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Abstract

In this paper, we study the impact of ultra-fast broadband (UBB) access on student performance. These networks are based on optical fiber, allowing significantly higher speed compared to traditional copper-line connections. Our empirical analysis leverages on a unique dataset that combines information on broadband diffusion with data on student performance in 2nd, 5th, and 8th grade 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 broadband 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 ultra-fast connections significantly decrease students' performance in Mathematics and Italian language in 8th grade. Instead, we do not find any significant effect in 2nd and 5th grade. Male students from low-educated parental backgrounds are those more adversely affected, especially if they attend schools with a low IT usage.

JEL Classification: C23, C26, I21, I28, J24

Keywords: ultra-fast broadband, internet, student performance, instrumental variables

1 Introduction

Investments in high-speed broadband have received considerable attention from policy-makers and researchers. Governments are committing to increase available internet connection speed. In March 2021, the European Commission launched the so-called ”2030 Digital Compass” that updated the previous 2010 plan named ”Digital Agenda for Europe”. In a nutshell, this plan aims at stimulating a substantial digital transformation in the EU.[1] These policies are motivated by arguments according to which broadband upgrades play an important role in fostering 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. Children are definitely among those most affected by broadband technologies. The cohort of people born in the late '90s -defined as Generation Z - has been the first to have broadband connections readily available at a young age. As a consequence, the use of internet is an integrated part of their daily life.

Despite the ubiquitous usage of internet among children, very little is known about the effect of advanced broadband technologies on their academic performance. In principle, improvements in ICT can affect learning outcomes in opposite ways. On the one hand, it might increase students' productivity, allowing them to access more information and online courses, to adopt more innovative learning approaches, and to foster the sharing of ideas. On the other hand, advanced broadband technologies might increase the value of leisure time, as students may have a wider variety of entertainment activities, including social media, online gaming, and video streaming.

[1]The new EU targets at 2030 are: i) all European 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 European citizens and businesses.

How advanced broadband technologies affect students' performance remains an empirical question. The goal of this paper is to shed some light on this issue using a detailed data set on the last generation of ultra-fast broadband in Italy, matched with the national standardized test scores in Italian language and Mathematics in 2nd, 5th, and 8th grade from the National Institute for the Evaluation of the Italian Education System (INVALSI) between 2012 and 2017. Our empirical strategy exploits the staggered roll-out of UBB, starting from 2015. Our baseline model performs a (two-way) *difference-in-differences* (DiD) estimation with variation in treatment timing, where treated units are those schools located in municipalities receiving ultra-fast connections. The model identifies the impact of UBB on student performance under the identifying assumption of UBB roll-out being *as-good-as-random* conditional on fixed effects, potential controls, and common time trends. We test the validity of such an assumption through an event study design that includes leads and lags from initial UBB access. Because we do not observe flat trends before treatment, we conclude that endogenous selection is in place, invalidating the DiD design. Therefore, we rely on an instrumental variable (IV) approach that exploits local variation in the main UBB essential input, namely Optical Line Terminal (OLT), a piece of equipment that is essential for digital data transmission into the network.

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 2nd and 5th grade. 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 exacerbate, rather than reduce, the educational gap between children in educated versus uneducated families as unattended consequence. We do not find any significant impact on parents' job status. In addition, we complement our data set with information on the digitization of Italian schools at the province level[2], collected by the Italian Ministry of Education (MIUR) in 2016. This helps us to disentangle the use of internet for learning purposes from the distraction generated by the access to faster internet. 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 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 faster 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. We describe the source of data we use and how we build our final data set in Section 4. The empirical strategy and the IV approach are outlined in Section 5. Section 6 includes some descriptive statistics and establishes the main results on the impact of broadband on students' performance. Finally, Section 7 concludes.

2 Literature Review

Our paper contributes to the literature on the impact of ICT on educational attainment. It specifically relates to studies that use microdata on students' standardized test scores. There are few papers focusing on the impact of the use of computers in schools (Angrist and Lavy [2002]; Falck et al. [2018]) or both at schools and home (Fuchs and Woessmann [2004]; Fairlie and Robinson [2013]). The evidence suggests mixed results at best (Bulman and Fairlie [2016]). Expanding the supply of computers in schools alone may not lead to actual benefits from the use of new technology. Home computers as well seem

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

to be ineffective in raising student performance due to an increased distraction time over the internet: Computer ownership alone is thus unlikely to have an impact on short-term outcomes.

Broadband internet, as well as other ICT, is perceived as a potential tool to improve quality in education and student's performance. A high-speed internet connection may provide real-time access to numerous information, foster new learning methods, increase students' interest, and enable the adoption of new technologies in education such as virtual classrooms or e-learning. However, high-speed internet access may also have negative effects: Teachers may find it hard to adapt traditional learning with ICT and students may use broadband to perform distracting activities, such as playing video games, online chatting, and video streaming. Some studies (Goolsbee and Guryan [2006]; Hazlett and Wright [2017]) focus on the effect of U.S. government subsidies on internet investment in schools, and find little evidence on the interplay between internet connectivity in schools and student achievement.

Other 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 et al. [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. At the opposite, using data from New Zealand 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. Other studies analyze the link between home broadband technology and student test scores. While Malamud et al. [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 et al. [2021] for the UK find that broadband technology increases students' performance. In particular, Sanchis-Guarner et al. [2021] show that increasing broadband speed by 1 Mbit/s increases 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 over many dimensions. First, we study the impact of the last generation ultra-fast broadband technology, which is based on optical fiber rather than copper line, enabling significantly higher speed (up to 1 Gbit/s per second) compared to old DSL connections (up to 7 Mbit/s) and thus allowing for more on line entertainment activities and potentially more distractions.[3] In contrast to Grimes and Townsend [2018], our event study evidence challenges the validity DiD research design, leading to an identification strategy similar to the one in Belo et al. [2014]. Second, we match our broadband data with information on the universe of Italian students in 2nd, 5th, and 8th grade performing 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 student characteristics. Finally, to isolate the potential mediated effect of internet at school, we also account for specific information on the intensity of use of internet at school through ad hoc survey datase 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 only at school.

Let T denotes the total time a student has in a day. She can use this time for traditional studying (S), for online studying (I) or for free time (F). Hence, $T = S+I+F$. Free time

[3]For more on the technological aspects of UBB, see Cambini and Sabatino [2021].

can be interpreted as the time spent in no-learning activities, hence as time withdrawn from traditional studying, hence $F = \gamma S$, where $0 < \gamma < 1$, implying that not all study time for studying can be reduced. Indeed, students are obliged to go to school in the morning and therefore at least part of the time are not withdrawn from the standard study. We thus have $T = (1+\gamma)S + I$. The total time for the student T is assumed to be fixed. Let P represent student performance at school. It depends on the effectiveness of standard study as well as the effectiveness of time spent online for studying purposes in general. We can thus represent student's performance as a production function $P = f(I, S)$, with $f_I \geq 0$ and $f_S \geq 0$, i.e. more online or traditional study improve student's performance. The effect of Internet on student performance is given by:

$$\frac{dP}{dI} = f_I + f_S S_I = f_I - \frac{f_S}{1+\gamma} \quad (1)$$

The use of internet improves overall student performance but also limits the time spent on traditional study. Note that the productivity of student traditional study is corrected by a $\frac{1}{1+\gamma}$ factor: This correction implies that the more free time reduces the time for studying, the lower is the productivity of traditional studying. All in all, the effect of internet remains ambiguous and depends on the trade-off between the productivity of internet for studying purposes and the productivity of traditional studying corrected by the time spent in no-learning activities.

Internet can be used not only at school, but also at home. Moreover, it may also distract the student and negatively impact her performance. To account for these effects, we rewrite time spent online as $I = L^s + L^h + D$, where L^s denotes the amount of time spent using 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 distractive activities both at school and at home. It results $0 \leq L_I^s \leq 1$, $0 \leq L_I^h \leq 1$, and $0 \leq D_I \leq 1$, which implies more internet improves learning both at school and at home but also raises student's distraction with a negative effect on her performance.

Consider student performance as a function of the overall time spent online both at school and home, $L = L^s + L^h$, and the time spent in traditional studying, i.e. $P = g(L, S)$. Given that $T = (1 + \gamma)S + I$, the overall effect of internet on student performance is provided by the following condition:

$$\frac{dP}{dI} = g_L(L_I^s + L_I^h) - \frac{g_S}{1 + \gamma} \tag{2}$$

The condition implies that student performance depends on the trade-off between the productivity of online learning weighted by the amount of time spent online at school (L_I^s) and at home (L_I^h), in addition to the productivity of traditional studying corrected by the time devoted to no-learning activities.[4]

We can generalize the model to account for student heterogeneity. Consider the presence of $i = 1, .., n$ 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.[5]

The overall impact of internet is thus given by:

$$\frac{dP_i}{dI_i} = \left[g_{iL}(L_{iI}^s + L_{iI}^h) - \frac{g_{iS}}{1 + \gamma_i}\right]\phi_i \tag{3}$$

[4]Note that student performance is thus higher if she can use internet both at school and home, while it is lower if she can use internet either at home or at school.

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

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

4 Data

Our empirical strategy makes use of a unique dataset collecting 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. Our final dataset covers the period 2012-2017.

Our broadband data comes from Telecom Italia Mobile (TIM), the Italian telecommunication incumbent. It collects data on broadband deployment in Italy, from which we get information on UBB diffusion. For each municipality, we observe the % of households with access to ultra-fast connections. We have also detailed information on TIM upstream infrastructure. In particular, we observe the diffusion of the primary input for UBB, namely Optical Line Terminal (OLT).[6] 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 for network deployment, is then used as instrument for the UBB diffusion.

Besides the dataset on UBB diffusion, we use the information on students' performance collected in a rich student-level dataset collecting Italian language and Mathematics scores for students enrolled in 2nd, 5th, and 8th grade 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), lower secondary school covering from 6th to 8th grade (scuola media), and high school (scuola superiore), which runs for 3-5 years.

[6] OLTs are specific devices that need to be installed in those local exchanges that act as telecommunication operator endpoint in a *passive optical network*. OLTs convert optical signals that are then rerouted through the last mile to final consumers.

Schools are organized into single- or multi-unit institutions. Italian schools have long used matriculation exams 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 in a national administration lasting two days in the Spring. Tests are proctored by local administrators and teachers. The pupils also fill a questionnaire for collecting variables which are proxies of the social, economic and cultural conditions of their families (e.g. parental nationality, education and work status), and student's characteristics (e.g. gender, age, birthplace, day nursery 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 zero and 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 province-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.[7] 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.2 provides summary statistics for these data.

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

The merging process between broadband and standardized test score data has been 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 such distance is lower than 10 kilometers. Even doing this, we neither lost a significant amount of information nor compromised the adoption of the IV approach.[8] 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 of 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. Given the fact that more than 70% of Italian students go to school in the same municipality where they live, this concern does not harm 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 to go to school or university[9].

The final panel of data contains 8.254.783 student-level observations over the period 2012-2017. As shown by Figure A.1 in Appendix A, the staggered roll-out of UBB implies an increasing pattern in the percentage of schools covered by ultra-fast connections. Table 1

[8]The within-municipality variation of UBB is highly discontinuous, as shown in Cambini and Sabatino [2021]. This happens because, given the presence of large economies of scale in infrastructure deployment, the telecommunication operator tends to cover immediately most of the households once reaching a municipality.

[9]Data is drawn from the most recent report by ISTAT - Censimento spostamenti pendolari [Link]

summarizes the main statistics by school grade and overall. For a more detailed description of the variables see Appendix B.

Table 1: Descriptive Statistics

Variable	**2nd Grade**	**5th Grade**	**8th Grade**	**Overall**
Observations	2.639.759	2.600.969	3.014.055	8.254.783
Male	0,435	0,430	0,431	0,432
	(0,496)	(0,495)	(0,495)	
Day Nursery	0,255	0,241	0,202	0,231
	(0,436)	(0,428)	(0,401)	
Kindergarten	0,737	0,768	0,718	0,740
	(0,440)	(0,422)	(0,450)	
Student Italian	0,963	0,951	0,932	0,948
	(0,189)	(0,215)	(0,251)	
Mother Italian	0,797	0,824	0,833	0,819
	(0,402)	(0,381)	(0,373)	
Father Italian	0,812	0,839	0,840	0,831
	(0,391)	(0,368)	(0,367)	
High-educated mother	0,192	0,171	0,137	0,165
	(0,394)	(0,376)	(0,344)	
High-educated father	0,140	0,134	0,115	0,129
	(0,348)	(0,340)	(0,319)	
Mother high-skill job	0,309	0,307	0,278	0,297
	(0,462)	(0,461)	(0,448)	
Father high-skill job	0,299	0,303	0,285	0,295
	(0,458)	(0,460)	(0,452)	
UBB coverage	0,344	0,349	0,351	0,348
	(0,475)	(0,477)	(0,477)	
Average OLT distance	0,328	0,334	0,329	0,330
	(0,470)	(0,472)	(0,470)	

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

5 Empirical strategy

5.1 Fixed Effect Models

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

$$y_{i,s,m,t} = \beta_0 + \gamma UBB_{m,t} + X_i'\beta_1 + \alpha_s + \tau_{p(s),t} + \varepsilon_{i,s,m,t} \tag{4}$$

where $y_{i,s,m,t}$ denotes either Italian language or math 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 identifying ultra-fast connection access in municipality m and year t. X_i is a vector of controls for student i, including, among others, information on family background, birthdate, nationality, and kindergarten attendance.[10] Finally, α_s collects school fixed effects, while $\tau_{p(s),t}$ are province-specific (of the school) year fixed effects.

Since $UBB_{m,t}$ is an indicator identifying schools located in municipalities with access to ultra-fast connections, equation (4) performs a two-way fixed effect difference-in-differences (DiD) estimation, where treated units are those cohorts of students covered by UBB services. Because of the staggered nature of the UBB roll-out (see Figure A.1 in Appendix A, the model implies variation in treatment timing (Goodman-Bacon [2021]).

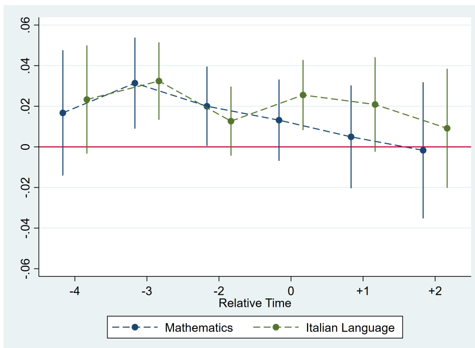
The model identifies the causal impact of UBB on student performance under the assumption of UBB roll-out being as-good-as-random with respect to student standardized scores. We test our identifying assumption through an event study model that allows us to look for parallel trends before the introduction of UBB. In particular, a failure of the flat trends test would suggest that UBB roll-out is not as-good-as random. In such a case, conditional on student characteristics, school fixed effects, and common time trends, UBB roll-out would be somehow correlated with the average student performance of schools in municipality m. To this aim, we estimate the following event study model:

$$y_{i,s,m,t} = \beta_0 + \sum_r \gamma_r \mathbb{I}\{r = t - T_{0m}\} + X_i'\beta_1 + \alpha_s + \tau_{p(s),t} + \epsilon_{i,s,m,t} \tag{5}$$

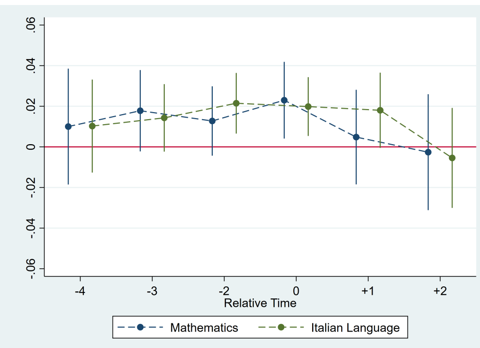
where T_{0m} denotes the time when school's municipality m initially receive UBB, and

[10] Control variables included in the regressions are collected in Appendix Table B.1.

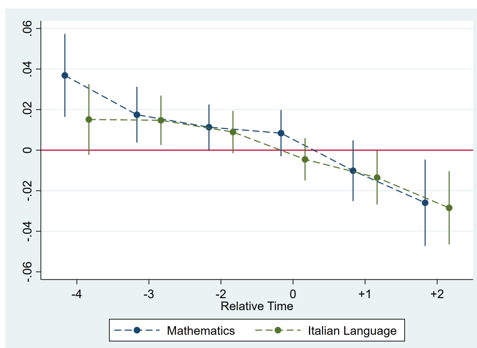
$r = t - T_{0m}$ is the relative time from ultra-fast connection introducton.[11] Given the staggered nature of the treatment, we need to drop two indicators identifying relative time from the treatment (Borusyak and Jaravel [2017]). Therefore we drop $r = \{-5, -1\}$.



(a) 2nd Grade



(b) 5th Grade



(c) 8th Grade

Figure 1: Event study estimates for each school grade.

Figure 1 depicts estimated γ_r coefficients together with the corresponding 95% confidence interval of equation (5) when the dependent variable is the standardized test score for Italian language and Mathematics for 2nd, 5th, and 8th grade. First, in general we do not observe flat trends prior to the treatment, pointing towards potential endogeneity between

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

UBB roll-out and average student performance. Second, we do not see any statistically significant treatment effect in 2nd and 5th grade, both for Mathematics and Italian score. Finally, the unique (negative) effect of UBB on student performance is concentrated in the 8th grade, where for both Italian language and math 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 correlation between 8th-grade student performance and UBB roll-out.

5.2 IV Approach

Our event study estimation provides useful insights on the potential effects of ultra-fast connections availability 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, biasing the OLS estimate of equation (4). 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 Central Office to provide UBB services to final customers. They act as endpoint devices of an Optical Passive Network, from which the so-called *last mile* – the portion of the telecommunication network that physically reaches customer premises – departs (Cambini and Sabatino [2021]). 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 ultra-fast connections to final consumers, providing a relevant instrument to be used in our IV estimation.

Given the constraints in terms of data (see Section 4), we cannot use directly the distance between the municipality and its closest OLT. However, given that information, we construct the following indicator variable:

$$z_{m,t} = \begin{cases} 1 & \text{if } Post_{2015} \times OLT_{m,t} \leq 10Km \\ 0 & \text{Otherwise} \end{cases} \tag{6}$$

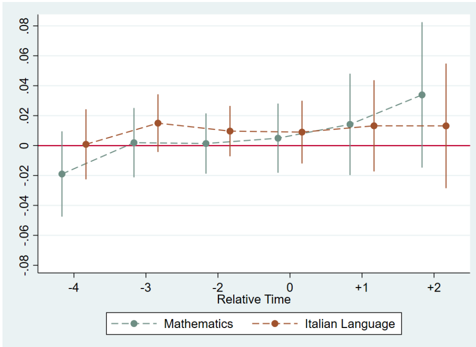
where $Post_{2015} \times OLT_{m,t}$ denotes the interaction between a $Post_{2015}$ dummy taking value one from the starting year of UBB introduction and $OLT_{m,t}$, the distance in kilometers between each municipality and the closest OLT. Since OLT distance and UBB diffusion are presumed to be negatively correlated, we expect a positive correlation between $z_{m,t}$ and $UBB_{m,t}$. Our prediction is confirmed by Figure A.2 in Appendix A, which shows that schools for which $z_{m,t} = 1$ are more likely to receive ultra-fast connections.

Our proposed instrument $z_{m,t}$ identifies those municipalities that are relatively closer to an OLT over time. The exclusion restriction requires such indicators 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 be itself a DiD regression with variation in treatment timing as the one of equation (4), 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:

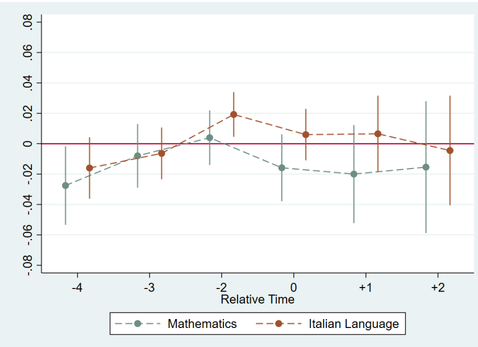
$$y_{i,s,m,t} = \theta_0 + \sum_r \pi_r \mathbb{I}\{r = t - Z_{0m}\} + X_i\theta_1 + \mu_s + \delta_{p(s),t} + u_{i,s,m,t} \tag{7}$$

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

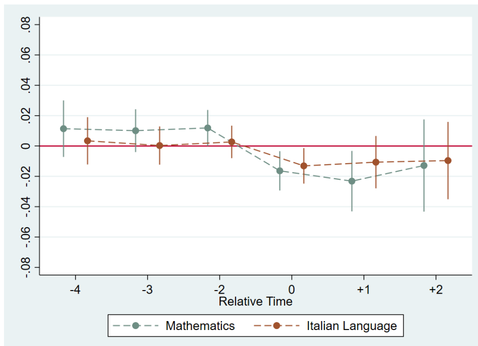
Figure 2 presents the OLS π_r coefficients together with the corresponding 95% confidence interval of equation (7) when the dependent variable is the standardized test score for Italian language and Mathematics for 2nd, 5th, and 8th grade. Estimates show that the



(a) 2nd Grade



(b) 5th Grade



(c) 8th Grade

Figure 2: Reduced form event study estimates for each grade.

parallel trend assumption is generally satisfied across tests and grades. Only in 5th grade we reject the null $\pi_r = 0$ for $r < 0$. Again, post-treatment coefficients are statistically significant only for 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 equation (4).

All in all, the reduced form analysis suggests that our proposed instrument satisfies the exclusion restriction assumption. It also provides evidence of the expected result in the second stage of a 2SLS estimation, where we expect a negative effect of UBB on student performance.

6 Results

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

We report heterogeneous effects by gender (Table 3), parental education (Table 4), daily usage of IT in class (Table 6), as well as combinations of parental education with student gender and daily usage of IT in class (Tables 5 and 7 respectively).

Table 2 presents our estimates of the effect of UBB on student performance in Italian language (columns 1-3) and Mathematics (columns 4-6) of students in 8th grade. Student performance is measured by the INVALSI standardized test scores. The 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 Equation 4, without accounting for endogeneity concerns. In these specifications, the explanatory variable is the dummy UBB that captures whether the municipality of the school attended by the student is equipped with 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.1. Columns 3 and 6 present results of the IV as given by equation (7), including both fixed effects and student-level controls.

The results presented in columns 1-2 of Table 2, both without and with covariates, show a very small and statistically insignificant relationship between change in Mathematics scores and UBB roll-out. OLS coefficients for Italian scores (columns 4-5) are instead significant and show a negative relationship with the presence of the UBB.[12].

[12]For the full table of results, including also the coefficients associated to student attributes, see Table D.1.

Table 2: Effect of broadband on student's 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	-0.002	-0.004	-0.083***	-0.011**	-0.012**	-0.069**
	(0.005)	(0.005)	(0.031)	(0.005)	(0.005)	(0.027)
Observations	3,014,039	3,014,054	3,014,054	3,014,039	3,014,054	3,014,054
First Stage F-test			356.2			356.2

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

Moving towards the IV estimates presented in columns 3 and 6 of Table 2, we find that the impact of UBB on student performance is negative, quite large, and statistically significant for both subjects (at the 1% significance level for Mathematics and 5% significance level for Italian language), suggesting an adverse effect of broadband on student performance. Having access to UBB decreases 8th grade standardized test scores in Mathematics and Italian language by 0.083 and 0.069 standard deviation from the mean respectively. On the contrary, we do not find any significant effect on none of the two subjects any specification in students in 2nd and 5th grade, as reported in Tables C.2 and C.5, in Appendix C.[13]
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 UBB roll-out.

[13]The first stage is strong in each grade, with an F-test in the range 350-400, implying that weak instrument bias is not a concern. Consistently, first-stage coefficient is highly significant and with the expected positive sign, as reported in Table C.1.

6.1 Heterogeneity by gender

Since males and females at the age of 13 might use broadband to perform activities that affect them differently, in Table 3 we explore heterogeneous effects by gender. If there are differences in the use of internet, 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,[14] 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 girls report in the age range 13-17, and five times more than girls report in the age range 9-12. Thus, since online gaming relies on ultra-fast broadband connection, faster internet may result in a higher amount of distraction time for boys. Accordingly, we should expect a stronger adverse effect of broadband use on boys' performance. We test this hypothesis by running separate regressions in Mathematics and Italian language for boys and girls. Results are reported in Table 3.

Both boys and girls' performance in Mathematics (columns 2 and 4 respectively) are negatively affected by broadband internet use, but boys seem to be slightly more affected, both in terms of magnitude and statistical significance. The gap is unambiguous if we compare student performance in Italian language: while girls are not affected (column 8), average score for boys decreases by .081 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]).

[14] The report can be found (in Italian) here.

Table 3: Effect of broadband on student's performance in 8^{th} 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	-0.003	-0.079**	0.003	-0.065*	-0.012**	-0.081**	-0.009	-0.032
	(0.006)	(0.037)	(0.007)	(0.039)	(0.006)	(0.034)	(0.006)	(0.034)
Observations	1,299,522	1,299,522	1,264,367	1,264,367	1,299,522	1,299,522	1,264,367	1,264,367
First Stage F-test		283.6		283.2		283.6		283.2

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

6.2 Heterogeneity by parental education

The INVALSI test scores are accompanied by questionnaires that collect information on students' background. As also shown in our theoretical model in Section 3, the purpose for which 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 internet. To test this hypothesis, we calculate separate average scores in Mathematics and Italian language for students with both high educated parents, with only one high educated parent and with both low educated parents.[15] Results are reported in Table 4. Both for Mathematics and Italian language, students with at least one high educated parent are not negatively affected by the introduction of the UBB, while students with both low-educated parents (column 6 Mathematics and column 12 Italian language) are considerably negatively affected. Considering IV estimates, the negative impact is larger and more significant for Mathematics (-0.107) than Italian language (-0.072). The results are in line with our hypothesis that parental edu-

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

cation is an important factor in affecting children online behavior. Hence, faster internet connections imply more distracting activities only for students from low-educated families.[16].

In Table 5, we investigate whether boys and girls are impacted differently by UBB roll-out if they come from a family with one high-educated parent or low-educated parents[17]. If we look at the performance in Mathematics (columns 1-4), it seems 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 affected are males from low-educated parents (column 7).

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

[16]We do not find any significant impact of parents' job status on the impact of broadband on performance. This is not surprising given the fact that high-skill jobs 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.

[17]We do not report results for students with both high-educated parents since we see in Table 4 that they are not affected by broadband.

Table 4: Effect of broadband on student's performance in 8th gradeth by parental education

	Both high educated		One high educated		Both low educated		Both high educated		One high educated		Both low educated	
	OLS	IV	OLS	IV	OLS	IV	OLS	IV	OLS	IV	OLS	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	-0.004	-0.022	-0.003	0.017	-0.006	-0.107***	-0.004	-0.117	-0.005	-0.053	-0.013***	-0.072**
	(0.013)	(0.078)	(0.008)	(0.044)	(0.006)	(0.033)	(0.012)	(0.074)	(0.007)	(0.042)	(0.005)	(0.029)
Observations	203,996	203,996	553,527	553,527	2,460,422	2,460,422	203,996	203,996	553,527	553,527	2,460,422	2,460,422
First Stage F-test		186.2		267.5		350.9		186.2		267.5		350.9

*Notes: Specifications in columns (1)-(3)-(5)-(7)-(9)-(11) are estimated using OLS. Specifications in columns (2)-(4)-(6)-(8)-(10)-(12) replicate columns (1)-(3)-(5)-(7)-(9)-(11) using IV. All specifications include controls for gender, place of birth, and citizenship of the student, nursing day and kindergarten attendance, place of birth of the mother and the father, education of the mother and the father, and job status of the mother and the father, and a year-province fixed effects. Columns from (1) to (6) report results in Mathematics. Columns from (7) to (12) report results in Italian language. Standard errors clustered at school level. Significant levels: *** p<0.01, ** p<0.05, * p<0.1*

Table 5: Effect of broadband on student's performance in 8th grade th 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	0.065	0.030	-0.118***	-0.090**	-0.055	0.007	-0.087**	-0.041
	(0.062)	(0.060)	(0.040)	(0.043)	(0.058)	(0.056)	(0.036)	(0.037)
Observations	235,320	226,955	1,064,035	1,037,221	235,320	226,955	1,064,035	1,037,221
First Stage F-test	225.3	227.5	274.7	271.6	225.3	227.5	274.7	271.6

*Notes: All specifications report IV results and include controls for gender, place of birth, and citizenship of the student, nursing day and kindergarten attendance, place of birth of the mother and the father, education of the mother and the father, and job status of the mother and the father, and a year-province fixed effects. Columns from (1) to (4) report results in Mathematics. Columns from (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 school level. Significant levels: *** p<0.01, ** p<0.05, * p<0.1*

6.3 Heterogeneity by school level of IT usage

Our main results is that 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 internet for distracting activities such music and video streaming, online gaming, and online networking, all of which leverage on ultra-fast connections. Such activities are likely conducted at the home address of the student. Hence, it is unclear whether schools play any role in the relation between ultra-fast connections and student performance. In principle, schools might exploit advanced IT to make more effective the use of internet for learning purposes, which may mitigate the negative effect resulting from an increase of distraction time.

We test this hypothesis in Table 6, 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.[18] The negative estimates are significant for both Italian language and Mathematics in schools located in provinces where internet is not used for learning purposes (columns 1 and 4). In Table 7, we further explore the combined effect of parental education with the daily use of IT at school. The estimates reported in the Table (columns 4 and 10) are in line with the picture emerged by our analysis: Students from low-educated families and in provinces where schools do not use IT for are those most adversely affected by UBB roll-out. This suggests that investments in advanced broadband technologies should be complemented with more digital learning at school, in order to fight the detrimental effect caused by the increased distractive activities associated to faster internet connection.

Table 6: Effect of broadband on student's performance in 8th gradeth 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	-0.084**	-0.099	-0.081	-0.081**	-0.118	-0.017
	(0.042)	(0.081)	(0.054)	(0.038)	(0.072)	(0.047)
Observations	743,672	1,471,126	756,552	743,672	1,471,126	756,552
First Stage F-test	207.1	46.66	136.8	207.1	46.66	136.8

*Notes: All specifications report IV results and include controls for gender, place of birth, and citizenship of the student, nursing day and kindergarten attendance, place of birth of the mother and the father, education of the mother and the father, and job status of the mother and the father, and a year-province fixed effects. Columns from (1) to (4) report results in Mathematics. Columns from (5) to (8) report results in Italian language. Standard errors clustered at school level. Significant levels: *** p<0.01, ** p<0.05, * p<0.1*

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

Table 7: Effect of broadband on student's performance in 8th grade th 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	0.013	0.014	-0.008	-0.106**	-0.126	-0.102*	-0.022	-0.205*	-0.026	-0.086**	-0.105	-0.021
	(0.056)	(0.118)	(0.083)	(0.046)	(0.086)	(0.056)	(0.052)	(0.116)	(0.081)	(0.041)	(0.075)	(0.049)
Observations	134,825	268,841	141,071	608,827	1,202,222	615,457	134,825	268,841	141,071	608,827	1,202,222	615,457
First Stage F-test	183.6	30.87	98.16	197.5	46.80	138.4	183.6	30.87	98.16	197.5	46.80	138.4

*Notes: All specifications report IV results and include controls for gender, place of birth, and citizenship of the student, nursing day and kindergarten attendance, place of birth of the mother and the father, education of the mother and the father, and job status of the mother and the father, and a year-province fixed effects. Columns from (1) to (6) report results in Mathematics. Columns from (7) to (12) report results in Italian language. Standard errors clustered at school level. Significant levels: *** p<0.01, ** p<0.05, * p<0.1*

7 Conclusion

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

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

Both OLS and IV estimates suggested that having access to ultra-fast connections harms student performance, but only in 8th grade. Students in 2nd and 5th grades are not affected by UBB roll-out. 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 reasonably more exposed to the speed of the connection with respect to younger students. Such a negative impact is larger for male student, 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 the negative effect of UBB roll-out. This evidence is in line with our theoretical framework, according to which the ambiguous effect of the internet is given by the purpose of its usage. The negative effect determined by the greater value of online leisure can be compensated by schools invest more in IT-related educational activities. This may mitigate the unattended effects of faster broadband connections on student performance.

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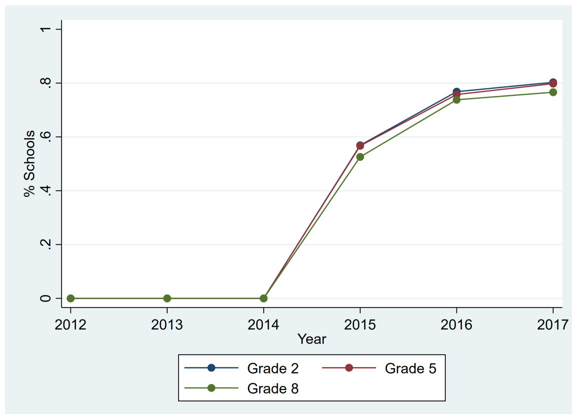
Appendices

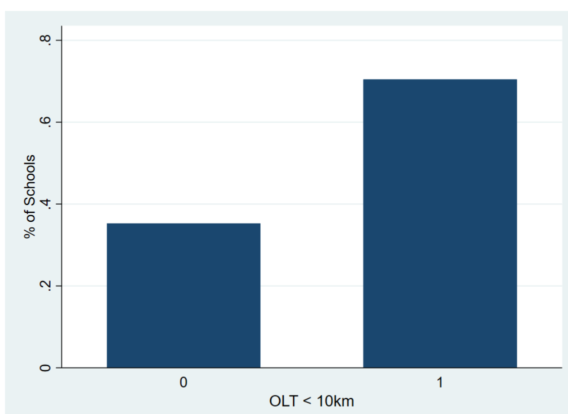
A Broadband data

Figure A.1: Ultra-fast broadband diffusion rate by grade from 2012 to 2017.



This figure shows the percentage of schools with access to UBB connections over time, for each grade.

Figure A.2: Relation between ultra-fast broadband and optical line terminal.



This figure shows the percentage of 8th grade schools with access to UBB connections, for schools located within a range of 10 kilometers from the closest OLT (1), and farther than 10 kilometers (0). Data from 2015 onwards.

B Description of variables

Table B.1 describes the original scales of the variables included in the main regressions. In Table 1 in Section 4, 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 4, 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 3-5-7 in the profession scale in Table B.1 are considered subjects with high-skill jobs, while parents whose job belongs to the categories 4-6-8 are considered subjects with low-skill jobs.

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.2.

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
Day Nursery 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) Medium license 3) Three-year professional qualification 4) High school diploma 5) Other qualification higher than high-school 6) Degree or higher qualification (doctoral studies)

Variable	Description
Father's profession	1) Unemployed
	2) Stay-at-home father
	3) Manager, university professor, etc.
	4) Entrepreneur / agricultural owner
	5) Employee professional, sub.
	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) Medium license
	3) Three-year professional qualification
	4) High school diploma
	5) Other qualification higher than high-school
	6) Degree or higher qualification (doctoral studies)

Variable	Description
Mother's profession	1) Unemployed
	2) Stay-at-home mother
	3) Manager, university professor, etc.
	4) Entrepreneur / agricultural owner
	5) Employee professional, sub.
	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: 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	0.004	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
Total	0.470	0.116	0.223	0.756	107

C Additional results

Table C.1: First-stage regressions for each grade

	(1)	(2)	(3)
VARIABLES	2nd Grade	5th Grade	8th Grade
z	0.190***	0.189***	0.196***
	(0.010)	(0.009)	(0.010)
R-squared	0.793	0.790	0.803
Observations	2,639,757	2,600,968	3,014,054

*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-fast connections. The excluded instrument z, is an indicator that takes value one if the closest OLT is within 10 kilometers from 2015 onward. Standard errors clustered at school level. Significant levels: *** p<0.01, ** p<0.05, * p<0.1*

Table C.2: Effect of broadband on student's performance in 2^{nd} 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	0.000	0.003	0.008	0.011	0.014*	0.034
	(0.009)	(0.009)	(0.054)	(0.008)	(0.008)	(0.050)
Observations	2,639,719	2,639,757	2,639,757	2,639,719	2,639,757	2,639,757
First Stage F-test			360.4			360.4

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

Table C.3: Effect of broadband on student's performance in 2^{nd} 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	-0.056	0.041	0.053	0.034	0.089	0.090	0.049	0.042
	(0.075)	(0.081)	(0.067)	(0.070)	(0.073)	(0.080)	(0.062)	(0.065)
Observations	271,881	262,124	876,832	849,139	271,881	262,124	876,832	849,139
First Stage F-test	248	244.2	267.6	269.3	248	244.2	267.6	269.3

*Notes: All specification report IV results and include controls for gender, place of birth, and citizenship of the student, nursing day and kindergarten attendance, place of birth of the mother and the father, education of the mother and the father, and job status of the mother and the father, and a year-province fixed effects. Columns from (1) to (4) report results in Mathematics. Columns from (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 school level. Significant levels: *** p<0.01, ** p<0.05, * p<0.1*

Table C.4: Effect of broadband on student's performance in 2^{nd} 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	-0.118*	0.178	0.048	-0.069	0.129	0.119
	(0.068)	(0.143)	(0.101)	(0.064)	(0.133)	(0.095)
Observations	657,460	1,275,450	668,441	657,460	1,275,450	668,441
First Stage F-test	240.4	50.30	109.2	240.4	50.30	109.2

*Notes: All specification report IV results and include controls for gender, place of birth, and citizenship of the student, nursing day and kindergarten attendance, place of birth of the mother and the father, education of the mother and the father, and job status of the mother and the father, and a year-province fixed effects. Columns from (1) to (4) report results in Mathematics. Columns from (5) to (8) report results in Italian language. Standard errors clustered at school level. Significant levels: *** p<0.01, ** p<0.05, * p<0.1*

Table C.5: Effect of broadband on student's 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	0.013	0.011	-0.054	0.011	0.008	0.009
	(0.009)	(0.009)	(0.050)	(0.007)	(0.007)	(0.038)
Observations	2,600,916	2,600,968	2,600,968	2,600,916	2,600,968	2,600,968
First Stage F-test			400.3			400.3

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

Table C.6: Effect of broadband on student's 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	-0.100	-0.011	-0.046	-0.023	0.003	0.048	0.025
	(0.075)	(0.077)	(0.063)	(0.068)	(0.063)	(0.065)	(0.051)	(0.053)
Observations	241,530	235,207	877,824	862,120	241,530	235,207	877,824	862,120
First Stage F-test	276.6	278	301.4	282.4	276.6	278	301.4	282.4

*Notes: All specification report IV results and include controls for gender, place of birth, and citizenship of the student, nursing day and kindergarten attendance, place of birth of the mother and the father, education of the mother and the father, and job status of the mother and the father, and a year-province fixed effects. Columns from (1) to (4) report results in Mathematics. Columns from (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 school level. Significant levels: *** p<0.01, ** p<0.05, * p<0.1*

Table C.7: Effect of broadband on student's performance in 5^{th} 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	-0.123*	-0.092	0.062	-0.022	-0.021	0.058
	(0.069)	(0.125)	(0.093)	(0.051)	(0.094)	(0.075)
Observations	651,511	1,253,828	656,729	651,511	1,253,828	656,729
First Stage F-test	253.4	59.16	123.6	253.4	59.16	123.6

*Notes: All specification report IV results and include controls for gender, place of birth, and citizenship of the student, nursing day and kindergarten attendance, place of birth of the mother and the father, education of the mother and the father, and job status of the mother and the father, and a year-province fixed effects. Columns from (1) to (4) report results in Mathematics. Columns from (5) to (8) report results in Italian language. Standard errors clustered at school level. Significant levels: *** p<0.01, ** p<0.05, * p<0.1*

D Full set of results for the main regression

Table D.1 is the extended version of Table 2. It displays the coefficients associated with the controls.

Table D.1: Description of Variables used in this Study

	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)
VARIABLES	std MAT	std MAT	std ITA	std ITA
UBB	-0.004	-0.083***	-0.012**	-0.069**
	(0.005)	(0.031)	(0.005)	(0.027)
Sex				
Male	0	0	0	0
	(empty)	(empty)	(empty)	(empty)
Female	-0.142***	-0.142***	0.242***	0.242
	(0.002)	(0.002)	(0.001)	(0.001)
Missing	0.118*	0.112*	0.388***	0.383
	(0.063)	(0.065)	(0.066)	(0.066)
Month of birth				
January	0	0	0	0
	(empty)	(empty)	(empty)	(empty)
February	0.021***	0.021***	0.026***	0.026***
	(0.003)	(0.003)	(0.003)	(0.003)
March	0.043***	0.043***	0.052***	0.052***
	(0.003)	(0.003)	(0.003)	(0.003)
April	0.042***	0.042***	0.064***	0.064***
	(0.003)	(0.003)	(0.003)	(0.003)
May	0.053***	0.053***	0.073***	0.073***
	(0.003)	(0.003)	(0.003)	(0.003)
June	0.03***	0.03***	0.048***	0.047***

	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)
VARIABLES	std MAT	std MAT	std ITA	std ITA
	(0.003)	(0.003)	(0.003)	(0.003)
July	0.012***	0.012***	0.026***	0.026***
	(0.003)	(0.003)	(0.003)	(0.003)
August	-0.008***	-0.008***	0.004	0.004
	(0.003)	(0.003)	(0.003)	(0.003)
September	-0.014***	-0.014***	-0.015***	-0.015***
	(0.003)	(0.003)	(0.003)	(0.003)
October	-0.024***	-0.024***	-0.03***	-0.03***
	(0.003)	(0.003)	(0.003)	(0.003)
November	-0.028***	-0.028***	-0.045***	-0.045***
	(0.003)	(0.003)	(0.003)	(0.003)
December	-0.04***	-0.04	-0.06***	-0.06***
	(0.003)	(0.003)	(0.003)	(0.003)
Missing	-0.178***	-0.18	-0.186***	-0.188***
	(0.069)	(0.069)	(0.071)	(0.072)
Place of birth				
Italy	0	0	0	0
	(empty)	(empty)	(empty)	(empty)
European Union	-0.113	-0.113***	-0.079	-0.079***
	(0.007)	(0.007)	(0.007)	(0.007)
Non EU Country	-0.21	-0.21***	-0.234***	-0.234***
	(0.007)	(0.007)	(0.008)	(0.008)
Other	-0.314	-0.314***	-0.361***	-0.361***
	(0.006)	(0.006)	(0.006)	(0.006)
Missing	-0.083	-0.084***	-0.098***	-0.099***
	(0.016)	(0.016)	(0.016)	(0.016)

	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)
VARIABLES	std MAT	std MAT	std ITA	std ITA
Day Nursery Attendance				
Yes	0	0	0	0
	(empty)	(empty)	(empty)	(empty)
No	0.014***	0.014***	0.03***	0.03***
	(0.002)	(0.002)	(0.002)	(0.002)
Missing	0.009**	0.009**	0.024***	0.024***
	(0.004)	(0.004)	(0.004)	(0.004)
Kindergarten Attendance				
Yes	0	0	0	0
	(empty)	(empty)	(empty)	(empty)
No	-0.021***	-0.022***	-0.038***	-0.039***
	(0.005)	(0.005)	(0.005)	(0.005)
Missing	-0.012**	-0.011**	-0.022***	-0.022***
	(0.005)	(0.005)	(0.005)	(0.005)
Father's place of birth				
Italy	0	0	0	0
	(empty)	(empty)	(empty)	(empty)
European Union	-0.021***	-0.021***	0.006	0.006
	(0.005)	(0.005)	(0.005)	(0.005)
Non EU Country	-0.092***	-0.092***	-0.066***	-0.066***
	(0.005)	(0.005)	(0.005)	(0.005)
Other	-0.092***	-0.092***	-0.137***	-0.137***
	(0.005)	(0.005)	(0.005)	(0.005)
Missing	-0.089***	-0.089***	-0.063***	-0.063***
	(0.004)	(0.004)	(0.004)	(0.004)

	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)
VARIABLES	std MAT	std MAT	std ITA	std ITA
Father's education				
1) Elementary school	0	0	0	0
	(empty)	(empty)	(empty)	(empty)
2) Medium license	0.109***	0.109***	0.137***	0.137***
	(0.003)	(0.003)	(0.004)	(0.004)
3) Three-year professional qualification	0.18***	0.18***	0.215***	0.214***
	(0.004)	(0.004)	(0.004)	(0.004)
4) High school diploma	0.279***	0.279***	0.325***	0.325***
	(0.004)	(0.004)	(0.004)	(0.004)
5) Qualification higher than high-school	0.248***	0.248***	0.309***	0.309***
	(0.007)	(0.007)	(0.006)	(0.006)
6) Degree or higher qualification	0.443***	0.444***	0.474***	0.474***
	(0.005)	(0.005)	(0.005)	(0.005)
Missing	0.185***	0.185***	0.226***	0.226***
	(0.005)	(0.005)	(0.005)	(0.005)
Father's profession				
1) Unemployed	0	0	0	0
	(empty)	(empty)	(empty)	(empty)
2) Stay-at-home father	0.067***	0.067***	0.064***	0.064***
	(0.013)	(0.013)	(0.011)	(0.011)
3) Manager, university professor, etc.	0.203***	0.203***	0.198***	0.198***
	(0.005)	(0.005)	(0.005)	(0.005)
4) Entrepreneur / agricultural owner	0.116***	0.116***	0.1***	0.1***
	(0.004)	(0.004)	(0.004)	(0.004)
5) Employee professional, sub.	0.126***	0.126***	0.149***	0.149***
	(0.004)	(0.004)	(0.004)	(0.004)
6) Self-employed worker	0.11***	0.11***	0.101***	0.101***
	(0.004)	(0.004)	(0.003)	(0.003)

	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)
VARIABLES	std MAT	std MAT	std ITA	std ITA
7) Teacher, clerk, military, etc.	0.169***	0.169***	0.175***	0.175***
	(0.004)	(0.004)	(0.004)	(0.004)
8) Worker, service agent, etc.	0.055***	0.055***	0.066***	0.066***
	(0.003)	(0.003)	(0.003)	(0.003)
9) Retired	0.074***	0.074***	0.122***	0.122***
	(0.006)	(0.006)	(0.006)	(0.006)
Missing	0.063***	0.063***	0.074***	0.074***
	(0.004)	(0.004)	(0.004)	(0.004)
Mother's place of birth				
Italy	0	0	0	0
	(empty)	(empty)	(empty)	(empty)
European Union	-0.002	-0.002	-0.005	-0.005
	(0.004)	(0.004)	(0.004)	(0.004)
Non EU Country	-0.036***	-0.036***	-0.036***	-0.036***
	(0.005)	(0.005)	(0.005)	(0.005)
Other	-0.06***	-0.06***	-0.078***	-0.078***
	(0.004)	(0.004)	(0.004)	(0.004)
Missing	-0.052***	-0.052***	-0.065***	-0.065***
	(0.006)	(0.006)	(0.006)	(0.006)
Mother's education				
1) Elementary school	0	0	0	0
	(empty)	(empty)	(empty)	(empty)
2) Medium license	0.096***	0.096***	0.133***	0.133***
	(0.004)	(0.004)	(0.004)	(0.004)
3) Three-year professional qualification	0.151***	0.151***	0.212***	0.212***
	(0.004)	(0.004)	(0.005)	(0.005)

	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)
VARIABLES	std MAT	std MAT	std ITA	std ITA
4) High school diploma	0.293***	0.293***	0.357***	0.357***
	(0.004)	(0.004)	(0.004)	(0.004)
5) Qualification higher than high-school	0.306***	0.306***	0.369***	0.369***
	(0.006)	(0.006)	(0.006)	(0.006)
6) Degree or higher qualification	0.478***	0.478***	0.542***	0.542***
	(0.005)	(0.005)	(0.005)	(0.005)
Missing	0.221***	0.221***	0.263***	0.263***
	(0.005)	(0.005)	(0.005)	(0.005)
Mother's profession				
1) Unemployed	0	0	0	0
	(empty)	(empty)	(empty)	(empty)
2) Stay-at-home mother	0.014***	0.014***	0.003	0.003
	(0.004)	(0.004)	(0.003)	(0.003)
3) Manager, university professor, etc.	0.142***	0.142***	0.109***	0.109***
	(0.007)	(0.007)	(0.007)	(0.007)
4) Entrepreneur / agricultural owner	0.04***	0.04***	0.006	0.006
	(0.006)	(0.006)	(0.006)	(0.006)
5) Employee professional, sub.	0.07***	0.07***	0.056***	0.056***
	(0.004)	(0.004)	(0.004)	(0.004)
6) Self-employed worker	0.065***	0.065***	0.022***	0.022***
	(0.004)	(0.004)	(0.004)	(0.004)
7) Teacher, clerk, military, etc.	0.132***	0.133***	0.109***	0.109***
	(0.004)	(0.004)	(0.003)	(0.003)
8) Worker, service agent, etc.	0	0	-0.003	-0.003
	(0.004)	(0.004)	(0.003)	(0.003)
9) Retired	-0.036***	-0.036***	-0.018	-0.018
	(0.014)	(0.014)	(0.014)	(0.013)

	OLS	IV	OLS	IV
	(1)	(2)	(3)	(4)
VARIABLES	std MAT	std MAT	std ITA	std ITA
Missing	0.057***	0.057***	0.047***	0.047***
	(0.005)	(0.005)	(0.005)	(0.004)
Student's citizenship				
Italian	0	0	0	0
	(empty)	(empty)	(empty)	(empty)
First-generation immigrant	0.135***	0.135***	-0.071***	-0.071***
	(0.008)	(0.008)	(0.008)	(0.008)
Second-generation immigrant	-0.029***	-0.03***	-0.134***	-0.134***
	(0.005)	(0.005)	(0.005)	(0.005)
Missing	0.032***	0.033***	-0.047***	-0.046***
	(0.011)	(0.011)	(0.012)	(0.012)

*Notes: Specifications in columns (1)-(3) are estimated using OLS, specifications in columns (2)-(4) using IV. All specification include also year-province fixed effects. Standard errors clustered at school level. Significant levels: *** p<0.01, ** p<0.05, * p<0.1*