Broadband Internet and Income Inequality*

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10th May 2017

Abstract

Internet access has been recognized as a human right by the United Nations and also in regional political organizations such as the European Union. However, there is still a lack of evidence about its effects on inequality and more specifically on income distribution. In this paper, we investigate the effects of fixed broadband Internet on income inequality using a unique town-level data on broadband adoption and quality in France. We find that broadband Internet raises income at all deciles, lowers income inequality, particularly when the adoption rate reaches a critical mass of 30%, but widens income-gap between towns. These results are robust to the estimation strategy, and accord well with the findings of previous studies.

Keywords: Broadband Internet, Income Inequality.

JEL Classification: D31, L96, O15.

*We thank participants of the Applied Economic Seminar of the Paris School of Economics for comments and suggestions, in particular Thomas Piketty, Denis Cogneau and Ekaterina Zhuravskaya. We would also like to thank Marc Lebourges and colleagues at the Paris School of Economics and Orange for comments and suggestions. The usual disclaimer applies.

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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. Adopted by a few in its inception, it is nowadays ubiquitous. According to the OECD, up to 90% of households in the members states have access to fixed broadband Internet in 2016.[1] This massive adoption have been followed by a dramatic spread of online services, among which Internet platforms' services are a case in point. For instance, a growing share of broadband users are selling and purchasing online. In the EU(27), 13% of firms are selling online, while 19% are purchasing online.

The falling cost of information and communication brings about by broadband Internet and the massive investment in broadband infrastructure generate significant economic benefits. For instance, Czernich *et al.* (2011) find that every 10 percentage point increase in the share of fixed broadband users raises annual income per capita by 0.9-1.5 percentage points in OECD countries. This positive impact has attracted the attention of policy makers who are now considering investment in high-speed Internet, based of fiber technology, as a top policy goal.[2] However, there is still a lack of evidence about its distributional effects.

In this paper, we investigate the effects of broadband Internet on income inequality using data from France. At the core of this paper are town-level data on broadband Internet adoption and quality we obtained from the French incumbent operator. This dataset provides information on the number of fixed broadband subscribers per town over five years, from 2009 to 2013. We complement these data with town-level distribution of income as well as socio-demographic characteristics. Preliminary Ordinary Least Squares estimates suggest that broadband Internet lowers income inequality. However, this effect can be biased by the endogeneity of broadband Internet diffusion or by unobserved labor demand.

Interestingly, the specific institutional feature of the French broadband market enables us to construct an instrument that overcomes the endogeneity of broadband diffusion within towns. Indeed, wholesale broadband access regulation lowers barriers to entry into local broadband markets. However, variation in the number of regulated lines, depends on the legacy of the traditional telephone network. This very specific feature provides an exogenous variation in broadband penetration rate within towns. Our dataset provides information on the number of regulated broadband connections which is used to construct the share of regulated connections as an instrument for broadband penetration.

[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.

[2] See the European Commission "Digital Agenda for Europe", as well as the "National Broadband Plan" in the Unites States of America.

We estimate the effect of broadband Internet on inequality using income deciles and the Gini coefficient. The IV estimates shows that broadband diffusion raises all income deciles, but more significantly for bottom income earners. Every percentage point increase in broadband penetration raises income by 1.7% at the first decile to 0.04% at the ninth decile. Consistently, the Gini coefficient falls by 0.11 percentage point. This downward sloping relationship is also observed for broadband quality. Several robustness checks using fuzzy difference-in-difference and controlling for initial conditions suggest a causal relationship. Our findings are further supported by the fact that the point estimates predict an effect on average income very close to existing estimates. More specifically, we find that 10 percentage increase in broadband penetration raises average income by 1.3%.

Policy implications analyses suggest that broadband Internet entails network effects such that its impact on income inequality become positive when the penetration rate, that is the share of adopters, is above the critical mass of 30%. In addition, estimates shows that increasing broadband Internet speed would generate significant economic benefits. Every megabit per second increase in the median broadband speed is predicted to raise income per capita by 63 euros, a benchmark that can be compared to the cost of high speed broadband deployment. However, broadband adoption widens the income gap between towns, because its positive effects on income is larger in richer towns.

The findings of this paper are related to literature on the effects of innovation on growth and inequality. Roller & Waverman (2001) and Czernich *et al.* (2011) study the effect of telecoms infrastructure on income per capita but did not investigate the effect on inequality. Recent studies on inequality include Forman *et al.* (2012) and Aghion *et al.* (2015). Forman *et al.* (2012) investigate the effect of ICT investment on wage gap between US counties. However, he did not focus on intra-town inequality as in our paper. Aghion *et al.* (2015) estimate the effect of innovation on top income inequality, and therefore did not analyze the whole distribution of income. 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 presents the econometric model and discusses the estimation strategy. Section 5 introduces the data along with some descriptive statistics. Section 6 presents the results and section 7 concludes.

2 Related literature

As reviewed by Bertschek *et al.* (2016), the economic impacts of telecommunications network and broadband internet have been the topic of a vast literature, starting from the early 90s. These studies have investigated the effects on several economic outcomes including GDP growth, employment and productivity, but few have explored the effects on income inequality.

Early studies such as Cronin *et al.* (1991), Madden & Savage (1998) and Lam & Shiu (2010) focus on the economic impacts of telecommunications at the country level. Most of these studies find positive effects of telecommunications infrastructure on economic growth. In particular, Roller & Waverman (2001) use country-level data from OECD countries with a simultaneous estimation approach and find that the adoption of fixed telecommunications has significant and positive effects on GDP growth. These effects emerge as the penetration of fixed telephony is higher than a critical mass of 40 percent. These positive effects are also found in developing countries (Lam & Shiu, 2010; Chakraborty & Nandi, 2011), for mobile telephony (Gruber & Koutroumpis, 2011) and for fixed broadband (Czernich *et al.* , 2011). In this latter study, Czernich *et al.* (2011) find that 10 percentage point increase in broadband penetration rate raises national income per capita by 0.9-1.5 percentage point. Interestingly, we will be able to recover similar estimates from our own analysis.

Country-level studies may suffer from differences in unobserved institutional features such as competition and regulatory policies, even though they apply country fixed effects. 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 the same issue in China. These studies tend to find that the positive effects of telecoms on growth only apply to high income areas.

To investigate the underlying mechanisms of the relationship between telecommunications infrastructure and economic growth, some recent papers have set the focus on the effects on employment, productivity and development outcomes. Kolko (2012) use county-level data from the US and find positive effects of the number of broadband providers on employment. However, using county-level data from the US, Forman *et al.* (2012) find that investment in Internet has raised wages and employment in only very few counties. The overall effect is not significant. Using town-level data from Germany, Czernich (2014) also find no effects of broadband availability on unemployment rate. Mack & Faggian (2013) show that the effect of broadband is positive for educated/skilled workers, but negative for uneducated/unskilled workers.

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) find that labor productivity increases with the share of employees with mobile Internet access in Germany. However, the effects on productivity may depend on sectors. For instance, Greenstein & Spiller (1995) show that telecommunications infrastructure 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. Ivus & Boland (2015) find that in Canada the effects of broadband on employment is positive only in the services sector.

Other papers also investigate how telecommunications infrastructure can empower people through political participation. Czernich (2012) find positive effects of broadband adoption and voter turnout, whereas Gavazza *et al.* (2015) find negative effects particularly for the less educated and younger individuals. 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 find a positive correlation between the penetration rate of fixed telephony and inequality.

More generally, the impact of innovation on growth and inequality has always attracted the curiosity of scholars as epitomized by Solow who observed that *"the computer age [is] everywhere but in the productivity statistics"* (Solow, 1987). In this tradition, early studies such as Jorgenson & Stiroh (1999) explore and find positive effects of ICT equipment (computers) on productivity and growth. More recently, these findings have been questioned by Acemoglu *et al.* (2014) who find limited evidence of ICT-induced productivity growth in the US town.

Another line of research has been developed in labor economics, emphasizing the skill-biased nature of technologies (Bound & Johnson, 1992) and, as a result, their negative effects on wage inequality and jobs. According to this theory, the diffusion of computers has increased the relative demand for skilled workers, thus increasing the wage gap and unemployment. Along this line, Autor *et al.* (1998) find that the diffusion of computers has widen the wage gap between skilled and unskilled workers in the US. Machin & Van Reenen (1998) confirm these findings for several OECD countries including France. Although Card & DiNardo (2002) underscored a more nuanced effect of ICT on wage inequality, Autor *et al.* (2008) emphasized the relevance of the skill-biased technology argument for top earners. More recently, Forman *et al.* (2012) find that ICT investment widen the wage gap across US towns.

3 Background on broadband Internet in France

The broadband Internet in France has started its deployment since 2000. Up to end 2013, the majority of the broadband coverage of the territory is provided by DSL technologies via the incumbent copper network, that is to say by the copper local loop. The copper local loop consists of about 33 million lines, deployed in several decades to provide fixed telephone. This historic copper network covers the entire territory, spread over more than 15,800 MDFs (Main Distribution Frame). It was therefore not designed to transport DSL signals and provide ADSL access. Indeed, the propagation of DSL signals supports very bad long distances. It is attenuated, measured in decibels (dB), which is a function of the distance traveled and the diameter of the copper lines. The eligibility threshold for a DSL line corresponds to a maximum attenuation of 78 dB (allowing a nominal speed up to 512 Kbit/s), 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 MDF and the household) has no major impact on fixed telephone, introduces, however, a wide disparity in access to the internet. Thus, while households located near the MDF can enjoy a speed of more than 20 Mbits/s, 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 ADSL.

For the deployment of broadband infrastructure, the incumbent operator has progressively installed its active equipment (DSLAM: Digital Subscriber Line Access Multiplexer) in all the MDFs. The arrival of new operators on a MDF through unbundling is gradually introduced since 2003. A MDF is "unbundled" if an alternative operator installs its own DSL equipment and accesses the infrastructure of the incumbent's local loop in order to directly serve the consumers. At December 2013, unbundling coverage is about 89.2% of existing lines which represents close to 7,600 MDFs unbundled out of the existing 15,800 MDFs. The unbundled MDFs serve an average of 3,600 lines each. The unbundling local loop contributes to the increase in the competitive offers.

In order to improve ADSL quality in terms of speed, The incumbent operator has progressively upgraded the copper local loop which consists of bringing the optical fiber to the sub-distributor and maintaining the copper network for the terminal part, that is between the sub-distributor and the households. Such an operation is therefore faster and less costly than fiber-to-the-home (FttH) deployments and can be an alternative and temporary solution meanwhile future FttH deployments. After the operation, The majority of the inhabitants concerned will benefit from speed higher than 5 Mbits/s. With ADSL2+ (VDSL) technology the theoretical speed could increase to 25 MBits/s (50 MBits/s), provided that the distance

does not exceed 2.5 km (1 km).

Figure 1 presents the evolution of broadband Internet penetration rate in France. As indicated in the Figure 1, ADSL technology is the main technology among all broadband accesses. It still represents 90% of fixed broadband connections, compared to 6% for cable and 3% for FTTH. During the period 2009-2013, the number of LLU ADSL lines has significantly increased. The total broadband subscribers have increased from 19.1 million in 2009 to 24.3 million in 2013. More than 5 millions households have adopted broadband access during this period. The correlation is visually positive between LLU ADSL progression and broadband penetration rate.

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. The broadband access provides to consumers 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 CREDOC (2014), 48% interviewees use Internet for social networking, 47% download music, 24% seek employment, 51% perform administrative procedure and 51% for e-commerce shopping.

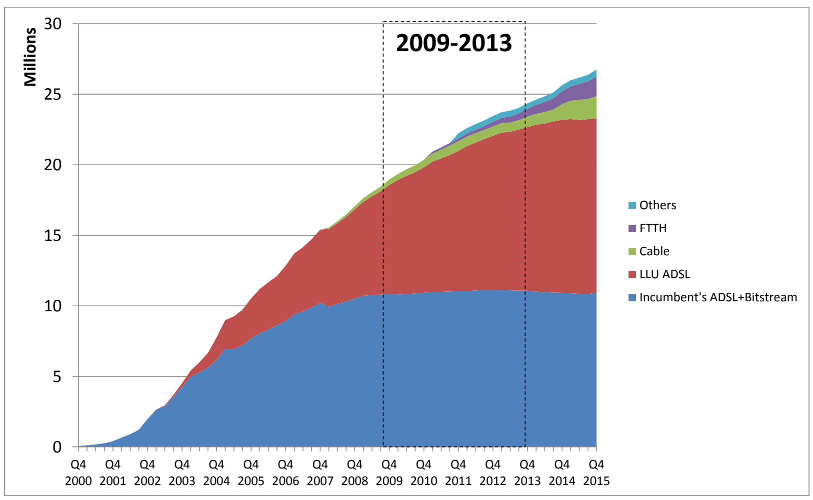
In terms of usage evolution, more and more people used Internet to search for an employment. In 2006 only 16% interviewees used Internet for employment search. This number has risen to 19% in 2009 and 25% in 2013. One person in two (55%) in 2013 (instead of 40% in 2008) used Internet for administrative 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 while in 2014 14.7 Million households have given up the usage of paper declaration. 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. The job searching and the participation in social networks are two exceptions. According to CREDOC (2014), a higher percentage of low-income people (31%) who used Internet to search an employment than high-income people (only 18%, 13% less). The social network sites had more participation among low-income people (%50) than high-income people (only 42%).

The European Commission cares about the quality of access in terms of broadband speed.

In September 2016, the Commission announced that by 2025 all European households should have access to connections with speed of at least 100 MBits/s. 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 telecom regulator statistics (ARCEP).

4 Econometric model

This section presents the econometric model and the estimation strategy.

4.1 Modeling

An economy hosts J types of workers with labor supply L_j. For the purpose of studying income inequality, a type of worker is defined as an income decile. All sectors of the economy produce output using a constant elasticity of substitution production function. We assume that each type of worker is employed in a specific sector of the economy, confounded with

her type. This assumption allows the elasticity of substitution between labor and capital to differ across workers' types. As such, a technology that raise the relative productivity of all workers, can also affect income inequality depending on how the elasticity of substitution varies according to the level of income.

Type j workers can become more productive by combining their labor supply with broadband Internet. Let P_j denotes broadband adoption by type j. Output Y_j produced in sector j can be expressed as:

$$Y_j = f(L_j, K) = A\big[\alpha_j (e^{P_j} L_j)^{\frac{\sigma_j - 1}{\sigma_j}} + (1-\alpha_j) K^{\frac{\sigma_j - 1}{\sigma_j}}\big]^{\frac{\sigma_j}{\sigma_j - 1}} \tag{1}$$

K denotes capital inputs, assumed to be common to all sectors of the economy. This assumption will be useful for the identification of the effect of broadband Internet adoption on income, given that capital inputs are not observed. The parameter $\sigma_j \geq 0$ is the elasticity of substitution between type j labor and capital in sector j.

Assuming that the labor market is perfectly competitive, wage of type j equals its marginal productivity:

$$w_j = \frac{\partial Y_j}{\partial L_j}$$

Using this equation, the relative wage of type j workers with respect to the return on capital r writes:

$$\frac{w_j}{r} = \frac{\alpha_j}{1-\alpha_j} e^{\frac{\sigma_j - 1}{\sigma_j} P_j} \big(\frac{L_j}{K}\big)^{-\frac{1}{\sigma_j}}$$

Taking the logarithm yields:

$$\ln w_j = \ln \frac{\alpha_j}{1-\alpha_j} + \frac{\sigma_j - 1}{\sigma_j} P_j - \frac{1}{\sigma_j} \ln L_j + \frac{1}{\sigma_j} \ln K + \ln r \tag{2}$$

In our framework, the effect of broadband Internet on income comes from wage. The parameter of interest $\frac{\sigma_j - 1}{\sigma_j} \equiv \beta_j$ is respectively positive, nil or negative, if the elasticity of substitution is greater than, equal to or smaller than 1. Therefore, for a given level of labor demand, broadband Internet raises income of type j workers if they can be easily substituted for capital as they become relatively more productive, that is if the elasticity of substitution in their sector is greater than 1. Furthermore, broadband Internet is expected to lower income inequality if

low-income workers are employed in sectors with higher elasticity of substitution.

Before taking equation (2) to the data, we assume that wage of workers j represents a constant fraction of their income y_j. In addition, capital market is open, and as a result the rate of return is independent from the local economy, but varies across time. Labor demand L_j depends on workers' skills and experience represented by a vector X and unobserved labor demand. Equation (2) will be estimated on the basis of a panel of N economies (towns), i=1, ..., N, observed over T periods (years), t=1, ..., T. As a result, for a given type of worker, the estimated equation can be expressed as:

$$\ln y_{ijt} = \delta_j + \beta_j P_{ijt} + \gamma_j X_{it} + \mu_i + \mu_t + \varepsilon_{ijt} \tag{3}$$

In equation (3), $\delta_j = \ln \frac{\alpha_j}{1-\tilde{\alpha}}$ is a constant, μ_i are towns fixed-effects including capital stock, rents and efficiency wage premium. μ_t are time fixed-effects representing the evolution of the return on capital and prices. ε_{ijt} denotes the residuals, including the unobserved labor demand as well as unobserved income components correlated with workers preferences for broadband Internet.

Finally, broadband adoption depends on its quality and, from a public policy perspective, governments are interested in improving the quality of broadband Internet. We will therefore investigate the effect of broadband quality on inequality by replacing adoption P_{ijt} by quality q_{it} in equation (3). To the extent that quality has positive, significant and monotone effect on adoption, we expect the effects of broadband adoption and quality on income and inequality to be qualitatively the same.

4.2 Estimation Strategy

Ordinary Least Squares estimate of parameter β_j in equation (3) would be biased due to unobserved labor demand and the correlation between the unobserved components of income and workers preferences for broadband Internet. In particular, OLS estimator would underestimate β_j if labor supply L_j is positively correlated to broadband adoption (see equation (2)). Likewise, the demand for broadband Internet is determined by income. Empirical data would not only reflect the relationship in equation (3), but also the reverse causality from income to broadband Internet. To identify β_j, the causal effect of broadband Internet, we need to rely on an instrument that shifts demand for broadband only through the supply. Alternative identification strategies following Duflo (2001) and Forman *et al.* (2012) are presented in the robustness checks section.

■ **Demand for broadband Internet**

Consumers in a given town can adopt broadband Internet, use other means of communication, or choose the outside option of not adopting. The utility of consumer (worker) j from broadband adoption in town i can be expressed as:

$$u_{ijt} = u(X_{ijt}, \tau_t, q_{it}, \theta) \tag{4}$$

Utility depends on consumer characteristics X_{ijt}, subscription price τ_t and quality q_{it}. The parameter θ is the common consumer preferences.

For the purpose of the empirical analysis, we adopt the following specification for the utility function:

$$u_{ijt} = \ln(\delta_j^{'} + \psi_j^{'} q_{it} + \gamma_j^{'} X_{it} + \nu_i + \nu_t + \mu_{it}) - \epsilon_{ijt} \tag{5}$$

ϵ_{ijt} is random taste variable, identical for all consumers, with a standard type-I extreme value distribution. It includes all unobserved characteristic of the consumers. Therefore the probability of adoption by worker j in town i can be expressed as:

$$P_{ijt} = \delta_j + \psi_j q_{it} + \gamma_j X_{it} + \mu_i + \mu_t + \nu_{it} \tag{6}$$

Equation (6) characterizes the demand for broadband internet by worker j. The subscription price is subsumed into the time trend.

■ **Supply of broadband Internet**

Price is set at the national level. At the local level, the supply of broadband depends only its quality. Operators enter the local market trading off between the marginal revenue and the marginal cost of quality:

$$R^{'}(q_{it}) = C^{'}(q_{it})$$

The revenue from quality can be expressed as a linear function of quality $R^{'}(q_{it}) = \eta q_{it}$, whereas quality cost can be expressed as: $C(q) = \frac{1}{Z_{it}} \frac{q^2}{2}$. Z_{it} is an instrument that exogenously shifts the marginal cost of quality downward. Lower marginal cost means higher quality and greater penetration of broadband.

The supply of quality writes:

$$q_{it} = \eta Z_{it} + \zeta_i + \zeta_t + \zeta_{it} \tag{7}$$

The reduced-form of the demand and supply for broadband Internet can be expressed as:

$$P_{ijt} = \delta_j + \upsilon_j Z_{it} + \gamma_j X_{it} + \upsilon_i + \upsilon_t + \upsilon_{it} \tag{8}$$

Equation (8) is the first-stage of the instrumental variable estimation that helps identify the parameters of equation (3). The measurement of the instrument Z is presented in section 5.2 below.

5 Data and descriptive statistics

5.1 Data

We estimate equations (3), (10) and (12) using a panel of 5,021 French towns over 5 years, from 2009 to 2013.[3] The panel is slightly unbalanced, with 4.8 observations per town, on average. The observed towns represent 75% of the French population. At the core of this paper is an original data from the French incumbent operator of broadband Internet, hosting information on broadband adoption of all households, including the customers of its rivals.

The broadband data include the number of residential connections under the major technologies, that is cooper (xDSL), cable and fiber (FTTH) technologies. Other technologies such as satellite and Wimax, have been omitted due to data availability. They represent 1-2% of total broadband connections. We approximate the total number of FTTH 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. For cable technology, we estimated the number of active 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.[4].

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

[4] We obtain the number of available connection from the national regulator. According the cable operator, 1.4 million households in 2013 have adopted cable-based broadband among 8.6 million available connections in France, corresponding to a take-up rate of 16%

A limitation of this dataset is that income is not matched with broadband adoption. To overcome this limitation, we complement the broadband data with data from a nationally representative survey (CREDOC) that provides information on broadband adoption and income. We use this data to infer the ratio of broadband adoption by income group. For each income group this ratio converts national broadband penetration rate into the rate of penetration within each income group. Table A-1 in the appendix presents the conversion ratio by income group.

Another key information provided by the broadband data is the distribution of download speeds within each town, from 2009 to 2013. Speed data correspond to the maximal download speed that can be experienced by users. It therefore provides and accurate and exhaustive measure of the quality of broadband Internet. More specifically, we have the number of broadband users per speed interval, corresponding to a density function. We use this data to calculate the median download speed per town, which is used throughout the paper as our measure of broadband quality. 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, European Commission aims at providing at least 100 megabytes per second to all European households.

Interestingly, the broadband data provides a measure of the average distance between each household and the nearest local exchange in each town. This measure is time-invariant but strongly determines the quality of broadband Internet. In addition, it is exogenous because predetermined by the traditional telephony network. It will be useful to assess the validity of our instrument.

The broadband data also provides information about the number of regulation-based connections. Indeed, fixed broadband network based on the cooper technology is entirely owned by the incumbent operator due to the historical monopolistic nature of telecommunications network in France. In order to enforce downstream competition, the national regulator requires the incumbent operator to provide wholesale access to competitors under regulated price. This regulated access is provided under local loop unbundling (LLU).

In towns without LLU offers, competitors enter the local market through bitstream access. Under this type of regulated offers, competitors typically resale the incumbent's wholesale DSL offer. They can no longer differentiate in terms of quality with respect to the incumbent, contrary to LLU. The incumbent operator's market share is higher in these areas than in the areas with LLU offers. The broadband adoption data also include the number of broadband connections under bitstream offers. They account for less than 10% of DSL lines.

A second data set comes from the national statistical office (INSEE) with information on

income distribution, and socio-demographic characteristics at the town level. Income distribution data include the deciles of income, the mean income, and the Gini coefficient of inequality (available for towns > 2000 inhabitants). Income is measured as total earnings per unit of consumption, before taxation and social benefits. As such, the observed income distribution is not affected by redistribution policies.

Socio-demographic characteristics include the share of population above 65 years old, the percentage of out-of-school individuals above 15 with at least bachelor's degree, and the share of employment in socio-professional categories.

Table 1 presents the data along with their sources.

Table 1: Data

Data	**Description**	**Source**
$\bar{y}_{it}$	mean income of town i at year t	INSEE
y_{ijt}	income at decile j	INSEE
$Gini_{it}$	Gini coefficient of inequality	INSEE
B_{it}	number of broadband connections	Operator
q_{it}	median broadband speed (Mbps) in town i	Operator
LLU_{it}	number of LLU-based connections	Operator
d_i	average distance between users and local exchanges (in decibel)	Operator
H_{it}	number of fiscal households	INSEE
X_{1it}	Households density	INSEE
X_{2it}	share of population above 65 years old	INSEE
X_{3it}	share of high-school graduates (education)	INSEE
X_{4itl}	share of workers in the socio-professional category l	INSEE

Socio-professional categories: 1) farmers, 2) entrepreneurs, traders, craftsmen, 3) engineers and professors, 4) unskilled workers, 5) employees, 6) workers

5.2 Instrument for broadband penetration

Broadband penetration rate is measured as:

$$P_{it} = \frac{B_{it}}{H_{it}}$$

Where B_{it} is the number of broadband connections in town i year t and H_{it} is the number of households. P_{it} can be greater than 1 in densely populated towns where several broadband connections are purchased by small businesses. We use the conversion ratios in Table A-1 in order to recover the penetration rate associated with each income decile: $P_{ijt} = \rho_{jt} P_{it}$.

Previous works such as Czernich (2014) use the distance to local exchanges (main distribution

frame) as an instrument for broadband penetration. This variable is useful in a cross-sectional study, but not when identification relies on the panel structure of the data as in our case. This is because, distance to MDF does not vary over time and is, as a result, rejected in fixed-effects estimation. We use data on the number regulation-based connections, denoted by LLU, to calculate the share of LLU connections as:

$$Z_{it} = \frac{LLU_{it}}{B_{it}}$$

This variable is our instrument for broadband penetration because LLU drives downstream competition in quality and is determined by exogenous distance between local exchanges and users' premises.

Figure A-1 in the appendix shows a positive within-town correlation between the share of LLU connections and the penetration rate. This correlation not only reflects consumers preferences that jointly determine both variables, but also quality competition induced by LLU. Indeed, broadband price is set at the national level and LLU enables competitors to differentiate the quality of their broadband offers with respect to the incumbent. As a result, broadband penetration increases. This effect of LLU regulation on broadband penetration is mentioned by Nardotto *et al.* (2015) in the UK. We also provide the estimates of this relationship on the basis of equation (8) and find support for a positive and significant effect of the share of LLU on broadband penetration.

Distance between local exchanges and users' premises is exogenous because it is predetermined by the traditional telephony network. Indeed, local exchanges were built to deploy fixed telephony when broadband Internet was not available. Their locations are thus predetermined. The lower the distance with respect to users, the lower the marginal cost of quality provision as fewer packets are lost in the transmission of information. As rival operators tradeoff between the marginal cost of quality and the marginal revenue, they increase quality supply as the marginal cost is lower in a town. The share of LLU connections increases as well as broadband penetration.

Finally, the share of LLU connections does not have a direct effect on the distribution of income or the labor market outcomes. The level of competition on broadband market depends on the telecommunications regulation through the obligation of LLU. These regulatory obligations aim only to increase the competition on the fixed broadband market. The change in inequality and unemployment is not in the scope of telecommunication regulator.

5.3 Descriptive statistics

Table 2 below presents the summary statistics. The average income is roughly 25,000 euros, above the national average at 23,000 euros in 2013. On average, the income distribution is characterized by a first decile at 8,700, a median income at 20,000 and a ninth decile at 37,200 euros per annum. The median and 9th decile incomes are very similar to the national figures provided by the statistical office. However, the first decile is smaller than the national figure, around 10,000. The average Gini coefficient stands at 0.32, larger than the national Gini which is about 0.30. In addition, the density of the average town is 531, well above the national level. These gaps reflect the selection of our panel which is a made of towns of more than 2000 inhabitants. They are typically richer, more unequal and more densely populated than the missing areas.

They experienced a sharp decline in their level of inequality as shown by the change in the Gini coefficient between 2003 and 2013. The average Gini coefficient falls by 10 percentage points during this period. Figure 2 presents the mean yearly growth rate of income deciles between 2009 and 2013. Income deciles increase on average by 2-2.5% per year. Income growth has been slightly larger for bottom deciles, except for the first decile. This growth rate could reflect the inflation rate as income is taken in nominal terms. The average yearly growth rate of real income is between 0.68 and 1.18%.[5]

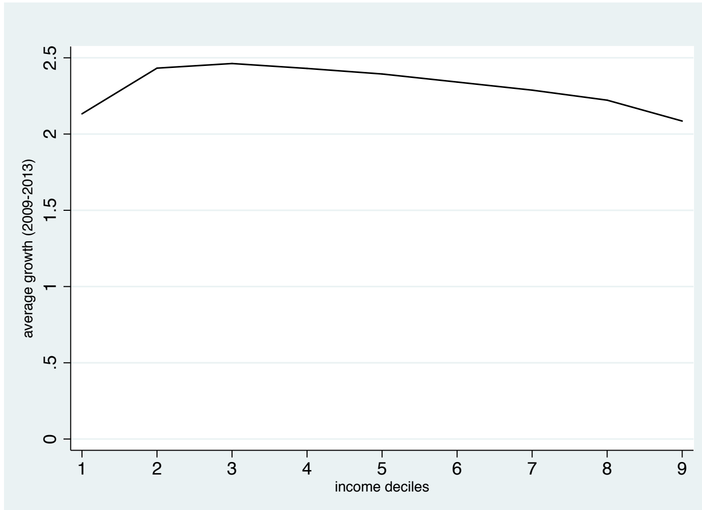
On average, broadband penetration rate is 60%, ranging from 0 to 182%. As a cumulative variable, the penetration rate increases in all towns except a few where the number of cancellations is greater than the number of new subscriptions. The penetration rate can be above 100% typically in densely populated towns due to multiple subscriptions per household. The average quality, measured by the median download speed, is 10 megabits per second (Mbps). It increases from 6 to 13 Mbps during 2009-2013, due to technological upgrading. The share of regulated lines is 40% on average, ranging from 0 to 87%. It also increases in all towns, except a few. The average distance between broadband users and local exchanges is 29 decibels.[6] It is measured in 2009, but remains basically constant, and is determined by the historical telephone network.

Variation in the share of regulated lines is positively correlated with the average distance between users and local exchanges. In addition, there is a positive correlation between broadband penetration and the share of regulated lines.

[5] According to INSEE, the national inflation rate was respectively 0.1, 1.5, 2.1, 2 and 0.9% from 2009 to 2013, that is 1.32% on average.

[6] In general, the longer the distance between user's premise and local exchange, the greater the so-called DSL line loss (also known as line attenuation). This is measured in decibel.

Figure 2: Average growth rate of income deciles, 2009-2013



Note: This figure presents the average growth rate (in %) of income deciles between 2009 and 2013. The average growth rate is calculated using the yearly average income decile across towns.

Table 2: Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
$\bar{y}_{it}$	24309	25493	7411	11701	105969
y_{i1t}	24309	8739	2938	1	19899
y_{i2t}	24309	12457	3090	2653	26799
y_{i3t}	24309	15220	3313	4851	33926
y_{i4t}	24309	17671	3623	7106	39752
y_{i5t}	24309	20075	4056	9306	47316
y_{i6t}	24309	22653	4645	11379	57640
y_{i7t}	24309	25705	5467	13660	72656
y_{i8t}	24309	29836	6768	16576	98884
y_{i9t}	24309	37211	9548	20845	161574
Gini	24309	0.318	0.045	0.215	0.596
X_{1it}	24309	531	1532	5	32859
Gini2003	21881	0.424	0.049	0.292	0.759
P_{it}	24309	0.604	0.103	0	1.815
q_{it}	24309	9.972	6.040	0.5	20
LLU_{it}	24309	0.402	0.217	0	0.868
d_{i2009}	24309	29.23	11.96	7.803	76.85
X_{2it}	24309	0.366	0.072	0.092	0.717
X_{3it}	24309	0.399	0.108	0.142	0.848
X_{41it}	24309	0.013	0.018	0	0.232
X_{42it}	24309	0.066	0.029	0.004	0.302
X_{43it}	24309	0.141	0.084	0.007	0.585
X_{44it}	24309	0.256	0.049	0.076	0.454
X_{45it}	24309	0.287	0.049	0.08	0.62
X_{46it}	24309	0.237	0.088	0.023	0.555
t	24309	2011.03	1.413	2009	2013

Note: The penetration rate can be greater than 1 due to multiple subscriptions per household. See table 1 for the definition of variables.

6 Results

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

6.1 Main results

Figure 3 presents the marginal effect of broadband adoption and quality on income deciles on the basis of equation 3. Panels A1 and A2 present OLS estimates, whereas panels B1 and B2 present IV estimates. The actuals figures are detailed in Table 3.

OLS estimates in panel A1 show a positive and significant correlation between broadband adoption and income deciles. More specifically, larger adoption of broadband Internet is associated with larger income growth. However, this correlation is stronger for lower deciles. For instance, a 10 percentage points increase in broadband penetration is associated with more than 0.5% income growth below the 6th decile, but less above the 7th decile. This downward sloping relationship between the marginal effect of broadband adoption and income deciles means a negative correlation between broadband adoption and income inequality, as confirmed by the figure in Table 3. The Gini coefficient falls by 0.22 percentage point in towns that experience 10 percentage points increase in broadband penetration.

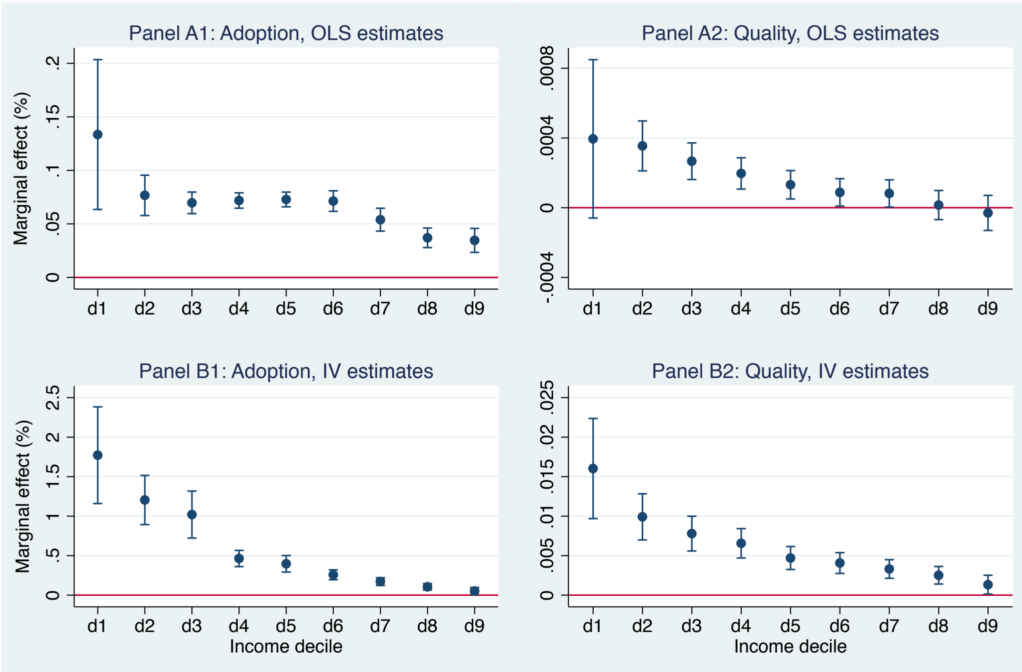
As expected, the outcome is similar with broadband quality due to a positive correlation between adoption and quality. Indeed, panel A2 shows positive, but downward sloping marginal effect of broadband quality on income deciles. The negative correlation between broadband quality and inequality is confirmed by the point estimate in Table 3. 10 Mbps increase in broadband quality is associated with 0.1 percentage point decrease in the Gini coefficient.

The IV estimates in panel B of Table 3 represented in panels B1 and B2 of Figure 3 accord well with the OLS estimates. Broadband adoption and quality raises income at all deciles, particularly for the bottom. This outcome means a positive impact of broadband Internet on income inequality. However, the magnitude of the points estimates is larger, probably due to the effect of unobserved labor demand discussed in section 4.2. Every percentage increase in broadband penetration is predicted to raise income deciles by 1.77% to 0.05% from the first decile to the ninth decile. This positive and downward sloping effect translates into lower inequality as confirmed by the negative and significant impact of broadband penetration on the Gini coefficient. A percentage point increase in broadband penetration lowers the Gini coefficient by 0.11 percentage point. Likewise, 1 Mbps increase in the median download speed raises income by 0.1-1.5%. The Gini coefficient falls by 0.2 percentage point.

The IV estimates pass all standard test statistics. In particular, we check that the share of regulated lines has positive and significant effect on broadband adoption and quality. In addition, the first-stage F-statistics are between 100 and 520 for broadband adoption, and 73 for broadband quality, well above the critical threshold of 10. In addition, Stock and Yogo's weak instrument test statistic is also above its critical threshold. These outcomes lend support to the validity of the share of regulated lines as instrument for broadband adoption.

On the basis of the theoretical predictions in section 4.1, these findings suggest that low-income workers are employed in high elasticity of substitution sectors, contrary to high-income workers.

Figure 3: Marginal impact of broadband Internet on income deciles



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. The share of regulated lines is used as instrument for broadband penetration and quality.

6.2 Robustness checks

We test the robustness of the main estimates with respect to the estimation strategy. First, we implement a fuzzy difference-in-difference estimation strategy following Duflo (2001). Second, we run a cross-sectional regression, controlling for initial conditions, following Forman *et al.* (2012).

■ Fuzzy Difference-in-Difference

Our experimental setting is similar to the one investigated by Duflo (2001) in Indonesia where she evaluates the impact of a large school construction program on education outcome. In this setting, all regions experience school construction but the targeted regions receive more. As a result, both treated (targeted regions) and controls (non-targeted regions) receive the treatment. In such a fuzzy design setting she uses the interaction between region dummies and birth cohorts as an instrument for the number of schools.

By analogy, some towns are more treated, that is they have higher broadband adoption or quality, because of their historical network structure, measured by the average distance between users and the local exchanges. The lower the distance, the higher the adoption and quality of broadband Internet. We use the interaction of average distance and time as an instrument for broadband Internet in equation (3). The results are presented in panel C of Table 3.

With the exception of the extreme deciles for which the point estimates are not significant, the outcomes are qualitatively similar to the main results. The Gini coefficient falls with broadband adoption and quality, but the magnitude is smaller.

■ **Controlling for initial conditions**

To test whether the main results are driven by town-specific trends, we implement the specification of Forman *et al.* (2012) who evaluate the effect of ICT investment on regional wage gap in the US. Using cross-sectional data on US counties, Forman and his co-authors regress wage variation before-and-after the diffusion of advanced ICT on investment, controlling for initial conditions and variation in factors not related to wage. We follow this specification by formulating the following model:

$$\ln y_{ijT} - \ln y_{ij03} = \delta_j + \beta_j P_{ijT} + \gamma_j X_{i99} + \lambda_j (X_{iT} - X_{i99}) + \varepsilon_{ijT} \tag{9}$$

The index T represents the year of observation, after the deployment of broadband Internet. Town-level data on income is not available before 2003. However, according to the OECD, the household penetration rate of broadband Internet was less than 6% in 2003. The penetration rate P_{ijT} will be substituted for town-level penetration rate P_{iT} and quality q_{iT}. We use the average distance between users and local exchanges as an instrument for broadband Internet. The outcome of the estimation is presented in panel D of Table 3. The main results still hold, even though the magnitude of the estimates is different.

6.3 Policy implications

We use the outcomes of the main specification in order to investigate the monetary benefit of broadband adoption and quality, the existence of a critical mass and heterogeneous effects with respect to initial level of income.

■ **Absolute effects**

We calculate the marginal effect of broadband Internet in monetary terms, using the mean

income deciles presented in Table 2. It ranges from 18 euros per year for the ninth decile to 151 euros per year for the first decile. Therefore, even in absolute terms, broadband Internet benefit more to the poor than the rich, thus reducing absolute income inequality. The mean marginal effect of broadband is roughly 80 euros per year, whereas the mean gross national income between 2009 and 2013 is approximatively 40,000 euros. Therefore, the marginal effect of broadband on mean income is 0.13%.[7] Interestingly, this figure is very close to one found by Czernich *et al.* (2011), that is 0.09-0.15% for OECD countries. This finding lends additional support to our main results.

The same evaluation made with the marginal effects of quality yields an estimated effects of 32-93 euros per 1 Mbps of additional download speed provided to half of the population. Given that the average median download speed is 10 Mbps, raising the median speed up to 30 Mbps would generate on average 1253 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 are not covered by our econometric model.

■ **Critical mass**

As emphasized by Roller & Waverman (2001), telecommunications technology entails network effects and, as result, its effects are non-linear. We investigate whether there is a critical mass above which the effects of broadband Internet on inequality become positive. To test the critical mass hypothesis, we use the Gini coefficient of inequality and add the squared penetration rate into equation (3). We estimate the following equation:

$$G_{it} = \delta + \beta_1 P_{it} + \beta_2 P_{it}^2 + \gamma X_{it} + \mu_i + \mu_t + \varepsilon_{it} \tag{10}$$

The critical mass is estimated as:

$$\hat{P}_j = -\frac{\hat{\beta}_1}{2\hat{\beta}_2} \tag{11}$$

Where $\hat{\beta}_1$ and $\hat{\beta}_2$ are the estimates from equation (10). A confidence interval can be calculated for $\hat{P}_j$ using the delta method, that is a linearization of the ratio $\frac{\hat{\beta}_1}{2\hat{\beta}_2}$ in the vicinity of its average.

The estimates of equation (10), exhibit an inverted-U relationship between broadband penetration and the Gini coefficient. The critical mass is at 30%, within the 5% confidence interval

[7]We first convert the marginal effect per consumption unit (CU) of 80 euros into a marginal effect per individual using the ratio 44 millions CU for 66 millions individuals.This conversion yields 53 euros per capita.

23-37%. In other words, inequality rises with broadband adoption until the penetration rate reaches 30%. Above this level, inequality falls with broadband adoption. This positive effects threshold stems from difference in the timing of adoption across deciles. Typically, top income earners adopt earlier than bottom earners. This finding accords well with Roller & Waverman (2001) who also find a critical mass at 40% above which telecommunications infrastructure has positive effect on GDP. Furthermore, the critical mass of 30% could explain the difference between our results (broadband Internet lowers inequality) and other papers (broadband Internet raises inequality). The papers such as Akerman *et al.* (2015) uses the data from the early years of Internet over the period 2000-2008 where the adoption rate is probably below this threshold. While our paper uses the data over the period 2009-2013 where the adoption rate has already exceeded this threshold.

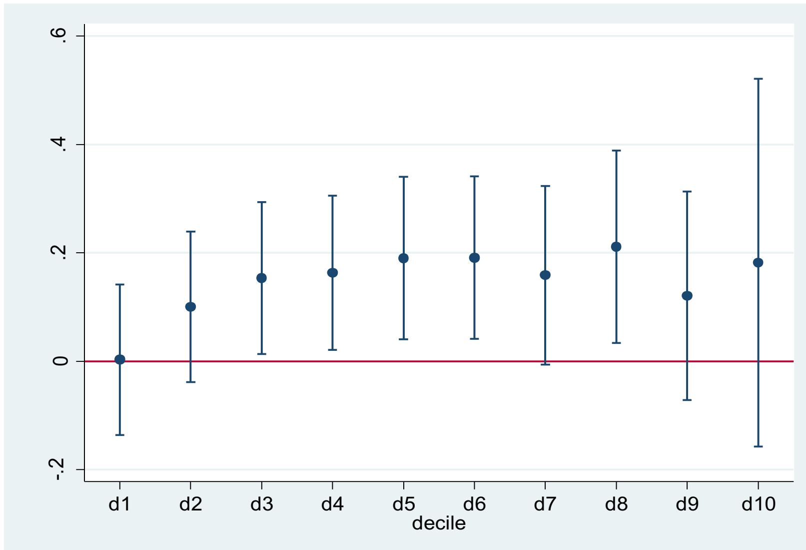
■ **Heterogeneous effects**

We also investigate the income-gap between town by estimating the following equation. Each town is represented by its average income y_{it} and its mean income's decile D_{ijt}, $j = 1$ to 10.

$$\ln y_{it} = \delta + \beta D_{ijt} * P_{it} + \lambda D_{ijt} + \gamma X_{it} + \mu_i + \mu_t + \varepsilon_{it} \tag{12}$$

As shown in Figure 4, broadband penetration exacerbates income-gap between towns. Indeed, the effect of broadband is positive, but tends to be larger in richer towns. It is not significant for the bottom 10 and 20 per cent, but positive and significant for the higher deciles (4-8). The magnitude of the effect at deciles 9 and 10 is comparable but not significant, probably due to less statistical power. The variation in penetration across the richest towns is very small as they are the early adopters. This result corroborates the finding by Forman *et al.* (2012) in the US, whereby IT investment widens the wage-gap between US counties. It suggests that broadband effects depends on its complementarity with respect to physical capital. Our main results presented in section 6.1 did not account for this complementarity due to the towns fixed-effects.

Figure 4: Effect of broadband penetration on between-town inequality



Note: IV estimates of coefficient β in equation (12).

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

	$\ln y_{i1t}$	$\ln y_{i2t}$	$\ln y_{i3t}$	$\ln y_{i4t}$	$\ln y_{i5t}$	$\ln y_{i6t}$	$\ln y_{i7t}$	$\ln y_{i8t}$	$\ln y_{i9t}$	$Gini_{it}$
Panel A: OLS estimates										
P_{ijt} or P_{it}	0.133***	0.077***	0.070***	0.072***	0.073***	0.071***	0.054***	0.037***	0.035***	-0.022***
	(0.036)	(0.010)	(0.005)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.006)	(0.004)
q_{it}	0.0004*	0.0004***	0.0003***	0.0002***	0.0001***	0.0001**	0.0001**	0.0000	-0.0000	-0.0001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Panel B: IV estimates										
P_{ijt} or P_{it}	1.771***	1.204***	1.020***	0.464***	0.397***	0.258***	0.172***	0.105***	0.052**	-0.115***
	(0.312)	(0.159)	(0.152)	(0.052)	(0.053)	(0.032)	(0.025)	(0.021)	(0.023)	(0.019)
q_{it}	0.015***	0.010***	0.008***	0.007***	0.005***	0.004***	0.003***	0.003***	0.001**	-0.002***
	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
Panel C: Robustness checks – Fuzzy Difference-in-Difference, Duflo (2001)										
P_{ijt} or P_{it}	0.213	0.316***	0.422***	0.286***	0.117***	0.087***	0.074**	0.022	0.033	-0.055***
	(0.158)	(0.076)	(0.109)	(0.066)	(0.032)	(0.028)	(0.033)	(0.028)	(0.031)	(0.019)
q_{it}	0.0007	0.0008***	0.0006***	0.0006***	0.0004***	0.0003***	0.0002**	0.0001	0.0001	-0.0002***
	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Panel D: Robustness checks – Controlling for initial conditions, Forman *et al.* (2012)										
P_{ijt} or P_{it}	2.038**	2.082***	1.690***	1.306***	1.240***	0.956***	0.728***	0.453***	0.317**	-0.204***
	(0.955)	(0.563)	(0.420)	(0.272)	(0.199)	(0.142)	(0.135)	(0.126)	(0.130)	(0.044)
q_{it}	0.004**	0.004***	0.004***	0.003***	0.003***	0.003***	0.002***	0.001***	0.001**	-0.001***
	(0.002)	(0.001)	(0.001)	(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, B and C are estimated on a panel of 5021 towns from 2009 to 2013, controlling for population above 65, share of high school graduates, population density, shares of socio-professional categories. Town and years fixed effects are included. Panel D is estimated on 4416 towns observed in 2013, controlling for initial conditions: dependent variable in 2003 and controls in 1999.

7 Conclusion

This paper investigates the impact of broadband Internet on inequality and finds that fixed broadband Internet adoption raises income at all deciles, reduces income inequality, particularly when the penetration rate reaches a critical mass of 30%, but exacerbates income gap between towns. These results are robust to the estimation strategy and accord well with previous findings.

The positive effect of broadband on income accords well with country-level analyses such as Roller & Waverman (2001) and Czernich *et al.* (2011) that also find positive effects of telecommunications infrastructure on GDP growth. Our critical mass of 30% is similar to the one by Czernich *et al.* (2011) who also find that broadband infrastructure have positive effect on GDP per capita as the penetration rate is above the threshold of 23%.[8] In addition, our finding that broadband increases between-town inequality corroborates the one by Forman *et al.* (2012) in the US.

The findings of this paper 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 critical mass can be used as threshold of public policy favoring broadband adoption by supporting digital literacy and broadband affordability.

The analysis in this paper entails some limitations that could be addressed in future works. First, by associating individual workers to income deciles, we overlook the issue of social mobility, whereby individuals move across deciles. Individual-level data is necessary to proceed with the study of social mobility. Second, deeper analyses of the effects on the labor market, education, political participation and between-group inequality are necessary to pinpoint why income inequality falls with broadband Internet.

[8] The actual critical mass is 10% on the basis of population penetration rate. Assuming 2.3 individuals per household, the equivalent critical mass in terms of household penetration rate is 23%.

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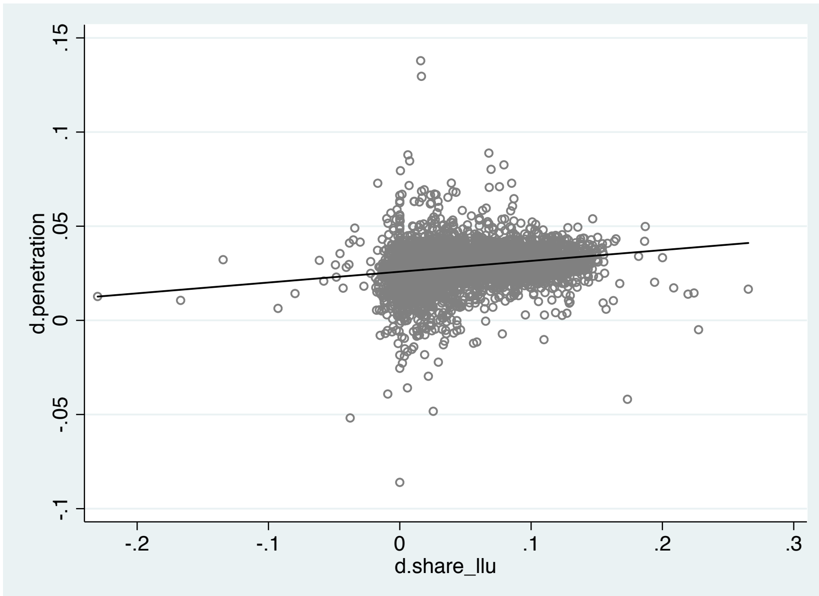
Appendix

Figure A-1: Correlation between broadband penetration share of LLU



Note: This figure presents the relationship between the share of LLU connections and broadband penetration. The solid line is the linear fit of this relationship. The x-axis and the y-axis correspond respectively to the average variation of the share of LLU connections and broadband penetration rate. Each dot represents a town.

Table A-1: Conversion ratio of penetration rate by income groups

Revenue	2009	2010	2011	2012	2013
0-900	0.5779	0.6213	0.6052	0.6354	0.7477
900-1500	0.6941	0.7227	0.7050	0.7206	0.7409
1500-2300	0.9519	0.9727	0.9857	0.9535	0.9656
2300-3100	1.1520	1.1890	1.1565	1.1452	1.0856
3100-4000	1.3742	1.2691	1.2168	1.2035	1.1678
4000 –		1.3224	1.3167	1.2456	1.1745

Each figure corresponds to the ratio of penetration per income group to the national penetration rate.