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The faster the better? Advanced internet access and student performance

Carlo Cambini [a], Lorien Sabatino [a,*], Sarah Zaccagni [b]

[a] *Department of Management, Politecnico di Torino, Italy*
[b] *Department of Economics and Business Economics, Aarhus University, Denmark*

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ABSTRACT

In this paper, we study the impact of high-speed internet access on student performance. Our empirical analysis leverages a unique dataset that combines information on ultra-broadband (UBB) diffusion in Italy with data on student performance in 2nd, 5th, and 8th grades for the period 2012–2017. We exploit the staggered roll-out of UBB, starting from 2015. Through an event study approach, we find evidence of endogeneity between student performance and UBB diffusion. We deal with this issue through an instrumental variable approach that exploits plausibly exogenous variation in the diffusion of the essential UBB input. Our results suggest that advanced internet connections significantly decrease student performance in Mathematics and Italian language in the 8th grade. In contrast, we do not find any significant effect in the 2nd and 5th grades. Male students from low-educated parental backgrounds are those more adversely affected, especially if they attend schools with a low IT usage.

1. Introduction

Investments in high-speed broadband have received considerable attention from policymakers and researchers. Governments are committing to increasing available internet connection speeds through massive public investments.[2] These policies are motivated by arguments according to which improvements in broadband connections play an important role in fostering productivity, economic growth, innovation, and knowledge.

At the same time, information and communication technologies (ICT) have dramatically affected the means through which individuals acquire, produce, and exchange information. The cohort of people born in the late 1990s – defined as Generation Z – has been the first to have broadband connections readily available at a young age. Since then, the use of the internet has become an integrated part of everyday life from the first years. In Italy, 80% of children in the age bracket between 11 and 15 are regular internet users, and in teenage years the percentage rises to 90%.[3]

Despite the ubiquitous usage of the internet among children and youth, very little is known about its effects on their academic performance. In principle, ICT can affect learning outcomes in opposite ways. On the one hand, a high-speed internet connection may provide real-time access to a vast amount of information, thus fostering new learning methods, increasing students' interest,

* Corresponding author.
E-mail addresses: carlo.cambini@polito.it (C. Cambini), lorien.sabatino@polito.it (L. Sabatino), Sarah.Zaccagni@econ.au.dk (S. Zaccagni).

[2] In March 2021, the European Commission launched the so-called "2030 Digital Compass" that updated the previous 2010 plan named "Digital Agenda for Europe". This plan aims at stimulating a substantial digital transformation in the EU, including the following goals: i) all EU households will be covered by a fiber-based network; ii) at least 75% of EU companies should introduce new digital services by 2030, such as cloud computing, artificial intelligence and machine learning, or the use of big data and data analytics; iii) 100% online provision of key public services available for all EU citizens and businesses.

[3] Source: Internet@Italia, ISTAT (2018).

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and enabling the adoption of new technologies in education, such as virtual classrooms or e-learning. On the other hand, high-speed internet access may also have negative effects: teachers may find it hard to adapt traditional learning with ICT and students may use the broadband access to perform distracting activities, such as playing video games, online chatting, surfing the social networks, and video streaming.

How advanced broadband internet affects student performance remains an empirical question, and the existing literature on the topic does not provide a conclusive answer (see Section 2). The goal of this paper is to shed some light on this issue using a municipality-level data set on the diffusion of ultra-broadband (UBB) connections in Italy, matched with the national standardized test scores in Italian language and Mathematics in 2nd, 5th, and 8th grades from the National Institute for the Evaluation of the Italian Education System (INVALSI) between 2012 and 2017.[4] The staggered roll-out of UBB in Italy started in 2015 as a result of the implementation of the Italian Ultra-Broadband Strategy.[5] These recent broadband connections are based on optical fiber cables linking telecommunications operators to final users, which allow a significantly higher performance compared to traditional copper-line connections.

Our baseline model performs fixed effects estimations that account for student attributes, school-specific unobserved characteristics and common time trends. The model estimates the impact of UBB on student performance under the identifying assumption of UBB roll-out being *as-good-as-random* conditional on controls. Yet, broadband diffusion may correlate with unobservable time-varying local shocks affecting student performance. We test the severity of this issue through an event study design that includes leads and lags from initial UBB access. Because we do not observe flat pre-trends, we conclude that endogenous selection is present, thereby potentially confounding our fixed effects estimates.

To deal with the endogeneity of UBB access, we implement an instrumental variable (IV) approach that exploits local variation in the main UBB essential input, called Optical Line Terminal (OLT). OLTs are specific tools that need to be installed in the local Central Offices of the telecommunications operator. They act as endpoint devices of a Passive Optical Network, converting optical signals that are then routed into the so-called *last mile* — the portion of network that physically reaches final users. Since optical fiber cables need to be installed underground in the last mile, the diffusion of OLTs proxies the deployment costs necessary to provide UBB connections. Our proposed instrument is an indicator that identifies municipalities sufficiently close to an OLT during the period of UBB deployment. We ensure the validity of such an instrument through reduced-form event study regressions that exhibit flat trends before the instrument activates. Through a placebo test, we also show that the instrument correlates with student performance only in municipalities actually receiving UBB, thus implying that any correlation between the instrument and student performance is only driven by UBB roll-out.

Our results show that more broadband availability is detrimental to school performance for students in 8th grade, whereas we find no effect on students in the 2nd and 5th grades, most likely because they are too young to engage in distracting online activities. Boys seem to be more affected by the distraction effect that faster broadband connections have on their performance, both in terms of magnitude and significance. The analysis of the heterogeneous effects shows that parental education plays a determinant role: the negative effect of UBB is driven by children with low-educated parents. Thus, UBB might have the unintended consequence of exacerbating, rather than reducing, the educational gap between children in educated versus uneducated families.

Exploring mechanisms, we do not find any significant impact on parents' occupation. In addition, we complement our data set with information on the digitization of Italian schools at the province level,[6] collected by the Italian Ministry of Education (MIUR) in 2016. This helps us to disentangle the use of the internet for learning purposes from the distraction generated by the access to faster internet speeds. We find evidence that the negative effect is mitigated in provinces where schools provide a higher level of IT usage in class. Students attending those schools are more likely to benefit from the use of the internet for learning purposes, and this positive effect displaces the negative one resulting from an increase in distraction time. This result highlights the importance of investing in the digitization of schools to counterbalance the adverse effect of high-speed broadband connections on student performance.

The outline of the rest of the paper is as follows. Section 2 provides an overview of the related literature. We present a theoretical framework in Section 3. Section 4 describes a background on UBB diffusion and online children behavior in Italy. We introduce the source of the data we use and how we build our final data set in Section 5. The empirical strategy and the IV approach are outlined in Section 6. Section 7 includes some descriptive statistics and establishes the main results on the impact of broadband on student performance. Finally, Section 8 concludes.

2. Literature review

Our paper contributes to the literature on the impact of broadband internet on microeconomic outcomes,[7] and specifically on educational attainment. It also relates to studies on the relationship between IT and standardized test scores. A few papers focus

[4] In the Italian school system, students are 7 years old in 2nd grade, 10 years old in 5th grade and 13 years old in 8th grade

[5] The Italian Ultra-Broadband Strategic Plan aims to develop a high-speed broadband network across the entire national territory to create a public telecommunications infrastructure consistent with the objectives of the European Digital Agenda Link.

[6] From a geographical perspective, Italy is partitioned into 20 administrative regions and 110 provinces.

[7] The impact of broadband internet has been extensively investigated along with other interesting economic outcomes, including local and aggregate GDP growth (Czernich, Falck, Kretschmer, & Woessmann, 2011; Kolko, 2012), firms' productivity (Cambini, Grinza, & Sabatino, 2023), labor market outcomes (Abrardi, Cambini, & Sabatino, 2023; Akerman, Gaarder, & Mogstad, 2015; Forman, Goldfarb, & Greenstein, 2012), political outcomes (Campante, Durante, & Sobbrio, 2018; Falck, Gold, & Heblich, 2014; Gavazza, Nardotto, & Valletti, 2019; Geraci, Nardotto, Reggiani, & Sabatini, 2022), and crime (Bhuller, Havnes, Leuven, & Mogstad, 2013).

on the impact of the use of computers in schools (Angrist & Lavy, 2002; Falck, Mang, & Woessmann, 2018) or both in schools and at home (Fairlie & Robinson, 2013; Fuchs & Woessmann, 2004). The evidence suggests mixed results at best (Bulman & Fairlie, 2016). Expanding the supply of computers in schools alone may not lead to actual benefits from the use of new technology. Home computers also seem to be ineffective in raising student performance due to increased distraction time spent on the internet. Thus, computer ownership alone is unlikely to have an impact on short-term outcomes.

Broadband internet, as well as other ICT, is perceived as a potential tool to improve the quality of education and student performance. Some studies (Goolsbee & Guryan, 2006; Hazlett & Wright, 2017) focus on the effect of government subsidies on internet investment in schools, and find little evidence on the interplay between internet connectivity in schools and student achievement. A few recent studies focus specifically on the impact of broadband connections at school on students' performance. Using data from more than 900 schools in Portugal from 2003 to 2009, Belo, Ferreira, and Telang (2014) show a strong negative effect of internet use at school on 9th-grade students' test scores. More broadband internet resulted in an average decrease of 0.78 standard deviation from the mean, with boys being those mostly affected. However, Derksen, Michaud-Leclerc, and Souza (2022) suggest that restricting internet access to a source of engaging and accessible reading material affect positively educational outcomes, especially among low achievers. Other studies analyze the link between home broadband and student test scores. While (Malamud, Cueto, Cristia, & Beuermann, 2019) find no significant effects of home internet access on student achievement in Peru, Dettling et al. (2018) for the U.S. and Sanchis-Guarner, Montalbán, and Weinhardt (2021) for the UK find that broadband technology increases students' performance. In particular, Sanchis-Guarner et al. (2021) show that increasing the broadband speed by 1 Mbit/s increased test scores of students at age 14 by 1.37 percentile ranks in the years 2005–2008.

We contribute to the economic literature on ICT and educational attainment in many dimensions. First, we study the impact of the latest generation broadband technology, which is based on optical fiber rather than copper line, enabling significantly a higher speed (up to 1 Gbit/s per second) compared to old DSL connections (up to 7 Mbit/s) and thus allowing for more online entertainment activities and potentially more distractions.[8] Only a few papers study the impact of last-generation broadband technologies on educational outcomes. Grimes and Townsend (2018) estimate the effect of fiber-based connections on school-level performance in New Zealand in a difference-in-differences (DiD) framework, finding a small but positive relationship between the availability of fiber broadband and school performance, as measured by school pass rates. Boeri (2020) focuses on the diffusion of UBB in "market failure areas" in Italy, finding a positive effect only on the academic performance of students from better backgrounds. Second, we match our broadband data with information on the universe of Italian students in the 2nd, 5th, and 8th grades who sat a standardized national test held on the very same day. This allows us to capture potential heterogeneous effects based on students' age, in addition to family characteristics. Finally, to isolate the potential mediated effect of internet at school, we also account for specific information on the intensity of internet use at school through ad hoc survey data recently collected by the Italian Ministry of Education, MIUR.

3. Theoretical framework

In this section, we introduce a model of student learning that accounts for the use of internet both at home and at school. In doing so, we extend the model in Belo et al. (2014), which focuses on the use of internet at school only.

Let T denotes the total time a student has in a day. The student can use this time for traditional study (S), for online activities (I) or for free time (F). Hence, $T = S + I + F$. Free time can be interpreted as the time spent on non-learning activities, that is as time withdrawn from traditional study. Hence, $F = \gamma S$ where $0 < \gamma < 1$, implying that not all of the study time can be reduced. Indeed, students are obliged to go to school in the morning; therefore, at least part of the time cannot be withdrawn from traditional study time. Then, we have $T = (1+\gamma)S + I$, where T is fixed.

Broadband internet can be used both at school and at home. Hence, it may also distract the students and negatively impact their performance. To account for these effects, we assume that the time devoted to online activities is $I = L^s + L^h + D$, where L^s denotes the amount of time spent using the internet at school for learning activities, L^h refers to time spent online at home for learning purposes, while D represents the time spent in distracting online activities, either at school, or at home, or both. The marginal effects of an increase in time spent online are $L_I^s \geq 0$, $L_I^h \geq 0$, $L_I^s + L_I^h \leq 1$, and $0 \leq D_I \leq 1$, which implies that internet improves learning both at school and at home but also increases student's distraction with a negative effect on performance.

Let P represent student performance at school, which depends on the effectiveness of online study both at school and home, $L = L^s + L^h$, and the effectiveness of traditional study, *i.e.*, $P = g(L, S)$. Given that $T = (1+\gamma)S + I$, the overall effect of the internet on student performance is provided by the following condition:

$$\frac{dP}{dI} = g_L(L_I^s + L_I^h) - \frac{g_S}{1+\gamma}. \qquad (1)$$

This condition implies that student performance depends on the trade-off between the productivity of online learning weighted by the amount of time spent for online learning, both at school (L_I^s) and at home (L_I^h), and on the productivity of traditional study corrected by the time devoted to free time ($\frac{1}{1+\gamma}$). We can now rewrite Eq. (1) as follows:

$$\frac{dP}{dI} = g_L(1 - D_I) - \frac{g_S}{1+\gamma}. \qquad (2)$$

[8] For more on the technological aspects of UBB, see Cambini and Sabatino (2023).

Condition (2) implies that any increase in time spent online has a negative effect on student performance when

$$D_I > 1 - \frac{g_s}{g_L(1+\gamma)}. \tag{3}$$

We can generalize the model to account for student heterogeneity. Consider the presence of $i = 1, \ldots, n$ students. For each student i, the total amount of time is $T = (1+\gamma_i)S_i + I_i$, with T fixed. Moreover, let $I_i = L_i^s + L_i^h + D_i$. Student i's performance is represented by the production function $P_i = g_i(L_i, S_i)\phi_i$, where ϕ_i denotes the idiosyncratic characteristics of student i.[9]

The overall impact of the internet is given by:

$$\frac{dP_i}{dI_i} = \left[g_{iL}(1 - D_{iI}) - \frac{g_{iS}}{1+\gamma_i}\right]\phi_i. \tag{4}$$

The main trade-off remains unchanged, while overall performance might be scaled up or down according to the student characteristics.

4. Background

4.1. Advanced internet expansion

The roll-out of fiber-based connections in Italy started in 2015 as a result of the implementation of the Italian Ultra-Broadband Strategy. The Italian UBB deployment plan was implemented through a combination of public and private investments. By leveraging on the pre-existing facilities used for voice telephone and copper-wire (ADSL) connections, the telecommunications incumbent *Telecom Italia Mobile* (TIM) was the first in investing in UBB infrastructures throughout Italy since 2015.[10]

The incumbent operator also owns the main upstream telecommunications infrastructure. At a national level, data transmission flows through the national backbone, which connects its exchanges via optical fiber. These represent the main *nodes* of the national infrastructure, aiming at rerouting the traffic towards the local Central Offices (COs). COs represent the intermediate level of the telecommunications infrastructure. The so-called *last mile* departs from the local CO, connecting service provider and final users. Both backbone nodes and COs are pre-existing facilities from the old telephone network. The traffic goes from the nodes to the local COs via optical fiber, and the signal is then converted to flow in the last mile. *Optical Line Terminals* (OLTs) are specific devices that need to be installed in the COs in order to convert those optical signals. Therefore, only the COs equipped with OLT serve as telecommunications operator endpoint. The deployment of UBB was widespread throughout the country, as shown by Figs. A.1 and A.2 which depict the diffusion of UBB and OLTs across Italian municipalities in 2015 and 2017, respectively.

The main deployment cost of UBB involves placing optical fiber cables underground in the last mile. The higher the portion of optical fiber in the last mile, the higher the costs, but also the performance of broadband connections. In this context, two configurations have been used in Italy. The first one is called Fiber-to-the-Cabinet (FTTC), and leverages on a first portion of optical fiber, up to a cabinet located nearby customer building from which copper line departs, enabling a speed range between 30–100 megabit per second (Mbps). The second configuration is called Fiber-to-the-Home (FTTH), which is characterized by a full fiber-based last mile, allowing the highest speed of 1 gigabit per second.[11] Both configurations provide a significant higher capacity compared to traditional ADSL connections, which imply a maximum speed of 20 Mbps.

4.2. Online children behavior

The theoretical framework above provides a useful method for thinking about how internet can affect student performance. Advanced internet connections provide a higher bandwidth speed, enabling more online activities from different devices simultaneously, both at home and at school. Some online activities require more speed bandwidth than others. While social media, email, or basic video streaming require a connection of 10–25 Mbps, online gaming, HD videos, and streaming contents requires a minimum connection speed between 50–100 Mbps. Therefore, fiber connections allow supporting effectively those high-demanding online activities, which in turn can lead to more distraction from traditional and online studying.

According to a survey of Italian Statistical Office (ISTAT),[12] 68% of children between 6 and 14 years old used internet in 2017. Of those, 80% declared to go online for playing/downloading games, films and movies (around 80%), while 45% consulted online encyclopedias (such as Wikipedia). Moreover, 50% of children between 11 and 14 years old participated in social network, while 33% of them created and uploaded online self-created content. Only a very small proportion followed online courses (less than 2%).

[9] The parameter ϕ_i captures student-specific attributes such as gender, country of origin, kindergarten attendance, as well as family educational background and parental occupation. In particular, a large strand of the economic literature (Angrist & Lavy, 2002; Barrow, Markman, & Rouse, 2009; Belo et al., 2014; Goolsbee & Guryan, 2006; Rouse & Krueger, 2004) emphasizes the linkage between family background and student performance.

[10] Before 2015 only the city of Milan enjoyed fiber-based connections realized by the local company Metroweb.

[11] In both settings, the length of the fiber portion of the last mile does not affect much connection performance, as fiber optical lines have a very low dispersion rate. However, in FTTC settings the length of the second part of the last mile – that is the distance between cabinet and final consumer – dampens connection performance because it is made of copper wire. In Italy, the average length of the last mile is 1.5 km, with an average distance between cabinet and consumer premises of 200 m. The short length of the final portion of the last mile ensures a significantly higher performance with respect to the old ADSL connections. Source here.

[12] Publicly available data from ISTAT *"Multipurpose survey on households: aspects of daily life - general part"*.

Consequently, the main use of internet for learning purposes appears to come from the browsing of online encyclopedia, carried out with a basic internet connection. On the contrary, the most frequent activities, such as online gaming and streaming, require connections with a higher bandwidth speed. This implies that the introduction of fiber connections might provide more space for students' distraction. In our model, this effect translates in a higher increase in distraction time (D) relative to student learning activities ($L = L^s + L^h$) when condition (3) holds. We test this prediction in our empirical analysis, in which we link the diffusion of UBB in Italy to INVALSI standardized test scores in Mathematics and Italian language.

5. Data

Our empirical strategy makes use of a unique dataset containing granular information on UBB deployment, student performance assessed through a standardized test designed by INVALSI, and the MIUR data on the intensity of IT usage in Italian schools. The final dataset covers the period 2012–2017.

Broadband data comes from TIM, the largest Italian telecommunications provider. TIM collects data on broadband deployment in Italy, from which we get information on UBB diffusion. For each municipality, we observe the percentage of households with access to UBB connections. We also have detailed information on TIM upstream infrastructure. In particular, we observe the diffusion of the primary input for UBB, namely the OLT. We then derive a variable called OLT Distance, defined as the distance in kilometers between each municipality and its closest OLT at each point in time. This variable, that in principle proxies the cost of network deployment, is then used to construct the instrument in our IV approach.

Besides the dataset on UBB diffusion, we use the information on student performance collected in a rich student-level dataset containing Italian language and Mathematics scores for students enrolled in the 2nd, 5th, and 8th grades over the period 2012–2017. Primary and Secondary schooling in Italy are compulsory from ages 6 to 16, with three stages: 5 years of elementary school (scuola elementare), 3 years of lower secondary school from 6th to 8th grade (scuola media), and high school (scuola superiore), which runs for 3–5 years. Schools are organized into single- or multi-unit institutions. Italian schools have long used final exams at the end of the three stages for tracking and placement in the transition from elementary to middle school and throughout high school, but standardized testing for evaluation purposes is a recent development. In 2008, INVALSI piloted voluntary assessments in elementary school; in 2009 these became compulsory for all schools and students. INVALSI assessments cover Mathematics and Italian language skills and are administered nationally over two days in the Spring. Tests are supervised by local administrators and teachers. The pupils also complete a questionnaire for collecting information about the social, economic and cultural characteristics of their families (*e.g.*, parental nationality, education and work status), and student characteristics (*e.g.*, gender, age, birthplace, childcare centre and kindergarten attendance). Test scores are normalized within each school year, with an average of 200 and a standard deviation of 40. We further standardize the scores so as to have mean of zero and a standard deviation equal to one in each school year and grade, for both Italian language and Mathematics.

The third source of data is the MIUR data on the use of digital technologies in Italian schools. This is a provincial-level cross-sectional dataset collected in a survey carried out by MIUR, concerning the entire 2016/2017 school year. To the best of our knowledge, these are the first data collected on information technologies (IT) in schools by the Italian Ministry of Education. The survey aimed to collect information on the state of digital development of Italian schools with a particular focus on primary and secondary schools.[13] The data set contains information on the following: number and percentage of schools with an internet connection, number and percentage of wired classrooms number and percentage of classrooms with an internet connection, the average percentage of teachers who use IT daily, weekly, monthly, or just a few times per year. Table B.3 provides summary statistics for these data.

The merging of the broadband and standardized test score data was carried out directly by the INVALSI statistical office. This results in some limitations imposed by the General Data Protection Regulation 2016/679. In particular, to avoid the risk of identification of a specific school/student, only dichotomous broadband variables were allowed to be merged. To comply with such restrictions, we matched INVALSI data with a dummy variable indicating the presence of UBB in the municipality where the school is located at each point in time. Similarly, we converted the continuous variable OLT Distance into an indicator that activates when the distance is lower than 10 km. Even doing this, we lost neither a significant amount of information nor compromised the adoption of the IV approach.[14] Finally, since the Italian school year starts in September and ends in June of the following year, broadband data in year t were merged with the standardized test scores for the academic year starting in September of the same year t.

The UBB and OLT variables identify the municipalities where the schools are located. Lack of information on the availability of UBB in the municipality of residence of the students may raise concerns about the role of distraction time at home. However, since more than 70% of Italian students go to school in the same municipality where they live, this concern does not significantly affect our analysis. Moreover, this percentage can be considered a lower bound since it is computed on the whole population of students, which includes older students who are more likely to commute.[15]

Finally, we keep a balanced panel of schools within the time frame of our analysis. The panel of dataset contains 7,575,829 student-level observations over the period 2012–2017. As shown by Fig. A.3 in Appendix A, the staggered roll-out of UBB implies an increasing pattern in the percentage of schools covered by fiber connections. Table 1 summarizes the main statistics by school grade and total. For a more detailed description of the variables see Appendix B.

[13] Valle d'Aosta and the Autonomous Provinces of Trento and Bolzano are not covered in the dataset.

[14] The within-municipality variation of UBB is highly discontinuous. This happens because, given the presence of large economies of scale in infrastructure deployment, the telecommunications operator tends to immediately cover most of the households once reaching a municipality.

[15] Data is drawn from the most recent report by ISTAT-Censimentospostamentipendolari[Link].

Table 1
Descriptive statistics.

Variable	2nd grade	5th grade	8th grade	Total
Observations	2,442,150	2,400,776	2,732,903	7,575,829
Male	0.435	0.430	0.434	0.432
	(0.496)	(0.495)	(0.496)	
Childcare Centre	0.255	0.241	0.200	0.231
	(0.436)	(0.428)	(0.400)	
Kindergarten	0.737	0.768	0.719	0.740
	(0.440)	(0.422)	(0.449)	
Student Italian	0.963	0.951	0.932	0.948
	(0.189)	(0.215)	(0.252)	
Mother Italian	0.797	0.824	0.832	0.819
	(0.402)	(0.381)	(0.374)	
Father Italian	0.812	0.839	0.840	0.831
	(0.391)	(0.368)	(0.367)	
High-educated mother	0.192	0.171	0.136	0.165
	(0.394)	(0.376)	(0.343)	
High-educated father	0.140	0.134	0.114	0.129
	(0.348)	(0.340)	(0.318)	
Mother high-skill occupation	0.309	0.307	0.278	0.297
	(0.462)	(0.461)	(0.448)	
Father high-skill occupation	0.299	0.303	0.285	0.295
	(0.458)	(0.460)	(0.452)	
UBB coverage	0.326	0.349	0.331	0.335
	(0.438)	(0.470)	(0.470)	
Average OLT distance	0.315	0.320	0.313	0.316
	(0.464)	(0.466)	(0.464)	

Notes: Data on students' characteristics are from the INVALSI dataset and data on broadband infrastructure are from Telecom Italia Mobile (TIM).

6. Empirical strategy

6.1. Fixed effect models

Following the stylized model described in Section 3, our baseline econometric model takes the following form:

$$y_{i,s,m,t} = \beta_0 + \gamma UBB_{m,t} + X'_{i,t}\beta_1 + \alpha_s + \tau_{p(s),t} + \varepsilon_{i,s,m,t}, \tag{5}$$

where $y_{i,s,m,t}$ denotes either the Italian language or the mathematics standardized test score for student i, in school s, located in municipality m, and (academic) year t. $UBB_{m,t}$ is our main variable of interest and identifies ultra-broadband connection access in municipality m and year t. $X_{i,t}$ is a vector of cohort-specific controls for student i, including, among others, information on family background, birthdate, nationality, and kindergarten attendance.[16] Finally, α_s collects school fixed effects, while $\tau_{p(s),t}$ is province-specific (of the school) year fixed effects. Throughout the analysis, we cluster standard errors at the labor local system (LLS)[17] level to allow for the possibility of serial correlation within each labor market area.

Since $UBB_{m,t}$ is an indicator identifying schools located in municipalities with access to ultra-broadband connections, Eq. (5) performs a two-way fixed effect difference-in-differences (DiD) estimation, where treated units are those cohorts of students in schools covered by UBB services. Because of the staggered nature of the UBB roll-out (see Fig. A.3 in Appendix A), the model reflects variation in treatment timing (Goodman-Bacon, 2021).

Eq. (5) identifies the causal impact of UBB on student performance under the assumption of UBB roll-out being as-good-as-random with respect to student standardized scores. We test such an identifying assumption through an event study model that allows us to look for parallel trends before the introduction of UBB. In particular, a failure of the flat trends test would suggest that conditional on student characteristics, school fixed effects, and common time trends, the UBB roll-out would be somehow correlated with the average student performance of schools in municipality m. To this end, we estimate the following event study model:

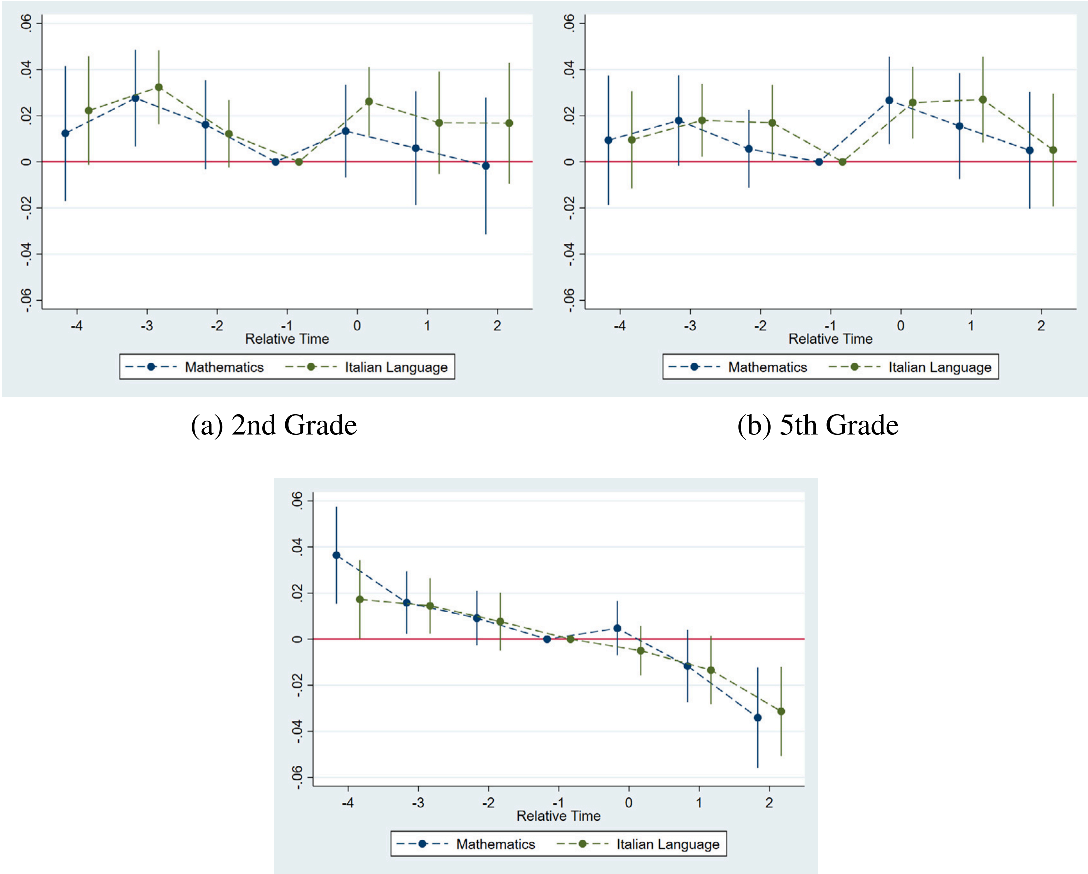
$$y_{i,s,m,t} = \beta_0 + \sum_r \gamma_r \mathbb{I}\{r = t - T_{0m}\} + X'_i\beta_1 + \alpha_s + \tau_{p(s),t} + \epsilon_{i,s,m,t}, \tag{6}$$

where T_{0m} denotes the time when a school's municipality m initially gets UBB, and $r = t - T_{0m}$ is the relative time from the introduction of UBB.[18] Given the staggered nature of the treatment, we need to drop two indicators identifying relative time from the treatment (Borusyak, Jaravel, & Spiess, 2021). Therefore we drop $r = \{-5, -1\}$.

[16] Control variables included in the regressions are collected in Appendix Table B.2.

[17] LLS are commuting areas designated by the Italian statistical office, grouping together contiguous municipalities that are statistically and geographically comparable, and in which the labor force moves and works.

[18] Since our sample covers the academic year from 2012/2013 to 2017/2018, and UBB was first introduced in the academic year 2015/2016, $r = \{-5, -4, -3, -2, -1, 0, +1, +2\}$.



(a) 2nd Grade (b) 5th Grade

(c) 8th Grade

Fig. 1. Presented are event study estimates for each school grade, together with the corresponding 95% confidence interval. Standard errors are clustered by LLS.

Fig. 1 depicts the estimated coefficients of γ_r together with the corresponding 95% confidence interval of Eq. (6) when the dependent variable is the standardized test score for Italian language and Mathematics for the 2nd, 5th, and 8th grades. First, in general, we do not observe flat trends prior to the treatment, pointing towards an endogeneity issue. In particular, treated schools display higher scores compared to the control group before actually receiving UBB. Second, we do not see any statistically significant treatment effects in the 2nd and 5th grade, for either Mathematics or Italian language scores. Finally, the unique (negative) effect of UBB on student performance is concentrated in the 8th grade, where, for both Italian language and mathematics scores, we observe negative and statistically significant post-treatment coefficients. However, both event studies display strong pre-trends prior to UBB, implying the existence of a significant correlation between 8th-grade student performance and UBB roll-out.

6.2. IV approach

Our event study estimation provides useful insights into the potential effects of the availability of UBB on standardized Mathematics and Italian language test scores. Yet, the existence of pre-trends suggests that the roll-out of UBB may be correlated with unobserved time-variant local shocks affecting student performance and biasing the OLS estimate of Eq. (5). As mentioned before, we deal with such an endogeneity issue through an instrumental variable approach that exploits local variation in the main UBB essential input, namely OLT.

OLTs are specific devices that need to be installed in the local COs to provide UBB services to final customers. They act as endpoint devices of an Optical Passive Network, from which begins the so-called *last mile* — the portion of the telecommunications network that physically reaches customers' premises. Since in this last portion of the network fiber cables need to be laid underground, the distance between a municipality and the closest OLT proxies the deployment cost needed to provide UBB connections to final consumers, providing a relevant instrument to be used in our IV estimation.

In terms of validity, two technological constraints are worth to be mentioned. First, as COs are pre-existing facilities of the incumbent telecommunication network, one fundamental condition for a municipality to receive an OLT is to have a CO where the operator can actually install the OLT. Second, Cambini and Sabatino (2023) notice that OLTs are first installed close to the nodes of the telecommunication backbone. These are large infrastructures that reroute traffic towards the local COs. Municipalities relative closer to the backbone nodes are more likely to receive first an OLT (if they have a CO) and, as a consequence, to be covered by UBB. Since distance between a municipality and the backbone nodes is time-invariant, such a variation is absorbed by fixed effects. Then, our exclusion restriction assumption is that the diffusion of OLT is exogenous to co-determinants of student performance given student-level controls and fixed effects included in Eq. (5).

Given the constraints in terms of data (see Section 5), we cannot directly use the distance between the municipality and its closest OLT. However, given that information, we construct the following indicator variable:

$$z_{m,t} = \begin{cases} 1 & \text{if } Post_{2015} \times OLT_{m,t} \leq 10 \text{ km} \\ 0 & \text{Otherwise,} \end{cases} \tag{7}$$

where $Post_{2015} \times OLT_{m,t}$ denotes the interaction between a $Post_{2015}$ dummy taking the value one from the starting year of UBB introduction, and $OLT_{m,t}$ is the distance in kilometers between each municipality and the closest OLT. Since OLT distance and UBB diffusion are presumed to be negatively correlated, we expect a positive correlation between $z_{m,t}$ and $UBB_{m,t}$. Our prediction is confirmed by Fig. A.4 in Appendix A, which shows that schools for which $z_{m,t} = 1$ are more likely to get fiber connections.

Our proposed instrument $z_{m,t}$ identifies those municipalities that are relatively closer to an OLT during the period of UBB roll-out.[19] The exclusion restriction requires such an indicator to be as-good-as random with respect to student performance once controlling for student-level characteristics and fixed effects. In essence, we want to observe flat trends in a reduced form regression of $y_{i,s,m,t}$ on $z_{m,t}$. Such a regression would itself be a DiD regression with variation in treatment timing like the one of Eq. (5), in which $UBB_{m,t}$ is replaced with $z_{m,t}$. Therefore, we test the parallel trend assumption of the instrument through the following event study:

$$y_{i,s,m,t} = \theta_0 + \sum_r \pi_r \mathbb{I}\{r = t - Z_{0m}\} + X'_{i,t}\theta_1 + \mu_s + \delta_{p(s),t} + u_{i,s,m,t}, \tag{8}$$

where Z_{0m} denotes the initial time from which $z_{m,t}$ is active.

Fig. 2 presents the OLS π_r coefficients together with the corresponding 95% confidence interval of Eq. (8) when the dependent variable is the standardized test score for Italian language and Mathematics for the 2nd, 5th, and 8th grades. The estimates show that the parallel trend assumption is satisfied for the 2nd and 8th grades, for both mathematics and Italian language scores. Only in the 5th grade we can reject the null hypothesis that $\pi_r = 0$ for $r < 0$, and only for Italian language.[20] Again, post-treatment coefficients are statistically significant only for the 8th grade. Since they are negative, and the correlation between $z_{m,t}$ and $UBB_{m,t}$ is expected to be positive in the first stage, we expect a negative second-stage γ coefficient in the two-stage least squares (2SLS) estimation of Eq. (5).

To further validate our exclusion restriction we run a series of placebo tests to assess whether our instrument effectively correlates with our dependent variables only through UBB roll-out. In particular, we exploit the presence of schools located in municipalities not receiving UBB during the time frame of our analysis, by running reduced form estimates separately on schools with and without UBB access as of 2017. If the instrument is not capturing spurious co-determinants of both UBB roll-out and student performance, we should observe no significant correlation between OLT and student performance in municipalities without UBB. At the opposite, we should observe a significant correlation for those schools actually receiving UBB. Table 2 collects estimated coefficients from this exercise for both Mathematics (Columns 1 and 2) and Italian language (Column 3 and 4) in the 8th grade.[21] We observe that only in schools actually receiving UBB there is a strong and significant correlation between our proposed instrument and student performance, while for schools not receiving UBB we observe estimated coefficients very close to zero and not statistically significant. These results provide important reassurance on the validity of our instrument and, therefore, of the identification approach used in the paper.

7. Results

In this section, we discuss the results of estimating the impact of the UBB roll-out on student performance in Italian language and Mathematics (Table 3). Since we only find significant effects on students in 8th grade, we report these tables in the main text. The same tables for students in the 2nd and 5th grades are reported in Appendix C.

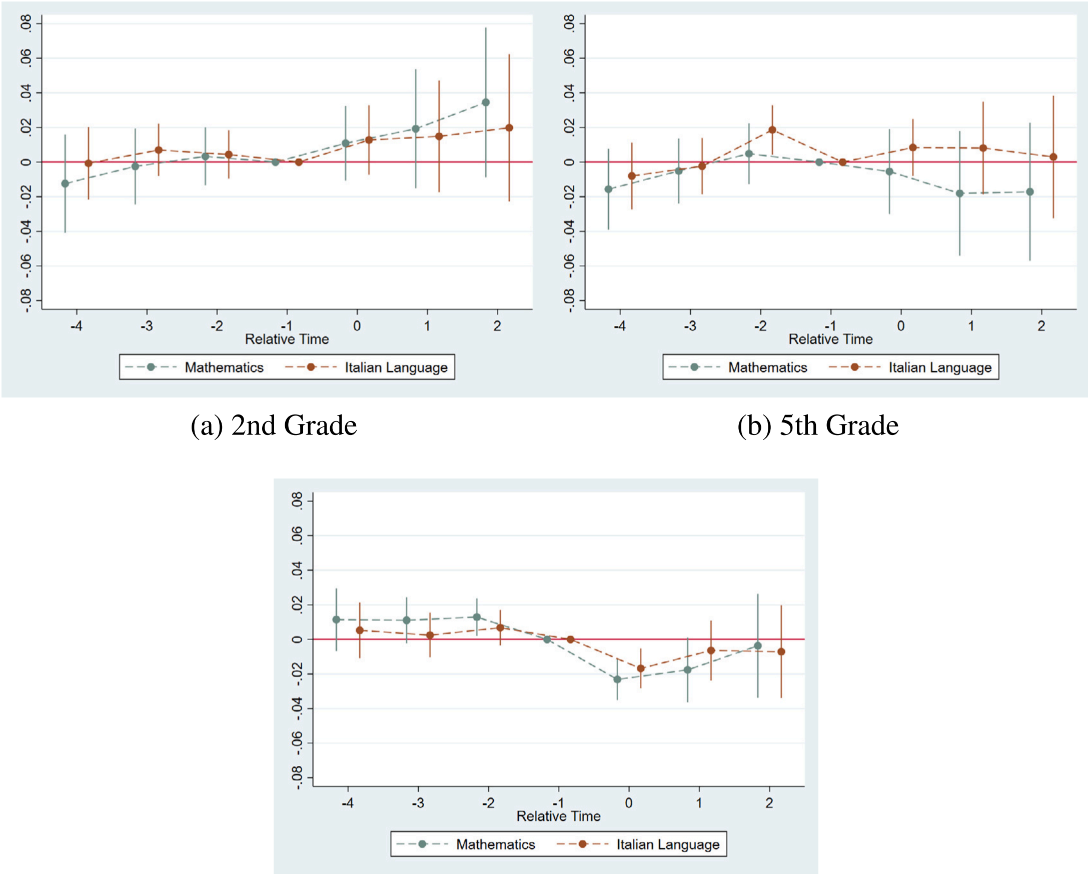
We report heterogeneous effects by gender (Table 4), parental education (Table 5), daily usage of IT in class (Table 7), as well as combinations of parental education with student gender and daily usage of IT in class (Tables 6 and 8, respectively).

Table 3 presents our estimates of the effect of UBB on student performance in Italian language (columns 1–3) and Mathematics (columns 4–6) for students in the 8th grade. Student performance is measured by the INVALSI standardized test scores. The

[19] The installation of OLTs started before the beginning of the UBB roll-out plan, although they were not active. Our broadband data show that only 110 out of 7900 municipalities had a CO equipped with OLT before 2015, mainly consisting of provincial capitals and large municipalities in metropolitan areas.

[20] Although the coefficients associated to $r = -2$ for mathematics in the 8th grade is statistically different than zero, we do not reject the null hypothesis of joint equality to zero for $r < 0$. That is, when we test the null that $\pi_{-4} = \pi_{-3} = \pi_{-2} = 0$, we fail to reject it, with an F-test= 1.82, and an associated p-value = 0.1427.

[21] When running the placebo test on 2nd and 5th grade, we do not find any significant correlation at standard 5% level for schools in municipalities both receiving and not receiving UBB by 2017 (Tables C.1 and C.2).



(a) 2nd Grade

(b) 5th Grade

(c) 8th Grade

Fig. 2. Presented are reduced form event study estimates for each school grade, together with the corresponding 95% confidence interval. Standard errors are clustered by LLS.

Table 2
Placebo test: 8th grade.

	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)
Variables	std MAT	std MAT	std ITA	std ITA
z	−0.004	−0.026***	−0.007	−0.017***
	(0.009)	(0.007)	(0.007)	(0.006)
UBB by 2017	No	Yes	No	Yes
Observations	604,979	2,127,924	604,979	2,127,924

Notes: Presented are OLS estimates from reduced form regressions of standardized test scores in mathematics and Italian language on our proposed instrument $z_{m,t}$. Columns 1 and 2 estimate the model on a sample of schools located in municipalities not receiving UBB during the time frame of our analysis. On the contrary, columns 2 and 4 focus on schools in municipalities actually receiving UBB. Standard errors clustered at the labor local system level. *** p<0.01, ** p<0.05, * p<0.1.

normalization of the score is done by grade and academic year. Columns 1, 2, 4, and 5 present the estimates obtained by OLS, as in Eq. (5), without accounting for endogeneity concerns. In these specifications, the explanatory variable is the dummy UBB that identifies whether the municipality of the school attended by the student has access to UBB. All specifications include school fixed effects and province-year fixed effects. Columns 2 and 5 differ from 1 and 4 for the inclusion of the student-level controls listed in Table B.2. Columns 3 and 6 present results of the IV as given by Eq. (8), including both fixed effects and student-level controls.

The results presented in columns 1–2 of Table 3, both without and with covariates, show a very small and statistically insignificant relationship between the change in Mathematics scores and the UBB roll-out. OLS coefficients for Italian scores (columns 4–5) are, instead, significant and show a negative relationship with the presence of UBB. Notably, including additional controls increases the magnitude of the coefficients, thus pointing to an attenuation bias from omitted variables.

Table 3
Effect of UBB on student performance in 8th grade.

	OLS	OLS	IV	OLS	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	std MAT	std MAT	std MAT	std ITA	std ITA	std ITA
UBB	−0.001	−0.007	−0.114***	−0.009*	−0.012**	−0.084***
	(0.006)	(0.006)	(0.038)	(0.005)	(0.005)	(0.028)
First Stage F-test			40.40			40.40
Observations	2,732,903	2,732,903	2,732,903	2,732,903	2,732,903	2,732,903

Notes: Specifications in columns (1), (2), (4) and (5) are estimated using OLS. The baseline OLS estimates in columns (1) and (4) do not include any controls. Specification in columns (2) and (5) include controls for gender, place of birth, and citizenship of the student, childcare centre and kindergarten attendance, place of birth of the mother and the father, education of the mother and the father, and occupation of the mother and the father, and a year-province fixed effects. Specifications in columns (3) and (6) replicate columns (2) and (5) using IV. Standard errors clustered at the labor local system level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 4
Effect of UBB on student performance in 8th grade by gender.

	Male		Female		Male		Female	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	std MAT	std MAT	std MAT	std MAT	std ITA	std ITA	std ITA	std ITA
UBB	−0.005	−0.116***	0.002	−0.083**	−0.013**	−0.106***	−0.009	−0.035
	(0.007)	(0.041)	(0.007)	(0.036)	(0.006)	(0.037)	(0.006)	(0.028)
First Stage F-test		33.96		33.46		33.96		33.46
Observations	1,186,211	1,186,211	1,154,718	1,154,718	1,186,211	1,186,211	1,154,718	1,154,718

Notes: Specifications in columns (1), (3), (5) and (7) are estimated using OLS. Specifications in columns (2), (4), (6) and (8) replicate columns (1), (3), (5) and (7) using IV. All specifications include controls for place of birth, and citizenship of the student, childcare centre and kindergarten attendance, place of birth of the mother and the father, education of the mother and the father, and occupation of the mother and the father, and a year-province fixed effects. Columns (1) to (4) report results in Mathematics. Columns (5) to (8) report results in Italian language. Standard errors clustered at the labor local system level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Moving to the IV estimates presented in columns 3 and 6 of Table 3, we find that the impact of UBB on student performance is negative, sizeable, and statistically significant (at the 1% significance level) for both subjects, suggesting an adverse effect of advanced broadband connections on student performance. Having access to UBB decreases 8th grade standardized test scores in Mathematics and Italian language by a 0.114 and a 0.084 standard deviation from the mean, respectively. On the contrary, we do not find any significant effect on either of the two subjects for any specification in students in the 2nd and 5th grades, as reported in Tables C.4 and C.7, in Appendix C.[22]

Thus, this first set of results points to a clear heterogeneous impact of UBB on educational attainment based on student age. Younger students are not significantly affected by faster connections, while students in 8th grade are adversely affected by the UBB roll-out.

7.1. Heterogeneity by gender

Since males and females at the age of 13 might carry out various online activities that affect them differently, in Table 4 we explore heterogeneous effects by gender. If there are differences in internet use, we may expect that students who are more inclined to be engaged in distracting activities to be more adversely affected by faster broadband connections.

According to a 2018 survey report,[23] boys and girls in the age range 9–17 tend to behave differently online. Some of these differences are considerable, especially the one regarding online gaming: boys report using online gaming more than twice as much as girls report in the age range 13–17, and five times more than girls in the age range 9–12. Thus, since online gaming relies on high-speed connections, faster internet may result in a higher amount of distraction time for boys. Accordingly, we should expect a stronger adverse effect of high-speed broadband use on boys' performance. We test this hypothesis by running separate regressions in Mathematics and Italian language for boys and girls. The results are reported in Table 4.

Performance of both boys and girls in Mathematics (columns 2 and 4, respectively) is negatively affected by UBB, but boys seem to be slightly more affected, both in terms of magnitude (γ_M=−0.116; γ_F=−0.083) and statistical significance (1%; 5%). The gap is unambiguous if we compare student performance in Italian language: while girls are not affected (column 8), the average score for boys decreases by a .106 standard deviation from the mean (column 6). These estimates are in line with our hypothesis that boys may be more affected than girls, and are also in line with previous findings (Belo et al., 2014).

22 The first stage is strong in each grade, with an F-test in the range of 37–40, implying that weak instrument bias is not a concern. Consistently, the first-stage coefficient is highly significant and with the expected positive sign, as reported in Table C.3.

23 The report can be found (in Italian) here.

Table 5
Effect of UBB on student performance in 8th grade by parental education.

	One high educated		Both low educated		One high educated		Both low educated	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	std MAT	std MAT	std MAT	std MAT	std ITA	std ITA	std ITA	std ITA
UBB	0.002	−0.056	−0.008	−0.127***	0.003	−0.080*	−0.014***	−0.082***
	(0.008)	(0.046)	(0.006)	(0.042)	(0.008)	(0.046)	(0.005)	(0.028)
First Stage F-test		31.26		42.18		31.26		42.18
Observations	499,323	499,323	2,233,483	2,233,483	499,323	499,323	2,233,483	2,233,483

Notes: Specifications in columns (1), (3), (5), and (7) are estimated using OLS. Specifications in columns (2), (4), (6), and (8) replicate columns (1), (3), (5), and (7) using IV. All specifications include controls for gender, place of birth, and citizenship of the student, childcare centre and kindergarten attendance, place of birth of the mother and the father, and occupation of the mother and the father, and a year-province fixed effects. Columns (1) to (4) report results in Mathematics. Columns (5) to (8) report results in Italian language. Standard errors clustered at the labor local system level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

7.2. Heterogeneity by parental education

The INVALSI test scores are accompanied by questionnaires that collect information on the background of students. As also shown in our theoretical model in Section 3, the purpose for which the internet is used is crucial. Clearly, parents play an important role in determining how children behave on the internet. Our hypothesis is that parents with higher education are more aware of the risks and potentials to which their children are exposed online, and therefore impose stricter rules on the use of the internet. To test this hypothesis, we calculate separate average scores in Mathematics and Italian language for students whose at least one parents is high-educated and whose parents are both low-educated.[24] Results are reported in Table 5. For Mathematics, students with at least one high-educated parent are not negatively affected by the introduction of UBB, while students whose parents are both low-educated (column 6) are considerably negatively affected (γ=−0.127). For Italian language, evidence is more ambiguous and the negative impact of the UBB seems to be more homogeneously spread among students with different parental education. However, the most significant negative effect is for those with both parents low-educated (γ=−0.082). The negative impact is larger and more significant for Mathematics than Italian language, as for the main estimates (see Table 3). The results are in line with our hypothesis that parental education is an important factor in affecting children's online behavior. Hence, faster internet connections imply more distracting activities only for students from low-educated families.[25]

In Table 6, we investigate whether boys and girls are impacted differently by the UBB roll-out if they come from a family with one high-educated parent or low-educated parents. If we consider the performance in Mathematics (columns 1–4), it appears that having one high-educated parent is enough to prevent UBB from harming both male and female children, while both boys and girls of low-educated parents are negatively affected (boys slightly more than girls in terms of magnitude and significance). In Italian language, the only students significantly affected are males with low-educated parents (column 7).

Summing up, our heterogeneity analysis suggests that student performance in Mathematics is more affected than student performance in Italian language, boys bear the most significantly consequences of the introduction of the ultra-broadband because they are more likely to be engaged in distracting activities, and this is especially true if they come from low-educated families.

7.3. Heterogeneity of IT usage by school level

Our main result is that the UBB roll-out adversely affects student performance, particularly for male students coming from low-educated families. Such a negative impact can be explained by the increased use of the internet for distracting activities such music and video streaming, online gaming, and online social networking, all of which leverage high-speed connections. Such activities are likely conducted at the home address of the student. We know from the theoretical framework presented in Section 3 that, in addition to the distraction effect, the internet can be used both at school and at home for learning purposes. However, it is unclear the role played by schools in the relationship between high-speed connections and student performance. In principle, schools might exploit advanced IT to make more effective use of the internet for learning purposes, which may mitigate the negative effect resulting from an increase in distraction time.

We test this hypothesis in Table 7, where we run the IV regressions separately for students in provinces where schools have a low, mid and high level of digitization. In particular, using the MIUR survey, we split the data into thirds based on the percentage of teachers who use IT on a daily basis.[26] The negative estimates are significant for both Italian language (γ=−0.131) and Mathematics (γ=−0.145) in schools located in provinces where the internet is not used for learning purposes (columns 1 and 4). In Table 8,

[24] For a detailed definition and description of these categories see Appendix B.

[25] We do not find any meaningful impact based on parents' occupation. This is not surprising given the fact that high-skill occupations do not always correspond to higher education and we do not expect different patterns according to family's wealth. Results are not included in the manuscript but are available upon request.

[26] For a detailed definition and description of these categories see Appendix B.

Table 6
Effect of UBB on student performance in 8th grade by gender and parental education.

	One high educated		Both low educated		One high educated		Both low educated	
	Male	Female	Male	Female	Male	Female	Male	Female
	IV	IV	IV	IV	IV	IV	IV	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	std MAT	std MAT	std MAT	std MAT	std ITA	std ITA	std ITA	std ITA
UBB	−0.026	−0.025	−0.140***	−0.096**	−0.082	−0.024	−0.112***	−0.034
	(0.058)	(0.053)	(0.046)	(0.042)	(0.065)	(0.053)	(0.037)	(0.029)
First Stage *F*-test	28.36	28.34	34.72	34.24	28.36	28.34	34.72	34.24
Observations	213,548	206,252	972,511	948,297	213,548	206,252	972,511	948,297

Notes: All specifications report IV results and include controls for place of birth, and citizenship of the student, childcare centre and kindergarten attendance, place of birth of the mother and the father, and occupation of the mother and the father, and a year-province fixed effects. Columns (1) to (4) report results in Mathematics. Columns (5) to (8) report results in Italian language. We dropped students with both parents high-educated because we do not find significant effects on them. Standard errors clustered at the labor local system level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 7
Effect of UBB on student performance in 8th grade by daily usage of IT in class.

	Low	Mid	High	Low	Mid	High
	IV	IV	IV	IV	IV	IV
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	std MAT	std MAT	std MAT	std ITA	std ITA	std ITA
UBB	−0.145***	−0.076	−0.113*	−0.131***	−0.053	−0.047
	(0.051)	(0.093)	(0.060)	(0.046)	(0.054)	(0.049)
First Stage *F*-test	45.78	6.057	26.90	45.78	6.057	26.90
Observations	696,822	1,299,978	693,490	696,822	1,299,978	693,490

Notes: All specifications report IV results and include controls for gender, place of birth, and citizenship of the student, childcare centre and kindergarten attendance, place of birth of the mother and the father, education of the mother and the father, and occupation of the mother and the father, and a year-province fixed effects. Columns (1) to (3) report results in Mathematics. Columns (4) to (6) report results in Italian language. Standard errors clustered at the labor local system level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table 8
Effect of UBB on student performance in 8th grade by parental education and daily usage of IT in class.

	One high educated			Both low educated			One high educated			Both low educated		
	Low	Mid	High	Low	Mid	High	Low	Mid	High	Low	Mid	High
	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Variables	std MAT	std MAT	std MAT	std MAT	std MAT	std MAT	std ITA	std ITA	std ITA	std ITA	std ITA	std ITA
UBB	−0.066	−0.047	0.016	−0.163***	−0.086	−0.141**	−0.097	−0.125	−0.028	−0.131***	−0.046	−0.054
	(0.068)	(0.101)	(0.083)	(0.057)	(0.106)	(0.063)	(0.064)	(0.113)	(0.085)	(0.048)	(0.056)	(0.051)
First Stage *F*-test	47.74	3.671	17.12	44.40	6.596	30.31	47.74	3.671	17.12	44.40	6.596	30.31
Observations	125,435	238,145	126,970	571,364	1,061,776	566,498	125,435	238,145	126,970	571,364	1,061,776	566,498

Notes: All specifications report IV results and include controls for gender, place of birth, and citizenship of the student, childcare centre and kindergarten attendance, place of birth of the mother and the father, and occupation of the mother and the father, and a year-province fixed effects. Columns (1) to (6) report results in Mathematics. Columns (7) to (12) report results in Italian language. Standard errors clustered at the labor local system level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

we further explore the combined effect of parental education and the daily use of IT at school. The estimates reported in the table (columns 4 and 10) are in line with the picture that has emerged from our analysis: students from low-educated families and in provinces where schools do not use IT for learning purposes are those most adversely affected by the UBB roll-out. For Mathematics, the role played by parental education seems to be more prominent: indeed, students with both parents low-educated, even if enrolled in schools that exploit advanced IT for learning purposed, are negatively affected by the UBB. This suggests that investments in advanced broadband technologies should be complemented by more digital learning at school in order to fight the detrimental effect caused by the increased distracting activities associated with faster internet connections.

8. Conclusion

While several studies provide evidence of a positive impact of ICT on productivity and economic growth, only a few studies focus on how high-speed internet affects student performance. In this context, a clear trade-off emerges. On the one hand, faster broadband connections can be used for learning purposes, thereby increasing the quality of teaching and in turn student performance. On the other hand, faster internet connections increase the value to students of online alternative activities, such as video streaming and gaming, thus resulting in a potential negative effect on educational attainment.

In this paper, we explored the impact of the ultra-broadband roll-out on student performance of Italian students in the 2nd, 5th, and 8th grades, measured using results of a standardized test in Mathematics and Italian language conducted at the national level. In addition to school fixed effects, we implemented an IV strategy that exploited the diffusion of the essential input necessary to provide fiber connections.

Both OLS and IV estimates suggested that having access to high-speed connections harms student performance, but only in the 8th grade. Students in the 2nd and 5th grades are not affected by the UBB roll-out, most likely because they are too young to engage in distracting online activities. Heterogeneous effects by age are compatible with our theoretical framework, in which we assume that the potential negative effect is due to an increase in the distraction time. Students in 8th grade are considerably more exposed to the speed of the connection than younger students. Such a negative impact is larger for male students, particularly for those coming from low-educated families.

We further investigated the role of school digitization. Our findings suggest that students attending schools with a low level of digitization are those who bear the most negative effects of the UBB roll-out. This evidence is in line with our theoretical framework, according to which the ambiguous effect of the internet arise from the purpose of its usage. The negative effect following from the greater value of online leisure can be compensated for by schools investing more in IT-related educational activities. Also, the development of educational application software plays a key role on the potential benefits student may obtain from faster connections. Therefore, both investments in IT within the schools and development of appealing educational applications are essential to mitigate the unintended effects of high-speed connections on student performance.

CRediT authorship contribution statement

Carlo Cambini: Writing – original draft, Formal analysis, Conceptualization. **Lorien Sabatino:** Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Sarah Zaccagni:** Writing – original draft, Formal analysis, Data curation, Conceptualization.

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Appendix A. Broadband data

See Figs. A.1–A.4.

Appendix B. Description of variables

Table B.2 describes the original scales of the variables included in the main regressions. In Table 1 in Section 5, we describe the population using a simplified scale for non-dichotomous variables. We use the variables with their original scale as controls in the main regressions, while we use the simplified versions when we look at the heterogeneous effects.

In Table 1 in Section 5, parents with a university degree or higher qualification are considered as high-educated, while parents with a high-school diploma or lower qualification are considered as low-educated. Parents whose job belongs to the categories 3, 5 and 7 in the profession scale in Table B.2 are considered subjects with high-skill occupations, while parents whose job belongs to the categories 4,6 and 8 are considered subjects with low-skill occupations.

In the analysis of the heterogeneous effects, we classify students according to their parent's education in the following way: students with both parents low-educated, students with both parents high-educated, students with one parent low-educated and one high-educated. In the analysis of the heterogeneous effects, we classify students according to the level of digitization of the school they attend in the following way: students attending a school with a low, medium of high level of digitization corresponding to the thirds of the distribution, as reported in the bottom part of Table B.3.

Appendix C. Additional results

See Tables C.1–C.9.

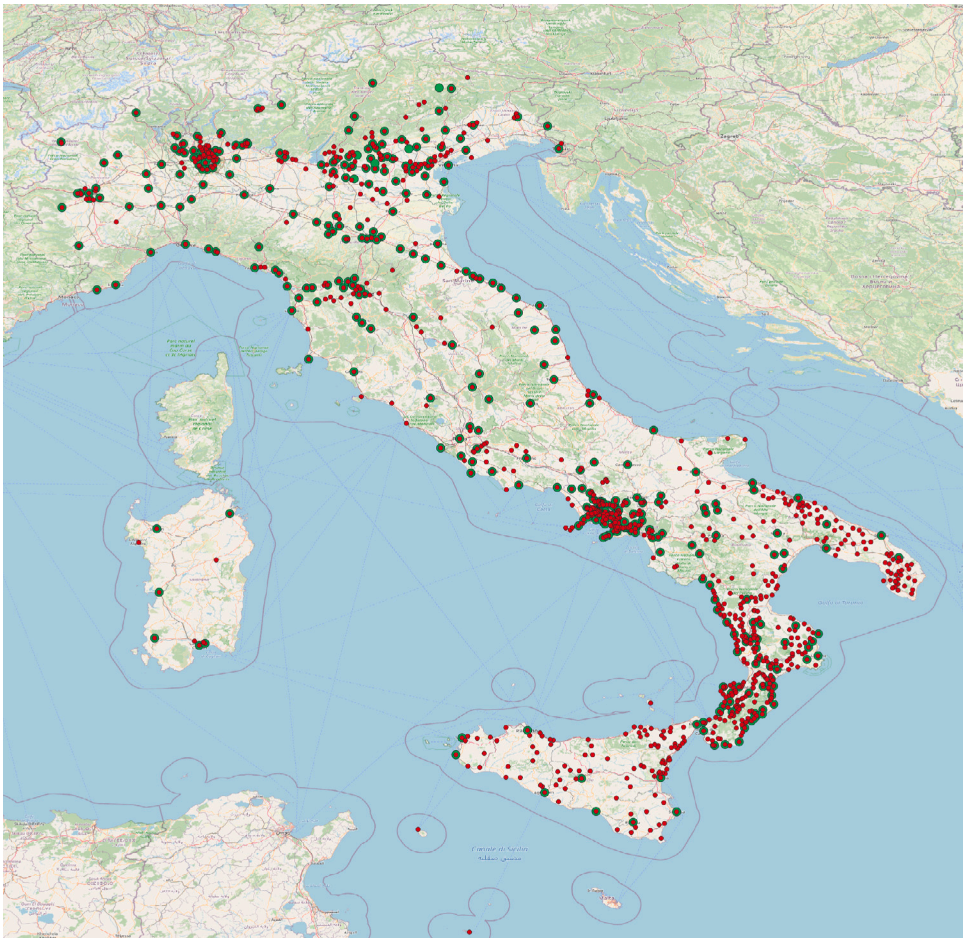

Fig. A.1. UBB and OLT diffusion in Italy in 2015.
This figure shows the municipalities with access to UBB (red dots), as well as those with at least one central office equipped with an OLT (green dots). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

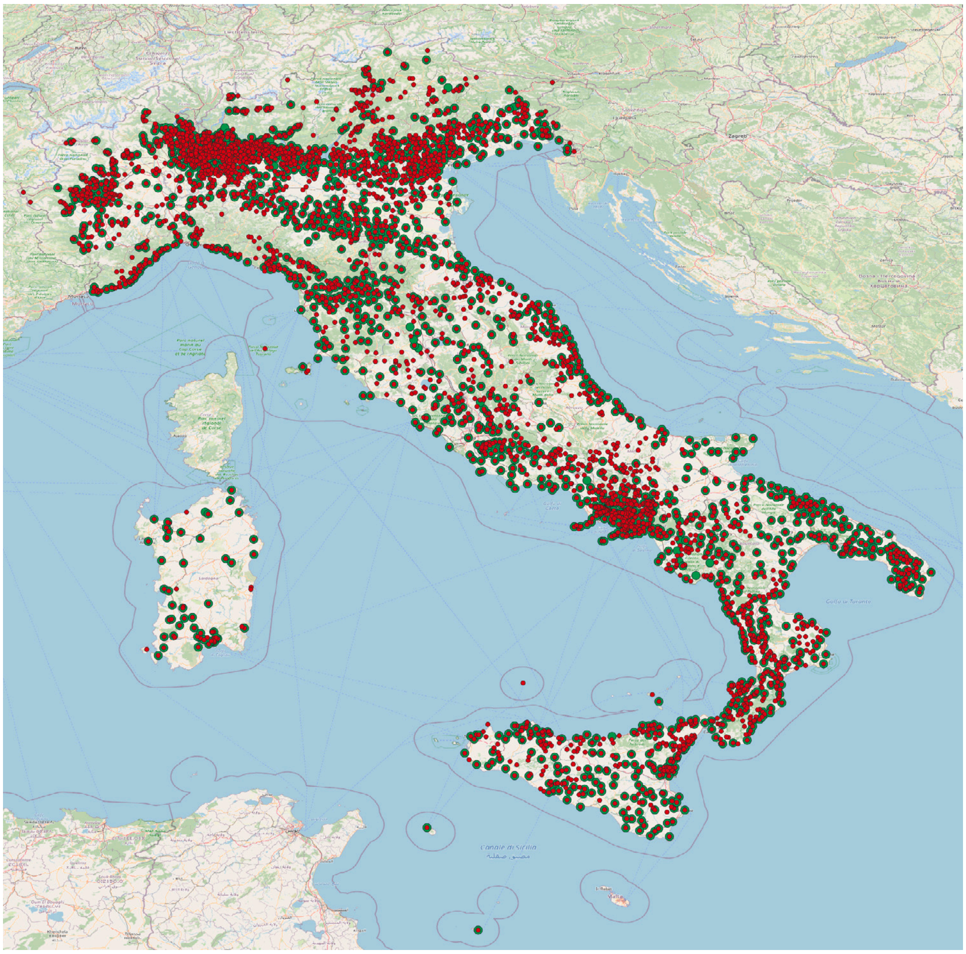

Fig. A.2. UBB and OLT diffusion in Italy in 2017.
This figure shows the municipalities with access to UBB (red dots), as well as those with at least one central office equipped with an OLT (green dots). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

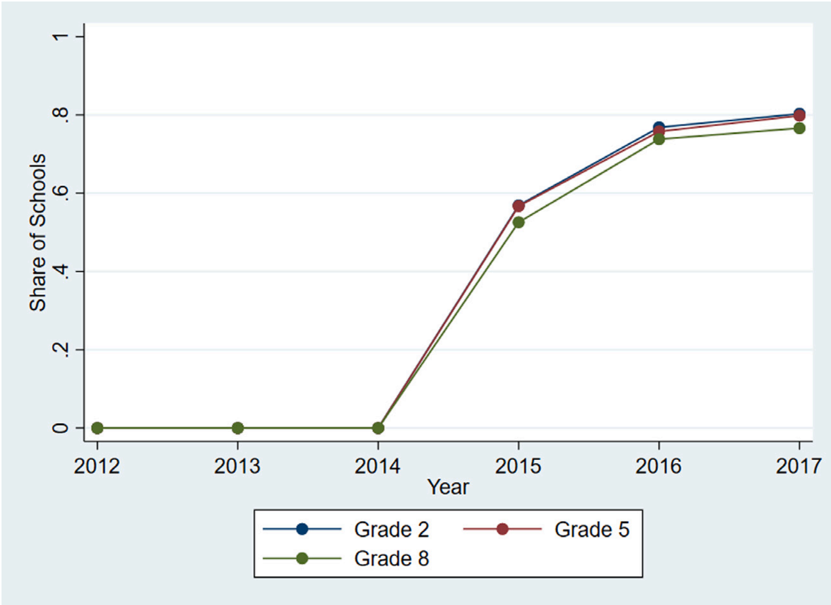

Fig. A.3. Ultra-broadband diffusion rate by school grade from 2012 to 2017.
This figure shows the percentage of schools with access to UBB connections over time, for each grade.

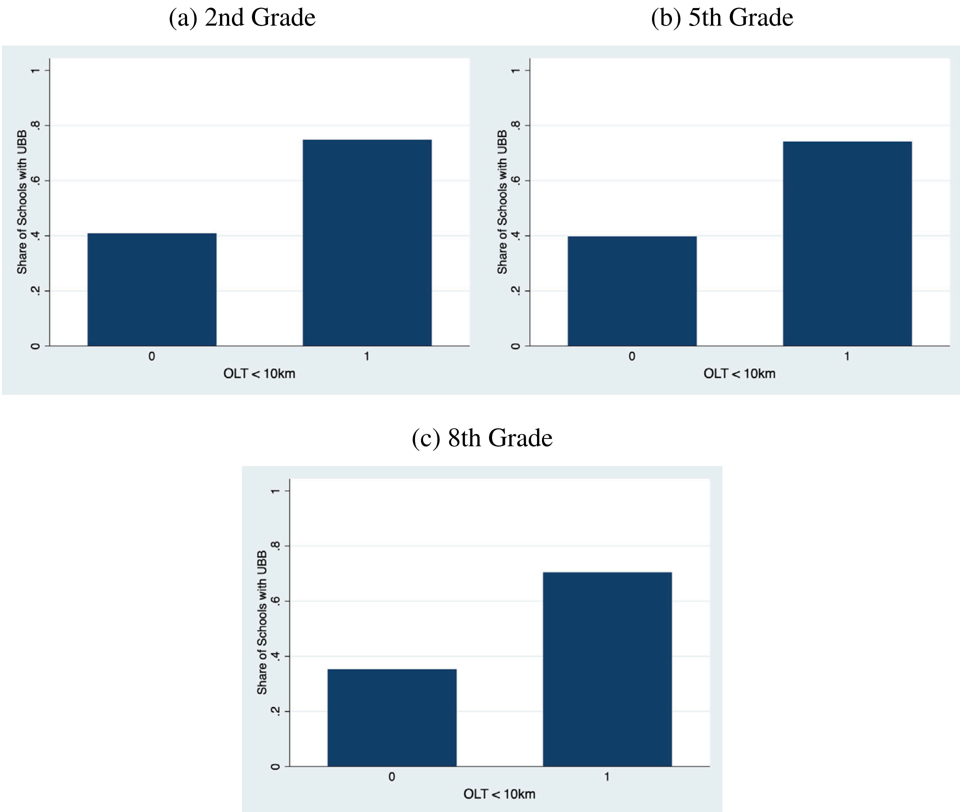

Fig. A.4. Relation between ultra-broadband and optical line terminal.
This figure shows the percentage of schools with access to UBB connections, for schools located within a range of 10 km from the closest OLT (1), and farther than 10 km (0). Data from 2015 onwards.

Table B.1
Description of variables used in this Study.

Variable	Description
Gender	Binary variable = 1 if respondent is male; 0 otherwise.
Place of birth	(1) Italy (or Republic of San Marino)
	(2) European Union
	(3) European Countries - Not EU Members
	(4) Other
Childcare centre attendance	Binary variable = 1 if yes; 0 otherwise.
Kindergarten attendance	Binary variable = 1 if yes; 0 otherwise.
Father's place of birth	(1) Italy (or Republic of San Marino)
	(2) European Union
	(3) European countries - Not EU members
	(4) Other
Father's education	(1) Elementary school
	(2) Middle school
	(3) Three-year professional qualification
	(4) High school diploma
	(5) Other qualification higher than high-school
	(6) Degree or higher qualification (doctoral studies)
Father's profession	(1) Unemployed
	(2) Stay-at-home father
	(3) Manager, university professor, etc.
	(4) Entrepreneur/agricultural owner
	(5) Employee professional
	(6) Self-employed worker
	(7) Teacher, clerk, military, etc.
	(8) Worker, service agent, etc.
	(9) Retired
Mother's place of birth	(1) Italy (or Republic of San Marino)
	(2) European Union
	(3) European Countries - Not EU Members
	(4) Other
Mother's education	(1) Elementary school
	(2) Middle school
	(3) Three-year professional qualification
	(4) High school diploma
	(5) Other qualification higher than high-school
	(6) Degree or higher qualification (doctoral studies)
Mother's profession	(1) Unemployed
	(2) Stay-at-home mother
	(3) Manager, university professor, etc.
	(4) Entrepreneur/agricultural owner
	(5) Employee professional
	(6) Self-employed worker
	(7) Teacher, clerk, military, etc.
	(8) Worker, service agent, etc.
	(9) Retired
Student's citizenship	(1) Italian
	(2) First-generation immigrant
	(3) Second-generation immigrant

Table B.2
Description of variables used in this study.

Variable	Description
Gender	Binary variable = 1 if respondent is male; 0 otherwise.
Place of Birth	(1) Italy (or Republic of San Marino) (2) European Union (3) European Countries - Not EU Members (4) Other
Childcare Centre Attendance	Binary variable = 1 if yes; 0 otherwise.
Kindergarten Attendance	Binary variable = 1 if yes; 0 otherwise.
Father's Place of Birth	(1) Italy (or Republic of San Marino) (2) European Union (3) European Countries - Not EU Members (4) Other
Father's education	(1) Elementary school (2) Middle school (3) Three-year professional qualification (4) High school diploma (5) Other qualification higher than high-school (6) Degree or higher qualification (doctoral studies)
Father's profession	(1) Unemployed (2) Stay-at-home father (3) Manager, university professor, etc. (4) Entrepreneur / agricultural owner (5) Employee professional (6) Self-employed worker (7) Teacher, clerk, military, etc. (8) Worker, service agent, etc. (9) Retired
Mother's place of birth	(1) Italy (or Republic of San Marino) (2) European Union (3) European Countries - Not EU Members (4) Other
Mother's education	(1) Elementary school (2) Middle school (3) Three-year professional qualification (4) High school diploma (5) Other qualification higher than high-school (6) Degree or higher qualification (doctoral studies)
Mother's profession	(1) Unemployed (2) Stay-at-home mother (3) Manager, university professor, etc. (4) Entrepreneur / agricultural owner (5) Employee professional (6) Self-employed worker (7) Teacher, clerk, military, etc. (8) Worker, service agent, etc. (9) Retired
Student's citizenship	(1) Italian (2) First-generation immigrant (3) Second-generation immigrant

Table B.3
Summary Statistics for the MIUR Data on the diffusion of digital technologies in Italian schools.

Variable	Mean	Std. Dev.	Min	Max	Obs
N connected schools	80.701	59.771	13	316	107
connected schools	0.970	0.039	0.844	1	107
N wired classrooms	511.271	504.620	14	3165	107
wired classrooms	0.765	0.127	0.378	0.990	107
N connected classrooms	538.421	507.223	9	3107	107
connected classrooms	0.801	0.127	0.232	1	107
IT daily usage	0.470	0.116	0.223	0.756	107
IT weekly usage	0.277	0.069	0.090	0.503	107
IT monthly usage	0.138	0.048	0.035	0.270	107
IT yearly usage	0.067	0.033	0.011	0.200	107
no IT usage	0.048	0.027	0.040	0.124	107
Daily usage of IT - thirds					
Low	0.344	0.059	0.223	0.42	36
Medium	0.472	0.031	0.421	0.52	36
High	0.599	0.061	0.521	0.756	35

Notes: Presented are the summary statistics for the province-level MIUR data survey on the intensity of IT usage in Italian schools. The last three rows shows the statistics for the tertiles of the distribution of IT daily usage, which are used in Tables 7 and 8 to identify schools with low, medium, and high daily IT use in class.

Table C.1
Placebo test: 2th grade.

	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)
Variables	std MAT	std MAT	std ITA	std ITA
z	0.025*	−0.000	0.023*	0.006
	(0.015)	(0.012)	(0.013)	(0.011)
UBB by 2017	No	Yes	No	Yes
Observations	604,979	2,127,924	604,979	2,127,924

Notes: Presented are OLS estimates from reduced form regressions of standardized test scores in mathematics and Italian language on our proposed instrument $z_{m,t}$. Columns 1 and 2 estimate the model on a sample of schools located in municipalities not receiving UBB during the time frame of our analysis. On the contrary, columns 2 and 4 focus on schools in municipalities actually receiving UBB. Standard errors clustered at the labor local system level. *** p<0.01, ** p<0.05, * p<0.1.

Table C.2
Placebo test: 5th grade.

	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)
Variables	std MAT	std MAT	std ITA	std ITA
z	0.006	−0.013	0.003	−0.001
	(0.014)	(0.012)	(0.011)	(0.009)
UBB by 2017	No	Yes	No	Yes
Observations	604,979	2,127,924	604,979	2,127,924

Notes: Presented are OLS estimates from reduced form regressions of standardized test scores in mathematics and Italian language on our proposed instrument $z_{m,t}$. Columns 1 and 2 estimate the model on a sample of schools located in municipalities not receiving UBB during the time frame of our analysis. On the contrary, columns 2 and 4 focus on schools in municipalities actually receiving UBB. Standard errors clustered at the labor local system level. *** p<0.01, ** p<0.05, * p<0.1.

Table C.3
First-stage regressions for each grade.

	(1)	(2)	(3)
Variables	2nd Grade	5th Grade	8th Grade
z	0.203***	0.200***	0.202***
	(0.033)	(0.032)	(0.032)
R-squared	0.770	0.767	0.779
Observations	2,442,149	2,400,775	2,732,903

Notes: First-stage estimates for 2nd (column 1), 5th (column 2), and 8th grade (column 3). The dependent variable is UBB, which is a dummy identifying schools located in municipalities with access to ultra-broadband connections. The excluded instrument z, is an indicator that takes the value one if the closest OLT is within 10 kilometers from 2015 onward. Standard errors clustered at the labor local system level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table C.4
Effect of UBB on student performance in 2nd grade.

	OLS	OLS	IV	OLS	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	std MAT	std MAT	std MAT	std ITA	std ITA	std ITA
UBB	−0.004	0.003	0.022	0.009	0.014*	0.043
	(0.009)	(0.008)	(0.046)	(0.007)	(0.007)	(0.043)
First Stage *F*-test			36.83			36.83
Observations	2,442,149	2,442,149	2,442,149	2,442,149	2,442,149	2,442,149

Notes: Specifications in columns (1), (2), (4) and (5) are estimated using OLS. The baseline OLS in columns (1) and (4) do not include any controls. Specification in columns (2) and (5) include controls for gender, place of birth, and citizenship of the student, childcare centre and kindergarten attendance, place of birth of the mother and the father, education of the mother and the father, and occupation of the mother and the father, and a year-province fixed effects. Specifications in columns (3) and (6) replicate columns (2) and (5) using IV. Standard errors clustered at the labor local system level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table C.5
Effect of UBB on student performance in 2nd grade by gender and parental education.

	One high educated		Both low educated		One high educated		Both low educated	
	Male	Female	Male	Female		Male	Female	
	IV	IV	IV	IV	IV	IV	IV	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	std MAT	std MAT	std MAT	std MAT	std ITA	std ITA	std ITA	std ITA
UBB	0.021	0.057	0.049	0.047	0.093	0.068	0.056	0.060
	(0.065)	(0.065)	(0.057)	(0.062)	(0.066)	(0.069)	(0.056)	(0.058)
First Stage *F*-test	26.82	29.78	30.53	31.27	26.82	29.78	30.53	31.27
Observations	251,937	242,845	817,260	791,062	251,937	242,845	817,260	791,062

Notes: All specification report IV results and include controls for place of birth, and citizenship of the student, childcare centre and kindergarten attendance, place of birth of the mother and the father, and occupation of the mother and the father, and a year-province fixed effects. Columns (1) to (4) report results in Mathematics. Columns (5) to (8) report results in Italian language. We dropped students with both parents high-educated because we do not find significant effects on them. Standard errors clustered at the labor local system level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table C.6
Effect of UBB on student performance in 2nd grade by daily usage of IT in class.

	Low	Mid	High	Low	Mid	High
	IV	IV	IV	IV	IV	IV
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	std MAT	std MAT	std MAT	std ITA	std ITA	std ITA
UBB	−0.105	0.186*	0.061	−0.055	0.143	0.123
	(0.089)	(0.109)	(0.089)	(0.071)	(0.104)	(0.091)
First Stage *F*-test	46.49	6.019	22.51	46.49	6.019	22.51
Observations	622,263	1,158,417	623,125	622,263	1,158,417	623,125

Notes: All specification report IV results and include controls for gender, place of birth, and citizenship of the student, childcare centre and kindergarten attendance, place of birth of the mother and the father, education of the mother and the father, and occupation of the mother and the father, and a year-province fixed effects. Columns (1) to (3) report results in Mathematics. Columns (4) to (6) report results in Italian language. Standard errors clustered at the labor local system level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table C.7
Effect of UBB on student performance in 5th grade.

	OLS	OLS	IV	OLS	OLS	IV
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	std MAT	std MAT	std MAT	std ITA	std ITA	std ITA
UBB	0.010	0.017**	−0.026	0.009	0.016**	0.015
	(0.009)	(0.009)	(0.055)	(0.007)	(0.007)	(0.036)
First Stage *F*-test			39.91			39.91
Observations	2,400,775	2,400,775	2,400,775	2,400,775	2,400,775	2,400,775

Notes: Specifications in columns (1), (2)y4) and (5) are estimated using OLS. The baseline OLS in columns (1) and (4) do not include any controls. Specification in columns (2) and (5) include controls for gender, place of birth, and citizenship of the student, childcare centre and kindergarten attendance, place of birth of the mother and the father, education of the mother and the father, and occupation of the mother and the father, and a year-province fixed effects. Specifications in columns (3) and (6) replicate columns (2) and (5) using IV. Standard errors clustered at the labor local system level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table C.8
Effect of UBB on student performance in 5th grade by gender and parental education.

	One high educated		Both low educated		One high educated		Both low educated	
	Male	Female	Male	Female		Male	Female	
	IV	IV	IV	IV	IV	IV	IV	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Variables	std MAT	std MAT	std MAT	std MAT	std ITA	std ITA	std ITA	std ITA
UBB	−0.036	−0.088	0.001	−0.023	−0.027	0.015	0.040	0.028
	(0.078)	(0.087)	(0.061)	(0.064)	(0.061)	(0.062)	(0.045)	(0.048)
First Stage *F*-test	28.63	30.61	33.58	32.74	28.63	30.61	33.58	32.74
Observations	222,870	217,225	815,971	802,168	222,870	217,225	815,971	802,168

Notes: All specification report IV results and include controls for place of birth, and citizenship of the student, childcare centre and kindergarten attendance, place of birth of the mother and the father, and occupation of the mother and the father, and a year-province fixed effects. Columns (1) to (4) report results in Mathematics. Columns (5) to (8) report results in Italian language. We dropped students with both parents high-educated because we do not find significant effects on them. Standard errors clustered at the labor local system level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Table C.9
Effect of UBB on student performance in 5th grade by daily usage of IT in class.

	Low	Mid	High	Low	Mid	High
	IV	IV	IV	IV	IV	IV
	(1)	(2)	(3)	(4)	(5)	(6)
Variables	std MAT	std MAT	std MAT	std ITA	std ITA	std ITA
UBB	−0.106	−0.072	0.091	−0.018	−0.043	0.068
	(0.082)	(0.134)	(0.098)	(0.062)	(0.071)	(0.069)
First Stage *F*-test	45.59	6568	25.55	45.59	6568	25.55
Observations	615,878	1,135,154	610,929	615,878	1,135,154	610,929

Notes: All specification report IV results and include controls for gender, place of birth, and citizenship of the student, childcare centre and kindergarten attendance, place of birth of the mother and the father, education of the mother and the father, and occupation of the mother and the father, and a year-province fixed effects. Columns (1) to (3) report results in Mathematics. Columns (4) to (6) report results in Italian language. Standard errors clustered at the labor local system level. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

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