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Impact of broadband quality on median income and unemployment: Evidence from Sweden

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ABSTRACT

Based on a unique and exhaustive database, including micro-level pooled cross-sectional data on 23 million observations over nine years, from 2009 to 2017, we assess whether broadband quality is correlated with income and unemployment reduction. Overall, the results do not tend to show any significant effect of download speed on either income or the unemployment rate. However, after distinguishing between educational attainment and city size, we obtained heterogeneous results. While we the results suggest a substitution effect between high-skilled workers and broadband in small and medium cities, we also show that broadband quality is positively correlated with unemployment reduction for low-skilled workers in small cities with broadband over 100 Mbit/s. However, the economic significance of the effect is rather low.

1. Introduction

Very high-speed broadband networks are seen as a key enabler for socio-economic development. Their roll-out comes along with the development of advanced digital services in all areas of the society. As an example, progresses made in artificial intelligence (AI) are opening doors to an unprecedented level of progress in health engineering and transportation. Digitalization of society also creates benefits for citizens. It gives them greater opportunities to participate in the civil society, to enjoy a broad range of services at home, such as welfare and healthcare services. In addition, job searches are facilitated, increasing opportunities to find a work in line with the person's competences. However, the relation between digitalization and socio-economic development is not straightforward, as advances realized in digitalization and what technologies can do have an impact on the number and types of jobs susceptible to be computerized.

In this article, we quantify to which extent broadband quality, measured in terms of download speed, impacts income and unemployment in both urban and rural areas. This will enable us to investigate whether the roll-out of NGN networks is a way to answer the challenges encountered in some cities and in rural areas, such as: lack of jobs, higher unemployment rate and lower income. These challenges could potentially be answered by the deployment of very high-speed broadband infrastructures. The possibility to work from home, to benefit from a reliable and sufficient internet connection to start a business could be a way to give a new life to non-attractive areas and help others to remain attractive.

This study relies on a unique and rich dataset including 23 million measurement tests realized by Internet users all over Sweden. The tests have been performed using "Bredbandskollen" a connection test managed by the Swedish Internet Foundation. It provides us

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with micro-level pooled cross-sectional data covering approximately 700 Swedish localities, located in 287 municipalities, over 9 years, from 2009 to 2017, giving us a wide coverage of Sweden.[1] Sweden has been particularly active in the roll-out of next generation broadband technologies, both fixed and mobile.[2] Given the recent deployment of next generation access networks (NGN), little empirical research has investigated the economic impact of very high-speed Internet on the society. Considering that Sweden is a frontrunner in very high-capacity connectivity in Europe, it is also a good candidate to assess the effects of broadband on socio-economics variables related to households.

The results highlight a positive effect of broadband quality on unemployment reduction in localities with a lower proportion of highly educated inhabitants. However, improvement in broadband quality is shown to have a detrimental effect on both income and unemployment in localities with a higher proportion of highly educated inhabitants. In addition, the estimations highlights heterogeneous effects while taking into account municipality size.

To the best of our knowledge, this is one of the first papers to estimate, at a granular local level in both urban and rural areas, the impact of very high-speed broadband network on socio-economic variables related to demand, median income and unemployment. The results provide policy-makers with better insights on the role of very high-speed broadband for local economic growth and social development.

The remainder of the paper is organized as follows. Section 2 discusses the relevant literature on the effect of broadband on income and unemployment. Section 3 presents the data, while Section 4 introduces the econometric framework. Section 5 presents the estimation results. Finally, Section 6 concludes.

2. Literature review

In the last decade, an extensive range of macro-level studies bring empirical evidence on the positive effect of broadband adoption on economic growth (see Holt and Jamison (2009), Greenstein and McDevitt (2011) and Bertschek et al. (2013) for comprehensive literature reviews). It is widely accepted that there is a positive relation between broadband adoption, broadband availability and economic growth, especially as measured by GDP, at the national and regional level. A positive relation has also been found among others by Gillet et al. (2006), Crandall et al. (2007) and Ford (2018), between broadband availability and employment at the macro-level. They find that communities with broadband experienced a more rapid growth in employment and a faster firm growth, especially in IT-intensive sectors than non-broadband communities.

Gruber et al. (2014) show that the economic benefits that would derive from the achievement of the objectives of the 2020 Digital Agenda for Europe outweigh the costs of investment. They show that the economic benefits mostly spill over to users and to the national economy highlighting the rationale for public subsidies in the roll-out of broadband networks. Another stream of literature has explored the relation between broadband and consumer surplus bringing positive evidence on the existence of a positive correlation (see for example Greenstein et al. (2012)).

The Great Recession of 2007-2009 has, however, led to challenge the common acceptance of the positive relationship between GDP and employment as digital technologies become more prevalent in all areas of the society. Analysing the situation in the US, Brynjolfsson and McAfee (2011) shed some light on the appearance of a weakening in this relation. They show that, even though GDP is increasing in the US, there is no net employment creation. They highlight a decline in the quantity of labour demanded bringing back the 1800s concept of technological unemployment introduced in the economic theory by Ricardo and popularized by Keynes in the 1930s. *"This means unemployment due to our discovery of means of economising the use of labour outrunning the pace at which we can find new uses for labour"*, Keynes, 1930. [3]

Though very high-speed broadband has been deemed to positively affect economic growth and social development at the local level, the empirical evidences are very limited, divergent and ambiguous, especially as regards rural areas. A burgeoning literature has explored the relation between broadband and income. Whitacre et al. (2014) find that broadband adoption, availability and download speeds have an impact on economic growth in rural areas. They highlight a positive impact on unemployment reduction and on median household income. They also show that rural areas with high levels of download speeds tend to attract more creative class workers and to have a lower poverty level.

Autor and Dorn (2013) and Akerman et al. (2015) focus on job polarization and wage inequality. They show that broadband availability and adoption impacts positively high-skilled workers' productivity, acting as a skill complement and lowers low-skilled workers' productivity, acting as a substitute for routine tasks. Goos et al. (2009), Brynjolfsson and McAfee (2011) and Autor and Dorn (2013) observe a trend towards the polarization of the labour market between high-income cognitive jobs and low-income manual jobs leading to a hollowing-out of middle-income routine jobs. Low-skilled workers being specialized in routine tasks reallocate into the service sector. The complementary effect between broadband and high-skilled workers has also been highlighted by

[1] A locality, DeSo in Swedish, is the smallest demographic and statistical area defined by the Swedish statistics institute. There are more than 5,000 DeSo in Sweden distributed in the 290 Swedish municipalities.

[2] The government is aiming for a completely connected Sweden, by 2025, with 98% of the population which should have access to broadband at a minimum speed of 1 Gbit/s both at home and at the workplace. The remaining 1.9% should have access to connections of at least 100 Mbit/s, and 0.1% at speeds of at least 30 Mbit/s. In addition, by 2023 everyone should have access to reliable and high-quality mobile services.

[3] Technological unemployment is associated to what is considered a temporary phase of structural unemployment. It happens when, in a period of rapid technological change, the skills offered by the workforce don't evolve fast enough and become redundant leading to a capital-labour substitution.

Hasbi (2020). In line with the existence of a job polarization effect, she also shows a higher positive effect of broadband on the creation of companies operating in the service sector in areas with a higher proportion of low-skilled workers.

Yvus and Boland (2015) show that broadband deployment in rural areas has stimulated wage increase and employment growth in service industries, but not in goods industries. Houngbonon and Liang (2019) confirm the positive impact of broadband diffusion on poverty reduction highlighted by Whitacre et al. (2014). They find that high-speed broadband availability reduces income inequality in spite of skill complementarity, with a greater effect in less densely populated areas. This result is in line with Czernich et al. (2011), who find a positive impact of broadband infrastructure on income per capita. Unlike Autor and Dorn (2013), Akerman et al. (2015) and Houngbonon and Liang (2019) show that the impact is larger at the bottom of the income distribution.

As regards broadband effect on employment, Czernich et al. (2011) and Czernich (2014) for German municipalities and Jayakar and Park (2013) for eight States in the US, find no evidence that broadband availability reduces unemployment. On the contrary, Kolko (2012) highlights that broadband expansion is associated with population and employment growth. However, he also finds that average wage and employment rate are unaffected by broadband expansion. Kolko underlines that the positive effects of broadband are stronger in industries that rely more on ICTs and in less densely populated areas. Atasoy (2013) confirms this result by showing that gaining access to broadband in a county is associated with an increase in employment rate, especially in rural areas. She underlines also a complementary effect between broadband and skilled workers with college educated workers encountering larger effects. On the contrary, Canzian and Poy (2015) and Briglauer et al. (2019) find no impact on employment creation. But Canzian and Poy (2015) find a positive effect of broadband diffusion on firm performance, especially in rural areas and Briglauer et al. (2019) a positive effect on depopulation reduction in rural areas. In 2017, Bai shows that even though broadband availability is positively correlated to county-level employment, fast broadband has no greater effect than “normal-broadband”.

In a report, commissioned by the Swedish Board of Agriculture and the Swedish Agency for Economic and Regional Growth in 2019, on the evaluation of funding from EU and the Swedish government supporting investments in broadband infrastructure in Swedish rural areas, the authors do not find any quantitative evidence supporting the existence of an impact of broadband availability on employment creation. However, after conducting qualitative interviews with companies, they show that access to broadband is crucial for businesses, especially as it helps them to maintain their current level of employment. A large number of interviewees reported that without access to broadband, they would have been compelled to dismiss employees.

Building up on the advances realized in digital technologies, Frey and Osborne (2017) categorize jobs in accordance to their susceptibility to be computerized and analyse how computerization impacts the occupational composition of the labour market. They show that computer substitution does no longer only affect cognitive and manual routine tasks. With the progress made in machine learning, machine vision or artificial intelligence and the increasing availability of big data, non-routine tasks, such as legal writing, truck driving, medical diagnoses or some bank and financial services are becoming computerized. They predict that 47% of total US employment is at high-risk of being computerized. Jobs that requires high dexterity, creativity or social intelligence are the least susceptible to be computerized. In addition, they show that wages and educational attainment are strongly negatively correlated with the probability of computerization. Using data on Sweden, Fölster (2014) shows that it is 53% of total employment, which is susceptible to be computerized within 20 years in Sweden. Brynjolfsson et al. (2011) argue that advances realized in what digital technology can do will inevitably continue increasing the number and types of jobs susceptible to be computerized.

3. Data

Data on broadband speed comes from Internetstiftelsen. The Swedish Internet Foundation, Internetstiftelsen, is an independent organization that works for the development and improvement of internet in Sweden. One of the main focus is to raise end-users’ awareness and knowledge about Internet. To that purpose Internetstiftelsen is managing an online tool called Bredbandskollen aiming at measuring access connection speed. This tool is free of use and allows everyone across the country to test their internet connection in terms of download and upload speed in Mbit/s and latency in seconds. We got a dataset with broadband measurements over 9 years, from 2009 to 2017. These data have been collected at an established aggregation level in Sweden (tätort). Tätort is defined as urban areas with contiguous buildings with no more than 200 metres between houses and at least 200 residents. There are around 2,000 tätorter in Sweden comprising around 87% of the population.

Using a dataset on broadband speed instead of on Internet technologies has a number of potential benefits. First, the importance of taking into account Internet speed to measure the impact of broadband on different socio-economic variables has been highlighted in the literature. With these data, we have information on demand and therefore, on Internet access speed at the household level. This gives us an overview of the network quality and enables us to avoid biases related to the different physical characteristics of a technology.[4] In addition, it avoids biases related to the use of theoretical speed marketed by operators, which is the maximal theoretical speed reachable under specific circumstances and not necessarily the speed experienced by customers. The use of speed to measure the economic impacts of broadband is considered as more and more important in the literature (see for example Middleton (2013) and Rohman and Bohlin (2012)).

However, the dataset includes some positive self-selection in which the user expresses an interest and demand in order to use the measurement test (Bredbandskollen). There are two main reasons to test an Internet connection. The first one is that the user is experiencing a problem, such as a slow download or upload speed or a high latency. To minimize this bias, all observations with

[4] For example, the connection speed on a DSL line is dependent on the line length. Longer is the line, lower is the speed. As such, for the same technology, the broadband speed experienced by the end user can vary significantly.

abnormally long latency or very slow download speed or upload speed are dropped out. The second main reason to use the test is when an Internet user has changed his or her subscription. However, because these behaviours repeat every year, it is reasonable to consider that it introduces a marginal bias in the data. There will be each year tests on new (and most probably faster) Internet subscriptions. All in all, because it is the user expressing an interest in testing its Internet connection, our data is closer related to expressed demand rather than supply.

Finally, the data set is very extensive. Over 9 years, the number of tests conducted through Bredbandskollen amounts to more than 300 million use cases, of which a third had usable location coordinates. After dropping observations related to unrealistic broadband speeds or latencies, only data on tests performed the second week of each month have been kept. The estimations have been performed on a representative sample of 23 million observations (tests). Considering the large number of measurements, we get a wide coverage of Sweden.

Data on unemployment and income come from the Swedish statistical agency, SCB. The data on unemployment represents the number of openly unemployed aged 18 to 64 registered as job seekers. Data on income from employment and business are available for the population aged 20 and over.

Finally, socio-demographic data on population, population density, country of birth, age groups, education level and number of new and reactivated companies come from SCB. As the geographical level of the data from Bredbandskollen are different from the socio-economic data received from SCB, we used a connection table between DeSo and tätort provided by SCB. (The so-called DeSo level of SCB is the smallest aggregation level provided by SCB.) Descriptive statistics are reported in Annex A in Tables 8,9a,9b,10.

4. Econometric strategy

How broadband can impact unemployment is still arguable. The relationship between broadband and unemployment has been shown to be ambiguous. Digitalization of companies has had an impact on the way goods are produced and delivered through the introduction of more automated processes. On the one hand, the use of more efficient technologies has led to productivity gains and an increase in economic growth. These would suggest a positive effect on employment. On the other hand, the use of more efficient technology has potentially substituted for labour, especially within low-skilled workforce, suggesting a negative impact on employment. Nonetheless, the demand for labour with specific skills has potentially increased, counterbalancing the substitution effect for more routine tasks.

The relation between broadband and income is not straightforward either. The skill complementarity between broadband and high-skilled workforce leads to an increase in income inequality. In contrast, the growth of low-skilled jobs in the service sector, resulting from the diffusion of new ICT technologies, is likely to have a positive impact on income.

The empirical strategy consists in investigating the effect of broadband quality on both median income and unemployment rate. Broadband quality is measured in terms of download speed. The use of broadband speed instead of broadband availability or the type of broadband technology gives a more accurate information and provides more details on specific areas (Kongaut and Bohlin, 2012). The empirical strategy consists in a stratification of broadband speed in 7 categories:

- No broadband: 0 to 256 Kbit/s;
- Low speed: over 256 Kbit/s to 5 Mbit/s;
- Medium speed: over 5 Mbit/s to 10 Mbit/s;
- Medium speed 2: over 10 Mbit/s to 30 Mbit/s;
- High-speed: over 30 Mbit/s to 50 Mbit/s;
- High-speed 2: over 50 Mbit/s to 100 Mbit/s;
- Very high-speed: over 100 Mbit/s.

To estimate the effect of broadband speed on (1) median income and (2) unemployment rate, we use data on 696 localities, (corresponding to 1,217 DeSo spread over 281 municipalities[5]) over 9 years, from 2009 to 2017. Only localities located in an urban settlement of at least 200 inhabitants (tätort) are included in the database.

So we have,

$$Y_{it} = \alpha + \delta\, hbb_{it-1} + \lambda\, Y_{it-1} + \beta\, X_{it-1} + \gamma\, Z_{it-1} + \mu\, year_t + \eta_i + \phi_t + \epsilon_{it}. \tag{1}$$

In model (1) Y_{it} refers to the median income whereas in model (2) Y_{it} refers to the unemployment rate, both in locality i at time t. The variable of interest, denoted hbb_{it-1}, is a proxy for broadband quality in locality i at time $t-1$. Broadband quality is approximated by download speed in Mbit/s. Y_{it-1} corresponds in model (1) to the previous level of median income and in model (2) to the previous level of unemployment, both in locality i at time $t-1$. X_{it-1} is a matrix of location characteristics for locality i at time $t-1$. Z_{it-1} is a matrix of labour market characteristics for locality i at time $t-1$. η_i controls for region-specific trends that are constant over time. $year_t$ is a set of dummy variables for each year that controls for year-specific effects that are constant over the different geographical areas. ϕ_t captures regional specific time trend. Finally, ϵ_{it} is a standard error capturing unobserved factors.

As highlighted in the literature, there is a potential endogenous effect, materializing in terms of reverse causality, between the

[5] DeSo is the smallest administrative division in Sweden. Socio-economic-data are provided at the DeSo level.

Table 1
Population distribution in municipalities and DeSo.

	p1	p5	p10	p25	p50	p75	p90	mean
municipality	5,552	10,748	18,937	44,813	132,536	844,838	920,608	354,349
DeSo	936	1,128	1,282	1,492	1,606	1,954	2,292	1,712

Table 2
Impact of broadband quality on median income.

	whole sample	rank 1	rank 2	rank 3	rank 4	rank 5
speed: 0.256–5	21.66	−120.92	−69.75	59.46	59.88	−5.12
speed: 5–10	156.25	−86.76	−5.98	−101.65	170.73*	−12.78
speed: 10–30	100.34	−91.16	−81.66	−155.41	145.58	−21.84
speed: 30–50	85.17	−81.86	54.67	−103.01	152.28	−26.13
speed: 50–100	23.58	−136.77	97.27	−249.45	84.96	−45.97
speed: 100+	−274.54	−182.82	−366.77	−521.056	5.81	−24.07
Observations	31,472,261	3,525,546	5,214,661	8,125,111	3,542,502	11,065,066
Region	Yes	Yes	Yes	Yes	Yes	Yes
Regional time trend	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.898	0.691	0.837	0.908	0.986	0.996

The reference category for speed is 0–0.256 Mbit/s, which is equivalent to no broadband.
Robust standard errors clustered at the DeSo level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
rank 1: pop ⩽18,937; rank 2: pop [19,938–44,813]; rank 3: pop [44,814–132,536];
rank 4: pop [132,537–354,349].
A blank case means no significant effect.

Table 3
Impact of broadband quality on income in localities characterized by a high proportion of highly educated inhabitants.

	whole sample	rank 1	rank 2	rank 3	rank 4
speed: 0.256–5	−19.15	−201.06**	15.06	−49.24	8.13
speed: 5–10	43.82	−242.81*	205.95	−17.02	16.02
speed: 10–30	17.01	−231.88*	207.22	−9.36	17.37
speed: 30–50	44.28	−332.32*	295.06	88.00*	15.83
speed: 50–100	53.33	−408.38**	563.89***	58.39	16.38
speed: 100+	−101.31	−676.56**	251.79	−70.08	15.45
Observations	15,741,382	1,762,937	2,607,396	4,032,688	1,754,337
Region	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Regional time trend	Yes	Yes	Yes	Yes	Yes
R-squared	0.926	0.640	0.736	0.947	0.991

The reference category for speed is 0–0.256 Mbit/s, which is equivalent to no broadband.Robust standard errors clustered at the DeSo level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
rank 1: pop ⩽18,937; rank 2: pop [19,938–44,813]; rank 3: pop [44,814–132,536];
rank 4: pop [132,537–354,349].
A blank case means no significant effect.

availability of broadband networks and broadband quality and the median income, see, for example, Kolko (2012) and McCoy et al. (2018). In other words, operators are more likely to upgrade network quality or deploy a next generation access network in areas with a higher quality of demand. In the meantime, areas with better broadband infrastructures are more likely to attract households with a higher income.

As argued by Lobo et al. (2020), the use of lagged explanatory variables is a common approach in the literature to mitigate problems related to endogeneity in social science. Following the literature, we control for pre-existing location characteristics and pre-existing labour market characteristics by using one-year lagged variables. Robustness checks are performed with lags of two years and three years, which give similar qualitative results. Nevertheless, one can suspect that the estimation results might suffer from an upward bias.

Omitted variables may also be a potential source of endogeneity. For example, operators may have higher incentives to deploy a very high-speed broadband network or upgrade network quality in areas in which they can benefit from a more favourable tax regime or in which there is higher demand for faster broadband services. To mitigate this problem, we follow the econometric literature by using time-varying and time invariant fixed effects.

Using (1), the median income can be derived:

Table 4
Impact of broadband quality on income in localities characterized by a low proportion of highly educated inhabitants.

	whole sample	rank 1	rank 2	rank 3	rank 4	rank 5
speed: 0.256–5	112.62	−32.46	70.39	206.22	131.52	−9.98
speed: 5–10	357.750*	−75.83	177.39*	150.76	304.07*	−30.60
speed: 10–30	307.06	−60.97	163.78	232.10	247.80	−50.59
speed: 30–50	444.12*	−76.23	152.05	585.85**	308.03	−58.29
speed: 50–100	352.35	−69.66	144.96	563.96*	227.27	−102.87
speed: 100+	200.69	−45.30	65.78	125.68	256.02	−53.51
Observations	15,730,879	1,762,609	2,607,265	4,092,423	1,788,165	4,531,405
Region	Yes	Yes	Yes	Yes	Yes	Yes
Regional time trend	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.803	0.428	0.780	0.932	0.964	0.997

The reference category for speed is 0–0.256 Mbit/s, which is equivalent to no broadband.Robust standard errors clustered at the DeSo level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
rank 1: pop ⩽18,937; rank 2: pop [19,938–44,813]; rank 3: pop [44,814–132,536];
rank 4: pop [132,537–354,349]; rank 5: pop > 354,349.
A blank case means no significant effect.

Table 5
Impact of broadband quality on unemployment rate.

	whole sample	rank 1	rank 2	rank 3	rank 4	rank 5
speed: 0.256–5	−0.0005	−0.0001	−0.0001	−0.0006*	0.0003	0.0000
speed: 5–10	−0.0008	−0.0004	−0.0004	−0.0004	0.0006	0.0000
speed: 10–30	−0.0008	−0.0001	−0.0001	−0.0003	0.0007	0.0000
speed: 30–50	−0.0009	0.0002	0.0002	−0.0003	0.0008	0.0000
speed: 50–100	−0.0009	0.0005	0.0005	−0.0002	0.0009	0.0000
speed: 100+	−0.0009	0.0019**	0.0019**	−0.0000	0.0007	0.0000
Observations	31,472,261	3,525,312	5,214,433	8,125,057	3,542,393	11,065,066
Region	Yes	Yes	Yes	Yes	Yes	Yes
Regional time trend	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.862	0.753	0.875	0.941	0.912	0.993

The reference category for speed is 0–0.256 Mbit/s, which is equivalent to no broadband.Robust standard errors clustered at the DeSo level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
rank 1: pop ⩽18,937; rank 2: pop [19,938–44,813]; rank 3: pop [44,814–132,536];
rank 4: pop [132,537–354,349].
A blank case means no significant effect.

Table 6
Impact of broadband quality on unemployment rate in localities characterized by a high proportion of highly educated inhabitants.

	whole sample	rank 1	rank 2	rank 3	rank 4
speed: 0.256–5	−0.0001	−0.0007***	0.0001	−0.0002**	−0.0000
speed: 5–10	−0.0001	−0.0012***	−0.0000	−0.0002**	−0.0000
speed: 10–30	−0.0002	−0.0013***	−0.0000	−0.0002**	−0.0000
speed: 30–50	−0.0002*	−0.0014***	−0.0001	−0.0001	−0.0000
speed: 50–100	−0.0002	−0.0012***	−0.0001	−0.0001	−0.0000
speed: 100+	−0.0002	−0.0014***	−0.0000	−0.0002*	−0.0000
Observations	15,741,382	1,762,710	2,607,396	4,032,640	1,754,337
Region	Yes	Yes	Yes	Yes	Yes
Regional time trend	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
R-squared	0.889	0.775	0.761	0.767	0.994

The reference category for speed is 0–0.256 Mbit/s, which is equivalent to no broadband.Robust standard errors clustered at the DeSo level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
rank 1: pop ⩽18,937; rank 2: pop [19,938–44,813]; rank 3: pop [44,814–132,536];
rank 4: pop [132,537–354,349].
A blank case means no significant effect.

Table 7
Impact of broadband quality on unemployment rate in localities characterized by a low proportion of highly educated inhabitants.

	whole sample	rank 1	rank 2	rank 3	rank 4	rank 5
speed: 0.256–5	−0.0012**	0.0000	−0.0006	−0.0013	0.0001	0.0000
speed: 5–10	−0.0016*	−0.0002	−0.0018	−0.0004	0.0003	0.0000
speed: 10–30	−0.0015*	0.0003	−0.0016	−0.0000	0.0004	0.0000
speed: 30–50	−0.0015	0.0008	−0.0014	−0.0001	0.0004	0.0000
speed: 50–100	−0.0012	0.0007	−0.0017	0.0005	0.0006	0.0000
speed: 100+	−0.0009	0.0038***	−0.0015	0.0010	0.0004	0.0000
Observations	15,730,879	1,762,602	2,607,037	4,092,417	1,788,056	4,531,405
Region	Yes	Yes	Yes	Yes	Yes	Yes
Regional time trend	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.830	0.667	0.880	0.942	0.883	0.998

The reference category for speed is 0–0.256 Mbit/s, which is equivalent to no broadband.Robust standard errors clustered at the DeSo level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$
rank 1: pop ⩽18,937; rank 2: pop [19,938–44,813]; rank 3: pop [44,814–132,536];
rank 4: pop [132,537–354,349]; rank 5: pop > 354,349.
A blank case means no significant effect.

$$\begin{aligned} income_{it} = {} & \alpha + \delta\ hbb_{it-1} + \lambda\ income_{it-1} + \beta_1\ ln\_pop_{it-1} + \beta_2\ ln\_pop\_m_{jit-1} \\ & + \beta_3\ density_{it-1} + \beta_4\ non\_EU_{it-1} + \gamma_1\ unempl_{it-1} + \gamma_2\ ln\_uni\_diploma_{it-1} \\ & + \gamma_3 establishment_{it-1} + \mu\ year_t + \eta_i + \phi_t + \epsilon_{it} \end{aligned} \quad (2)$$

With $income_{it}$ the yearly income from employment and business in locality i at time t, which is expected to be influenced by broadband quality hbb_{it-1}, the previous level of income, locality size, i.e. local population denoted by ln_pop_{it-1} and population density $density_{it-1}$.[6] Unemployment, $unempl_{it-1}$, is also likely to impact the median income as well as the population's education level, measured by the proportion of the population having a diploma from superior education, $ln\_uni\_diploma_{it-1}$. It has also been shown for the US (Lobo et al., 2020), that areas with a higher proportion of non-whites are more likely to experience a higher unemployment rate. This potential impact is captured by non_EU_{it-1}, which measures the proportion of inhabitants born outside Scandinavia and outside the European Union. In addition, the model includes information number of new establishments $establishment_{it-1}$ operating in the locality. All socio-demographic variables are estimated in locality i at time $t-1$. One variable is measured at a different geographical level, as the model includes information on municipal population, denoted by $ln\_pop\_m_{jit-1}$.

Using (1), the unemployment rate could be derived as follows:

$$\begin{aligned} unempl_{it} = {} & \alpha + \delta\ hbb_{it-1} + \lambda\ unempl_{it-1} + \beta_1\ ln\_pop_{it-1} + \beta_2\ ln\_pop\_m_{jit-1} \\ & + \beta_3\ density_{it-1} + \beta_4\ ln\_income_{it-1} + \beta_5\ non\_EU_{it-1} + \gamma_1\ ln\_uni\_diploma_{it-1}, \\ & + \gamma_2 establishment_{it-1} + \mu\ year_t + \eta_i + \phi_t + \epsilon_{it} \end{aligned} \quad (3)$$

With $unempl_{it}$, the proportion of openly unemployed aged 18 to 64 registered as job seekers in locality i at time t, defined as a function of broadband quality, the previous number of unemployed in the locality, local and municipal populations, the local population density, the proportion of inhabitants born outside Scandinavia and outside the EU, the educational level, the number of new establishments. In addition, the yearly income, ln_income_{it-1}, is expected to influence the unemployment rate.

It has been shown in the literature that some benefits of broadband were found to be complementary with high-skilled labour forces and highly educated inhabitants (Akerman et al., 2015; Hasbi, 2020). To assess whether broadband quality affects differently areas with (1) a higher, (2) a lower proportion of highly educated inhabitants, the estimations are run on two different sub-samples depending on whether the proportion of inhabitants having obtained a diploma from superior education is (1) higher than the median or (2) lower or equal to the median.

The potential effects of broadband may also differ across municipality size. Political decisions are not made at the DeSo level but at a higher administrative level, such as the region or the city. Cities of different sizes have also different budgets or possibilities to grow and develop. This is why, it is important to compare localities belonging to the same type of cities. In our database, 50 % of the population lives in municipalities with less than 135,500 inhabitants, while 10% lives in municipalities with less than 19,000 inhabitants or more than 920,600 inhabitants. See Table 1.

To analyse whether the effects of broadband quality materialize differently depending on municipality sizes, the estimations are run on five sub-samples: localities belonging to

– a municipality with a number of inhabitants equal or lower than 18,937 inhabitants (rank 1);
– a municipality with a number of inhabitants comprised between 18,938 and 44,813 (rank 2);

[6] The estimations have been run using the median income in real terms, i.e. deflated by the consumer price index. The results were qualitatively similar in terms of significance. This is explained by the use of year-fixed effects that capture the evolution of the consumer price index over the years.

– a municipality with a number of inhabitants comprised between 44,814 and 132,536 (rank 3);
– a municipality with a number of inhabitants comprised between 132,537 and 354,349 (rank 4);
– a municipality with more than 354,349 inhabitants (rank 5).

5. Impacts of broadband quality on the society

In this section are presented both the estimation results for the impact of broadband quality on income (5.1) and on unemployment (5.4). Only the results on the impact of download speed are presented here. The exhaustive estimation results are displayed in Annex B, Tables 12–14.

Tables 2–4 show the estimation results of the impact of broadband quality, in terms of download speed, on median income. Tables 5–7 display the estimation results of the impact of broadband quality on unemployment rate for the 18-64 years old.

The estimations are performed at the locality level for the years 2009 to 2017. As the effects of broadband may not be equally distributed into the society and instead may depend on (1) educational level or (2) city size, the estimations have been run on seven sub-samples. Tables 3 and 6 (high skilled) shows the estimation results for localities having a high-skilled population, i.e. the proportion of inhabitants having obtained a diploma from superior education is higher than the median. While Tables 4 and 7, low skilled), displays the estimation results for localities having a low-skilled population, i.e. the proportion of inhabitants having obtained a diploma from superior education is lower than the median.

The database is further divided in 5 sub-samples (ranks 1 to 5) based on the size of the city to which the locality belongs. Therefore, it enables us to make within-group estimations and see how broadband quality affects income and unemployment within a group. Column 1 of each table presents the estimation results for the whole sample and column 2 for localities located in smaller municipalities of rank 1. Columns 3 and 4 shows the results for localities located in medium-sized municipalities of ranks 2 and 3 respectively. Column 5 presents the results for localities located in bigger cities of rank 4. In addition, Tables 4 and 7 column 6 shows the results for localities located in the biggest cities, those having a population higher than the average: rank 5. In the tables, only the coefficients which are significant at least at the 5% level are displayed.

5.1. *Impacts of broadband quality on income*

The exhaustive estimation results are displayed in Annex B in Tables 12–14.

Table 2 do not show any significant effect of broadband quality on median income. This result holds irrespective of the size of the city to which the locality belongs. Therefore, we cannot conclude that broadband quality has an impact on income.

Overall, the results displayed in Table 2 tend to highlight a positive effect of the size of the municipal population and of the median income on unemployment reduction. However, and in the same way as for the previous estimations, the proportion of inhabitants born outside Scandinavia or outside the EU seems to have a negative impact on unemployment reduction. We also observe a negative correlation between population density and median income.

In addition, the results suggest a negative effect of the local population on unemployment rate. However, after distinguishing between the different city sizes, we observe that this potential negative effect only holds for localities belonging to a small or medium-small municipality (ranks 1 and 2). As previously, the models tend to predict a positive effect of educational attainment on unemployment reduction

5.2. *High-skilled localities*

The second part of the results concerns localities characterized by a high proportion of highly educated inhabitants. Overall, the estimated parameters do not seem to predict any correlation between broadband quality and median income in areas characterized by a high proportion of high-skilled workers. However, after distinguishing between the different city sizes, the estimations suggest that broadband quality is negatively correlates with the median income in localities belonging to a small city. However, this correlation is of small economic significance. Indeed, for a one unit change in broadband speed the predicted difference of income in localities having broadband speeds comprised between 0.256 Kbit/s and 5 Mbit/s is of about 200 Swedish crowns (about 20 euro) or about 0.1% lower than in other localities of rank 1 without broadband. For a one unit increase in broadband speed, everything else equals, this difference seems to increase to around 408 and 676 Swedish crowns (about 41 and 68 euro) in localities with broadband speeds comprised between 50 and 100 Mbit/s and broadband speed over 100 Mbit/s respectively. This corresponds to a difference of income of less than 0.3%.

On the contrary, in smaller medium-sized cities of rank 2, broadband quality is found to be positively correlated with the income of high-skilled workers for broadband speed comprised between 50 Mbit/s and 100 Mbit/s. On average, the median yearly income in these localities is predicted to be of about 564 Swedish crowns (about 56 euro) higher than in localities without broadband for a one unit change in broadband speed.

Columns 4 and 5 shows that localities located in bigger cities (rank 3 and 4) do not tend to encounter any significant impact of a higher broadband quality.

5.3. *Low-skilled localities*

The third part of the results concerns localities characterized by a low proportion of highly educated inhabitants (inferior to the median). All in all, the estimations do not seem to suggest that broadband quality is correlated with income in areas characterized by a high proportion of low-skilled workers. This result holds regardless of the city size.

Overall, for both "high-skill" and "low-skill" groups, the results, displayed in Annex B, show that the median income is more likely to be higher in more populated localities as well as in localities with lower unemployment. However, localities having a higher proportion of inhabitants born outside Scandinavia or outside the EU are more likely to have a lower median income.

5.4. Impacts of broadband quality on unemployment

The exhaustive estimation results are displayed in Annex B in Tables 15–17.

Similarly to the previous estimations for income and at two exceptions, Table 5 do not suggest any significant correlation between broadband quality and unemployment rate. Localities belonging to a small city or a medium municipality of rank 2 (with a population comprised between approximately 20,000 and 45,000 inhabitants) seem to benefit positively of higher download speeds. In these localities, very high-speed broadband, over 100 Mbit/s, seems to be positively correlated with unemployment reduction. For one unit change in broadband speed, the predicted unemployment rate is 0.0019 percentage points higher, everything else equals, in these localities compare to similar localities without broadband. In terms of economic significance, the positive correlation found is rather weak.

Overall, the results, displayed in Table 15, highlight a positive effect of the size of the municipal population and of the median income on unemployment reduction. However, and in the same way as for the previous estimations, the proportion of inhabitants born outside Scandinavia or outside the EU has a negative impact on unemployment reduction. We also observe a negative impact of population density.

In addition, the results highlight a negative effect of the local population on unemployment rate: more populated is a locality, more likely it is to have a higher unemployment rate. However, after distinguishing between the different city sizes, we observe that this negative effect only holds for localities belonging to a small or medium-small municipality (ranks 1 and 2). As previously, the models predict a positive effect of educational attainment on unemployment reduction.

5.5. High-skilled localities

The second part of the results concerns localities characterized by a high proportion of highly educated inhabitants (superior to the median). Overall, the estimation results do not suggest any effect of broadband on unemployment reduction in areas with better broadband quality. However, after taking the city size into account, the model highlights a negative correlation between broadband speed and the unemployment rate of high-skill workers in localities belonging to a small city of rank 1 and in medium cities of rank 3.

More precisely, the second column of Table 6 highlights an overall negative association, increasing with speeds, between broadband quality and unemployment reduction. In localities with basic broadband (under 5 Mbit/s), a one unit change in broadband speed would result in a reduction of the unemployment rate by 0.0007 percentage points compare to localities without broadband. This negative correlation increases linearly. For a one unit change in broadband speed, the unemployment rate would decrease by 0.0014 percentage points for broadband speeds over 100 Mbit/s compare to similar cities without broadband.

Similarly, column 6 of Table 6 tends to suggest a negative effect of lower broadband speed, under 30 Mbit/s on unemployment reduction in localities located in medium cities of rank 3. In these localities, the unemployment rate is predicted to decrease by 0.002 percentage points for one unit change in broadband speed compare to localities of the same rank not having broadband.

This result is in line with the negative correlation found between broadband quality and income in areas with a high proportion of highly educated inhabitants. However, the significance of the correlation is far too small to support the findings of Brynjolfsson and McAfee (2011) and Frey and Osborne (2017) that suggest that a new substitution effect between certain types of high-skill jobs and new ICT technologies is appearing.

Columns 3 and 5 do not show any correlation between broadband quality and unemployment in localities located in a small-medium city of rank 2 and in a big city of rank 4.

5.6. Low-skilled localities

The third part of the results concerns localities characterized by a low proportion of highly educated inhabitants (inferior to the median). All in all, the estimations results do not show any correlation between broadband quality and the unemployment rate of low-skilled workers, at one exception. Low-skill workers seem to be are more at risk to be unemployed in localities characterised by low broadband speed, inferior to 5 Mbit/s.

Taking account of the city size tends to reveal the existence of a complementary association, between very high-speed broadband, over 100 Mbit/s, and low-skilled workers in localities located in a small city. It is worth mentioning that unlike (Akerman et al., 2015), we do not find any evidence that would suggest the existence of a substitution effect between broadband and low-skilled workforce. These results may confirm the job polarization effect highlighted by Autor and Dorn (2013).

Potentially, the absence of significant correlation between broadband quality and income could also result from the creation of new jobs created in the service sector, to replace the jobs lost as a consequence of automation of routine tasks. As broadband acts as a substitute to low-skilled workers to perform routine tasks, they reallocate into the service sector. A sector which is expected to benefit the most from ICT technologies (Hasbi, 2020). Therefore, low-skilled workers may have been able to find a new job and maintain a stable income.

Overall, the results show, for both the “high-skill” and “low-skill” groups, that the unemployment rate is more likely to be lower in more populated localities. In the same way, localities with a higher median income are more likely to experience a lower unemployment rate.

6. Conclusion

Based on a unique and rich dataset, provided by the Swedish Internet Foundation, we assess whether broadband quality is correlated with income and unemployment reduction. We exploit micro-level pooled cross-sectional data covering approximately 700 localities over 9 years, from 2009 to 2017. The results do not show any significant impact of broadband quality on either median income or the unemployment rate. However, within-group analyses suggest heterogeneous effects across localities depending on both the education level of the local population and the municipality size. On average, broadband quality is shown to be positively correlated with download speeds over 50 Mbit/s, with some variations depending on the type of localities. Download speeds are reflecting the real download speed experienced by the users and not the theoretical download speed advertised by the operators. However, though statistically significant, the effects suggested by the estimations are of little economic significance.

The results underline a clear distinction between localities having a high and a low proportion of college graduates. Broadband quality seems to have a detrimental effect on both the median income and the unemployment rate in localities with highly educated inhabitants that are located in a small city of less than 19,000 inhabitants. Lower broadband speeds, under 30 Mbit/s are negatively correlated with unemployment reduction in localities located in a medium city. Apart from small municipalities, the estimations do not suggest that broadband quality has an effect on the income of the high-skilled workforce.

Overall, no correlation between broadband quality and median income is found in areas characterised by a high proportion of low-skilled workers. The same is true as regards the association between broadband quality and unemployment rate. Though the model suggests that living in an area with low broadband speed, under 5 Mbit/s has a detrimental effect on the unemployment rate. Localities located in a small city and having very high-speed broadband over 100 Mbit/s have a lower unemployment rate. These results may potentially support the existence of a job polarization effect. As in a process of destruction creation, low-skilled workers, whose routine tasks have been first automated are now reallocating to the tertiary sector, where new jobs have been created.

With this article, we show that the relation between broadband quality and income or unemployment is not straightforward but rather based on complex mechanisms. Both positive and negative effects are encountered, but they are of rather small economic significance. The economic impacts of broadband quality measured in this paper appears to be marginal, in the order of half a percent to one percent when it comes to income and of about 0.0002 to 0.0038 percentage points as regards the unemployment rate. Therefore, the use of high-speed broadband as tool to reduce unemployment and to improve the yearly income of the citizens is of little economic significance. However, it has been shown in the literature, that access to broadband has enabled companies, especially in rural areas to maintain their number of employees. Besides, the use of high-speed broadband as tool to increase digital inclusion and reduce digital divide has proven efficient in terms of company creation and in the institutional sector, with for example public administrations and in the medical sector. Therefore, further research is needed in this area.

A limitation of this paper is that we use a user-driven database, which as a matter of fact includes a bias of self-selection. Though, we have taken great care in the construction of the database to minimize this bias, this issue cannot be completely resolved. Another limitation is that the data on unemployment and income are measured at a pre-defined geographic level and do not enable us to account for individual-level characteristics. Besides, though we follow the literature by using fixed effect as well as regional specific effects and lagged variables, some issues related to endogeneity may remain.

In future research, when more detailed information becomes available on mobile data, it may become possible to estimate to which extent mobile broadband complement the effect of fixed broadband. Besides, it may also be interesting to compare how broadband quality affects company creation and entrepreneurship, especially in rural areas.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Representativeness of the sample dataset and Descriptive Statistics

See Tables 8–10.

Table 8
Summary statistics of municipalities characteristics depending on the presence of a very high-speed broadband network for 2007–2017.

Variable	Obs	Mean	Std. Dev.	Min	Max
Whole dataset					
download	100,361,834	33.23089	65.96432	0	8161.384
upload	100,361,834	16.48973	49.47689	0	1929.298
latency	100,361,834	46.23508	163.6344	0	170655
pop_deso	100,361,834	1712.266	382.3808	346	3072
dens_deso	100,361,834	4954.929	5431.137	.1	65600
pop_municipality	100,361,834	353725.3	363618.7	974	932630
perc_sup	100,361,834	45.68388	16.15105	9.885057	91.75947
median income	100,361,834	257584.4	62173.22	1060	549496
perc_med_inc	100,361,834	47.43201	7.003945	4.074585	71.32743
perc_low_inc	100,361,834	25.0947	11.59378	4.938272	95.64917
perc_high_inc	100,361,834	27.47329	11.79748	.2762431	72.22222
unemployment 18–24	100,361,834	15.16282	14.0131	0	100
unemployment 18–64	100,361,834	76.22385	69.30409	3	458
born in SE	100,361,834	1363.247	287.7859	176	2804
born in Northern Europ	100,361,834	46.22218	26.65154	0	772
born EU	100,361,834	58.22672	33.59497	0	525
born international	100,361,834	244.5703	277.7754	3	1440
Sample dataset					
Variable	Obs	Mean	Std. Dev.	Min	Max
download	23,328,045	33.21822	66.01512	0	3750.311
upload	23,328,045	16.50191	49.42707	0	1891.674
latency	23,328,045	46.12913	162.8382	0	63495
pop_deso	23,328,045	1711.518	382.006	551	2993
dens_deso	23,328,045	4963.939	5434.482	.1	45050
pop_municipality	23,328,045	354349	363810.4	974	932630
perc_sup	23,328,045	45.71177	16.15994	9.885057	89.06089
median income	31,475,068	47.83512	7.097901	15.3481	71.3274
perc_med_inc	23,328,045	257621.8	62207.43	13046	439797
perc_low_inc	23,328,045	25.09577	11.59842	8.197989	81.30272
perc_high_inc	23,328,045	27.48434	11.8005	1.874414	60.8662
unemployment 18–24	23,328,045	15.15269	14.01278	0	81
unemployment 18–64	23,328,045	76.20619	69.34793	3	451
born in SE	23,328,045	1362.666	287.4906	392	2492
born in Northern Europe	23,328,045	46.20187	26.59538	4	772
born EU	23,328,045	58.23239	33.60254	0	525

Table 9a
Summary statistics of broadband speed by years: all year and from 2010 to 2013.

Whole dataset				Sample dataset			
All years							
	download	upload	latency		download	upload	latency
mean	33.22212	16.5019	46.13684	mean	33.21775	16.50142	46.1285
p25	4.602	.847	9	p25	4.602	.847	9
p50	11.802	3.018	21	p50	11.801	3.017	21
p75	38.046	11.90835	41	p75	38.04525	11.90809	41
iqr	33.444	11.06135	32	iqr	33.44325	11.06109	32
2010							
	download	upload	latency		download	upload	latency
mean	15.54365	5.837233	66.37854	mean	15.46758	5.796616	66.3235
p25	2.22	.424	10	p25	2.216	.426	10
p50	6.906	.865	24	p50	6.901	.865	24
p75	15.301	4.379	61	p75	15.221	4.288	61
iqr	13.081	3.955	51	iqr	13.005	3.862	51
2011							
	download	upload	latency		download	upload	latency
mean	17.98695	6.458129	65.72102	mean	18.07544	6.474116	65.59982
p25	2.446	.597	10	p25	2.478	.602	10

(continued on next page)

Table 9a (*continued*)

Whole dataset				Sample dataset			
p50	6.893	.96	26	p50	6.913	.961	26
p75	16.884	7.016	73	p75	17.008	7.115	73
iqr	14.438	6.419	63	iqr	14.53	6.513	63
2012							
	download	upload	latency		download	upload	latency
mean	17.67088	6.614338	68.80112	mean	17.72645	6.637543	68.63141
p25	2.476	.692	11	p25	2.484	.694	10
p50	6.762	1.079	32	p50	6.776	1.081	32
p75	16.187	6.449	76	p75	16.277	6.629	76
iqr	13.711	5.757	65	iqr	13.793	5.935	66
2013							
	download	upload	latency		download	upload	latency
mean	17.67088	6.614338	68.80112	mean	21.14339	8.745704	57.32525
p25	2.476	.692	11	p25	3.541	.823	12
p50	6.762	1.079	32	p50	8.646	1.691	29
p75	16.187	6.449	76	p75	22.467	9.542	61
iqr	13.711	5.757	65	iqr	18.926	8.719	49

Table 9b
Summary statistics of broadband speed by years: from 2014 to 2017.

Whole dataset				Sample dataset			
2014							
	download	upload	latency		download	upload	latency
mean	21.17917	8.775536	57.57728	mean	30.23776	14.35815	43.37939
p25	3.548	.822	12	p25	5.999	.94	10
p50	8.689	1.688	28	p50	13.497	5.106	23
p75	22.487	9.539	60	p75	37.549	11.603	38
iqr	18.939	8.717	48	iqr	31.55	10.663	28
2015							
	download	upload	latency		download	upload	latency
mean	30.33757	14.31322	43.02006	mean	44.59054	22.17102	26.99246
p25	6.014	.935	10	p25	7.289	1.097	7
p50	13.535	5.029	23	p50	19.57	9.774	15
p75	37.876	11.605	38	p75	58.214	14.975	29
iqr	31.862	10.67	28	iqr	50.925	13.878	22
2016							
	download	upload	latency		download	upload	latency
mean	49.47903	26.71417	26.99776	mean	49.43423	26.79826	26.91774
p25	7.906	1.954	8	p25	7.886	1.949	8
p50	21.256	10.388	16	p50	21.134	10.387	16
p75	63.513	19.786	32	p75	63.261	19.805	32
iqr	55.607	17.832	24	iqr	55.375	17.856	24
2017							
	download	upload	latency		download	upload	latency
mean	59.81593	35.14223	25.3606	mean	59.7599	35.10861	25.29899
p25	9.442	2.931808	7	p25	9.345	2.924	8
p50	26.548	11.177	15	p50	26.30617	11.177	15
p75	81.713	38.43973	31	p75	81.3578	38.658	31
iqr	72.271	35.50792	24	iqr	72.0128	35.734	23

Table 10
Summary statistics of broadband speed by week.

Whole dataset				Sample dataset			
week 1							
	download	upload	latency		download	upload	latency
mean	33.22212	16.5019	46.13684	mean	33.27197	16.37436	46.07875
p25	4.602	.847	9	p25	4.605	.848	9
p50	11.802	3.018	21	p50	11.857	3.078	21
p75	38.046	11.90835	41	p75	38.431	11.905	41
iqr	33.444	11.06135	32	iqr	33.826	11.057	32
week 2							
	download	upload	latency		download	upload	latency
mean	33.22212	16.5019	46.13684	mean	33.21775	16.50142	46.12854
p25	4.602	.847	9	p25	4.602	.847	9
p50	11.802	3.018	21	p50	11.801	3.017	21
p75	38.046	11.90835	41	p75	38.04525	11.90809	41
iqr	33.444	11.06135	32	iqr	33.44325	11.06109	32
week 3							
	download	upload	latency		download	upload	latency
mean	33.22212	16.5019	46.13684	mean	33.25254	16.57967	46.25885
p25	4.602	.847	9	p25	4.611	.848	9
p50	11.802	3.018	21	p50	11.82479	2.999	22
p75	38.046	11.90835	41	p75	38.087	11.907	42
iqr	33.444	11.06135	32	iqr	33.476	11.059	33
week 4							
	download	upload	latency		download	upload	latency
mean	33.22212	16.5019	46.13684	mean	33.19263	16.50193	46.42016
p25	4.602	.847	9	p25	4.596	.845	10
p50	11.802	3.018	21	p50	11.77885	2.924	22
p75	38.046	11.90835	41	p75	37.992	11.904	42
iqr	33.444	11.06135	32	iqr	33.396	11.059	32

Appendix B. Estimation results

See Tables 11–17.

Table 11
Number of cities and DeSo per population's group and per education level.

	rank 1	rank 2	rank 3	rank 4	rank 5	Average
Median % sup	25.98	33.54	41.94	59.37	60.97	42.79
City	114	65	76	51	8	290
DeSo	370	316	578	686	226	2,212
City if % sup > median	79	36	47	19	7	114
City if % sup ⩽median	106	62	73	51	8	282
DeSo if % sup > median	156	77	108	55	46	608
DeSo if % sup ⩽median	280	262	500	639	185	1,702

Table 12
Impact of broadband quality on median income.

	whole sample	rank 1	rank 2	rank 3	rank 4	rank 5
speed: 0.256–5	21.6591	−120.9224	−69.7463	59.4634	59.8767	−5.1177
	(96.444)	(111.995)	(73.252)	(194.961)	(44.258)	(7.209)
speed: 5–10	156.2517	−86.7588	−5.9804	−101.6540	170.7285*	−12.7794
	(141.408)	(125.555)	(113.493)	(250.405)	(95.643)	(14.977)
speed: 10–30	100.3382	−91.1553	−81.6572	−155.4143	145.5765	−21.8363
	(145.283)	(125.295)	(117.188)	(250.274)	(93.238)	(23.169)
speed: 30–50	85.1693	−81.8604	54.6686	−103.0114	152.2751	−26.1324

(continued on next page)

Table 12 (*continued*)

	whole sample	rank 1	rank 2	rank 3	rank 4	rank 5
	(160.496)	(148.766)	(153.024)	(261.643)	(98.398)	(25.118)
speed: 50–100	23.5783	−136.7686	97.2716	−249.4530	84.9550	−45.9720
	(180.317)	(167.196)	(203.750)	(280.706)	(81.819)	(43.224)
speed: 100+	−274.5357	−182.8199	−366.7693	−521.0558	5.8129	−24.0693
	(274.059)	(245.665)	(232.965)	(330.118)	(79.644)	(21.892)
income_n-1	196,046.4007***	234,088.2351***	249,952.9187***	193,873.1555***	163,208.7926***	224,692.1345***
	(11,649.439)	(3,173.325)	(4,356.252)	(10,653.084)	(8,172.604)	(18,273.780)
pop DeSo	−1,463.9995	−1,780.3645*	3,331.8524	−3,145.8057	9,725.7545***	−8,167.8012
	(2,479.529)	(915.738)	(2,041.230)	(3,295.230)	(3,321.136)	(9,955.113)
pop city	−366.6672					
	(739.240)					
density DeSo	−0.4537*	−1.4150**	−0.6039	−1.9969***	−0.7709***	1.5501
	(0.264)	(0.635)	(0.483)	(0.720)	(0.122)	(1.121)
perc sup	365.9536***	184.5195***	325.6451***	338.4685***	505.0434***	38.3232
	(141.324)	(48.709)	(62.515)	(115.671)	(81.864)	(100.886)
unemployment	−6.7608	10.4368	19.5425	10.8571	−40.6276	−9.6898
	(28.564)	(9.458)	(18.315)	(22.403)	(26.473)	(26.771)
born international	3.5378	−3.4333	9.0662	9.9493	−18.9486***	−6.0792
	(5.028)	(2.361)	(6.096)	(10.247)	(6.443)	(7.359)
new company	−0.0137	1.4900	−1.1207**	−0.0978	0.0106	−0.0002
	(0.016)	(1.704)	(0.471)	(0.119)	(0.009)	(0.000)
Constant	−2.1737e+06***	−2.6394e+06***	−2.8879e+06***	−2.1290e+06***	−1.8700e+06***	−2.4856e+06***
	(146,634.373)	(37,556.317)	(54,904.928)	(130,393.533)	(83,603.384)	(218,921.447)
Observations	31,472,261	3,525,312	5,214,433	8,125,057	3,542,393	11,065,066
Region	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Regional time trend	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.973	0.974	0.992	0.988	0.997	1.000
R-squared	0.985	0.982	0.990	0.986	0.998	1.000

The reference category for speed is 0–0.256 Mbit/s, which is equivalent to no broadband.
Robust standard errors clustered at the municipal level in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 13
Impact of broadband quality and median income in localities characterized by a high proportion of highly educated inhabitants.

	whole sample	rank 1	rank 2	rank 3	rank 4
speed: 0.256–5	−19.1542	−201.0643**	15.0647	−49.2413	8.1328
	(29.353)	(100.724)	(111.542)	(35.612)	(9.121)
speed: 5–10	43.8190	−242.8113*	205.9479	−17.0228	16.0178
	(51.032)	(138.027)	(145.851)	(39.240)	(15.190)
speed: 10–30	17.0124	−231.8830*	207.2214	−9.3616	17.3704
	(43.703)	(138.673)	(157.846)	(44.707)	(16.168)
speed: 30–50	44.2811	−332.3170*	295.0554	88.0038*	15.8336
	(56.686)	(186.241)	(184.922)	(45.290)	(14.565)
speed: 50–100	53.3275	−408.3759**	563.8886***	58.3935	16.3815
	(61.745)	(199.590)	(211.777)	(46.787)	(15.314)
speed: 100+	−101.3118	−676.5641**	251.7931	−70.0767	15.4456
	(92.762)	(262.786)	(203.919)	(58.252)	(15.367)
income_n-1	288,391.3201***	254,069.0311***	281,868.1338***	295,011.3379***	361,841.0784***
	(6,665.049)	(5,459.705)	(6,660.207)	(12,381.771)	(4,877.408)
pop DeSo	7,078.9834**	−1,928.2872*	5,942.9894**	4,232.4195*	1,514.5693
	(2,975.556)	(1,149.525)	(2,906.952)	(2,263.213)	(1,611.956)
pop city	−1,585.7883***				
	(558.030)				
density DeSo	0.7937***	−1.2150	0.1428	−1.0972	−0.0268
	(0.073)	(0.885)	(0.687)	(0.852)	(0.048)
unemployment	23.3279	6.9158	−6.6797	21.5859	−0.3119
	(19.379)	(12.585)	(22.629)	(14.760)	(0.424)
born international	−10.9766	3.5142	−17.0399	8.6866	−2.1246
	(10.079)	(4.296)	(12.388)	(8.059)	(2.461)
new company	−0.0023	−1.2317	0.4826	0.0183	0.0006
	(0.003)	(1.169)	(0.706)	(0.019)	(0.001)
Constant	−3.3676e+06***	−2.8815e+06***	−3.2890e+06***	−3.4449e+06***	−4.2629e+06***
	(85,146.002)	(65,104.578)	(87,584.179)	(167,601.238)	(51,609.917)
Observations	15,741,382	1,762,710	2,607,396	4,032,640	1,754,337
Region	Yes	Yes	Yes	Yes	Yes

(*continued on next page*)

Table 13 (*continued*)

	whole sample	rank 1	rank 2	rank 3	rank 4
Year	Yes	Yes	Yes	Yes	Yes
Regional time trend	Yes	Yes	Yes	Yes	Yes
R-squared	0.995	0.982	0.987	0.996	1.000

The reference category for speed is 0–0.256 Mbit/s, which is equivalent to no broadband.
Robust standard errors clustered at the municipal level in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 14
Impact of broadband quality on median income in localities characterized by a low proportion of highly educated inhabitants.

	whole sample	rank 1	rank 2	rank 3	rank 4	rank 5
speed: 0.256–5	112.6154	−32.4589	70.3860	206.2247	131.5169	−9.9831
	(134.180)	(90.061)	(85.066)	(206.652)	(86.860)	(18.386)
speed: 5–10	357.7508*	−75.8296	177.3911*	150.7572	304.0746*	−30.5998
	(207.127)	(98.751)	(107.156)	(250.633)	(181.108)	(37.419)
speed: 10–30	307.0550	−60.9721	163.7800	232.1031	247.8046	−50.5909
	(227.043)	(104.593)	(102.691)	(243.378)	(161.542)	(52.009)
speed: 30–50	444.1150*	−76.2277	152.0548	585.8496**	308.0277	−58.2930
	(258.219)	(125.507)	(116.607)	(276.311)	(194.161)	(53.690)
speed: 50–100	352.3508	−69.6598	144.9600	563.9648*	227.2674	−102.8746
	(293.862)	(158.953)	(137.330)	(314.297)	(174.351)	(89.072)
speed: 100+	200.6851	−45.3004	65.7808	125.6787	256.0183	−53.5089
	(374.836)	(313.871)	(144.956)	(271.976)	(187.205)	(50.110)
income_n-1	188,806.6466***	218,820.3592***	223,033.3563***	175,769.1435***	179,789.0931***	222,406.8171***
	(8,141.822)	(2,906.727)	(2,236.534)	(8,797.301)	(7,180.276)	(20,501.861)
pop DeSo	−87.1551	773.1578	4,611.0004***	2,603.9700	8,753.5586*	−7,834.2118
	(2,103.332)	(786.877)	(798.479)	(4,972.521)	(4,492.213)	(9,638.047)
pop city	1,792.6521***					
	(583.241)					
density DeSo	−0.2127	0.1951	−0.3477	−0.9676	−1.1346***	1.9579
	(0.871)	(0.332)	(0.260)	(1.085)	(0.386)	(1.350)
unemployment	−26.2130	−13.1304**	−28.2588***	−50.6267	−108.6424***	−20.3286
	(24.087)	(6.257)	(5.798)	(33.256)	(34.987)	(22.045)
born international	−2.0954	−2.6318	6.0299***	4.2652	1.0960	−9.2392
	(5.536)	(1.689)	(1.870)	(9.097)	(7.189)	(8.977)
new company	−0.0620	2.8401**	−0.7657	0.9709	0.1091	−0.0003
	(0.112)	(1.405)	(0.514)	(0.747)	(0.085)	(0.000)
Constant	−2.1009e+06***	−2.4739e+06***	−2.5560e+06***	−1.9356e+06***	−2.0400e+06***	−2.4644e+06***
	(103,795.345)	(33,620.499)	(25,739.800)	(92,125.984)	(67,329.160)	(243,771.664)
Observations	15,730,879	1,762,602	2,607,037	4,092,417	1,788,056	4,531,405
Region	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Regional time trend	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.973	0.974	0.992	0.988	0.997	1.000

The reference category for speed is 0–0.256 Mbit/s, which is equivalent to no broadband.
Robust standard errors clustered at the municipal level in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 15
Impact of broadband quality on unemployment rate.

	whole sample	rank 1	rank 2	rank 3	rank 4	rank 5
speed: 0.256–5	−0.0005	−0.0001	−0.0001	−0.0006*	0.0003	0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
speed: 5–10	−0.0008	−0.0004	−0.0004	−0.0004	0.0006	0.0000
	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
speed: 10–30	−0.0008	−0.0001	−0.0001	−0.0003	0.0007	0.0000
	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
speed: 30–50	−0.0009	0.0002	0.0002	−0.0003	0.0008	0.0000
	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)
speed: 50–100	−0.0009	0.0005	0.0005	−0.0002	0.0009	0.0000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)
speed: 100+	−0.0009	0.0019**	0.0019**	−0.0000	0.0007	0.0000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)
pop DeSo	−0.0395***	−0.0432***	−0.0432***	−0.0440***	−0.0310***	−0.0217*
	(0.008)	(0.004)	(0.004)	(0.015)	(0.011)	(0.010)

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Table 15 (*continued*)

	whole sample	rank 1	rank 2	rank 3	rank 4	rank 5
pop city	−0.0017					
	(0.001)					
density DeSo	−0.0000***	0.0000	0.0000	−0.0000	−0.0000	0.0000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
perc sup	−0.0001	0.0000	0.0000	−0.0003	−0.0006**	−0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
unemployment_n-1	0.0006***	0.0006***	0.0006***	0.0003*	0.0001*	−0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
born international	−0.0000	0.0000***	0.0000***	0.0001**	0.0001***	0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
new company	0.0000	−0.0000	−0.0000	−0.0000	0.0000	0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
income	−0.0919***	−0.1083***	−0.1083***	−0.1047***	−0.0813***	−0.1212***
	(0.009)	(0.013)	(0.013)	(0.028)	(0.023)	(0.016)
Constant	1.4989***	1.6865***	1.6865***	1.6558***	1.3021***	1.6965***
	(0.083)	(0.167)	(0.167)	(0.300)	(0.217)	(0.166)
Observations	31,472,261	3,525,312	3,525,312	8,125,057	3,542,393	11,065,066
Region	Yes	Yes	Yes	Yes	Yes	Yes
Regional time trend	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.926	0.818	0.818	0.962	0.990	0.999

The reference category for speed is 0–0.256 Mbit/s, which is equivalent to no broadband.
Robust standard errors clustered at the municipal level in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 16
Impact of broadband quality on unemployment rate in localities characterized by a high proportion of highly educated inhabitants.

	whole sample	rank 1	rank 2	rank 3	rank 4
speed: 0.256–5	−0.0001	−0.0007***	0.0001	−0.0002**	−0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
speed: 5–10	−0.0001	−0.0012***	−0.0000	−0.0002**	−0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
speed: 10–30	−0.0002	−0.0013***	−0.0000	−0.0002**	−0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
speed: 30–50	−0.0002*	−0.0014***	−0.0001	−0.0001	−0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
speed: 50–100	−0.0002	−0.0012***	−0.0001	−0.0001	−0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
speed: 100+	−0.0002	−0.0014***	−0.0000	−0.0002*	−0.0000
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)
pop DeSo	0.0001	−0.0222***	−0.0042	0.0051	−0.0022
	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)
pop city	−0.0014***				
	(0.000)				
density DeSo	0.0000***	0.0000*	0.0000*	0.0000	0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
income	−0.0467***	−0.0769***	−0.0613***	−0.0245	−0.0162**
	(0.008)	(0.009)	(0.009)	(0.017)	(0.005)
born international	−0.0000	0.0000	0.0000	0.0000	0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
new company	−0.0000	−0.0000**	0.0000	0.0000	−0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
unemployment_n-1	0.0001***	0.0006***	0.0003***	0.0001**	−0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.6290***	1.1337***	0.8165***	0.2866	0.2507***
	(0.100)	(0.110)	(0.107)	(0.227)	(0.057)
Observations	15,741,382	1,762,710	2,607,396	4,032,640	1,754,337
Region	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Regional time trend	Yes	Yes	Yes	Yes	Yes
R-squared	0.963	0.857	0.889	0.968	1.000

The reference category for speed is 0–0.256 Mbit/s, which is equivalent to no broadband.
Robust standard errors clustered at the municipal level in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 17
Impact of broadband quality on unemployment rate in localities characterized by a low proportion of highly educated inhabitants.

	whole sample	rank 1	rank 2	rank 3	rank 4	rank 5
speed: 0.256–5	−0.0012**	0.0000	−0.0006	−0.0013	0.0001	0.0000
	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)
speed: 5–10	−0.0016*	−0.0002	−0.0018	−0.0004	0.0003	0.0000
	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)
speed: 10–30	−0.0015*	0.0003	−0.0016	−0.0000	0.0004	0.0000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)
speed: 30–50	−0.0015	0.0008	−0.0014	−0.0001	0.0004	0.0000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
speed: 50–100	−0.0012	0.0007	−0.0017	0.0005	0.0006	0.0000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
speed: 100+	−0.0009	0.0038***	−0.0015	0.0010	0.0004	0.0000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
pop DeSo	−0.0451***	−0.0539***	−0.0431***	−0.0303	−0.0272***	−0.0210**
	(0.010)	(0.004)	(0.014)	(0.020)	(0.010)	(0.008)
pop city	−0.0026					
	(0.002)					
density DeSo	−0.0000	−0.0000	0.0000*	−0.0000	0.0000	0.0000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
income	−0.1065***	−0.1138***	−0.1787***	−0.1692***	−0.1199***	−0.1057***
	(0.012)	(0.016)	(0.027)	(0.034)	(0.016)	(0.021)
born international	−0.0000	0.0000***	0.0000	0.0000	0.0000	0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
new company	−0.0000**	−0.0000	0.0000	−0.0000	−0.0000	0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
unemployment_n-1	0.0006***	0.0006***	0.0004***	0.0003*	0.0002***	0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	1.7014***	1.8268***	2.5536***	2.3305***	1.7283***	1.5057***
	(0.119)	(0.194)	(0.319)	(0.345)	(0.145)	(0.249)
Observations	15,730,879	1,762,602	2,607,037	4,092,417	1,788,056	4,531,405
Region	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
Regional time trend	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.904	0.756	0.922	0.965	0.988	0.999

The reference category for speed is 0–0.256 Mbit/s, which is equivalent to no broadband.
Robust standard errors clustered at the municipal level in parentheses: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

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