Thus, the idea that broadband

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internet and borrowed size are related is pervasive, but to date there is no empirical work that investigates this relationship. The main aim of the present paper is to fill in this gap.

We expect the effects of the local availability of broadband internet on borrowed size to be highly pronounced when it comes to labour market relations. High-speed internet allows workers to live further from spatial concentrations of employment opportunities. This may arise because broadband internet enables people to work from home one or more days per week, which in turn makes them accept longer commutes on the other days (de Vos, Meijers, & van Ham, 2018). In addition, high-speed internet allows for a more efficient (online) job-search process (Autor, 2001), for instance because 'word of mouth' on labour market opportunities is moving online, and because a specific search for jobs in a particular place is now often replaced with search for jobs within a certain radius. Likewise, this gives entrepreneurs more freedom to settle in smaller cities. Phelps et al. (2001) show that firms can locate to small towns while still accessing specialized labour and informational external economies of larger nearby places. This all increases labour market accessibility overall and may lead to higher employment rates, especially in smaller cities at some distance from larger metropolitan areas.

The present paper analyses the relation between broadband internet and labour market outcomes across space more in detail. It uses a unique data set that traces the spatial diffusion of broadband internet technologies in Sweden between 2007 and 2015, and it combines this with register data on all Swedish working-age individuals. We first assess whether broadband internet improved labour accessibility outside of Sweden's large cities. Second, we assess whether the local introduction of broadband leads to higher employment rates outside of the largest cities.

In our empirical approach we distinguish between the effect of broadband availability at the residence location and place level. The former measure should pick up broadband effects on individual labour market decisions, whereas the latter should pick up effects on the local economic environment. We estimate the effects of changes in broadband on changes in labour market outcomes – commuting and employment – using fixed effects models. Because it takes time for people to adapt their labour market status to a new situation, we focus on the effect of broadband two years after its introduction. To uncover potential 'borrowed size' interactions, we allow the effects of broadband to differ between urban cores, urban regions and rural regions, and across distance from the nearest urban core.

The paper is structured as follows. In the literature review, we discuss the literatures that deal with interactions between information technology (IT), borrowed size, ommuting, and local economic performance. Next, we introduce the data. The methodology section discusses the empirical approach in more detail. We then present the results; the final section concludes.

LITERATURE REVIEW

Borrowed size in labour markets

Alonso (1973) understood borrowed size as a process in which small places have some characteristics of larger nearby cities. Meijers and Burger (2017) distil five features of borrowed size from Alonso's original description. Borrowed size is (1) an analytical concept, (2) concerning small cities, (3) in geographical proximity of larger metropolitan areas, (4) that retain the advantages of smaller cities but enjoy the benefits of agglomeration nearby (5) through accessibility and network connectivity. Broadband connections are a clear example of infrastructure that allows for both accessibility and network connectivity. It appears relevant to distinguish an accessibility effect for individuals, which can be captured with broadband availability at the residential location, and a network connectivity effect that affects the local economy, which can be captured by the share of broadband connections in the place of residence.

As mentioned in the introduction, several authors suggest that borrowed size can be derived from fast internet (Dijkstra et al., 2013; Hesse, 2016; Phelps, 1992). We expect the effect of broadband internet on borrowed size to be most pronounced when it comes to labour market outcomes. As Alonso (1973) put it, labour markets of small cities in large metropolitan regions 'enjoy a wider and more flexible range of demand and supply' (p. 200) than isolated cities, but in the literature on borrowed size labour market outcomes has received little attention compared with outcomes for business services (Phelps, 1998; Phelps et al., 2001) and access to urban functions such as shopping and leisure amenities (Meijers & Burger, 2017; Meijers, Burger, & Hoogerbrugge, 2015). Therefore, in this paper we measure whether broadband enables borrowed size by looking at the differential effects of broadband on employment rates across urban and non-urban areas.

With borrowed size likely being a result of interaction between cities, it makes sense to consider commuting as an enabler of borrowed size on the labour market, with different effects on the level of individuals and of places. On the individual level, we expect longer commutes as high-quality internet is a precondition for working from home. Interestingly, recent evidence confirms the longstanding hypothesis that home-based teleworking using the internet leads to longer commutes, and an increased geographical scale of labour markets for several different jobs. Using data from the Netherlands, de Vos et al. (2018) find that working from home at least two days per month allows people to accept a 5% longer commute, and over time this can increase to 32%. This means that for those able to work from home,[1] labour market accessibility increases significantly with the advent of broadband internet. On the place level, it could be that commuting distances actually decrease. On the one hand, broadband internet allows the benefits of agglomeration to spread over a larger territory, enabling firms to locate in smaller places at some distance from larger cities, and perhaps closer to workers, while still being able to tap into the agglomeration benefits of the larger city. On the other hand, broadband internet may lead to a more efficient job-search process that eliminates the extent of excess commuting. This may especially be relevant in large cities with a lot of employment opportunities, and possibilities to shorten the commute. By assessing the direct, *reduced-form* relation between internet connections and commuting distance, the current paper also adds to the literature on teleworking and commuting.

Local performance and IT

While there are no studies on the relationship between internet and borrowed size, several studies investigated to what extent advances in digital technology complement or substitute agglomeration economies (Gaspar & Glaeser, 1998; Sinai & Waldfogel, 2004). These studies focused on the effects on product variety, and the importance of face-to-face contact, but the effects of information technology on labour market outcomes have been ignored. However, there are studies that go into the relationship between information technology and more efficient matching on the labour market, without reference to spatial issues. Autor (2001) discusses the potential consequences of improved worker–firm communications through the internet, stressing the effect on matching between employers and employees. He provides several arguments of why search costs in the labour market are lower when using the internet. One of the main findings of basic labour market search theory is that lowering the cost of finding a job increases productivity through higher match quality.

While there are several empirical studies on the link between the internet and (labour) productivity, only a limited number of studies have taken the proposed relationship between the internet and better matching to the data, with inconclusive results. Kuhn and Skuterud (2004) use data from the 1998 and 2000 US Current Population Survey and find that among online job searchers, unemployment spells are not shorter, and possibly even longer than their offline counterparts. In contrast, a follow-up on this study that uses 2005–08 data finds that online searchers find jobs about 25% more quickly (Kuhn & Mansour, 2014). Kroft and Pope (2014) use the geographical penetration of the local advertising website Craigslist. They find evidence that Craigslist crowded out traditional job advertising outlets, but they find no effect on the unemployment rate. Czernich (2014) uses an instrumental variables strategy based on technical constraints of telephone connections to assess the effects of broadband penetration on unemployment in Germany, and finds no significant effect.

Research on the link between broadband provision and firm location behaviour does suggest that broadband is associated with new firm establishment. The strength of the relationship appears to vary over space (Tranos & Mack, 2016) and over different industries (Mack & Grubesic, 2009). Importantly, early research pointed out that the urban bias of IT may have hampered firm location outside core regions (Mack & Grubesic, 2009; Sohn, Kim, & Hewings, 2003). More recent research highlights the manner in which broadband technologies substitute the agglomeration benefits of large cities in rural and remote areas. For instance, Mack (2014) finds that broadband is correlated with the presence of agricultural and rural firms, in line with the hypothesis that IT substitutes face-to-face contact.

Atasoy (2013) is perhaps most similar to the current study. That study estimates the effect of broadband expansion on labour market outcomes in the United States between 1999 and 2007. In this study broadband penetration is measured as the share of the county population living in an area where broadband internet is available. The main finding is that broadband is associated with a 1.8 percentage point higher employment rate, with larger effects in more remote areas.

We add to the literature on the relation between internet and employment by paying attention to potential heterogeneous effects across space. Specifically, we allow the effect of internet connections on employment to differ between urban, suburban and rural areas, and assess the intermediating effect of distance to urban cores. We analyse the effect of broadband availability on employment at a finer geographical scale than Atasoy (2013) and, importantly, we disentangle the effects of broadband penetration at the level of places and broadband availability at the residential location.

Hypotheses

Here we define our hypotheses for the effects of broadband on commuting and employment, and what we interpret as evidence for borrowed size. First, based on the working-from-home mechanism (de Vos et al., 2018), we expect residential broadband availability to increase commuting distances. We also expect a positive effect on employment rates, because distant employment opportunities become more accessible. Second, we expect that as place-level broadband rates increase, places become more attractive to firms, consistent with Phelps et al. (2001) and Mack and Grubesic (2009). This should lead to an increase in local employment (Atasoy, 2013), and it may correlate negatively with commuting because more people can find a job nearby. Third, we consider it evidence of borrowed size if the effects of broadband are largest at some distance from larger cities rather than close by, namely in places that were at the edge of labour market areas but that have become more closely incorporated through broadband internet. Note that borrowed size can either arise through workers being increasingly able to find a job in the nearby city or through the place becoming more attractive for firms to locate.

DATA

ASTRID data

We use longitudinal register data from the Swedish ASTRID database at Umeå University. The data include all Swedish individuals aged 18–64 years, between 2007 and 2015, with information on earnings, education, demographics, residential location and workplace data, including firm and establishment identification, location, industry, sector and size.

The earnings variable denotes annual income from working. Education levels are given according to the *Svensk Utbildningsnomenklatur* (SUN). This classification includes seven levels that range from primary school to doctorate-level education. Demographic variables include sex and age. The residential location is available with great geographical detail, with an accuracy of 100 m. We recode the data to 250*250 m grid cells so they can easily be matched to the grid level data of broadband availability. For every worker we have ID variables for both the establishment and the firm at which the worker works. A unique feature of the ASTRID data is that there is information on the location of the exact workplace, which is especially relevant for multi-plant firms. Industry information is available according to the *Standard för Svensk näringsgrensindelning 2007* (SNI 2007), which corresponds with international standards. We take into account two digits, so we end up with 21 industries.

We use the register data to construct relevant control variables, and to measure commuting and employment. Having both information on residential and work locations allows one to calculate the (Euclidean) commuting distance for every working individual. The Euclidean measure of distance may introduce a measurement error, but it is not clear in which direction, because short distances are generally associated with lower travel speeds (Duranton & Overman, 2005). However, Combes and Lafourcade (2005) show that Euclidean distance correlates strongly (0.97) with generalized transportation costs, so we do expect this measurement error to be limited. For every grid cell we record the average commuting distance of all *working* individuals. The distribution of this variable is shown in Figure 1(a).

We measure the employment rate at the level of grid cells, and following Andersson Joona and Wadensjö (2013) we define every individual with an annual income higher than 160,000 SEK (about €15,000) as employed. Using this cut-off point we may measure the employment rate with an error, because, for instance, students or part-time workers may be considered unemployed. However, as the cut-off point is lower than the lowest collectively agreed income (Andersson Joona & Wadensjö, 2013), we do not expect the error to differ between years. Therefore, we expect the measurement error related to changes in the employment rate to be limited. The distribution of this variable is shown in Figure 1(b).

Using the ASTRID data, we measure aggregate socio-economic indicators and industrial structure at the level of local labour market areas (*lokala arbetsmarknadsregioner* of *Funktionell analysregion* regions). This regional division was constructed by the Swedish Agency for Economic and Regional Growth (Tillväxtverket) and consists of 60 regions. Note that this regional division covers the whole of Sweden, and is different from the functional urban area (FUA) definition we use to delineate cities and their hinterlands. On average, these labour market regions have a working-age population of 100,000.

Broadband data

Broadband penetration data come from annual surveys of internet suppliers, conducted by the Swedish Post and Telecom Authority (PTS) starting from 2007. The internet suppliers are requested to produce a list of all addresses that have a connection, by connection type. These data are used by the PTS to construct a geographically referenced data set that expresses the availability of broadband internet in 250*250 m grid cells. Broadband internet is considered available if at least one address in a grid cell has a broadband connection. We use data on the number of addresses in each grid to construct a measure of broadband penetration for each grid. Figure 2 shows time variation in the penetration rate of different internet technologies across grid cells in Sweden. While DSL access (high-speed internet through telephone lines) is almost ubiquitous, 3G mobile access has increased significantly between 2007 and 2009, and broadband access through cable and glass fibre has increased in the years after, with a significant bump after 2014.

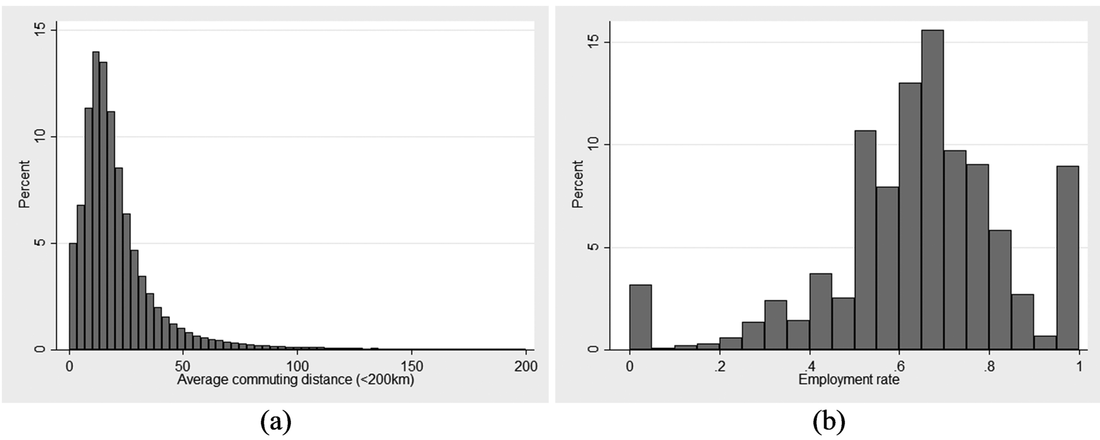

Figure 1. Distributions of (a) commuting distance and (b) employment rate across grid cells.

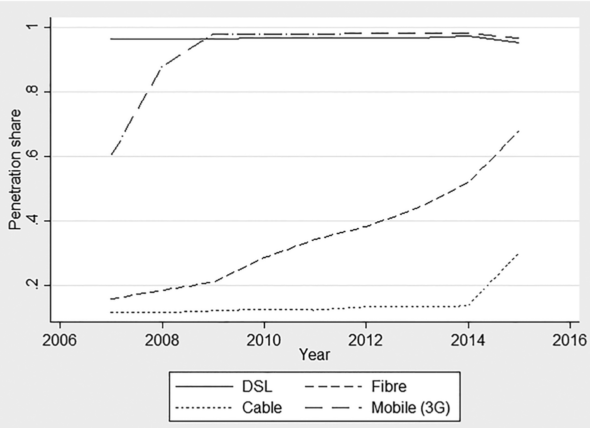

Figure 2. Penetration of different internet technologies.

The main results are based on a dummy variable that indicates any *fixed* connection at the residential location (DSL, cable or glass fibre). While according to the *Bredbandskartläggning* report of 2011 (Swedish Post and Telecom Authority, 2012) the average speed of DSL is slower than the speed of cable and fibre (14 versus 100 mbit/s), in the sensitivity analysis we show that models based on the *fastest fixed connection* deliver similar results, and the effects of DSL and cable/fibre are comparable. In our models, we also estimate the effect of the introduction of mobile internet. Because of the limited speed (6.5 mbit/s), we expect 3G internet to have a smaller effect on working from home and the attractiveness of places for business, and thus a smaller effect on commuting and employment.

Summary statistics

Table 1 shows the summary statistics. The average employment rate in grid cells is about 64%. This is consistent with other sources, for instance the Swedish Labour Force Survey of 2017 reports an employment rate of 67.6%. The average commuting distance in grid cells is 23.6 km, which is slightly higher than usual values reported in the literature because low-density grid cells (with longer commutes) have equal weights as high-density grid cells. Broadband penetration levels are close to 100% on average in both grid cells and in places, but especially at the grid cell level there is still a lot of variation. Table 1 also reports a summary of control variables at the grid cell level and at the local labour market level. These control variables are similar to the ones used in Atasoy (2013). At the level of grid cells, we include population and median income to control for the effects of population dynamics that may coincide with, or even cause, broadband adoption. At the level of local labour markets, we include variables on demographic structure, education and firm dynamics to control for changes in demographic and economic structure that may coincide with broadband expansions. Since broadband internet has been more common in urban areas, we include the share of urban population as a control variable. Omitted from Table 1 are 21 variables that indicate employment shares in different industries, which should control for further changes in economic structure.

METHODOLOGY

To investigate the effect of broadband availability on commuting and employment rates, we aggregate the data to the level of 250 *250 m grid cells and we assess whether access to broadband is associated with the outcomes. To estimate the effect of *time variation* in broadband availability on *time variation* in outcomes, we use a fixed effects model. The models are specified as follows:

$$O_{gt} = \alpha B^{r}_{gt} + \beta B^{p}_{lt} + \gamma X_{glrt} + \eta_g + \theta_t + \epsilon_{gt} \quad (1)$$

where O_{gt} denotes the outcome (commuting distance or employment) in grid cell g at time t; B^r is a residential broadband dummy; B^p is the place-level broadband penetration rate; X_{glrt} are control variables at the grid cell, place and regional level; η_g are grid cell fixed effects; θ_t are time fixed effects; and ϵ is the error term.

To assess whether the effects are larger in areas surrounding large cities, we estimate a model including interactions between broadband and an indicator for urban core, urban hinterland and rural region. We define these areas using the Organisation for Economic Co-operation and Development’s (OECD) FUA definition.[2] It is somewhat unfortunate that these FUAs are defined from a monocentric perspective, defining the commuting zone of a single city. These zones sometimes touch each other, while in reality they probably overlap to some extent (e.g., Linköping and Norrköping; see Figure A1 in Appendix A in the supplemental data online). However, the OECD’s definition has the important advantage of being readily available and consistent, which allows the reproduction of results. Finally, we interact the broadband variables with a more flexible measure of urbanization based on distance to the nearest FUA.

There are several identification problems when analysing the relationship between broadband internet and commuting distance and employment rates. First, there may be omitted variables that correlate with both broadband adoption and the outcomes, without there being a direct causal relationship. For instance, the introduction of broadband in a place may be part of a larger development project, that may include new infrastructure or new housing. We tackle this issue to a large extent by controlling for several variables, including income and population at the level of grid cells, and a socioeconomic indicators and industrial structure at the level of local labour market areas. Specifically, changes in broadband availability in grid cells may be correlated with broadband penetration in the place of residence, so the broadband indicator may pick up on effects of broadband penetration on the local economy. Therefore, we include broadband penetration at the level of the place[3] to which the grid cell belongs to isolate the effect on personal outcomes from the effects of broadband availability on the local structure of the economy. We report the effects of both variables, where the effects of residential broadband are more likely to be causal. The effects of the place level broadband rate should be interpreted with

Table 1. Summary statistics.

Variables	(1) Mean	(2) SD	(3) Minimum	(4) Maximum
250 m grid cell				
Employment rate	0.639	0.208	0	1
Avg. commuting distance[a]	23.60	29.06	0.0354	500.0
Broadband (res.)	0.975	0.158	0	1
Cable/fibre (res.)	0.393	0.489	0	1
DSL (res.)	0.581	0.493	0	1
Mobile (3G)	0.926	0.262	0	1
Population	53.29	111.3	1	3058
Median income	238,005	105,639	0	11,353,600
Place				
Broadband (place)	0.986	0.0826	0	1
DSL (place)	0.490	0.383	0	1
Cable/fibre (place)	0.496	0.383	0	1
Labour market area				
Share male	0.510	0.00681	0.501	0.548
Share low educated	0.0308	0.0101	0.00706	0.0591
Share medium educated	0.185	0.0257	0.115	0.282
Share high educated	0.520	0.0447	0.447	0.648
Share college educated	0.250	0.0526	0.121	0.344
Share young	0.297	0.0147	0.241	0.360
Share old	0.299	0.0295	0.257	0.421
Number of firms	39,647	49,448	190	147,185
Total payroll (in millions)	11,514	15,028	21.00	48,840
Employees/establishment (avg.)	8.555	1.040	4.190	11.14
Population	495,546	587,662	1,588	1,720,469
Urban population	242,294	327,414	0	955,805
Income	23,267	2499	10,710	32,160
N		871,688		

Note: [a]Owing to grid cells without employment, there are only 837.368 commuting distance observations.

some caution due to potential confounders such as new infrastructure or housing projects.

Second, commuting behaviour and employment levels may also drive broadband adoption, instead of the other way around. We tackle this issue to a large extent by taking the two-year lag of broadband (penetration) as our independent variable of interest. It should be noted that we analyse the effects of *changes* in broadband penetration on *changes* in employment rates and commuting. Although current and future outcomes may be correlated, it is less straightforward that future changes in these outcomes drive current changes in broadband penetration.

Finally, the institutional setting in Sweden is such that broadband adoption is not dependent on market forces alone. Public funding supports broadband initiatives of rural municipalities that lack commercial incentives to invest.[4] Sweden's wish to provide broadband to all its citizens is one of the main reasons for the existence of the broadband data that we use, and it is reflected in the recent broadband strategy titled 'A Completely Connected Sweden by 2025' (Government Offices of Sweden, 2017). While the effort of communities for broadband initiatives may be random, the timing of these initiatives, and of the arrival of broadband in rural municipalities (in one year or the next) may have an element of randomness, which increases the likelihood that our estimates can be interpreted as causal effects. To the extent that local effort is endogenous, our results should be interpreted as upper bounds of the effect of broadband introduction.

RESULTS

Broadband and labour market outcomes

Our first hypothesis wat that residential broadband availability increases commuting distances as it enables working from home, and increases employment rates because distant employment opportunities become more accessible. Table 2 shows the results of six regression models with commuting distance (columns (1–3)) and the employment rate (columns (4–6)) as dependent variables. In all models

Table 2. Regression results.

	(1)	(2)	(3)	(4)	(5)	(6)
Variables	**Commuting distance**			**Employment rate**		
Broadband (res.) (*t*)	−1.721***			0.00843***		
	(0.302)			(0.00141)		
Broadband (res.) (*t* − 2)		−1.149***	−0.708		0.00344*	0.00117
		(0.377)	(0.431)		(0.00177)	(0.00201)
Broadband (place) (*t* − 2)			−1.750**			0.00920**
			(0.826)			(0.00389)
Mobile (3G) (*t*)	0.480***			0.00122*		
	(0.140)			(0.000678)		
Mobile (3G) (*t* − 2)		−0.0505	−0.0741		0.00206***	0.00219***
		(0.143)	(0.144)		(0.000685)	(0.000687)
Constant	−203.1	−263.0*	−260.0	−0.0541	1.702**	1.686**
	(137.7)	(158.6)	(158.6)	(0.669)	(0.763)	(0.763)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Year and grid cell fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	825,353	634,033	634,033	844,449	646,345	646,345
R^2	0.530	0.579	0.579	0.732	0.764	0.764

Note: Standard errors are shown in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Control variables include Population (log) and Income (log) at the grid cell level, and Population (log), Income (log), Share urban population, Share male, Share lower, medium, higher and college educated, Share young and old, Number of establishments, Number of employees per establishment, aggregate income and 21 industry share variables at the level of labour market areas. For the full regression results, see Tables A1 and A2 in Appendix A in the supplemental data online.

observations correspond to grid cells. As our control variables at the local labour market level have several multicollinearity problems that affect their coefficients, we only focus on the effects of our independent variables of interest, that have consistently low variance inflation factor (VIF) values. Column (1) shows a regression of commuting distance in year t on the broadband indicator in the same year. According to this model, the introduction of broadband internet in a grid cell coincides with a 1.7 km decrease in commuting distance on average. This model also shows that the introduction of 3G internet correlates positively with commuting distance. The high r^2 of 0.530 is mainly due to the fixed effects. Table A1 in Appendix A in the supplemental data online shows that a model without control variables has an r^2 of 0.525.

In column (2) we take the two-year lag of the broadband indicator and the mobile (3G) variable. As argued in the methodology section, changes in commuting distance and employment may cause broadband adoption rather than the other way around, but it is unlikely that current changes in these behaviours affect broadband adoption in the past. According to this model, the introduction of broadband in year $t-2$ coincides with a decrease in commuting distance of 1.15 km on average in year t. The effect of 3G internet is not significant.

The findings of these models run counter to our first hypothesis. Most likely, broadband availability at the residence in grid cells is correlated with the overall broadband penetration in a place. Therefore, our broadband variable may pick up on the effect of broadband on local economic structure and business climate (Eriksson, Hansen, & Lindgren, 2014). Especially outside of central cities, broadband availability may improve the business environment and attract more firms (which results in higher employment, our second hypothesis). This may explain why we find a negative effect of broadband on commuting, as a higher share of people may be able to find employment locally rather than further away. In column (3), therefore, we include the two-year lag of place-level broadband penetration (share of connected individuals in places) as an additional independent variable. Consistent with our hypothesis, the negative effect of broadband internet on commuting is largely driven by place-level broadband penetration, rather than the residential availability of broadband for households. A 0.1 increase in the share of connected individuals at the place level (slightly more than 1 SD) leads to a small decrease of commuting distance by 0.18 km, or about 0.8% of average commuting distance.

In columns (4–6) we repeat the steps above with the employment rate as dependent variables. Column (4) shows that the introduction of broadband in grid cells coincides with a 0.8 percentage point employment increase on average. Taking the two-year lag in column (5), this effect is only 0.3 percentage points. If we take into account the two-year lag of the place-level broadband rate, in column (6) again we find that broadband penetration at the place level drives this effect. The effect is rather small, as a 0.1 increase in the share of connections corresponds with a 0.09 percentage point increase in employment. Moving from no connections to 100% connectivity increases employment by 0.9 percentage points, about 1.4% of the average employment rate. Across these three models, 3G introduction has a positive and significant but small effect on employment rates.

In summary, we find that overall, changes in the availability of broadband internet affect commuting distance negatively and employment rates positively. These effects are primarily driven by the penetration of broadband in the place of residence, rather than by the availability of broadband at the residence. The effect on commuting distance is relatively small: every 10 percentage point increase in broadband connection is associated with an average decrease of 0.18 km in commuting distance. Our estimate of the effect of residential broadband availability on employment is lower than the estimates by Atasoy (2013) (0.8 versus 1.8 percentage point). This may be because the estimates of Atasoy (2013) refer to the period 1999–2007, and regions that stand to gain most from broadband may be expected to connect earlier rather than later. When taking lags and controlling for the place-level broadband rate, mobile (3G) internet does not affect commuting distance, but it has a small effect on the employment rate.

Broadband and borrowed size

In the preceding section we have assumed that broadband affects commuting and employment similarly across the urban hierarchy and across space. However, this is not straightforward, for instance if there are interaction effects between information technology, agglomeration and borrowed size (Gaspar & Glaeser, 1998; Hesse, 2016; Sinai & Waldfogel, 2004). Our third hypothesis stated that the effects of broadband are largest at some distance from larger cities rather than close by, namely in places that were at the edge of labour market areas, but that have become more closely incorporated through broadband internet. Table 3 estimates the models again, taking into account this spatial heterogeneity in two ways. First, by allowing the effect of the availability of broadband to differ between urban cores, the remainder of their urban regions, and rural areas. Second, by allowing the effect of broadband to depend on distance to the nearest urban core.

Column (1) is similar to Table 2, column (3), except that the effects of both broadband measures are estimated separately for grid cells within FUA cores, outsides of cores within FUAs and outside of FUAs. There seems to be a great deal of heterogeneity. First, we find no significant effects of broadband on commuting within urban cores. Second, in the urban regions surrounding urban cores, we find that residential broadband availability reduces commuting distances (by 2.2 km), while it increases commuting distances (1.3 km, only significant at the 10% confidence level) outside of urban regions, in rural areas. These effects may seem modest, but since the average commuting distance in our sample is 23.6 km, a 2.2 (1.3) km increase means that commutes are 9.3% (5.5%) longer. This is in line with estimates of the effect of working from home on commuting distance (de Vos et al., 2018). Third, the effects of place-level broadband are only present

Table 3. Spatial heterogeneity.

	(1)	(2)	(3)	(4)
Variables	**Commuting distance**		**Employment rate**	
Functional urban area (FUA) core				
Broadband (res.) ($t-2$)	−0.933		0.00365	
	(1.058)		(0.00506)	
Broadband (place) ($t-2$)	−1.605		0.143*	
	(15.33)		(0.0741)	
FUA outside core				
Broadband (res.) ($t-2$)	−2.175***		0.00223	
	(0.615)		(0.00288)	
Broadband (place) ($t-2$)	0.316		0.0140**	
	(1.191)		(0.00564)	
Outside FUA				
Broadband (res.) ($t-2$)	1.304*		−0.000732	
	(0.699)		(0.00323)	
Broadband (place) ($t-2$)	−4.325***		0.00529	
	(1.202)		(0.00562)	
Distance decay		Figure 3(a)		Figure 3(b)
Mobile (3G) ($t-2$)	−0.0680	−0.0600	0.00205***	0.00215***
	(0.144)	(0.144)	(0.000690)	(0.000688)
Constant	−261.8*	−264.9*	1.693**	1.635**
	(158.6)	(158.6)	(0.763)	(0.763)
Control variables	Yes	Yes	Yes	Yes
Year and grid cell fixed effects	Yes	Yes	Yes	Yes
Observations	634,033	634,033	646,345	646,345
R^2	0.579	0.579	0.764	0.764

Note: Standard errors are shown in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Control variables include Population (log) and Income (log) at the grid cell level, and Population (log), Income (log), Share urban population, Share male, Share lower, medium, higher and college educated, Share young and old, Number of establishments, Number of employees per establishment, aggregate income and 21 industry share variables at the level of labour market areas. For the full regression results, see Tables A1 and A2 in Appendix A in the supplemental data online.

outside of urban regions. Here, moving from 0% to 100% connected individuals leads to a 4.3 km decrease in commuting distance on average. The reason for this may again be that local employment growth due to broadband leads to a larger share of local workers compared with longer distance commuters. In this model mobile (3G) internet has no significant effect.

Column (2) and Figure 3(a) show the results of a regression in which the effects of broadband are allowed to differ over distance categories from the nearest FUA core. The closest category includes the urban core itself. Figure 3 offers two broad conclusions. First, the effect of residential broadband availability on commuting distance is small and negative up until 30 km from urban cores, while in the more distant places, from 50 km and onwards, it is positive and slightly larger. In these more distant areas, the availability of broadband at the residence (blue line) leads to a 4.3 km increase in commuting distance on average. This effect may well be driven by working from home (de Vos et al., 2018). Second, the overall penetration of broadband at the place level (red line) is associated with longer commutes at intermediate distance from urban cores, between 20 and 30 km. This suggests that high-speed internet makes the places at this distance part of the labour market area of the urban core, while they were previously not or only weakly integrated with this labour market. This is a clear sign of 'borrowed size' as these places can now reap the advantages of being part of the larger urban labour market. For the places up until 20 km that were probably already included in this labour market, the general availability of broadband in a place does not alter the situation much. This also holds for the places at greater distance (50 km and more away), that are still too distant to really integrate in the labour market.

In column (3) we allow the effect of broadband on employment to differ across urban cores, urban regions and rural regions. Here the only significant broadband effects come from place-level broadband penetration. In urban cores, increasing the broadband share with 0,1 results in 1.4% higher employment rates, while within FUAs outside of urban cores a 0.1 increase results in a much smaller 0.14% increase in employment. These results may indicate that broadband not only allows people to search and maintain jobs at longer distances but also that it limits the extent of

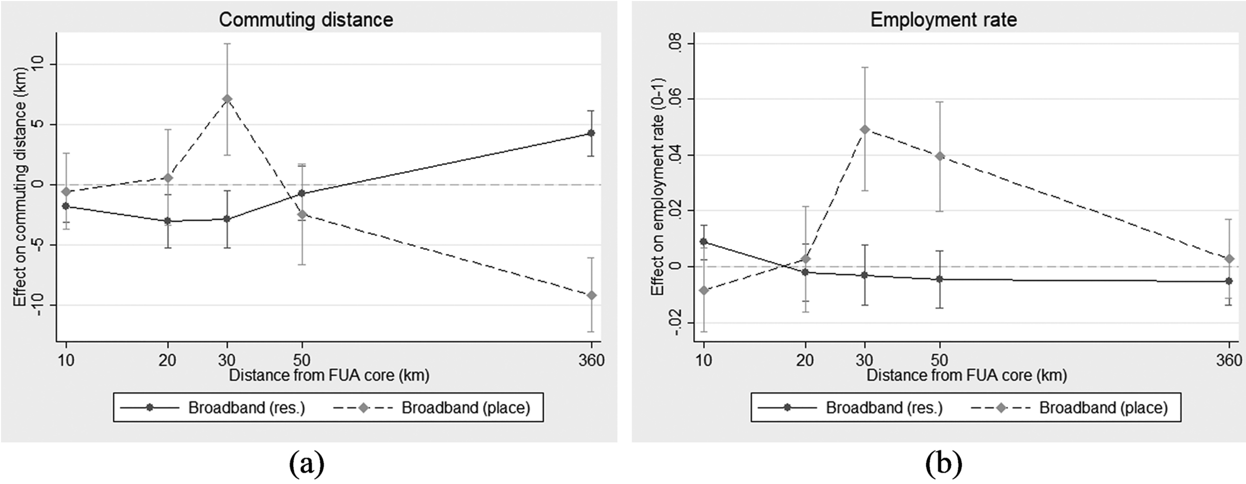

Figure 3. Distance decay of broadband effects on (a) commuting distance and (b) employment rate.
Note: FUA, functional urban area.

excess commuting at the local scale. In more remote places, such a borrowed size effect cannot be seen, suggesting that it is indeed available only in reasonable proximity to an urban core. The effect of mobile (3G) internet is again small and similar to the result from Table 2, column (6).

Column (4) and Figure 3(b) show the results of a regression in which the effects of broadband on employment are allowed to differ with distance from FUA cores. We can conclude from Figure 3 that broadband availability at the residential location (blue line) leads to increased employment rates only near and in the urban core; this is where broadband internet connection seems to lead to better matching. However, the effects of the overall penetration of broadband in places (red line) on employment rates are significant at intermediate distances from urban cores, between 20 and 50 km. Again, this suggests that effect of broadband internet are largest in the 'expansion zone' of the labour market – the area that gets added to, or more integrated with, the urban labour market area through broadband.

Sensitivity analysis: internet technologies

Up until now we have made no distinction in the speed of broadband internet. In this subsection we show the robustness of our results to accounting for the difference in speed between DSL technology (14 mbit/s) and cable and fibre technologies (100 mbit/s). Table A4 in Appendix A in the supplemental data online includes two dummies that denote the *fastest fixed connection* at the residence, being either DSL or cable/fibre, instead of a simple broadband dummy. We also include the mobile (3G) variable and allow it to vary over space. We still include the overall place-level broadband penetration rate as a separate variable, and again we lag the internet variables by two years. Column (1) again shows that the only positive effects of broadband at the residence are found outside FUAs, and it seems this is driven by cable/fibre technologies. Column (3) shows that the employment effects of broadband are driven by place-level broadband rates rather than residential availability. This effect is only present in intermediate areas (within FUA, outside core) and in these areas mobile

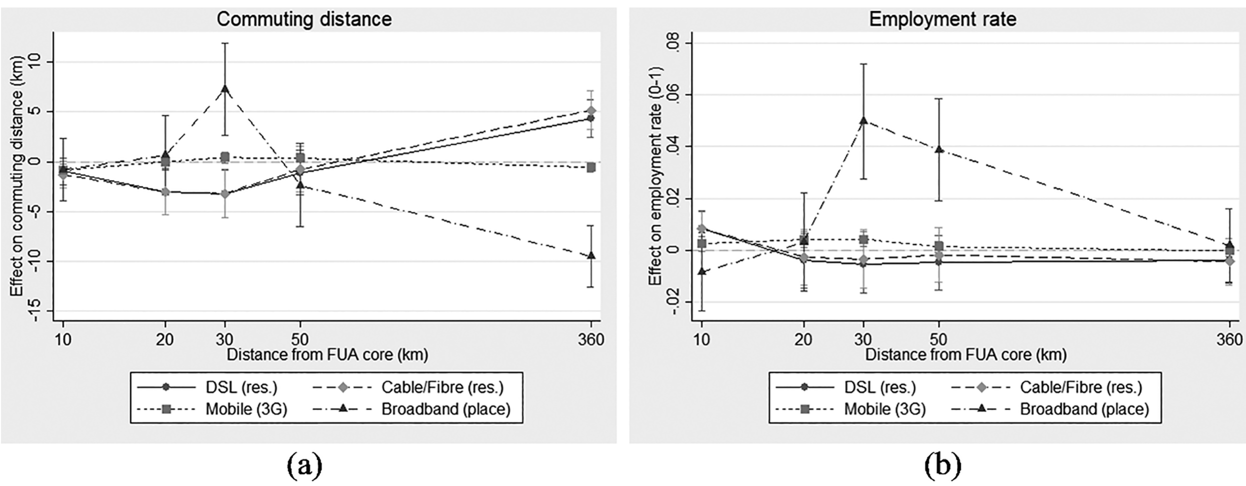

Figure 4. Distance decay of technology effects on (a) commuting distance and (b) employment rate.
Note: FUA, functional urban area.

(3G) internet has a small but significant effect on employment. Figure 4 shows that the respective decay patterns of the effects of the different technologies on commuting distance (a) and employment (b) are very similar, to each other and to the earlier estimates. Compared with the fixed technologies, mobile (3G) internet has a consistently smaller effect, and shows the least variability over space. The results are thus robust to accounting for differences in speed of broadband technologies.

CONCLUSIONS

In this paper we have estimated the relation between broadband penetration and commuting behaviour and employment. The main goal was to test the hypothesis that broadband internet aids the process of borrowed size (Dijkstra et al., 2013; Hesse, 2016; Phelps, 1992). To this end we estimated the effect separately for urban cores, urban areas and rural areas, and we allowed the effect to differ with distance to the nearest core of a FUA. We innovated by explicitly modelling a potential mechanism behind borrowed size (broadband) by using time variation in broadband, and by distinguishing between broadband effects at the residence and place level.

The results suggest that residential broadband availability is associated with longer commutes in remote areas, which can be explained as a *working-from-home* effect (de Vos et al., 2018). Within urban cores, residential broadband has a positive effect on employment, which suggests that broadband has enabled better labour market searching and matching in and closely around urban cores (Autor, 2001). Considering the absence of significant results in proximity of urban cores, our results suggest no causal relation between residential broadband connections and 'borrowed size' in the labour market.

The spatial variation in the effect of place-level broadband penetration on employment does show a clear borrowed size pattern. Growth in broadband penetration only affects employment rates in areas between 20 and 50 km from urban cores, and commuting distances in areas between 20 and 30 km from urban cores. This suggests that increased broadband penetration makes these places more attractive for firms and people to locate. From these locations they can tap into the benefits of the urban labour market nearby. Broadband internet thus seems an important driver behind the spatial expansion of the urban labour market. This is consistent with the assertion of Dijkstra et al. (2013) that broadband access has aided the growth of small and medium-sized cities in proximity of larger cities.

There are limitations to the research approach of this paper that could inspire further research. First, Sweden is a specific country with a very high urbanization rate, combined with long distances between central and remote places. Future research should uncover whether our results also hold in other countries. Second, growth in broadband rates may be correlated with other dynamics that promote employment in cities, including new infrastructure and housing projects. We note that our control variables capture a lot of these potential confounders, but more research is needed into the causal nature of this effect. Third, we measure better matching in the labour market using the employment rate, but this may also translate into a better fit between workers and employers (lower overeducation, higher salaries). Future research may uncover whether there are also effects of broadband on these measures. Fourth, while we believe that working from home is a highly plausible explanation of the effect on broadband internet on commuting distance in remote regions, we lacked data on working from home rates or the number of commutes, that may give more conclusive evidence. Fifth, the small positive effects of mobile (3G) internet on employment suggest that during the study period mobile internet was not a strong substitute for broadband internet, but with the arrival of 4G this may have changed. Finally, the concept of borrowed size needs further empirical substantiation, most notably explaining how local factors affect the capacity to borrow size and a better view of which agglomeration benefits can be 'borrowed'. And while this paper is one of the first to explicitly model an underlying, other studies could explore other mechanisms potentially driving processes of borrowed size.

We distil three policy implications from our research. First, if governments aim to increase the economic fortunes of places by introducing broadband, they should be aware that, at least in the short run, the effects on employment are small and vitally dependent on proximity to other employment centres. Second, the results suggest that governments should consider prioritizing fixed connections, as the effects of mobile internet are much smaller (but note that this was before the introduction of 4G). At the same time we do not see effects of broadband upgrades from DSL to cable or fibre. Finally, outside cities we find no effects of residential broadband availability on employment prospects for residents, but we do find significant effects of place-level broadband penetration on these prospects. This suggests that policies that aim to connect rural regions to fast internet to increase employment prospects should initially prioritize connecting places rather than connecting every single inhabitant.

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NOTES

1. In 2012, about 23% of commuting-based workers performed telework regularly (Vilhelmson & Thulin, 2016).
2. See http://www.oecd.org/cfe/regional-policy/Sweden.pdf/.
3. We use Statistics Sweden's *tätorter* (localities) and *småorter* (smaller localities) to define places. Localities are places with at least 200 inhabitants and less than 200 m between buildings. Smaller localities have between 50 and 200 inhabitants and no more than 150 m between buildings.
4. See https://ec.europa.eu/digital-single-market/en/country-information-sweden/.

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