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Broadband Internet and Income Inequality[*]

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Abstract

Policy makers are aiming for a large coverage of high-speed broadband Internet. However, there is still a lack of evidence about its effects on income distribution. In this paper, we investigate the effects of fixed broadband Internet on mean income and income inequality using a unique town-level data on broadband adoption and quality in France. We find that broadband adoption and quality raise mean income and lower income inequality. These results are robust to initial conditions, and yield policy implications for the deployment of faster broadband Internet.

Keywords: Broadband Internet, Income Inequality, Telecommunications.

JEL Classification: D31, L96, O15.

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1 Introduction

Broadband Internet is a more advanced telecommunications technology that provides faster access to the Internet. It enables users to access information online and communicate with other users at lower cost. Within a decade, it has been adopted by the vast majority of households in developed economies. According to the Organization for Economic Co-operation and Development (OECD), up to 90% of households in its region have access to fixed broadband Internet in 2016.[1] This massive adoption have been associated with a dramatic spread of online services, among which job search and posting. According to a nationwide survey conducted in France, a growing share of broadband users, particularly in the low-income segment, rely on their household's Internet connection to search for jobs. This usage pattern is likely to affect household's income, as suggested by Roller & Waverman (2001) and Czernich *et al.* (2011), and more specifically its distribution.

In the meantime, full coverage of faster broadband Internet has become an important policy objective in several countries. The European Commission has designed a "Digital Agenda for Europe" targeting large coverage of high-speed broadband Internet access. This agenda has been declined into national policies. In France for instance, the government is aiming for full coverage of the territory by 2020. Similar objectives have been set in the United States "National Broadband Plan". However, there is still a lack of evidence about the effects of broadband Internet on the distribution of income, and particularly at the household level.

In this paper, we take advantage of a unique town-level data to investigate the effects of broadband adoption and quality on the distribution income using data from France. Our data set provides information about the yearly number of fixed broadband subscribers and the distribution of download speed per town, from 2009 to 2013. We complement these data with town-level distribution of income as well as socio-demographic characteristics. Broadband adoption is measured by the penetration rate, that is the ratio of the number of users to the number of households. Broadband quality is measured by the median download speed. We use the Gini index as well as inter-decile ratios as measures of income inequality. Ordinary Least Squares (OLS) estimates suggest that broadband adoption and quality raise mean income and lower income inequality. However, these effects could be biased by the endogeneity of broadband Internet diffusion.

We rely on measures of signal attenuation of broadband Internet, a time-invariant variable which strongly determines the trend in broadband adoption and quality. Interestingly, signal attenuation is predetermined by the initial deployment of the historical telephony network,

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[1] The penetration rate of fixed broadband reached 30% in 2016 in OECD countries, corresponding to 90% household penetration rate, under the assumption of 3 members per household.

and does not directly affect the distribution of income. In addition, this variable is a better measure of the distance between users and local exchanges, a typical instrument for broadband adoption (Czernich *et al.* , 2011; Czernich, 2014). Following Duflo (2001), we implement a Wald Difference-in-Difference (Wald-DiD) estimation strategy, whereby the interaction between time and signal attenuation serves as an instrument for both broadband penetration and download speed.

The Wald-DiD estimates confirm the sign of the OLS estimates. More specifically, both broadband adoption and quality raise mean income, and lower income inequality. A percentage point increase in broadband penetration raises mean income by 0.14% and lowers the Gini index by 0.0005 unit, that is 1% of standard deviation. Likewise, 1 megabit per second (Mbps) additional increase in download speed raises mean income by 0.04% and lowers the Gini index by 0.0002 unit, that is 0.4% of standard deviation. Using the inter-decile ratios as measures of income inequality, we find that the positive effects of broadband Internet on income inequality is driven by a relatively greater benefit accruing to the bottom deciles, particular the second to the fifth deciles. These findings are robust to initial conditions which could drive trends in income inequality and broadband diffusion.

We use these estimates to conduct some counterfactual analyses. First, we find that between 2009 and 2013 in France, broadband adoption alone contributes to 34% of income growth and 80% of inequality reduction, while quality improvement accounts for 6% and 20% respectively. Second, a percentage point increase in broadband penetration raises income per capita by 0.06%, not far from the estimates by Czernich *et al.* (2011), while 1 Mbps increase in download speed raises income per capita by 0.02%. Third, the effects of broadband penetration is non-linear with maximal impact at early stage of diffusion, when the penetration rate is below 50%. Finally, we also find that the positive effects of broadband Internet on income distribution depends on education, measured by the number of years of schooling. Higher level of education, as well as lower inequality in education, increase the magnitude of the effects of broadband Internet.

The findings of this paper are closely related to literature on the economic effects of Information and Communication Technologies (ICT). Roller & Waverman (2001) and Czernich *et al.* (2011) study the effects of telecoms infrastructure on income per capita but did not investigate the effects on income inequality. Recent studies on inequality include Forman *et al.* (2012) who investigate the effects of ICT investment on the wage gap between US counties. However, they did not focus on household broadband usage. Akerman *et al.* (2015) use detailed micro data for Norway and find that skilled workers' wages are improved when firms start to use broadband.

The remaining of the paper is organized as follows. Section 2 summarizes the related literature, emphasizing the lack of studies on the effects of broadband Internet on income inequality. Section 3 presents some background information about the diffusion of broadband Internet in France. Section 4 introduces the data along with some descriptive statistics. Section 5 presents the econometric model and discusses the estimation strategy. Section 6 presents the results and section 7 concludes.

2 Related literature

As reviewed by Bertschek *et al.* (2016), the economic effects of ICT have been the topic of a vast literature, starting from the early 90s. Most studies have investigated the effects of ICT on several economic outcomes such as gross domestic product (GDP), employment and productivity, but few have evaluated its effects on income inequality.

Early empirical studies such as Cronin *et al.* (1991), Madden & Savage (1998) and Roller & Waverman (2001) were conducted at the country level and find positive effects of telecommunications infrastructure on economic growth. For instance, Roller & Waverman (2001) use country-level data from the OECD member countries and find that 10 percentage points increase in the penetration rate of fixed telephony raises GDP per capita by 0.45%. These effects become substantially larger when the penetration rate of fixed telephony is higher than the critical mass of 40%, due to network externalities. As suggested by Lam & Shiu (2010) and Chakraborty & Nandi (2011), the positive effects of telecommunications infrastructure on income are also found in developing countries. More specifically, Gruber & Koutroumpis (2011) also find positive effects for mobile telephony.

Czernich *et al.* (2011) is the closest to our paper as they investigate the effects of fixed broadband Internet. Using country level data from the OECD, they find that 10 percentage point increase in fixed broadband penetration raises gross national income per capita by 0.9-1.5 percentage point. As in Roller & Waverman (2001), they also investigate and find a critical mass of 20% above which the effects of broadband on income becomes larger. However, their study was conducted at the country level and they did not estimate the impact on income distribution.

Country-level studies may suffer from differences in unobserved institutional features such as competition and regulatory policies, even though they use country fixed-effects or rely on a set of countries with similar level of development. Some recent studies investigate the effects of telecommunications infrastructure at the infra-country level, thus controlling for institutional differences. For instance, Yilmaz *et al.* (2002) use state-level data from the US to study the effects of telecommunications infrastructure investment on output growth. Shiu & Lam

(2008) and Ward & Zheng (2016) investigate similar effects in China. These studies suggest that the positive effects of telecoms investment typically apply to high-income areas.

To investigate the underlying mechanisms of the relationship between telecoms investment and economic growth, some recent papers have analyzed the effects on employment and productivity. Basically, broadband Internet tends to promote employment and raise wages, but with mixed effects on productivity. More specifically, Kolko (2012) use county-level data from the US and find positive effects of the number of broadband providers on employment. Likewise, Forman *et al.* (2012) find that investment in Internet has raised wages and employment, but only in very few counties, the overall effect being not significant. Using town-level data from Germany, Czernich (2014) find no effects of broadband availability on unemployment rate. Ivus & Boland (2015) find that in Canada the effects of broadband on employment is positive only in the services sector.

Regarding productivity, Bertschek *et al.* (2013) in Germany find positive and significant effects of broadband usage on firms' innovation activities, but no effect on labor productivity. In the same vein, Colombo *et al.* (2013) in Italy find that the adoption of basic broadband application does not increase firms' productivity, however higher speed broadband can increase productivity if combined with strategic and organizational changes. Likewise, Bertschek *et al.* (2016) in Germany find that labor productivity increases with the share of employees with mobile Internet access. However, the effects on productivity may depend on sectors. For instance, Greenstein & Spiller (1995) show that telecommunications investment has positive impact on firms' revenue in technology-intensive sectors such as finance, insurance and real estate. On the contrary, they find no effect in the manufacturing sector.

This paper takes a closer look at the distribution of income, thus going beyond average income. To the best of our knowledge, the literature has not yet dealt with the effects of broadband on income inequality. One exception is Forestier *et al.* (2002) who rely on country-level data and find a positive correlation between the penetration rate of fixed telephony and inequality.

3 Background on broadband Internet in France

Broadband Internet has been deployed in France since 2000. Until 2013, the majority of the broadband coverage of the territory is provided by digital subscriber line (DSL) technologies via the incumbent operator's copper network. This network consists of about 33 million lines, deployed during several decades to provide fixed telephony. It covers the entire territory and spreads over more than 15,800 local exchanges. It was, therefore, not designed to convey DSL signals and provide DSL access. Indeed, the propagation of DSL signals is weaken over long distances. This signal attenuation is measured in decibels (dB) and depends on the distance traveled and the diameter of the copper lines. The eligibility threshold for a DSL line corresponds to a maximum signal attenuation of 78 dB, allowing a nominal speed up to 512 Kilobits per second (Kbps), or slightly more than 5 km for a copper pair with a diameter of 0.4 mm.

The length of the copper line, between the local exchange and the household, has no major impact on fixed telephony. However, it introduces a wide disparity in access to broadband Internet. Thus, while households located near the local exchange can enjoy a speed of more than 20 Megabits per second (Mbps), those over 5 km away cannot benefit from broadband access. The longest lines are mostly located in rural areas, but also in areas which have been recently urbanized. At the end of 2013, less than 1% of the lines were not eligible for broadband services via DSL technology.

In order to improve DSL quality in terms of speed, the incumbent operator has progressively upgraded the copper local loop which consists of bringing optical fiber to the sub-distributor and keeping the copper network for the last miles, that is between the sub-distributor and the households. Such an operation is therefore faster and less costly than fiber-to-the-home (FTTH) deployment and can be an alternative and temporary solution before future FTTH deployment. After the operation, the majority of the inhabitants concerned will benefit from speed higher than 5 Mbps. With ADSL2+ or VDSL technology the theoretical speed could increase to respectively 25 Mbps or 50 Mbps, provided that the distance does not exceed 2.5 km or 1 km.

Figure 1 presents the evolution of broadband Internet penetration rate in France. ADSL is the main technology among all broadband connections. It still represents 90% of fixed broadband connections, compared to 6% for cable and 3% for FTTH. The total broadband subscribers have increased from 19.1 Million in 2009 to 24.3 Million in 2013. More than 5 Million households have adopted broadband access during this period.

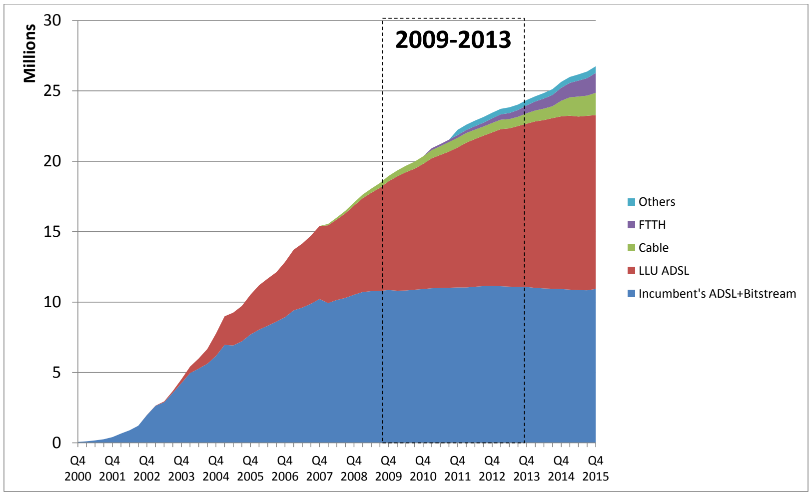
The rapid growth in broadband Internet usage is having a dramatic effect both on private and public sectors. The online environment has become a more efficient alternative to traditional offline setting. Broadband Internet access provides consumers with an abundance of products and services in a short amount of time. The Internet offers a centralized solution and increase the efficiency in many usages. According to a national survey conducted in France (CREDOC, 2014), 48% of interviewees use Internet for social networking, 47% to download music, 25% for job search, 51% for administrative procedures and 51% for online shopping.

In terms of usage evolution, an increasing number of individuals used the Internet to search for job. In 2006 only 16% interviewees used Internet for job search. This number has risen to 19% in 2009 and 25% in 2013. One person in two (55%) in 2013 (instead of 40% in 2008) used the Internet for administrative procedure and income tax return (for people aged 18-year-old population and more). For income tax return, only 7.4 Million households in 2009 used Internet for the declaration compared to 14.7 Million in 2014. Other usage growth is also observed in e-commerce. In addition, more than one person in two used Internet for shopping. If the number of people concerned did not change between 2011 and 2012, the volumes of transaction, 45 Billion Euros in e-commerce in 2012, compared with 38 Billion Euros in 2011, were steadily increasing due to the increase in the average number of transactions per buyer.

Depending on the income level, the usage of Internet may vary. In general, high-income people use more Internet than low-income people whether for e-administration, e-commerce, or for entertainment. However, job search and social networking are two exceptions. According to CREDOC (2014), 31% of low-income individuals used the Internet to search for job, compared to 18% of high-income individuals.

The European Commission cares about the quality of broadband Internet access in terms of download speed. In September 2016, it announced that by 2025 all European households should have access to connections with speed of at least 100 Mbps. The Commission proposed "a new European Electronic Communications Code including forward-looking and simplified rules that make it more attractive for all companies to invest in new top-quality infrastructures, everywhere in the EU, both locally and across national borders". According to the Commission, these investments could "boost the GDP of the EU by an additional 910 billion Euros and create 1.3 million new jobs by 2025".

Figure 1: Evolution of fixed broadband access by technology



Source: National telecoms regulator statistics (ARCEP).

4 Data and descriptive statistics

4.1 Data

We build a panel of 5,021 French towns over 5 years, from 2009 to 2013.[2] This set of towns represents 75% of the French population. The panel is slightly unbalanced with 4.8 observations per town on average. For each town, we obtain information on broadband adoption and quality, income distribution, as well as socio-demographic characteristics.

The broadband data comes from the French incumbent operator, but covers all households, including the customers of its rivals. It includes the number of residential connections under the major technologies, that is cooper (xDSL), cable and fiber (FTTH) technologies, and the distribution of maximal download speeds.[3]

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[2] In this paper we define a town as a municipality with more than 2000 inhabitants, the income data disclosure threshold used by the statistical office, INSEE.

[3] Data on other technologies such as satellite and Wimax, was not available. These technologies represent 1-2% of total broadband connections. We approximate the number of active cable connections per town by multiplying the number of available connections by the national take-up rate, that is the share of active connections at the national level. We obtain the number of available cable connections from the national regulator. According the cable operator, 1.4 million households in 2013 have adopted cable-based broadband

We calculate broadband penetration per town as the ratio of the number of residential connections to the number of households. We use the distribution of maximal download speeds to construct the median download speed per town as our measure of the quality of broadband Internet access. This way of measuring quality is consistent with the framing of broadband policies. Typically, they aim at increasing the speed available to a certain proportion of the population. For instance, the European Commission aims at providing at least 100 Megabits per second to half European households by 2020.

Interestingly, the broadband data also provides a measure of signal attenuation. This measure the intensity of data transmission signal, expressed in decibels, and is highly correlated with the distance between users' premises and local exchanges. In general, the longer the distance, the greater the noise. It is time-invariant and strongly determines the quality of broadband Internet. The greater the noise, the lower is the quality of broadband Internet access. It is exogenous because predetermined by the traditional telephony network. It will be useful for our identification strategy. This variable mimics the distance between users' premises and local exchanges as used in Czernich (2014). We obtain measures of signal attenuation conducted by the incumbent operator in 2009.

The income distribution data comes from the national statistical office (INSEE). It includes the deciles of income, the mean income, and the Gini coefficient of inequality, available for towns with at least 2000 inhabitants to protect tax payers' privacy. Income is measured at the household level as total earnings per unit of consumption, before taxation and social benefits. As such, the observed income distribution is not affected by ex-post redistribution policies. We do not observe income generated from some online sharing platforms such as Airbnb that households were not requested to report to the tax administration. We use both the Gini index as well as inter-deciles ratios as measures of inequality.

Town-level socio-demographic characteristics also come from INSEE and include the distribution of age and education. We use both the average and standard deviation of age and education as controls for socio-demographic characteristics of the population.

Table A-1 in the Appendix presents the data along with their summary statistics.

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among 8.6 million available connections in France, corresponding to a take-up rate of 16%. For fiber technology, we estimated the total number of lines by multiplying the incumbent's number by a surcharge coefficient given that we know the number of incumbent's FTTH consumers per town and that its market share is around 70% on FTTH.

4.2 Descriptive statistics

In Table 1 we present the characteristics of the 5021 towns in 2013 and compare with national statistics. It turns out that our sampled towns are richer, more educated, more densely populated and more unequal. The average income is 26758 euros compared to 23,634 euros at the country level. On average, 42% of adults graduated from college compared to 37% at the country level. The average population density is 8 times larger and the Gini coefficient is 0.31 on average, compared to 0.29 at the country level. These features are characteristics of urban areas. Table 2 presents the initial level and the evolution of broadband internet and income inequality in these areas.

Broadband adoption was already significant in 2009. The average penetration rate stood at 54%, meaning that more than half of the households had access to broadband Internet in 2009. It spanned from 16% to 146% in 2009.[4] By 2013, average broadband adoption increased by 11 percentage points up to 65%, corresponding to a yearly increase of 2.2 percentage points. The lowest and largest penetration rates rose respectively to 21 and 181%. This rising trend reduces heterogeneity in broadband adoption across towns, suggesting a convergence. The standard deviation drops from 9.4 in 2009 to 9.2 in 2013.

In the meantime, the quality of broadband Internet access, measured by the median download speed, has improved. The average download speed doubled between 2009 and 2013, from 6.5 Mbps to 13 Mbps. This improvement in quality stems from the deployment of faster broadband technologies such as cable, VDSL and fiber.[5] More importantly, quality improvement also reflect DSL network upgrade which basically consists in reducing the distance between users' premises and local exchanges. Contrary to the convergence in broadband adoption, we observe rising heterogeneity in the quality of broadband Internet across towns. The standard deviation of the median download speed more than doubled between 2009 and 2013, from 2.8 to 6.7.

Variation in broadband penetration is positively correlated to variation in broadband quality. As can be observed from Figure A-1 in the Appendix, larger increase in broadband penetration is observed in towns with higher increase in the median download speed. This positive correlation is driven by the effect of quality on the valuation of Internet access. In addition, and as emphasized in the background section, variation in broadband quality is strongly determined by the signal attenuation. Towns with smaller signal attenuation experience bigger increase in the quality of broadband Internet access. As a consequence, the penetration rate of broadband Internet increases more in towns with smaller signal attenuation. This negative

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[4] The penetration rate can be above 100% due to multiple subscriptions per household.

[5] VDSL stands for Very-high-bit-rate Digital Subscriber Line. It is a faster variant of the standard DSL technology.

correlation is depicted in Figure 2 by the downward sloping linear fit.

Mean income grew at 2.3% per year between 2009 and 2013. Given a yearly average inflation rate of 1.4%, the yearly growth rate of real income is 0.9%. Cross-town income heterogeneity, as measured by the coefficient of variation, the ratio of standard deviation to the average income, does not change significantly. The coefficient of variation remains flat at 0.28. Therefore, there is not enough variations to study cross-town inequality.

On average, within-town income inequality, measured by the Gini index at the town level, rises slightly between 2009 and 2011 before falling afterwards. The average Gini index rises from 0.319 in 2009 to 0.320 in 2011, and falls to its initial level in 2013. This break in the trend of income inequality is primarily due to a change in economic policies as the political power switched from the right to the left-wing in 2012. We introduce year fixed effects into the econometric model to account for this break.

Overall, income inequality tends to falls between 2009 and 2013. As shown in Figure 2, the magnitude of this falls tends to be smaller in towns with higher signal attenuation. It turns out that there is a negative relationship between the diffusion of broadband Internet and income inequality, driven by the magnitude of signal attenuation. We exploit this relationship in order to estimate the causal impact of broadband Internet on income inequality.

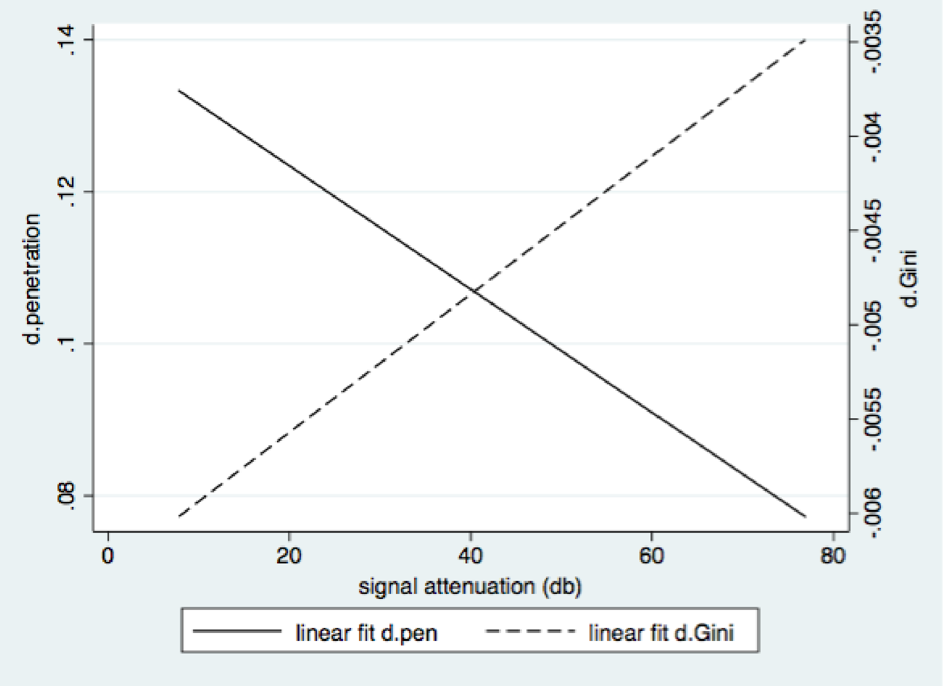
Table 1: Sample description in 2013

	sampled towns	country
mean income $\bar{y}$	26758	23634
1st decile y_1	9096	10730
2nd decile y_2	13030	13530
3rd decile y_3	15936	15800
4th decile y_4	18493	17890
5th decile y_5	20991	20000
6th decile y_6	23659	22340
7th decile y_7	26808	25230
8th decile y_8	31067	29580
9th decile y_9	38619	37200
Gini	0.31	0.29
Population density ($inhab/km^2$)	888	119
age	41	41
share of college graduates X_{21} (%)	42	37

Table 2: Descriptive statistics of the main variables

	Year	Mean	St. Dev.	Min	Max
Penetration (%)	2009	53.6	9.4	16.1	146.3
	2013	65.2	9.2	20.8	181.0
Quality (Mbps)	2009	6.5	2.8	0.5	12.0
	2013	13.0	6.7	0.5	20.0
Mean income (euros)	2009	23883	6739	11737	89243
	2013	26758	7511	12332	100872
Gini	2009	0.319	0.043	0.222	0.573
	2011	0.320	0.046	0.218	0.596
	2013	0.312	0.045	0.214	0.567

Figure 2: Broadband adoption, inequality and signal attenuation



Note: This figure presents the relationship between packet signal attenuation and linear trends in the change in broadband adoption and inequality.

5 Econometric model and estimation

This section presents the econometric model and the estimation strategy.

5.1 Econometric model

The effects of Internet diffusion on income inequality stem from several sources. In this paper, we focus on the short-term effects of broadband internet usage by households. By doing so, we discard wage effects stemming from factors productivity, as well as long-term effects stemming from health and education.

Households' Internet usage can affect their income mainly due to employment. It eases access to job information and improve the quality of job matching. In addition, wider Internet adoption by other households generates demand for electronic equipment that could boost labor demand, and creates the virtual network necessary for the deployment of online platforms dealing with new economic activities such as e-commerce, search and social-networking.

The impact of Internet adoption on households' income may differ according to their profiles due to differences in terms of usage and skill biases. While some households mainly use Internet access for leisure, others use it for job purposes. As emphasized in the background section, poor households are more likely to search for job on the Internet. Likewise, the labor demand generated by the wider diffusion of the Internet can be biased in favor of low-skilled workers. While the creation and maintenance of Internet platforms require high-skilled workers, the delivery of goods to end-users heavily relies on low-skilled workers.

In order to test the effect of broadband Internet on income distribution, we specify the following reduced-form econometric model:

$$Y = \alpha + \beta P + \gamma X + \epsilon \tag{1}$$

Where Y is a measure of income inequality in the population, typically the Gini index. We take advantage of the availability of income deciles by using inter-decile ratios as alternatives measures of income inequality. These latter enable us to identify, when relevant, losers and winners from broadband Internet. We also use average income as a dependent variable in order to estimate the overall effect of broadband Internet on income.

P denotes the measure of broadband adoption. In the context of significant penetration rate in advanced countries, the impact of quality upgrading, using cable or fiber technology, has become a more important policy question. We estimate the impact of quality q by replacing penetration in equations (1). We expect the impact of quality on income distribution to be qualitatively similar to the impact of adoption because the two are positively correlated.

X is a vector of households' socio-demographic characteristics including the distribution of age and education. ϵ is a vector of unobservables including wage productivity stemming from firms, household's labor supply and income shocks.

5.2 Estimation strategy

We introduce town and year fixed effects into equation (1) in order to account for time invariant wage effects as well as common income shocks. The estimated equation can be expressed as:

$$Y_{it} = \alpha + \beta P_{it} + \gamma X_{it} + \mu_i + \nu_t + \varepsilon_{it} \tag{2}$$

Ordinary Least Squares estimate of parameter β in equation (2) would be biased due to unobserved labor supply and the correlation between the unobserved determinants of income inequality and households' preferences for broadband Internet. In order to identify the causal impact of broadband Internet on income inequality, we implement a Wald-difference-in-difference (Wald-DiD) estimation strategy which basically corresponds to the ratio of the DiD in income distribution to the DiD in broadband Internet. We use a Wald-type estimator because towns differ only in the intensity of treatment and, as a result, do not allow implementing a sharp DiD, but rather a fuzzy DiD. As suggested by Figure 2, difference in treatment intensity is mainly driven by the time-invariant and exogenous signal attenuation. This latter does not directly affect the distribution of income, because it is predetermined by the initial structure of the fixed telephony network. Therefore, it can be used a group variable. Causal identification relies on the assumption that variation in income inequality is identical across towns with the same level of signal attenuation. As emphasized by de Chaisemartin & D'Haultfoeuille (2017), the wald-DiD can be biased when treatment effect is unstable or heterogeneous. We assume stability and homogeneity of the treatment effect.

The Wald-DiD estimator writes:

$$\hat{\beta} = \frac{(Y_{it} - Y_{it'}) - (Y_{jt} - Y_{jt'})}{(P_{it} - P_{it'}) - (P_{jt} - P_{jt'})}$$

Where i and j index two groups of towns, with different level of signal attenuation, and t and t' index time.

Implementing the Wald-DiD with a continuous group variable amounts to using the interaction of signal attenuation and time as an instrument for broadband Internet in equation (2).

This estimator is similar to the one used by Duflo (2001) in the evaluation of the impact of school construction on education and wage in Indonesia.[6]

We employ an alternative identification strategy that relies on cross-sectional variations in broadband Internet and inequality and controls for initial conditions.

6 Results

This section presents the main results, some robustness checks and policy implications.

6.1 Main results

Table 3 presents a synthesis of the main results. Detailed results are presented in Tables A-2 to A-7 in the appendix.

We start by estimating the impact of broadband Internet on mean income and present the main results in the first column of Table 3. Overall, mean income increases with broadband adoption and quality. A percentage point increase in broadband penetration raises mean income by 0.20%, according to the OLS estimate, and 0.14%, according to the Wald-DiD estimate. Likewise, 10 Mbps increase in broadband download speed raises mean income by respectively 0.1% and 0.4%.

The Wald-DiD estimate of the impact of broadband adoption is smaller than the OLS estimate, contrary to the estimate of the impact of broadband quality. This is because variation in income is positively correlated with variation in broadband adoption but negatively correlated with variation in quality. Indeed, larger variation in income is observed in poorer towns where variation in broadband adoption is stronger while variation in quality is weaker. However, Wald-DiD estimates are less precise than OLS'. The confidence interval of the Wald-DiD overlaps that of the OLS estimates.

As discussed in section 4.2, broadband penetration increases by 2.2 percentage point per year. The Wald-DiD estimate implies that mean income should rise by 0.31%, compared to 0.9% overall increase in mean income. Therefore, broadband adoption contributes to the third of the increase in mean real income between 2009 and 2013. Similarly, average download speed increase by 1.3 Mbps per year, implying 0.05% yearly rise in mean income. Therefore, broadband quality accounts for 6% of the increase in mean income between 2009 and 2013.

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[6] Duflo (2001) uses Wald difference-in-difference to estimate the impact of school construction on schooling in Indonesia. Basically, she compares change in schooling between regions with different intensity of school construction.

The second column of Table 3 presents the estimates of the impact of broadband Internet on income inequality, measured by the Gini index. It turns out that income inequality falls with the diffusion of broadband Internet. Ten percentage points increase in broadband penetration lowers the Gini coefficient by 0.002 and 0.005 under OLS and Wald-DiD respectively. Similarly, 10 Mbps increase in broadband download speed lowers the Gini coefficient by respectively 0.001 and 0.002. OLS tend to underestimate the magnitude of the effect of broadband Internet on inequality due to reverse causality. Indeed, an increase in income inequality is expected to reduce broadband penetration or quality improvement because of smaller income accruing to the poor.

Using the same figures of the yearly change in broadband penetration and download speed, we expect the Gini index to fall yearly by 0.001 due to broadband adoption and by 0.0003 point due to the improvement in broadband quality. As a result, broadband adoption and quality account for respectively 80% and 20% of the fall in income inequality between 2009 and 2013.

The remaining columns of Table 3 report the estimates when income inequality is measured by inter-decile ratios, that is the ratio of bottom deciles to the ninth decile. Using this dependent variable enable us to identify winners and losers from the diffusion of broadband Internet. It turns out that the inequality reducing effect of broadband Internet is mainly driven by a relative improvement in the income of the bottom deciles. Figure 3 depicts the OLS and Wald-DiD point estimates of the effect of broadband Internet on inter-deciles ratios. While, the first decile seems not to be affected by broadband Internet, we observe that the second to the fifth deciles benefit relatively more from broadband Internet than the top income deciles.

Regarding the controls, Tables A-2 to A-7 in the appendix show that there is no relationship between income and age probably because income is per consumption unit. Income inequality is lower in towns where the population is more aged or more educated. In addition, income inequality is higher in towns where the population is more heterogeneous in terms of demographics and education. Finally, the year fixed effects exhibits the break in the trend of income inequality, rising from 2009 to 2011 and falling afterwards.

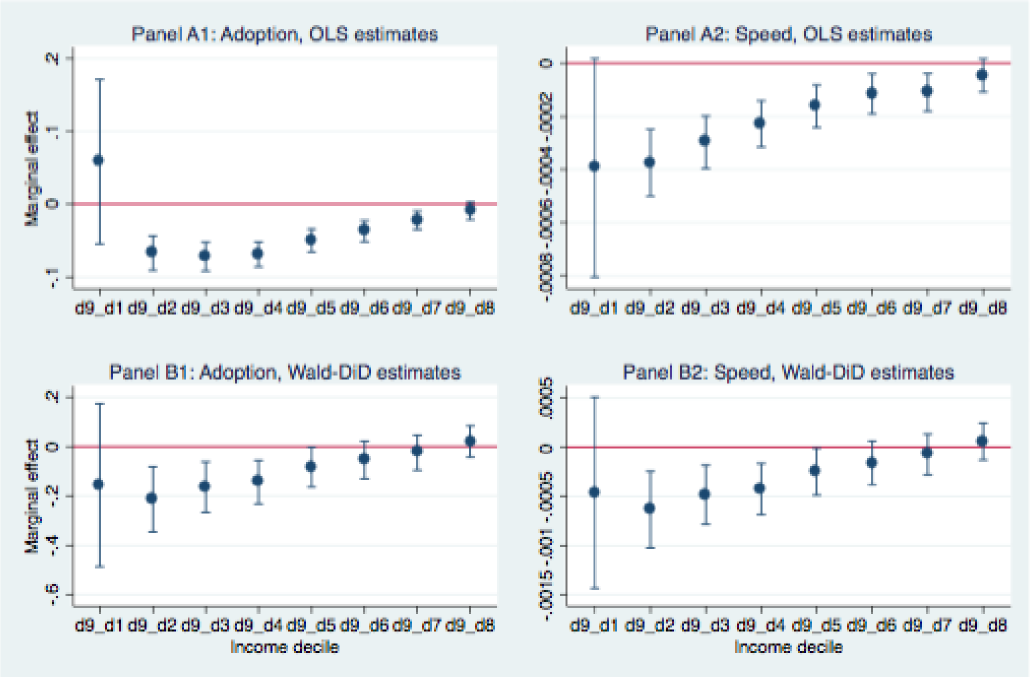
The instrumental variable estimation strategy underlying the Wald-DiD estimates passes all standard statistical tests. In particular, the first-stage F-statistic is greater than 300 in the case of broadband penetration and 1000 in the case of broadband download speed. These statistics are largely above the critical threshold of under-identification, meaning that signal attenuation is a strong predictor of broadband adoption and quality. In addition, Stock and Yogo's weak identification test statistic is also above its critical threshold, rejecting the hypothesis that the interaction between time and signal attenuation is a weak instrument.

Table 3: Estimates of the effects of broadband Internet on income inequality

	$\bar{Y}_{it}$	G_{it}	R_{i1t}	R_{i2t}	R_{i3t}	R_{i4t}	R_{i5t}	R_{i6t}	R_{i7t}	R_{i8t}
Panel A: Fixed-Effects Ordinary Least Squares										
P_{it}	0.199***	-0.020***	0.058	-0.067***	-0.072***	-0.069***	-0.050***	-0.037***	-0.022***	-0.009
	(0.017)	(0.004)	(0.058)	(0.012)	(0.010)	(0.009)	(0.008)	(0.007)	(0.006)	(0.006)
q_{it}	0.0001**	-0.0001***	-0.0004*	-0.0004***	-0.0003***	-0.0002***	-0.0002***	-0.0001***	-0.0001***	-0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Panel B: Wald-Difference-in-Difference										
P_{it}	0.138**	-0.051***	-0.157	-0.215***	-0.164***	-0.144***	-0.084**	-0.054	-0.025	0.019
	(0.064)	(0.018)	(0.168)	(0.067)	(0.052)	(0.045)	(0.041)	(0.039)	(0.036)	(0.032)
q_{it}	0.0004**	-0.0002***	-0.0005	-0.0006***	-0.0005***	-0.0004***	-0.0002**	-0.0002	-0.0001	0.0001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)

Robust standard errors in parentheses. Significant at 1%(***), 5%(**) and 10%(*). Panels A, and B are estimated on a panel of 5021 towns from 2009 to 2013, controlling for mean and standard deviation of age and share of high school graduates. Town and years fixed effects are included. $\bar{Y}_{it}$, G_{it} and R_{ijt} stand respectively for mean income, Gini index and the ratio of decile j to decile 9.
The first-stage F-statistics is greater than 300, that is higher than the critical threshold. The Wald-DiD estimates pass the weak identification test of Stock and Yogo.

Figure 3: Marginal effects of broadband Internet on inter-decile ratios



Note: This figure presents the main estimation results of the impact of broadband Internet on income inequality. Panels A1 and A2 present Ordinary Least Squares (OLS) estimates of the effects of broadband adoption and quality, respectively. Panels B1 and B2 present Instrumental Variable (IV) estimates of the impact of broadband adoption and quality, respectively.

6.2 Robustness checks

We test the robustness of the Wald-DiD estimates with respect to initial conditions. Indeed, the negative relationship between broadband Internet and income inequality may be driven by difference across towns in terms of initial conditions. We specify the following model, in accordance with Forman *et al.* (2012):

$$Y_{iT} - Y_{i0} = \alpha + \beta(P_{iT} - P_{i0}) + \gamma(X_{iT} - X_{i0}) + \lambda X_{i0} + \varepsilon_i \tag{3}$$

This equation regresses variations of the dependent variable Y over variations of broadband Internet P, controlling for variation in characteristics X and initial characteristics X_0. The initial date, denoted by 0, is set to 1999, before the deployment of broadband Internet: P_{i1999}=0. T, the final date, is set to the year 2013. The outcomes of the estimation are qualitatively similar when we use other years as the final date.

Equation (3) is estimated using instrumental variable strategy. As discussed in section 5.2, signal attenuation is a strong determinant of the diffusion of broadband Internet but does not directly affect income distribution. It is, therefore, used as an instrument for both broadband penetration and download speed. The outcomes of the estimation are reported in Tables A-6 and A-7 in the Appendix.

The initial characteristics are statistically significant. In particular, mean income increase less in towns with initially higher level of education, and more in towns with initially more aged population. Likewise, the Gini coefficient falls less in towns with initially higher level of education or more aged population. In spite of these effects, the estimates of the effects of broadband Internet remain qualitatively the same. Broadband adoption and quality significant increase income and reduces income inequality. In addition, broadband Internet benefits to the bottom deciles relatively more than the top deciles. However, the magnitude of the estimates is larger probably because we include earlier periods of broadband deployment into the estimation.

6.3 Policy implications

We use the estimates of the Wald-DiD estimator in order to investigate the monetary benefit of broadband adoption and quality, the existence of a critical mass and heterogeneous effects with respect to town characteristics.

■ **Monetary benefit of broadband Internet**

We calculate the marginal effect of broadband Internet on the income of the average town in 2013. As presented in Table 2, its mean income is 26758 euros. The monetary benefit of 1 additional percentage of broadband penetration is 37.5 euros per year, per consumption unit. Given that the gross national income in 2013 is roughly 40,000 euros, the marginal effect of broadband Internet on income per capita is 0.06%.[7] Interestingly, this figure is not far from the one found by Czernich *et al.* (2011), that is 0.09-0.15% for OECD countries, lending additional support to our main results.

The same evaluation made with the marginal effects of quality yields an estimated effects of 10.7 euros per 1 Mbps of additional download speed provided to half of the population. This marginal effect corresponds to an increase by 0.02% of income per capita. Given that the average median download speed is 13 Mbps in 2013, raising the median speed up to 30 Mbps in 2020 as targeted by the European Commission would generate on average 121.3 euros per capita. We do not evaluate the European digital agenda of reaching a median speed of 100 Mpbs because it involves a technological change, that is investment in fiber and cable, that is not covered by our econometric model.

■ Non-linear effects

As emphasized by Roller & Waverman (2001), the adoption of telecommunications technology entails network effects and, as result, the effect of adoption becomes positive only after a critical mass of early users. This critical mass is typically low, between 20 and 40% as suggested by Roller & Waverman (2001) and Czernich *et al.* (2011). However, our data set covers a period during which broadband penetration was already significant. For instance, the fifth percentile of broadband penetration was already 40% in 2009, our first year of observation of broadband data. Therefore, our data set does not allow the identification of a critical mass. Yet, we explore the existence of non-linear effects in order to determine the level at which the effect of broadband adoption is maximal.

We test non-linearity of the impact of broadband adoption on income distribution by specifying the following equation:

$$Y_{it} = \delta + \sum_j \beta_j \Delta_j P_{it} + \gamma X_{it} + \mu_i + \nu_t + \varepsilon_{it} \tag{4}$$

Where Δ_j is a dummy for a certain range of broadband penetration. We experiment several cut-off points of broadband penetration and retain the following three: up to 50%, between 50 and 70%, above 70%. The coefficient β_j represents the impact of broadband adoption on

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[7] We first convert the marginal effect per consumption unit (CU) of 37.5 euros into a marginal effect per individual using the ratio 44 millions CU for 66 millions individuals. This conversion yields 25 euros per capita.

income inequality, measured by the Gini index G_{it}, when broadband penetration is within the range j.

Equation (4) is estimated using OLS estimator as well as the Wald-DiD estimator which relies on the interactions between the dummy variables, year and signal attenuation as instruments. The outcome of the estimation is reported in Table 4 below. It turns out that the impact of broadband adoption is positive and concave on income, and negative and convex on income inequality. Therefore, the effect of broadband adoption is the highest at lower level of penetration. In particular, the effect is higher when the penetration rate is below 50%. The t-test shows significant difference only between the first and second dummies. This result is consistent with the finding that the second to the fifth deciles benefit relatively more from broadband adoption.

■ Heterogeneous effects

We also investigate the heterogeneity of the effects of broadband adoption with respect to education. This investigation follows from the underlying mechanisms of the effects of broadband Internet on income distribution. As discussed in section 5.1, these effects work through the use of Internet for job purposes. However, this mechanism requires that broadband users possess basic skills to search for job using the Internet. We specify the following econometric model in order to determine whether the effect of broadband adoption on income distribution hinges upon education.

$$Y_{it} = \alpha + \beta P_{it} + \lambda P_{it} * X_{1it} + \gamma X_{2it} + \mu_i + \nu_t + \varepsilon_{it} \tag{5}$$

X_{1it} is a vector of education-related variables, namely the share of high-school graduates and the standard deviation of the number of years of schooling. The parameter λ captures the heterogeneity of the effect of broadband adoption. X_{2it} is a vector of mean and standard deviation of age. Equation (5) is estimated using Wald-DiD estimator, with the interactions between education, time and signal attenuation as instruments. The outcome of the estimation is reported in Table 4. It turns out that all the effect of broadband adoption on the distribution of income works through education. The effect of broadband alone on mean income is positive, but not statistically significant. On the contrary, the interaction is positive and highly significant. The effect of broadband adoption on income inequality increases with the number of years of schooling, but decreases with the dispersion of schooling.

Table 4: Non-linear and heterogeneous effects of broadband adoption

	Non-linear effects		Heterogeneity	
	$\bar{Y}_{it}$	G_{it}	$\bar{Y}_{it}$	G_{it}
$P_{it} * \Delta_0$	0.159**	-0.055**		
	(0.076)	(0.022)		
$P_{it} * \Delta_1$	0.152**	-0.054***		
	(0.073)	(0.021)		
$P_{it} * \Delta_2$	0.156**	-0.052**		
	(0.071)	(0.021)		
P_{it}			0.092	-0.097***
			(0.063)	(0.027)
X_{11it}	0.103***	-0.018***		
	(0.013)	(0.005)		
$P_{it} * X_{11it}$			0.182***	-0.025***
			(0.025)	(0.009)
X_{12it}		0.008***		
		(0.002)		
$P_{it} * X_{12it}$				0.013***
				(0.003)
X_{21it}	-0.001*	-0.001***	-0.001*	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
X_{22it}		0.003***		0.003***
		(0.001)		(0.001)
y2010	0.015***	0.003***	0.014***	0.003***
	(0.002)	(0.001)	(0.002)	(0.001)
y2011	0.060***	0.006***	0.059***	0.007***
	(0.005)	(0.002)	(0.005)	(0.001)
y2012	0.073***	0.005**	0.072***	0.005***
	(0.007)	(0.002)	(0.007)	(0.002)
y2013	0.088***	0.001	0.087***	0.001
	(0.008)	(0.002)	(0.008)	(0.002)
N	24309	24309	24309	24309
N_g	5021.00	5021.00	5021.00	5021.00
g_avg	4.84	4.84	4.84	4.84
F	5685.29	242.74	7133.00	291.27

Robust standard errors in parentheses. Significant at 1%(***), 5%(**) and 10%(*). $\bar{Y}_{it}$ and G_{it} stand respectively for mean income and the Gini coefficient. $P_{it} \equiv$ penetration rate. Δ_j are dummies for penetration. $\Delta_0 \equiv 0 < \text{P} \leq 50$, $\Delta_1 \equiv 50 < \text{P} \leq 70$ and $\Delta_2 \equiv 70 < \text{P} \leq 1$. $X_{11it} \equiv$ mean education, $X_{12it} \equiv$ std. education, $X_{21it} \equiv$ mean age, $X_{22it} \equiv$ std. age. Wald-DiD estimates.

7 Conclusion

This paper investigates the impact of broadband Internet on the distribution of income. It finds that both broadband adoption and quality raises mean income and reduces income inequality. More specifically, a percentage increase in broadband penetration raises income per capita by 0.06%, not far from cross-country estimates by Roller & Waverman (2001) and Czernich *et al.* (2011) in the OECD area. Likewise, 1 Mbps additional download speed raises income per capita by 0.02%.

These effects are economically significant. Between 2009 and 2013 in France, broadband adoption contributes to 34% of the rise in average income and 80% of the fall in the Gini index of income inequality, whereas quality improvement accounts for 6% of income growth and 20% of inequality reduction. The positive effect of broadband on income inequality stems from a relative greater monetary benefit accruing to the bottom deciles, particularly form the 2nd to the 5th deciles.

However, the effects of broadband adoption is slightly non-linear: positive and concave on mean income and negative and convex on income inequality. As a result, the effects of broadband Internet is maximal when the penetration rate is still low, below 50%. Early broadband data are necessary to access the existence of a critical mass. In addition, the effects of broadband adoption is highly dependent on the level and inequality in education. The positive effects of broadband Internet on the distribution of income is stronger when the level of education is higher or when there is less inequality in education. These findings are robust to initial conditions which may drive trends in income inequality and the diffusion of broadband Internet.

They imply that public subsidy of broadband adoption targeted at the poor may be welfare enhancing because they have higher return but lower rate of adoption. The effect of raising broadband speed is economically significant. The estimated benefit can be compared to the cost of fiber deployment in public policy assessment. The heterogeneous effects with respect to education suggest that broadband diffusion policies should be complemented with access to education.

The analysis in this paper entails some limitations that could be addressed in future works. First, by focusing on income deciles, we overlook the issue of social mobility, whereby individuals move across deciles. Second, we assume in the analysis that the effects of broadband on inequality work through employment, but have not investigate the effects of broadband diffusion on the labor market. Finally, education is assumed exogenous in our short-term analysis. However, broadband diffusion may affect schooling in the longer run. Future works should address these issues.

References

Akerman, Anders, Gaarder, Ingvil, & Mogstad, Magne. 2015. The Skill Complementarity of Broadband Internet *. *The Quarterly Journal of Economics*, **130**(4), 1781.

Bertschek, Irene, Cerquera, Daniel, & Klein, Gordon J. 2013. More bits-more bucks? Measuring the impact of broadband internet on firm performance. *Information Economics and Policy*, **25**, 190–203.

Bertschek, Irene, Briglauer, Wolfgang, Huschelrath, Kai, Kauf, Benedikt, & Niebel, Thomas. 2016. *The economic impacts of telecommunications networks and broadband internet: A survey.* ZEW Discussion Papers, No. 16-056.

Chakraborty, Chandana, & Nandi, Banani. 2011. 'Mainline' Telecommunications Infrastructure, Levels of Development and Economic Growth: Evidence from a Panel of Developing Countries. *Telecommunications Policy*, **35**, 441–449.

Colombo, Massimo G., Croce, Annalisa, & Grilli, Luca. 2013. ICT services and small businesses' productivity gains: An analysis of the adoption of broadband Internet technology. *Information Economics and Policy*, **25**, 171–189.

CREDOC. 2014. *La diffusion des technologies de l'information et de la communication dans la societe francaise.* Report.

Cronin, Francis J., Parker, Edwin B., Colleran, Elisabeth K., & Gold, Mark A. 1991. Telecommunications Infrastructure and Economic Growth. *Telecommunications Policy*, **15**, 529–535.

Czernich, Nina. 2014. Does broadband internet reduce the unemployment rate? Evidence for Germany. *Information Economics and Policy*, **29**, 32–45.

Czernich, Nina, Falck, Oliver, Kretschmer, Tobias, & Woessmann, Ludger. 2011. Broadband Infrastructure and Economic Growth. *The Economic Journal*, **121**, 505–532.

de Chaisemartin, Clement, & D'Haultfoeuille, Xavier. 2017. *Fuzzy Difference-in-Differences.* Forthcoming in the Review of Economic Studies.

Duflo, Esther. 2001. Schooling and Labor Market Consequences of School Construction in Indonesia: Evidence from an Unusual Policy Experiment. *The American Economic Review*, **91**, 795–813.

Forestier, Emmanuel, Grace, Jeremy, & Kenny, Charles. 2002. Can information and communication technologies be pro-poor? *Telecommunications Policy*, **26**, 623–646.

Forman, Chris, Goldfarb, Avi, & Greenstein, Shane. 2012. The Internet and Local Wages: A Puzzle. *American Economic Review*, **102**, 556–575.

Greenstein, Shane, & Spiller, Pablo. 1995. Modern Telecommunications Infrastructure and Economic Activity: An Empirical Investigation. *Industrial and Corporate Change*, **4**, 647–665.

Gruber, Harald, & Koutroumpis, Pantelis. 2011. Mobile telecommunications and the impact on economic development. *Economic Policy*, **26**, 387–426.

Ivus, Olena, & Boland, Matthew. 2015. The employment and wage impact of broadband deployment in Canada. *Canadian Journal of Economics*, **48**, 1803–1830.

Kolko, Jed. 2012. Broadband and local growth. *Journal of Urban Economics*, **71**, 100–113.

Lam, Pun-Lee, & Shiu, Alice. 2010. Economic Growth, Telecommunications Development and Productivity Growth of the Telecommunications Sector: Evidence around the World. *Telecommunications Policy*, **34**, 185–199.

Madden, Gary, & Savage, Scott. 1998. CEE Telecommunications Investment and Economic Growth. *Information Economics and Policy*, **10**, 173–195.

Roller, Lars-Hendrik, & Waverman, Leonard. 2001. Telecommunications Infrastructure and Economic Development: A Simultaneous Approach. *American Economic Review*, **91**, 909–923.

Shiu, Alice, & Lam, Pun-Lee. 2008. Causal Relationship between Telecommunications and Economic Growth in China and its Regions. *Regional Studies*, **42**, 705–718.

Ward, Michael R., & Zheng, Shilin. 2016. Mobile telecommunications service and economic growth: Evidence from China. *Telecommunications Policy*, **40**, 89–101.

Yilmaz, Serdar, Haynes, Kingley E., & Dinc, Mustafa. 2002. Geographic and Network Neighbors: Spillover Effects of Telecommunications Infrastructure. *Journal of Regional Science*, **42**, 339–360.

Appendix

Table A-1: Summary statistics

Variable	description	Obs	Mean	Std. Dev.	Min	Max
$\bar{y}_{it}$	average income	24309	25493	7411	11701	105969
y_{i1t}	1st decile	24309	8739	2938	1	19899
y_{i2t}	2nd decile	24309	12457	3090	2653	26799
y_{i3t}	3rd decile	24309	15220	3313	4851	33926
y_{i4t}	4th decile	24309	17671	3623	7106	39752
y_{i5t}	5th decile	24309	20075	4056	9306	47316
y_{i6t}	6th decile	24309	22653	4645	11379	57640
y_{i7t}	7th decile	24309	25705	5467	13660	72656
y_{i8t}	8th decile	24309	29836	6768	16576	98884
y_{i9t}	9th decile	24309	37211	9548	20845	161574
G_{it}	Gini coefficient	24309	0.318	0.045	0.215	0.596
P_{it}	penetration	24309	0.604	0.103	0	1.815
q_{it}	speeds (Mbps)	24309	9.972	6.040	0.5	20
d_{i2009}	signal attenuation (db)	24309	29.23	11.96	7.803	76.85
X_{11it}	mean education	24309	0.399	0.108	0.142	0.848
X_{12it}	std education	24309	0.399	0.108	0.142	0.848
X_{21it}	mean age	24309	0.366	0.072	0.092	0.717
X_{22it}	std age	24309	0.366	0.072	0.092	0.717
X_{3it}	density	24309	531	1532	5	32859
t	year	24309	2011.03	1.413	2009	2013

Note: The penetration rate can be greater than 1 due to multiple subscriptions per household.

Figure A-1: Relationship between broadband penetration and download speed

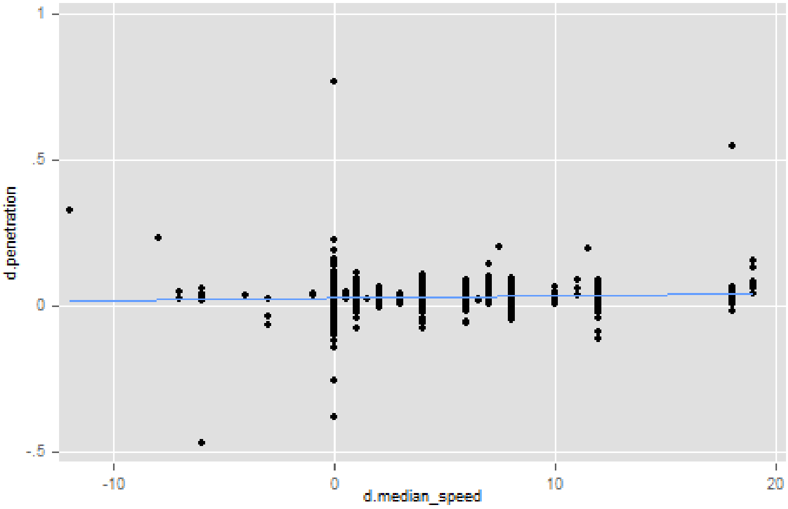

Table A-2: Broadband adoption and income inequality - OLS

	income	Gini	ratio_d9d1	ratio_d9d2	ratio_d9d3	ratio_d9d4	ratio_d9d5	ratio_d9d6	ratio_d9d7	ratio_d9d8
pen_FBB	0.199***	-0.020***	0.058	-0.067***	-0.072***	-0.069***	-0.050***	-0.037***	-0.022***	-0.009
	(0.017)	(0.004)	(0.058)	(0.012)	(0.010)	(0.009)	(0.008)	(0.007)	(0.006)	(0.006)
age_mean	-0.001*	-0.001***	-0.006***	-0.004***	-0.002***	-0.001**	-0.001**	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
share_bac	0.106***	-0.021***	-0.180***	-0.092***	-0.059***	-0.052***	-0.039***	-0.036***	-0.023***	-0.015**
	(0.013)	(0.004)	(0.053)	(0.016)	(0.012)	(0.010)	(0.010)	(0.009)	(0.008)	(0.008)
edu_sd		0.006***	0.148***	0.032***	0.016***	0.008**	0.003	0.000	-0.000	0.000
		(0.002)	(0.036)	(0.006)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)
age_sd		0.004***	0.028***	0.014***	0.008***	0.007***	0.005***	0.004***	0.003***	0.001*
		(0.000)	(0.004)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
y2010	0.013***	0.002***	0.009***	0.004***	0.003***	0.003***	0.002***	0.001***	0.001	0.000
	(0.001)	(0.000)	(0.003)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
y2011	0.056***	0.004***	0.014***	0.009***	0.007***	0.006***	0.004***	0.003***	0.001**	0.000
	(0.002)	(0.000)	(0.005)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
y2012	0.068***	0.001***	-0.001	0.005***	0.005***	0.004***	0.002**	0.002**	0.001	-0.000
	(0.002)	(0.000)	(0.007)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
y2013	0.082***	-0.003***	0.016**	0.006***	0.001	-0.001	-0.003***	-0.003***	-0.003***	-0.003***
	(0.002)	(0.001)	(0.008)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	24,309	24,309	24,309	24,309	24,309	24,309	24,309	24,309	24,309	24,309
R-squared	0.729	0.125	0.014	0.025	0.044	0.056	0.054	0.044	0.030	0.016
Number of commune	5,021	5,021	5,021	5,021	5,021	5,021	5,021	5,021	5,021	5,021

Table A-3: Broadband quality and income inequality - OLS

	income	Gini	ratio_d9d1	ratio_d9d2	ratio_d9d3	ratio_d9d4	ratio_d9d5	ratio_d9d6	ratio_d9d7	ratio_d9d8
median_Speed	0.0001**	-0.0001***	-0.0004*	-0.0004***	-0.0003***	-0.0002***	-0.0002***	-0.0001***	-0.0001***	-0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
age_mean	-0.0006	-0.0009***	-0.0060***	-0.0037***	-0.0020***	-0.0010***	-0.0007**	-0.0004	-0.0004	0.0001
	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
share_bac	0.1010***	-0.0223***	-0.1763***	-0.0966***	-0.0635***	-0.0559***	-0.0420***	-0.0383***	-0.0242***	-0.0159**
	(0.013)	(0.004)	(0.053)	(0.016)	(0.012)	(0.010)	(0.010)	(0.009)	(0.008)	(0.008)
y2010	0.0201***	0.0013***	0.0120***	0.0019***	0.0007	0.0003	-0.0001	-0.0001	-0.0001	-0.0001
	(0.001)	(0.000)	(0.002)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
y2011	0.0711***	0.0028***	0.0198***	0.0055***	0.0030***	0.0016***	0.0008**	0.0004	0.0002	-0.0002
	(0.001)	(0.000)	(0.003)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
y2012	0.0877***	-0.0001	0.0077**	0.0003	-0.0013**	-0.0020***	-0.0020***	-0.0015***	-0.0012***	-0.0010***
	(0.001)	(0.000)	(0.003)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
y2013	0.1048***	-0.0045***	0.0256***	0.0007	-0.0053***	-0.0073***	-0.0076***	-0.0067***	-0.0052***	-0.0039***
	(0.001)	(0.000)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)
edu_sd		0.0057***	0.1508***	0.0299***	0.0135***	0.0061	0.0014	-0.0010	-0.0010	-0.0001
		(0.002)	(0.037)	(0.006)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)
age_sd		0.0040***	0.0266***	0.0145***	0.0087***	0.0074***	0.0058***	0.0045***	0.0030***	0.0014**
		(0.000)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	24,309	24,309	24,309	24,309	24,309	24,309	24,309	24,309	24,309	24,309
R-squared	0.725	0.125	0.014	0.025	0.042	0.053	0.053	0.043	0.030	0.016
Number of commune	5,021	5,021	5,021	5,021	5,021	5,021	5,021	5,021	5,021	5,021

Table A-4: Broadband adoption and income inequality, Wald-DiD

	income	Gini	ratio__d9d1	ratio__d9d2	ratio__d9d3	ratio__d9d4	ratio__d9d5	ratio__d9d6	ratio__d9d7	ratio__d9d8
pen__FBB	**0.138****	**-0.051*****	**-0.157**	**-0.215*****	**-0.164*****	**-0.144*****	**-0.084****	**-0.054**	**-0.025**	**0.019**
	(0.064)	(0.018)	(0.168)	(0.067)	(0.052)	(0.045)	(0.041)	(0.039)	(0.036)	(0.032)
age__mean	-0.001	-0.001***	-0.006***	-0.003***	-0.002***	-0.001*	-0.001	-0.000	-0.000	0.000
	(0.000)	(0.000)	(0.002)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
share__bac	0.104***	-0.019***	-0.166***	-0.083***	-0.053***	-0.047***	-0.037***	-0.035***	-0.023***	-0.017**
	(0.013)	(0.005)	(0.052)	(0.016)	(0.012)	(0.011)	(0.010)	(0.009)	(0.009)	(0.008)
y2010	0.015***	0.003***	0.017***	0.009***	0.006***	0.005***	0.003*	0.002	0.001	-0.001
	(0.002)	(0.001)	(0.007)	(0.003)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
y2011	0.061***	0.006***	0.030**	0.021***	0.015***	0.012***	0.007**	0.004	0.002	-0.002
	(0.005)	(0.001)	(0.013)	(0.005)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)
y2012	0.074***	0.005**	0.022	0.021***	0.014***	0.012**	0.006	0.003	0.001	-0.003
	(0.007)	(0.002)	(0.018)	(0.007)	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)	(0.003)
y2013	0.089***	0.001	0.041**	0.023***	0.012**	0.008	0.001	-0.001	-0.003	-0.006*
	(0.007)	(0.002)	(0.020)	(0.008)	(0.006)	(0.005)	(0.005)	(0.005)	(0.004)	(0.004)
edu__sd		0.007***	0.156***	0.038***	0.019***	0.011***	0.004	0.001	-0.000	-0.001
		(0.002)	(0.037)	(0.006)	(0.005)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)
age__sd		0.003***	0.024***	0.011***	0.006***	0.005***	0.005***	0.004***	0.003***	0.002**
		(0.000)	(0.004)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	24,309	24,309	24,309	24,309	24,309	24,309	24,309	24,309	24,309	24,309
R-squared	0.729	0.121	0.013	0.016	0.038	0.051	0.053	0.044	0.030	0.015
Number of commune	5,021	5,021	5,021	5,021	5,021	5,021	5,021	5,021	5,021	5,021
First-Stage F-statistic	413.8	384.2	323.9	323.9	323.9	323.9	323.9	323.9	323.9	323.9

Table A-5: Broadband speed and income inequality, Wald-DiD

	income	Gini	ratio_d9d1	ratio_d9d2	ratio_d9d3	ratio_d9d4	ratio_d9d5	ratio_d9d6	ratio_d9d7	ratio_d9d8
median_Speed	**0.0004****	**-0.0002*****	**-0.0005**	**-0.0006*****	**-0.0005*****	**-0.0004*****	**-0.0002****	**-0.0002**	**-0.0001**	**0.0001**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
age_mean	-0.0006	-0.0009***	-0.0059***	-0.0036***	-0.0019***	-0.0010***	-0.0007**	-0.0004	-0.0004	0.0001
	(0.000)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
share_bac	0.1020***	-0.0223***	-0.1762***	-0.0965***	-0.0635***	-0.0559***	-0.0420***	-0.0383***	-0.0242***	-0.0160**
	(0.013)	(0.004)	(0.053)	(0.016)	(0.012)	(0.010)	(0.010)	(0.009)	(0.008)	(0.008)
y2010	0.0197***	0.0014***	0.0121***	0.0022***	0.0009*	0.0005	-0.0000	-0.0000	-0.0002	-0.0002
	(0.001)	(0.000)	(0.002)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
y2011	0.0699***	0.0030***	0.0201***	0.0065***	0.0038***	0.0024***	0.0012*	0.0006	0.0000	-0.0006
	(0.001)	(0.000)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
y2012	0.0860***	0.0003	0.0081**	0.0018	-0.0002	-0.0009	-0.0015*	-0.0013*	-0.0014*	-0.0016**
	(0.001)	(0.000)	(0.004)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
y2013	0.1027***	-0.0040***	0.0261***	0.0024	-0.0040***	-0.0059***	-0.0070***	-0.0064***	-0.0054***	-0.0046***
	(0.002)	(0.000)	(0.004)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
edu_sd		0.0057***	0.1509***	0.0301***	0.0136***	0.0062	0.0015	-0.0009	-0.0011	-0.0002
		(0.002)	(0.037)	(0.006)	(0.004)	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)
age_sd		0.0039***	0.0265***	0.0144***	0.0086***	0.0073***	0.0058***	0.0045***	0.0030***	0.0014**
		(0.000)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	24,309	24,309	24,309	24,309	24,309	24,309	24,309	24,309	24,309	24,309
R-squared	0.724	0.124	0.014	0.024	0.041	0.052	0.052	0.043	0.030	0.016
Number of commune	5,021	5,021	5,021	5,021	5,021	5,021	5,021	5,021	5,021	5,021
First-Stage F-statistic	1873	1853	1537	1537	1537	1537	1537	1537	1537	1537

Table A-6: Broadband adoption and income inequality - Forman

	d_income	d_Gini	d_decile1	d_decile2	d_decile3	d_decile4	d_decile5	d_decile6	d_decile7	d_decile8
pen_FBB	0.700***	-0.177***	-1.876***	-1.175***	-1.103***	-0.630***	-0.649***	-0.642***	-0.426***	-0.155
	(0.139)	(0.044)	(0.654)	(0.304)	(0.305)	(0.214)	(0.164)	(0.155)	(0.141)	(0.151)
d_share_bac	-0.906***	-0.279***	-3.500***	-0.570***	0.776***	0.017	-0.119	0.271***	0.284***	0.305***
	(0.086)	(0.027)	(0.381)	(0.183)	(0.188)	(0.144)	(0.109)	(0.097)	(0.089)	(0.099)
d_pop_65p	-1.362***	-0.291***	-0.812**	0.413**	0.974***	0.099	0.039	0.355***	0.421***	0.307***
	(0.089)	(0.027)	(0.386)	(0.169)	(0.174)	(0.130)	(0.101)	(0.091)	(0.081)	(0.091)
share_bac1999	-2.125***	-0.023	2.108***	0.957***	0.768***	0.039	0.010	0.112	0.049	-0.124
	(0.081)	(0.026)	(0.394)	(0.190)	(0.190)	(0.133)	(0.105)	(0.100)	(0.092)	(0.102)
pop1999_65p	0.271***	-0.120***	-1.895***	-1.559***	-1.611***	-0.643***	-0.374***	-0.348***	-0.297***	-0.123***
	(0.046)	(0.013)	(0.179)	(0.088)	(0.098)	(0.077)	(0.050)	(0.048)	(0.043)	(0.045)
Constant	-7.143***	0.082***	-0.360	-0.120	-0.014	0.081	0.170**	0.142**	0.095	0.016
	(0.060)	(0.019)	(0.277)	(0.128)	(0.129)	(0.092)	(0.069)	(0.066)	(0.060)	(0.064)
Observations	4,917	4,418	4,416	4,416	4,416	4,416	4,416	4,416	4,416	4,416
R-squared	0.666	0.110	0.085	0.053	0.025	-0.051	-0.036	-0.075	-0.028	0.015
First-Stage F-statistic	184.6	163.1	162.9	162.9	162.9	162.9	162.9	162.9	162.9	162.9

Table A-7: Broadband quality and income inequality - Forman

	d__income	d__Gini	d__decile1	d__decile2	d__decile3	d__decile4	d__decile5	d__decile6	d__decile7	d__decile8
median__Speed	0.002***	-0.0005***	-0.0055***	-0.0035***	-0.0033***	-0.0019***	-0.0019***	-0.0019***	-0.0013***	-0.0005
	(0.000)	(0.000)	(0.002)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
d__share__bac	-0.600***	-0.3575***	-4.3354***	-1.0933***	0.2844**	-0.2636***	-0.4080***	-0.0153	0.0944	0.2359***
	(0.049)	(0.018)	(0.267)	(0.119)	(0.121)	(0.099)	(0.073)	(0.064)	(0.062)	(0.070)
d__pop__65p	-1.181***	-0.3375***	-1.3008***	0.1065	0.6865***	-0.0655	-0.1304	0.1873**	0.3095***	0.2666***
	(0.066)	(0.023)	(0.353)	(0.144)	(0.143)	(0.116)	(0.085)	(0.078)	(0.073)	(0.082)
share__bac1999	-1.706***	-0.1315***	0.9596***	0.2382***	0.0928	-0.3464***	-0.3874***	-0.2813***	-0.2123***	-0.2190***
	(0.029)	(0.007)	(0.111)	(0.064)	(0.061)	(0.052)	(0.049)	(0.049)	(0.043)	(0.055)
pop1999__65p	0.286***	-0.1234***	-1.9365***	-1.5845***	-1.6355***	-0.6567***	-0.3885***	-0.3618***	-0.3065***	-0.1262***
	(0.037)	(0.012)	(0.172)	(0.078)	(0.085)	(0.071)	(0.046)	(0.043)	(0.041)	(0.044)
Constant	-6.878***	0.0159***	-1.0584***	-0.5576***	-0.4244***	-0.1536***	-0.0716***	-0.0973***	-0.0634***	-0.0421**
	(0.014)	(0.005)	(0.067)	(0.030)	(0.033)	(0.027)	(0.018)	(0.017)	(0.016)	(0.017)
Observations	4,917	4,418	4,416	4,416	4,416	4,416	4,416	4,416	4,416	4,416
R-squared	0.738	0.212	0.110	0.159	0.159	0.045	0.075	0.046	0.035	0.021
First-Stage F-statistic	2868	2554	2553	2553	2553	2553	2553	2553	2553	2553