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Esther Arenas-Arroyo
Vienna University of Economics and Business and IZA

Daniel Fernandez-Kranz
IE-University

Natalia Nollenberger
IE University

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ISSN: 2365-9793

IZA – Institute of Labor Economics

Schaumburg-Lippe-Straße 5–9
53113 Bonn, Germany

Phone: +49-228-3894-0
Email: publications@iza.org

www.iza.org

ABSTRACT

High Speed Internet and the Widening Gender Gap in Adolescent Mental Health: Evidence from Hospital Records

Increases in mental health problems among adolescents have been concurrent with increased use of digital media, with bigger changes among girls after the mid-2010s. This study exploits exogenous variation in the deployment of optic fiber across Spanish provinces between 2007 and 2019 to analyze the effect of access to high-speed Internet (HSI) on hospital discharge diagnoses of behavioral and mental health cases among adolescents. We find a positive and significant impact on girls but not on boys. Exploring the mechanism behind these effects, we show that HSI increases addictive Internet use and significantly decreases time spent sleeping, doing homework, and socializing with family and friends. Girls again power all these effects. We find no evidence of an increase in online bullying. Finally, we show that fiber expansion harms the quality of the relationship between fathers and daughters, especially when that relationship suffers from a previous conflict. Our results help explain the observed widening gender gap in mental health among adolescents and are robust to various sensitivity tests.

JEL Classification: J13, J16, I10, I12, I18, H31, L86

Keywords: high-speed internet, adolescents, mental health

Corresponding author:
Esther Arenas-Arroyo
Department of Economics
Vienna University of Economics and Business (WU)
Welthandelsplatz 1
1020 Vienna
Austria

E-mail: esther.arenas.arroyo@wu.ac.at

1. Introduction

In the United States, hospital admissions for suicide attempts and suicide ideation in adolescents doubled from 2008 to 2015, with increases up to 500% in the case of youngest girls (CDCP, 2020, Plemmons et al., 2018, Twenge et al., 2019a). In the U.K., episodes of admission completed with a primary diagnosis of self-harm and self-intoxication increased by 42% for boys ages 11-17 and 60% for girls the same age between 2005 and 2019, with most of the increase also occurring after 2010[1]. In Spain, hospital discharge diagnoses for self-harm and suicide attempts by adolescents between the ages of 15 and 19 increased fivefold for girls and quadrupled for boys between 2012 and 2019[2]. Similar trends have been found in other countries, such as Canada and Italy. In most cases, the increases in indicators of poor mental health have been larger among girls than among boys and accelerated in the second decade of the 2000s.

Data such as these have led many to conclude that we are in the midst of an adolescent mental health crisis (Sohn, 2022, Twenge, 2020; Orben et al., 2022). It seems unlikely that these trends have been caused by increased awareness of mental health conditions or greater comfort with seeking help, given that life-threatening cases, such as self-harm and attempted suicide, has also increased. But despite clear evidence that we are facing a serious problem, little is known about its causes and how to tackle it. A usual suspect in public debates is social media and teens' exposure to other content via the Internet, as increases in depression among adolescents have been concurrent with increases in digital media use. In Spain, the country on which this article focuses, the wide distribution of HBO began in 2015, Netflix also in 2015, Instagram in 2012, and TikTok in 2017. Experts mention at least three possible channels. One viewpoint is that adolescents are unable to cope and process the huge influx of information and stimulus maturely that they receive from online media[3]. According to this view, this has created a "widening gap" between the explosion of Internet-driven stimulation and what the young brain can process, leading to feelings of confusion, emptiness, low self-worth, anxiety, or even depression at an age when self-identity is extremely fragile. This can range from the

[1] Information available at: https://digital.nhs.uk/.
[2] Information available at: https://www.sanidad.gob.es/estadEstudios/estadisticas/cmbdhome.htm.
[3] To make matters worse, there is evidence that the age of puberty onset dropped markedly for girls, to 12 years old today from 14 years old in 1990, with similar trends for boys (see, *Puberty Starts Earlier Than It Used To. No One Knows Why*. NYT, May 19th, 2022). According to this view, when puberty hits, the brain becomes hypersensitive to social and hierarchical information, and the ability to maturely grapple with the resulting self-identity questions lags behind.

spread of information about self-harm and suicide techniques (Lewis et al., 2011) to platforms that foster unhealthy amounts of social comparison (Braghieri et al., 2022). For example, a recent correlational study found that teen suicide in the United States spiked 28.9% in the month after the debut of Netflix's '13 Reasons Why' (Bridge, et al., 2020). Another point of view argues that the anonymity that characterizes Internet use can lead to pathological, compulsive or even self-harmful uses such as 'digital self-harm' (Patchin et al., 2022) [4] , FOMO or 'fear-of-missing-out' (Alt and Nissim, 2018)[5] , the 'online disinhibition effect' (Lapidot and Barak, 2012)[6] , and addiction. Finally, and partially related to the addictive component of the Internet, another viewpoint argues that the Internet may have an indirect effect on happiness by crowding-out healthier activities, like in-person interactions, exercise, or sleep (Hale and Guan, 2015; Sachs, 2017; Sachs 2018; Twenge, 2019; Twenge et al., 2019b).

Initial efforts by observational studies came from the fields of medicine and psychology. Those studies tended to be based on small sample sizes and found associations or correlations between teens' screen time and mental health problems (Orben and Przybylski, 2019; Kelly et al., 2019; Lin et al., 2016; Riehm et al., 2019). However, these studies tend to be inconclusive regarding the direction of causality. One problem is that teens are just as likely to turn to the Internet to alleviate feelings of loneliness and anxiety as it is for the Internet to be the cause of these same problems. Also, Internet use is often correlated with other socio-demographic characteristics, which might be the true cause of mental health issues. Ideally, one would use an exogenous source of variation in online media exposure, but those are hard to come by. Another problem arises from studies using self-reported mental health measures (e.g., Golin, 2022), as the Internet is a frequent source of information about emotional issues, which can affect a person's perception regardless of whether there is an actual effect on health or not. Finally, the few studies that have analyzed a specific platform to see its effects on mental health have focused on Facebook (Braghieri et al., 2022; Tromholt, 2016; Yuen

[4] Digital self-harm has been defined as the anonymous online posting, sending, or otherwise sharing of hurtful content about oneself.
[5] FOMO has been defined as the feeling of apprehension that one is either not in the know or missing out on information, events, experiences, or life decisions that could make one's life better and is often associated with anxiety and compulsive use of Internet.
[6] The online disinhibition effect relates to the increase in incivility and aggressive behavior in online environments due to anonymity.

et al., 2019), a platform rarely used by adolescents, so the results of these studies are difficult to extrapolate to teens.

In this study, we overcome these identification issues by exploiting exogenous variation in the deployment of optic fiber across Spanish provinces between 2007 and 2019 and use this variation to analyze the effect of access to high-speed Internet (HSI) on hospital discharge diagnoses of behavioral and mental health cases (BMH) of adolescents aged 15 to 19 years. Although Spain is a leader in the implementation of HSI through fiber, with more than 80% of the population covered by fiber networks in 2019, fiber use (or fiber penetration) did not increase homogeneously throughout the territory. Instead, fiber use came after the deployment of fiber infrastructure, which was the result of a strategic decision by the industry leader, Telefónica, whose presence in the different territories had more to do with historical and political factors than with socioeconomic or demographic ones. We leverage this plausibly exogenous variation in fiber infrastructure to instrument access to HSI. The use of exogenous variation in the rollout of the Internet infrastructure as an identification strategy is common in this literature (Bhuller et al. 2013; Akerman et al. 2015; Hvide et al. 2021; Falck et al. 2014; Donati et al. 2022; and Golin, 2022) although papers differ by the outcomes of interest and the source of exogeneity. [7]

To measure the prevalence of mental health problems among adolescents, we use administrative data from Spanish public and private hospital discharge diagnoses of behavioral and mental health cases (BMH). Our data comes at the province level and covers the period from 2007 to 2019[8]. Although we focus on boys and girls aged 15 to 19 years, we also report results for other age groups.

We focus on a period when mental health indicators among adolescents deteriorated greatly while new online media platforms surged to become extremely popular among teens.

We find fiber penetration significantly increases BMH cases in adolescents aged 15 to 19. One standard deviation (SD) increase in fiber penetration increases cases of BMH by 13.3%. Girls entirely drive this effect. When we analyze older individuals (20

[7] Bhuller et al. (2013) study the effect of Internet on sex crime, Akerman et al. (2015) on skill complementarity, and Hvide et al. (2015) on stock market investments. In these three papers the source of exogenous variation in the rollout of broadband infrastructure comes from a public program with limited funding. Falck et al. (2014) study the effect of Internet on voting behavior. Donati et al. (2022) and Golin (2022) also analyze the effect of Internet access on youth mental health, but their source of exogenous variation is different from ours as it comes from the distance of households to older pre-existing infrastructure (also in the case of Falck et al. 2014).

[8] Spain has 50 provinces plus the autonomous cities of Ceuta and Melilla, which due to their extremely sample size we exclude from our analysis.

to 24 years old), we do not find statistically significant results. Instead, we do find negative effects of Internet exposure for younger girls (ages 10-14) but, again, no effect for boys of that age. When we look at BMH cases by condition type, we find that fiber penetration increases the incidence of anxiety, mood disorders, drug abuse, self-harm, and suicide attempts, with most effects again due to girls. We document an exceptionally large effect on cases of self-harm and suicide attempts among girls aged 15 to 19 years (+112.3%) but no significant effect for boys.

To study the potential mechanisms, we use data from ESTUDES, a survey on Spanish teens aged 14 to 18 years, which asks them questions about their daily habits and about the quality of their relationship with their parents. Our sample has 184,587 individuals covering the period from 2006 to 2018. Using the same instrumental variable regression and we find support for the crowding-out hypothesis as access to HSI increases the addictive use of the Internet and significantly decreases time devoted to sleep, homework, and socializing with family and friends. All these effects are driven by girls. We do not find evidence of increased online bullying. We also find that fiber expansion has a negative effect on the quality of the relationship between parents and girls, but no effect is found for boys. Furthermore, we find that the impact of HSI on the parent-girl relationship is more negative when that relationship suffers from prior conflict.

Our results fit in a small, but growing, economics literature that uncovers causal links between access to online media and youth mental health. Our findings are consistent with Braghieri et al. (2022), who find that the gradual introduction of Facebook in US Universities worsened the mental health of college students due to Facebook fostering unfavorable social comparisons. They are also consistent with the findings of Nieto and Suhrcke (2021), who found that access to digital television in the UK led to unhealthy habits, which increased children's BMI and ended up worsening their mental health. Our finding of a more negative effect of the Internet on girls than boys is consistent with Braghieri et al (2022), Golin (2022)[9], and McDool et al. (2020)[10] . Closest to our paper, Donati et al (2022), find a causal negative effect of the expansion of broadband Internet (ADSL) on youth mental health in Italy between 2001 and 2013. Unlike their paper,

[9] Golin (2022) uses self-reported measures of wellbeing and mental health from the German Socio Economic Panel (SOEP) and finds that broadband Internet leads to worse mental health for women (primarily those aged 17–30) but not for men, thus widening the gender gap in mental disorders.
[10] They find that internet use is negatively associated with wellbeing across a number of domains for children aged 10 to 14 in England. The strongest effect is for how children feel about their appearance, and the effects are worse for girls than boys.

which focuses on a period when the use of social media was still limited, our paper focuses on a later period when teens were being exposed to new and very popular media and content platforms (Instagram, Tik-Tok, Netflix, HBO). Additionally, since ADSL preceded fiber, our study can be understood as an analysis of the marginal effects of an increase in Internet quality and speed. Overall, our results point to negative marginal effects of HSI on mental health at a time when the quantity and variety of online media available to teens skyrocketed. Given the particular emphasis on that technological change in social media and given girls' larger sensitivity to social interactions, especially during adolescence (LaFontana and Cillessen, 2010; Flook, 2011; Shih, 2006), it's not surprising that we find large negative effects for girls but not for boys.

We contribute to the literature in various ways. We are the first to study the link between access to HSI and adolescent mental health using data from hospital records at a time when teens were being exposed to new and very popular media and content platforms (Instagram, TikTok, Netflix, HBO). Second, we contribute to the debate about whether HSI worsens adolescent mental health due to crowding-out effects or other reasons, such as compulsive behavior or a widening gap in the adolescent brain's ability to process complex stimuli. We find support for both theories. Third, we are the first to document the negative effect of HSI on the quality of the relationship between adolescents and their parents. Finally, we complement the finding from previous studies of a gender gap in the effects of online media, where girls suffer more negative consequences than boys when exposed to the Internet.

The rest of the paper is organized as follows. Section II describes the fiber rollout in Spain. Section III presents the empirical methodology and the main results. Section IV discusses some potential mechanisms, and section V concludes.

2. Fiber penetration in Spain

Spain is one of the leading countries in the world in terms of fiber deployment. In 2019, 80% of the Spanish population was covered by FTTH fiber with more than 55% of Spanish homes connected to a fiber network. FTTH networks promise download speeds of over 100 Mbps, 20 to 100 times faster than typical cable modem or xDSL (Digital Subscriber Line) connections. FTTH networks also allow for greater symmetry, that is, more similar values for data upload and download speeds. The expansion of fiber and, consequently, of high-speed Internet, more stable and with greater symmetry, allowed the development and expansion of new online media platforms, such as HBO, Netflix,

Instagram and Tiktok, especially those that offer transmission media, that is, video or audio content sent in compressed form over the Internet and played immediately on a user's device.

Important for our identification strategy, the deployment of the fiber infrastructure was not homogeneous throughout the Spanish territory. Between 2007 and 2019, the number of lines installed went from almost 0 to an average of 121 lines per 100 inhabitants. But as shown in panel (a) of Figure 1, this increase was very uneven between the different provinces, reaching 156 lines per hundred inhabitants in Malaga in 2019 compared to only 62 in Lugo. More importantly, these differences between provinces do not seem to be explained by socioeconomic factors such as the level of GDP per capita or population density. In some cases, fiber deployment from provinces that were quite similar in terms of baseline characteristics followed very different trajectories, resulting in very different levels of fiber coverage (panel b in Figure 1). In other cases, provinces that followed very different trajectories started and reached the same level of fiber coverage in 2019 (panel c in the figure). Finally, in other cases, provinces followed a similar fiber deployment path despite radically different baseline characteristics (panel d).

The reasons why the deployment of fiber optics has been so uneven between provinces can range from regulatory issues to the average age of buildings or the need to compete strategically in the *premium* content market. Related to the latter, by 2010, the view of most telecommunication operators was that future competitive advantages would largely depend on the position in the *premium* content market. Given that this market is subject to significant economies of scale, telecommunications operators saw the need to build a broad customer base. Fiber networks, as opposed to the local loop of copper that was inherited and represents a sunk cost for operators, require new and significant levels of investment to be deployed. It's been estimated that operators have invested in Spain a total of 8 billion euros in the deployment of fiber networks, with civil engineering works accounting for up to 75% of FTTH CapEx spending.[11] Telefónica (or Movistar, its branding name), being the industry leader in Spain and the operator with the largest customer base, had the incentives and the financial muscle to lead this investment process. Successful fiber rollout models have been driven by incumbents in other countries as

[11] https://think.ing.com/articles/fibre-rollout-the-hardest-part-is-yet-to-come

well.[12] In addition, the Spanish regulator kept fiber networks closed to access by competitors in order to encourage investment efforts. Competitors could use Telefónica's old physical infrastructure to offer their services, but not so with the fiber networks that were excluded from the regulatory framework called MARCo until 2015. [13] It is in this context that Telefónica's strategy is clear: to reach the most far and as quickly as possible with the FTTH footprint, leaving the commercial effort for customers to switch to fiber for the future. This resulted in a large excess capacity whereby the percentage of lines in use did not exceed 10% of the total lines installed during much of the initial period.[14] Not surprisingly, the rush to develop this infrastructure was greater in those provinces where Telefónica faced greater competition in older xDSL technologies, which depended on factors such as the presence of newer operators (Vodafone, Orange, etc.) or operators with historical ties to certain northern regions.[15] Thus, Telefónica's ADSL market share in 2007 varied greatly between provinces, ranging from a minimum of 36% in Albacete to a maximum of 80% in Teruel. Note that these are two Spanish provinces that are quite similar in terms of GDP per capita and population density,[16] and yet Telefónica's presence in each of them was radically different. Interestingly, the increase in FTTH lines per 100 inhabitants made by Telefónica between 2007 and 2014 was 10 times greater in Albacete (16 lines) than in Teruel (1.63 lines), in line with the idea that the operators, led by Telefónica, used the deployment of fiber as a competitive strategy, especially in those provinces with neck-to-neck competition.

This competitive strategy was intensified in 2015 when the regulatory framework, MARCo, was modified, forcing Telefónica to offer competitors equal access to its infrastructure but only in those geographic areas identified by the Spanish regulator as 'low competition' areas, that is, areas in which Telefónica had a relatively high market share.[17] This did nothing more than amplify the differential in the incentives on the part

[12] https://www.adlittle.com/sites/default/files/viewpoints/ADL_RacetoGigabitFiber.pdf
[13] MARCo stands for Wholesale Access to Registers and Conduits Offer.
[14] Source: http://data.cnmc.es/datagraph/jsp/inf_anual.jsp
[15] This pattern has been seen in other countries as well: https://www.adlittle.com/sites/default/files/viewpoints/ADL_RacetoGigabitFiber.pdf
[16] In 2007 Albacete had a GDP per capita of 17,910€ compared to 25,005€ in Teruel. Albacete's population density in 2007 was 26 inhabitants per 100 sq km, compared to 10 in Teruel. By means of comparison, Madrid's GDP per capita that same year was 31,887€ and its population density was 756 inhabitants per sq km.
[17] According to the CNMC (Spanish National Commission for Markets and Competition), these 'low competition' areas represented 42% of the broadband market and Telefónica's market share climbed up to 64%, compared to the rest of areas where Telefónica's market share was significantly lower (34%). (https://blog.cnmc.es/2015/01/14/la-competencia-en-banda-ancha-segmentacion-geografica/)

of Telefónica to invest in the 'competitive' areas versus the other areas, since from that moment on, the greater need to compete in the 'competitive' areas was combined with the greater relative protection granted to the investment made there.

In short, for a combination of regulatory reasons and competitive strategy, the development of fiber networks has been very uneven throughout the Spanish territory, giving rise to penetration rates that have increased very differently over the years in these provinces. In the next section we show that the timing of fiber deployment is orthogonal to province baseline characteristics that might be correlated with adolescent mental health. We also show that the reference level of the degree of competition in broadband services is a statistically significant determinant of the timing of fiber expansion in each province. We will take advantage of this plausibly exogenous variation in fiber deployment to investigate the causal effect of HSI on adolescent mental health.

3. Empirical Methodology and Results

3.1 Hospital cases of behavior and mental health

To measure the prevalence of mental health problems among adolescents we use administrative data from Spanish public and private hospital discharge diagnoses of behavioral and mental health cases (BMH). They include nutrition disorders, anxiety, ADHD[18], mood disorders, personality disorders, schizophrenia, alcohol abuse, drugs abuse and, self-harm and suicide attempts.[19] [20] To measure fiber penetration, we use administrative data from the National Commission of Markets and Competition at province level. Our data comes at the province level and covers the period 2007 to 2019.

As a starting point, we explore the raw data to check the existence of patterns or relationships between our outcomes of interest and fiber penetration. Figure 2 displays on the left vertical axis the incidence of behavior and mental health cases (BMH) among boys and girls aged 15 to 19 years against fiber penetration, which is shown on the right vertical axis. The incidence of BMH cases is defined as the number of hospital diagnoses of BMH divided by one hundred inhabitants. Fiber penetration is the number of fiber lines

[18] ADHD stands for attention deficit hyperactivity disorder.
[19] We choose chapter 5 of the International Classification of Diseases (ICD-10) and add self-harm and suicide attempt.
[20] Data on health outcomes are available here: https://pestadistico.inteligenciadegestion.sanidad.gob.es/publicoSNS/N/siae/escri-siae, and data on fiber penetration are available here: http://data.cnmc.es/datagraph/

in use per inhabitant. The three series remain stable until 2013, the year after which they grow with similar intensity, although BMH cases grow slightly more among girls than in boys.

The patterns shown in Figure 2 are only illustrative or suggestive of a relationship between fiber penetration and BMH cases among adolescents. Obviously, they could be explained by underlying trends correlated with our outcomes of interest and with fiber penetration. To try to correct this, Figure 3 shows the results of removing province and year fixed effects from our raw data in the context of the following specification:

$$Y_{pt} = \propto_p + \tau_t + \varepsilon_{pt} \quad (1)$$

Where Y_{pt} is our outcome of interest, $\propto_p$ are province fixed effects and τ_t are year fixed effects. Panel a displays the residuals of separate regressions of equation (1) using fiber penetration and BMH cases as the dependent variables. We can see a substantial variation across provinces in the paste at which fiber penetration and mental health changed, something that later we will exploit as our source of identification. Also, and more importantly, there is a positive relationship between fiber penetration and mental health of adolescents: the provinces that compared to the general trend had a higher growth in fiber penetration also experienced a higher growth in BMH cases among adolescents aged 15 to 19 years. This pattern is confirmed in panel b of the same figure, which shows the coefficient estimates, β_i, of a regression of BMH cases, BMH_{pt}, against a set of dummy variables capturing five different levels of fiber penetration, $FiberP_{pt}^{i}$, and after controlling for year and province fixed effects (equation 2). Increasing fiber penetration has a positive and significant effect on the incidence of BMH cases among adolescents, with the maximum level of fiber penetration (>0.30) increasing BMH cases by 0.232 percentage points (35% of the sample average – 0.65).

$$BMH_{pt} = \sum_{i=1}^{5} FiberP_{pt}^{i}\beta_i + \propto_p + \tau_t + \varepsilon_{pt} \quad (2)$$

Despite the addition of province and year fixed effects, an OLS estimate of β_i will be biased if province-specific time-varying omitted variables are correlated with both mental health and fiber use. To address this concern, we propose that a source of exogenous variation in fiber use comes from the gradual expansion of fiber infrastructure over the period 2007-2019. More specifically, our main analysis is based on two-stage least-squares (2SLS) estimation of β with equation (3) as the "second stage":

$$BMH_{pt} = FiberP_{pt}\beta + X'\gamma + Z'\theta + \propto_p + \tau_t + \varepsilon_{pt} \quad (3)$$

and equation (4) as the "first-stage":

$$FiberP_{pt} = FiberI_{pt-1}\mu + X'\gamma + Z'\theta + \propto_p + \tau_t + \sigma_{pt} \quad (4)$$

$FiberI_{pt}$ in equation (4) is the number of lines of optic fiber installed (not necessarily in use) in province p and time t-1 and measures the deployment of fiber infrastructure. Note that equation (3) expands equation (2) by adding two new sets of controls: $X' \; and \; Z'$. X' includes time-varying, i.e., contemporaneous, controls for the level of GDP, GDP per capita, population, population density and the total number of hospital diagnoses for the entire population of each province and year (expressed as hospital cases per one hundred inhabitants). This last variable allows us to capture all factors that affect the general health of the population as well as factors that might influence the access to health services in a given province and year. Additionally, Z' includes the interaction of year dummies with the same covariates as in X' evaluated at their baseline level, that is in 2007. This allows us to control not only for time-invariant province characteristics but also for differential trends related to key demographics. Hence, our identification strategy requires that – once we account for those demographic related trends – the correlation between fiber infrastructure and adolescents' mental health did not change other than through the use of fiber-optic internet.

Although the exogeneity assumption of our instrument cannot be evaluated empirically, we can provide suggestive evidence in support of that assumption. One concern with our instrument is that provinces with different fiber infrastructure shocks could be also different in terms of their baseline characteristics and outcomes before the shocks.[21] One way to assess this concern is to estimate the following specification separately for each calendar year of the deployment of fiber-optic:

$$\Delta FiberI_{pt} = S'_{p,2007}\beta + \varepsilon_{pt} \quad (5)$$

where, $\Delta FiberI_{pt} = \Delta FiberI_{pt} - \Delta FiberI_{pt-1}$, and $S'_{p,2007}$ is a vector that includes the same characteristics as Z' (GDP, GDP per capita, population, population density, GDP per capita * population density) and the incidence of BMH cases among adolescents, all measured in the initial year 2007. Figure 4 plots the estimated coefficients from the vector β for every year, with associated 95% confidence intervals.[22] Importantly, we find no general correlation between changes in the instrument and baseline levels of key demographics including the baseline level of adolescent mental health. Put

[21] In reality, because our specifications include different trends related to key demographics, the exogeneity assumption is that the instrument is exogenous conditional on those controls.
[22] This is the same diagnostic test as the one used in Bhuller et al. (2013), Akerman et al. (2015) and Hvide et al. (2021).

differently, neither the level nor the timing of the roll-out of optic fiber seem to be correlated with our key demographics. In those few instances in which the estimated coefficients are statistically significant, there is no clear or consistent pattern of a relationship between the deployment of optic fiber and a given demographic. Recall also, that any residual correlation between our instrument and baseline levels of key demographics will be captured by the inclusion of Z' in our regressions. Interestingly, panel g of Figure 4 shows a clear pattern between the roll-out of optic fiber and the market share of the leader, Movistar, in 2007. Those provinces in which Movistar enjoyed a bigger xDSL market share in 2007 had a later expansion of fiber infrastructure, that is, the growth of installed lines was significantly lower in the initial years, between 2014 and 2017, to then catch-up in 2018 and 2019. Also relevant for our analysis, the market share of Movistar in 2007 seems to be orthogonal to the key demographics of our model (panel h).

3.1.1. Results from the IV specification

Columns (2) to (6) in Table 1 report IV estimates of β from equation (3). Moving from one column to the next shows the impact of adding controls progressively. For the sake of comparability, we also show the results of OLS regressions (in column 1) and of IV estimates for young individuals aged 20 to 24 (columns 7 to 9). The OLS fixed-effects estimate (column 1) shows a positive and significant impact of fiber penetration on BMH cases of adolescents aged 15 to 19. A one standard deviation (SD) increase of fiber penetration raises BMH cases by 13.3%. Moving from the OLS to the IV estimate in column (2) leads to a bigger and statistically significant impact. The coefficient grows from 1.295 to 1.822, and the economic effect of one SD increase of fiber penetration, from 13.3% to 18.8%. Adding contemporaneous controls (X') decreases the coefficient, but adding trends interacted with baseline levels of the covariates (Z') increases it. At the end, moving from the unadjusted estimate of column (2) to the fully adjusted estimate of column (4) results in a larger coefficient, with the economic impact increasing from 13.3% to 24.5%, statistically significant at the 10% level. Columns (5) and (6) report the IV estimates by gender and show that the positive effect of fiber penetration on BMH cases is driven by girls. The estimated coefficient for males is 1.199, not statistically significant, whereas the estimated coefficient for females is 3.631, significant at the 5% level, and with an economic impact of 35.3%. These results are consistent with the

patterns shown in Figure 1 displaying a stronger correlation between fiber penetration and BMH cases among girls than boys. Finally, columns (7) to (9) show the IV fully adjusted estimates for young individuals aged 20 to 24 (column 7) and for boys (column 8) and girls (column 9) of the same age, separately. All three estimated coefficients are statistically insignificant and of a much smaller magnitude than the ones found for adolescents. Similarly insignificant effects for individuals 20 to 24 years of age across different types of BMH cases are shown in appendix table A.1. Overall, Table 1 indicates that optic fiber penetration worsens the mental health of adolescent girls and has smaller and insignificant effects for adolescent boys and individuals of an older age.

We turn now to the results of Table 2 which shows the impact of fiber penetration on adolescents' BMH by type of medical condition. The table shows the IV estimates for cases of: nutrition disorders, anxiety, ADHD, mood disorders, personality disorders, schizophrenia, alcohol abuse, Drugs abuse and, self-harm and suicide attempts. We present results for all individuals in Panel (a), for boys in Panel (b) and for girls in Panel (c). A first thing to note from Table 2 is the pervasiveness of positive coefficients (negative health effects of fiber penetration) across the nine dimensions, except for nutrition disorders. Being quite rare events and given the small number of observations itis not surprising that standard errors are often high and some of the coefficients are not statistically significant despite their large magnitudes. Focusing on the statistically significant effects, fiber penetration increases the incidence of cases of anxiety (column 2), mood disorder (column 4), drugs abuse (column 8) and self-harm and suicide attempts (column 9). The economic effects of a one SD increase of fiber penetration are large, ranging from 52.4% in the case of mood disorders to 81.5% in the case of self-harm and suicide attempts. A third clear pattern from Table 2 is that those significant effects are driven by girls and not by boys. This is true for all medical conditions with significant effects except for mood disorders, where the coefficient and the economic effect for girls are bigger than those of boys but not statistically significant. The case of self-harm and suicide attempts is quite striking with an exceptionally large positive and significant effect for girls (+112.3%) but no significant effect for boys. Overall, Table 2 portrays a picture that again is consistent with the patterns observed in Figure 1. Interestingly, appendix table A.2 shows a quite similar pattern for boys and girls aged 10-14 years. In that table, fiber penetration is shown to increase the incidence of drugs abuse cases and self-harm and suicide attempts cases among girls aged 10-14 years but not among boys. As already

mentioned, appendix table A.1 shows no significant effects for individuals aged 20-24 years.

3.1.2. Placebo and robustness tests

Table 3 shows the results of two placebo tests. In panel (a) we show the results of estimating the impact of fiber penetration on the mental health of adolescents during the period prior to 2013, when fiber penetration increased very modestly from 0.03 to 0.04 lines per inhabitant. The first stage estimate of the coefficient on installed fiber infrastructure is statistically significant and with the correct sign, but the IV estimates of the effects of fiber penetration (step 2) are all statistically insignificant and only positive (but of a much smaller magnitude) in the case of girls. In panel (b) we show the results of estimating our preferred specification but in which the variable to be instrumented is xDSL penetration instead of fiber penetration. We perform this analysis for the period between 2007 and 2012 because during that period the xDSL penetration was growing and, that technology was still not being substituted by optic fiber. One concern is that our IV (fiber infrastructure at t-1) could be spuriously correlated with another technology (e.g., xDSL) and this be the cause of the evolution of BMH cases. Reassuringly, our first stage parameter estimates are not statistically significant, and the second stage coefficients are also statistically insignificant. Overall, the results of both panel (a) and (b) of Table 4 indicate that our results are not picking up the effect of xDSL on the mental health of adolescents.

Table 4 shows the results of various sensitivity tests. We focus on the main results, that is, the aggregate effects for the entire population, for boys and for girls, separately, and for the three types of BMH cases with significant effects (anxiety, drugs abuse and self-harm and suicide attempts). Panel (a) shows the results of our preferred specification to facilitate comparison with the rest of the results. In panel (b) we estimate our preferred specification removing the contemporaneous population and population density controls. This is to rule out that these controls are absorbing the effect of fiber penetration on BMH cases due to changes in the population of a province caused by the expansion of fiber infrastructure. If the improvement of fiber optic networks in a province attracted more population and if more population had effects on the mental health of its inhabitants, the inclusion of population controls in our regression would not allow our variable of interest to capture this effect. As can be seen in panel (b) of Table 5, excluding population controls from our specification has little or no effect in our estimated results.

In panel (c) we estimate the effects of fiber penetration on BMH cases, evaluated at the extensive margin. We estimate linear probability models using the same IV technique as before but where the dependent variable is a dummy variable which takes value 1 if that province-year had a positive number of cases of a given medical condition. We do not report the estimated effects for all BMH cases (columns 1 to 3) because the lack of variability in the dependent variable, which takes value 1 across all provinces and years. The results of this exercise should be taken with caution given the reduced number of zeroes of the dependent variable in some cases (for example, only 5% of province-year observations had no drugs abuse cases among males). The effect of fiber penetration on anxiety cases and self-harm and suicide attempts cases among girls continues to be positive and statistically significant, not so for drugs abuse cases, with a negative and statistically insignificant coefficient.

We move now to panel (d), where we show the results of estimating our main specification using only the years from 2012 to 2019. We perform this test to rule out that our estimates are capturing the effect of xDLS expansion, rather than fiber optics, on adolescent mental health. By excluding the years 2007-2011 from our sample, we exclude a time period in which xDSL was still being expanded contrary to fiber optics, which remained close to nonexistent in most provinces. Note that the exclusion of 2007-2011 reduces the efficiency of our estimates, by eliminating more than 40% of our sample. Therefore, it's not surprising to see an overall increase of standard errors in panel (d). Despite this, most estimates remain close to their previous values and statistically significant, with the exception of the coefficient of all BMH cases and all genres (2.405 in column 1), which has a very similar value than before but is not statistically significant. Panel (e) reports the p-values of the estimated coefficients after implementing the Romano-Wolf (2016) step-down multiple hypothesis correction method of the standard errors on each of the nine outcomes (the nine medical conditions displayed in Table 2). Intuitively, the multiple hypothesis correction methods adjust p-values for the fact that the number of false positives (type-1 error) increases with the number of tests performed. Typically, these methods result in considerable increases of the p-values. The estimated effect of fiber penetration on drugs abuse cases and on self-harm and suicide attempts cases among girls continues to be statistically significant, not so the coefficient on anxiety cases.

Finally, Appendix table A.3 replicates the estimates of Table 1 but excluding from our measure of BMH the cases of self-harm and suicide attempts. We perform this final

robustness test for two reasons. One, to be consistent with the international classification system ICD-10, which excludes self-harm and suicide attempts from mental health cases, included in chapter 5. Second, to check to what extent our BMH aggregate effects are driven by self-harm and suicide attempts, the type of behavioral disorder that shows the strongest effects. Overall, Table A.3 shows a similar pattern than Table 1: fiber penetration increases the incidence of BMH cases among adolescents aged 15-19 years, a result that is driven by girls of that age group.

4. Mechanisms

In this section we explore if the expansion of fiber has changed the patterns of Internet use among adolescents and if this has had an effect on other uses of time. For this purpose, we use data from ESTUDES, a biannual cross-sectional survey of adolescents between 14 and 18 years of age, which seeks to identify the habits of adolescents in matters such as drug use, Internet use, and relationships with friends and family. The survey sample size varies but averages around 30,000 respondents for each wave. The available waves cover the period 2006-2018 and we use those that consistently contain the information we are interested in. In section 4.1 we analyze Internet usage patterns and their impact on other uses of time. These questions are covered in a battery of questions that unfortunately are only present in the waves from 2014 onwards, so the analysis of these questions must be taken with caution given the short time span and small sample that we can use. Even so, we have a total sample size of 95,998 individuals, 48,842 of which are girls, and the rest (47,156) are boys. In section 4.2 we analyze the impact of Internet use on the relationships between teens and their parents. For this analysis we use all waves from 2006 onwards, with a total sample size of 184,587 individuals (94,649 girls; 89,938 boys).

To estimate the impact of fiber expansion on other uses of time and on the relationship between adolescents and their parents we follow the same 2SLQ specification as before and fit the following equation:

$$IUD_{ipt} = FiberP_{ipt}\beta + X'\gamma + \propto_p + \tau_t + \varepsilon_{pt} \quad (6)$$

with equation (7) as the "first-stage":

$$FiberP_{ipt} = FiberI_{ipt-1}\mu + X'\gamma + \propto_p + \tau_t + \sigma_{pt} \quad (7)$$

$FiberI_{pt}$ in equation (7) is again the number of lines of optic fiber installed (not necessarily in use) in province p and time t-1. $FiberP_{pt}$ are fiber lines in use per 100 inhabitants in province p, at time t, and IUD_{ipt} are dummies indicating patterns of Internet

use by individual i living in province p, at time t. The vector X includes individual controls (age and country of origin) plus household level controls (the work status and level of education of each parent). Finally, $\propto_p$ are province fixed effects and τ_t are year fixed effects.

a. Patterns of Internet use and impact on alternative uses of time

In this section we explore patterns of Internet use and its impact on other uses of time by adolescents. The detail of the questions is shown in Appendix Table 4. We construct an indicator of signs of addictive behavior towards Internet use. This indicator is a dummy variable taking value 1 if the individual answers frequently or very frequently to any of statements 1, 2, 3, 6, 7, 8, 9 or 14. All these statements point to the difficulty or anxiety in trying to reduce Internet use. We then construct an indicator of Internet use potentially crowding-out sleep time by means of a dummy variable taking value 1 if the individual answers frequently or very frequently to statement 5; an indicator of Internet use crowding-out time devoted to homework if the individual answers frequently or very frequently to statement 10 or 11; an indicator of Internet use crowding-out time devoted to socializing if the individual answers frequently or very frequently to statement 4; an indicator of Internet use to cope with feelings of sadness if the individual answers frequently or very frequently to statements 12 or 13; and an indicator of bullying through the Internet if the individual answer frequently or very frequently to statement 15. These dummy variables are our outcomes of interest in equation (6).

Table 5 shows the results of this analysis separately for boys and girls. The first noticeable thing from table 5 is that the expansion of fiber has very significant effects on patterns of Internet use for girls but not for boys, something that is consistent with our previous finding of a gender gap in mental health effects of Internet. More specifically, the expansion of fiber results in a significant increase in the use of the Internet in an addictive way for girls. A one standard deviation increase in fiber penetration increase the use of Internet in an addictive way by almost 9%, statistically significant at the 5% level. The effect is 3.6% for boys and not statistically significant. Consistent with this pattern of addictive use, the results of the table show that exposure to high-speed Internet crowds out other uses of time among girls, such as sleep time (21%), time devoted to homework (30%) and time socializing with family and friends (44%). Again, we do not find statistically significant effects for boys, except for time devoted to homework, but even in this case the magnitude of the effect is much larger for girls than for boys (+30%

for girls versus +17% in the case of boys). The analysis reveals that the expansion of fiber increases the proportion of girls that respond that they rely on the Internet as a coping mechanism to deal with negative feelings or when they feel 'low'. Finally, and perhaps a little surprisingly, column (6) of the table shows that fiber expansion has no effect on the probability of being a victim of online bullying, neither for girls nor for boys.

Overall, the results of Table 5 portray a situation in which girls develop 'unhealthy' habits towards the Internet as they get access to high-speed networks. And although they rely on the Internet to deal with negative emotions and do so increasingly when the quality of the networks improves, it is not clear that this use derives any benefit for them, as we will see in the next section.

b. Internet use and the relationship between adolescents and their parents

Previous research in the fields of medicine and psychology has found a negative association between pathological Internet use (PIU) and the quality of the parent-adolescent relationship (Matalí-Costa et al., 2014; Liu et al., 2019; Alt and Boniel, 2018; Özaslan et al., 2022). In that literature, the direction of causality is often unclear, potentially working both ways. For example, girls often state that they turn to the Internet to deal with anxiety problems caused, among other things, by a bad relationship with their parents. At the same time, excessive Internet use can negatively affect the relationship between teens and their parents by isolating them from each other. In fact, one could think of a self-reinforcing effect whereby adolescents in conflict with their parents develop patterns of excessive Internet use and isolation that worsen the relationship between them. High-speed Internet could exacerbate these effects by making it easier for parents and teens to view content in silos, separate from one another. Whether the Internet in general, and the expansion of fiber in particular, is detrimental to the parent-teen relationship is ultimately an empirical question, but if the effects were negative, one would expect to see more negative effects for relationships that already were problematic. For example, if girls have a more conflictive relationship with their parents during adolescence than do boys (which is supported by the data), then the effect of fiber expansion on the parent-adolescent relationship could be more negative for girls than for boys.

To analyze this question, we exploit the information from two questions in ESTUDES that directly asks teens about the relationship with their parents. The first of these questions asks if the adolescent has had any major arguments or conflicts with their parents or siblings in the last year. On average, 34% of individuals answer YES to that

question (30% of all boys and 38% of all girls). We later use this question to identify relationships potentially conflictive. The second question asks about the quality of the relationship with each parent as of now, with five given options (1 – very bad; 2 – quite bad; 3 – neither good nor bad; 4 – quite good; 5 – very good). We construct a dummy variable that takes value 0 if the individual answers 1, 2 or 3, and 1 otherwise. On average, 80% of the adolescents in the sample state that they have a fairly good or very good relationship with their father. This percentage rises to 86% when the question refers to the relationship with the mother. Looking at gender differences, girls have more conflict with their parents than boys, especially when the question refers to the relationship with the father. While 83% of boys say they have a good or very good relationship with their father, this percentage drops to 77% in the case of girls. Similarly, 87% of boys claim to have a good or very good relationship with their mother, compared to 84% in the case of girls.

To estimate the impact of fiber expansion on the relationship between adolescents and parents we estimate equations (6) and (7) by 2SLQ. The results of this analysis are shown in Table 6. The results in the table show two interesting patterns: (1) fiber expansion has a negative effect on the quality of the relationship between parents and adolescents, an effect that is driven by girls; (2) the impact of fiber expansion on the father-adolescent relationship is more negative when that relationship is already conflict-prone, that is, the girl-father relationship and relationships with significant conflict in the previous year. For example, in panel (a) of column (4) a one standard deviation increase in fiber penetration decreases the probability of a good relationship between girl and father by 1.57% (significant at the 5% level) but has a smaller negative effect on the girl-mother relationship (-1.01% in panel (b) of the same column) and no statistically significant effect on the boy-father relationship (column 7). Also, the negative effect of high-speed Internet on the girl-father relationship increases to -2.43% when that relationship suffered from important conflicts the previous year but is zero when the relationship presented no conflict the previous year. It is not clear why fiber expansion has a detrimental effect on the relationship between girls and their parents, but not on that of boys. One possibility, consistent with our previous results, is that more girls than boys develop a tendency to pathologically use the Internet when they feel anxious about a troubled relationship with their parents, crowing out healthier strategies to deal with family conflicts. Another possibility is that behavioral and mental health problems caused by inappropriate use of

the Internet, which we have shown affect girls more than boys, hinder a good and healthy relationship between them and their parents.

5. Conclusion

In many countries, suicide attempts and suicide ideation among adolescents have been increasing, especially among girls and after the mid-2010s. This paper shows consistent evidence suggesting a causal relationship between access to high-speed internet and behavioral and mental health cases of adolescents aged 15 to 19 years, particularly for girls. We focus on the period 2007-2019 when mental health indicators among adolescents deteriorated greatly while new online media platforms surged to become extremely popular among teens. We find that fiber penetration significantly increases BMH cases in adolescents aged 15 to 19 years (one standard deviation increase in fiber penetration increases cases of BMH by 13.3%), and girls entirely drive this effect. We document an exceptionally large effect on cases of self-harm and suicide attempts among girls aged 15 to 19 years (+112.3%), but no significant effect for boys.

In terms of potential mechanisms, we find support for the crowding-out hypothesis as access to HSI increases the addictive use of the Internet and decreases significantly time devoted to sleep, homework, and socializing with family and friends. Girls drive all these effects. We do not find evidence of increased online bullying. We also find that fiber expansion has a negative effect on the quality of the relationship between parents and girls, but no effect is found for boys.

Adolescence is a critical and potentially vulnerable time for social and emotional development. Mental health problems during adolescence play a substantial role in explaining later education and employment; they do even more than physical health problems (Currie et al. 2010). So understanding social media's effects on health at this stage is vital. The evidence presented in this paper calls for policy interventions to mitigate the impact of social media on adolescents' mental health.

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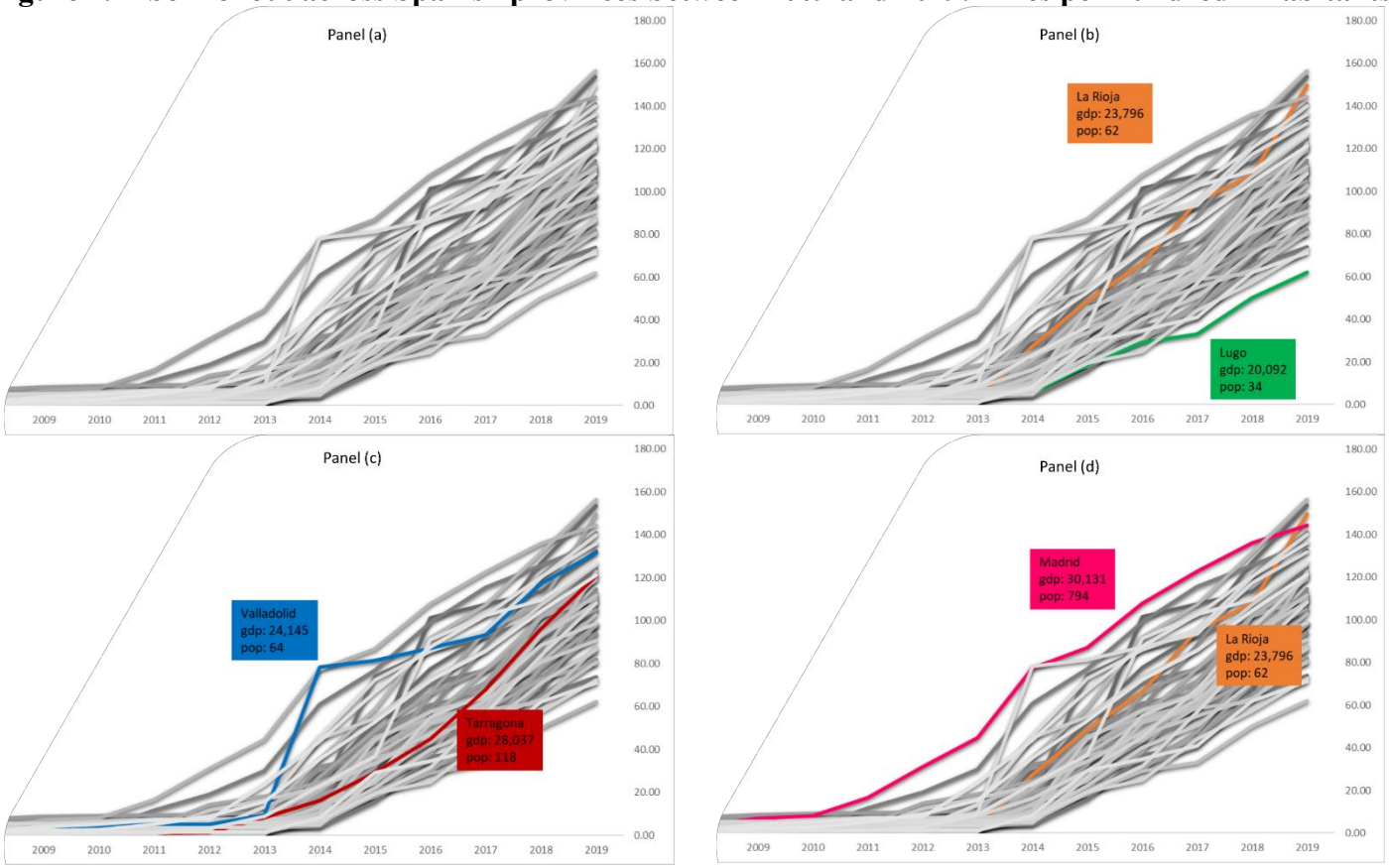
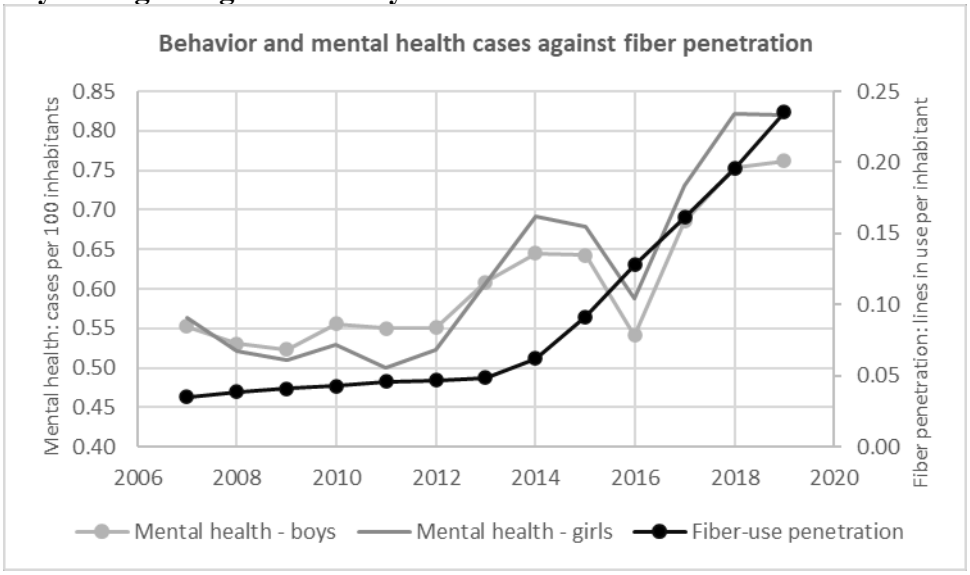
Figures and Tables

Figure 1. Fiber rollout across Spanish provinces between 2009 and 2019. Lines per hundred inhabitants



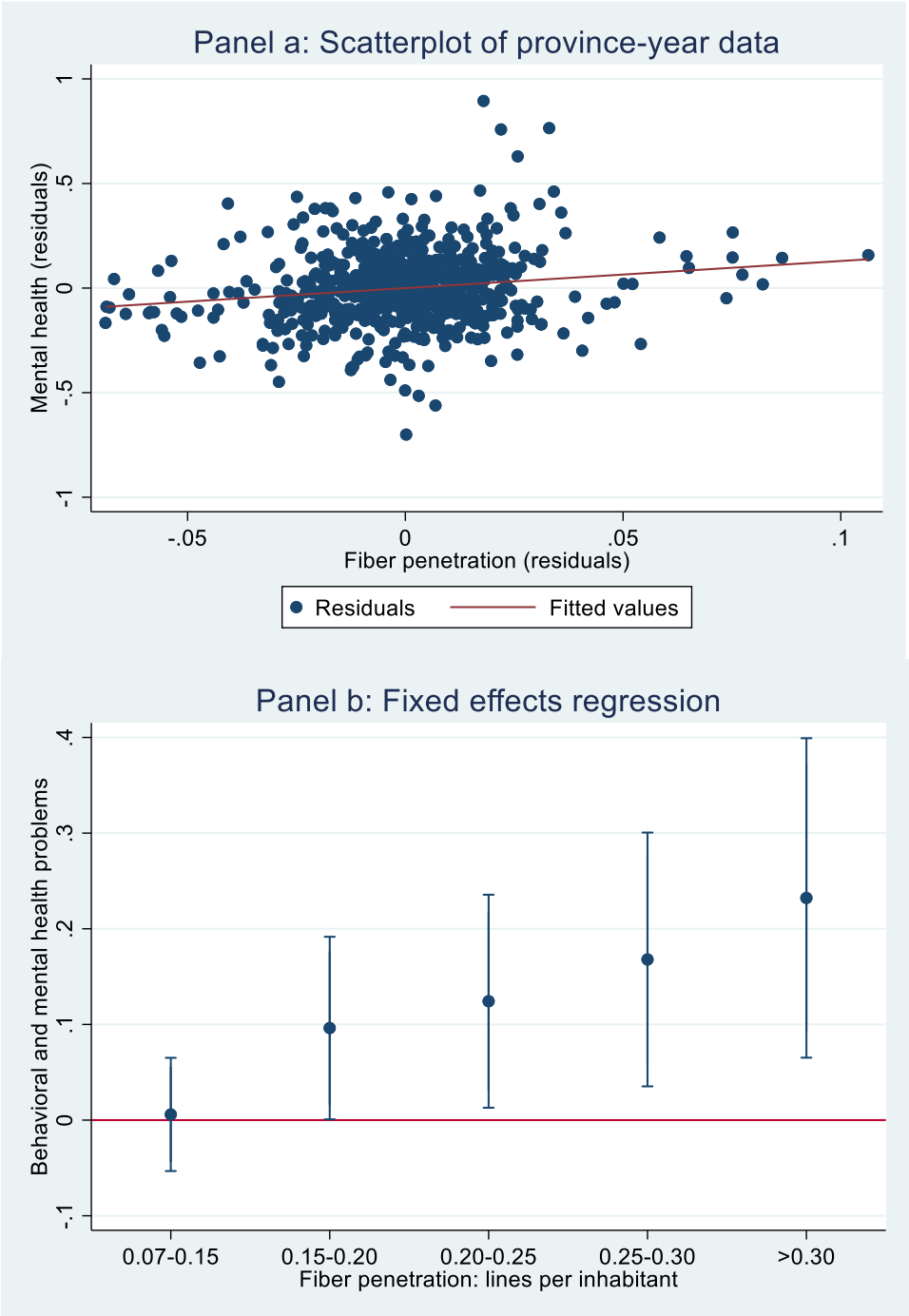
Source: Elaborated by the authors based on official data available in http://data.cnmc.es/datagraph/index.jsp. 'gdp' shows the level of GDP per capita (€) in the province in 2007. 'pop' shows the population density (inhabitants per km^2) in the province in 2007.

Figure 2. Fiber penetration and behavioral and mental health (BMH) cases among boys and girls aged 15 to 19 years – Raw Data: 2007-2019.



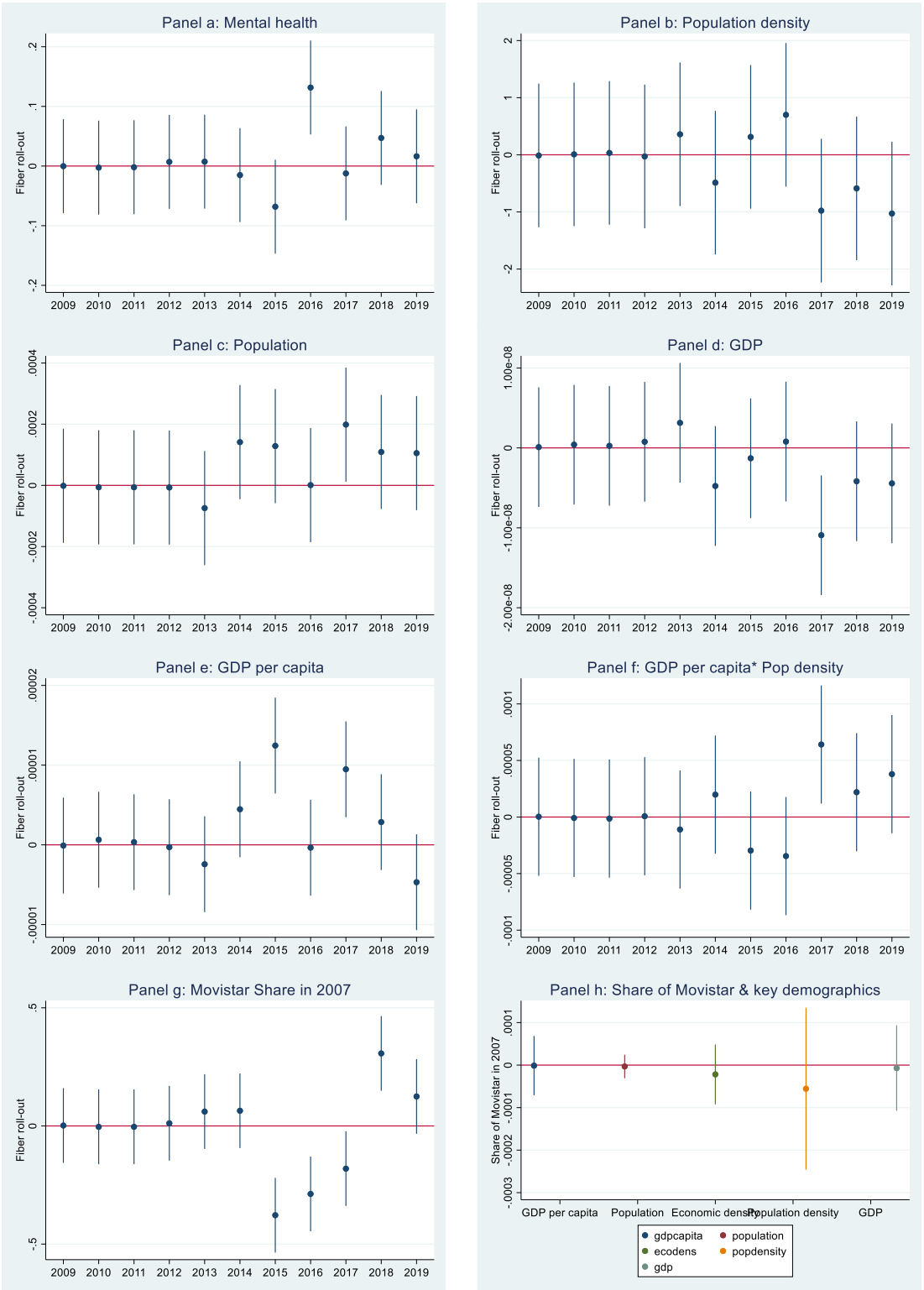
Notes: Elaborated by the authors based on administrative data from Spanish public and private hospital discharge diagnoses of behavioral and mental health cases and data from of fiber use from the National Commission of Markets and Competition.

Figure 3. Fiber penetration and behavioral and BMH cases among boys and girls aged 15 to 19 years – Raw data after removing province and year fixed effects: 2007-2019.



Notes: Panel a) plot the residuals of our mental health indicator (BMH cases) versus the residuals of fiber penetration after removing province and year fixed effects from both series (see equation 1). Panel b) shows the coefficient estimates of a regression of BMH cases by province-year against a set of dummy variables capturing five different levels of fiber penetration and after controlling for year and province fixed effects (equation 2).

Figure 4. Timing of fiber roll-out and baseline covariates



Notes: Panels a) to g) display the coefficient estimates of regressing, speparately for each calend year, the increase of fiber infraestructure (annual change in the number of lines installed) versus a vector of province characteristics in the initial year 2007. Panel h) displays the coefficient estimates from regressing the Movistar market share in 2007 versus socioeconomic characteristics of different provinces.

Table 1. The effect of fiber penetration on the mental health of adolescents aged 15 to 19 years: 2007-2019

	Dependent variable: hospital cases of BMH per one hundred inhabitants								
		15 to 19 years old					20 to 24 years old		
	OLS	IV							
	All	All	All	All	Boys	Girls	All	Boys	Girls
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Fiber penetration (lines per inhabitant)	**1.295****	**1.822****	1.300	**2.378***	1.199	**3.631****	0.282	1.295	-0.727
SE	**(0.607)**	**(0.935)**	(0.888)	**(1.419)**	(1.750)	**(1.629)**	(1.085)	(1.755)	(1.724)
Impact of a one SD increase in fiber penetration	13.3%	18.8%	13.4%	24.5%	13.2%	35.3%	1.9%	7.7%	-5.7%
Mean of dependent variable	0.65	0.65	0.65	0.65	0.61	0.69	1.00	1.12	0.86
First stage coefficient		0.146***	0.138***	0.111***	0.111***	0.111***	0.111***	0.111***	0.111***
SE		(0.026)	(0.020)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
N	650	600	600	600	600	600	600	600	600
Adj R2	0.30	0.31	0.41	0.44	0.24	0.42	0.32	0.21	0.29
State and year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Contemporaneous controls (X')	NO	NO	YES	YES	YES	YES	YES	YES	YES
Baseline covariates interacted with year effects (Z')	NO	NO	NO	YES	YES	YES	YES	YES	YES

Notes: * Significant at 10%, ** significant at 5%, and *** significant at 1%. Robust standard errors clustered at the province level. Behavior & BMH cases is chapter 5 of the International Classification of Diseases (ICD-10). Self-harm and suicide attempt does not belong to chapter 5 of ICD-10 and it's added to the calculation of BMH. IV regression (except for column 1) of BMH against fiber penetration, where fiber penetration (lines in use) is instrumented with installed FTTH infrastructure at t-1. The SD of fiber penetration is 0.067 for the entire sample period. Contemporaneous controls X' include population density, total population, real GDP per capita, aggregate real GDP and the total incidence (cases per 100 inhabitants) of hospital cases for all age groups and all medical conditions. All controls are measured at the province level. Baseline characteristics at the province level interacted with year dummies (Z') are the same covariates as in X measured at their value in 2007.

Table 2. The effect of fiber penetration on the mental health of adolescents aged 15 to 19 years by type of medical condition: 2007-2019

	IV estimates Dependent variable: hospital cases of BMH per one hundred inhabitants								
	Nutrition disorder (1)	Anxiety (2)	ADHD (3)	Mood disorder (4)	Personality disorder (5)	Schizophrenia (6)	Alcohol abuse (7)	Drugs abuse (8)	Self-harm and suicide attempt (9)
Panel a. all adolescents									
Fiber penetration	-0.142	**0.319***	0.082	**0.297***	0.130	0.075	0.017	**0.953****	**0.499***
SE	(0.130)	**(0.191)**	(0.280)	**(0.177)**	(0.185)	(0.139)	(0.168)	**(0.488)**	**(0.268)**
Impact of a one SD increase in fiber penetration	-45.3%	68.9%	13.4%	52.4%	19.8%	17.3%	3.8%	50.7%	81.5%
Mean of dependent variable	0.021	0.031	0.041	0.038	0.044	0.029	0.030	0.126	0.041
panel b. boys									
Fiber penetration	0.014	0.098	0.171	0.171	-0.051	0.086	-0.061	0.761	-0.089
SE	(0.123)	(0.202)	(0.379)	(0.129)	(0.171)	(0.208)	(0.284)	(0.634)	(0.181)
Impact of a one SD increase in fiber penetration	6.3%	34.6%	21.2%	45.8%	-14.2%	14.1%	-10.0%	33.5%	-33.1%
Mean of dependent variable	0.015	0.019	0.054	0.025	0.024	0.041	0.041	0.152	0.018
panel c. girls									
Fiber penetration	-0.309	**0.551***	-0.008	0.427	0.318	0.066	0.102	**1.157****	**1.123*****
SE	(0.257)	**(0.323)**	(0.219)	(0.288)	(0.346)	(0.128)	(0.089)	**(0.577)**	**(0.463)**
Impact of a one SD increase in fiber penetration	-76.7%	83.9%	-1.8%	56.1%	33.3%	26.0%	36.0%	79.1%	112.3%
Mean of dependent variable	0.027	0.044	0.029	0.051	0.064	0.017	0.019	0.098	0.067
N	600	600	600	600	600	600	600	600	600
State and year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Contemporaneous controls (X')	YES	YES	YES	YES	YES	YES	YES	YES	YES
Baseline covariates interacted with year effects (Z')	YES	YES	YES	YES	YES	YES	YES	YES	YES

Notes: * Significant at 10%, ** significant at 5%, and *** significant at 1%. Robust standard errors clustered at the province level. Behavior & BMH cases is chapter 5 of the International Classification of Diseases (ICD-10). Self-harm and suicide attempt does not belong to chapter 5 of ICD-10. IV regression (except for column 1) of BMH against fiber penetration, where fiber penetration (lines in use) is instrumented with installed FTTH infrastructure at t-1. The SD of fiber penetration is 0.067 for the entire sample period. Contemporaneous controls X' include population density, total population, real GDP per capita, aggregate real GDP and the total incidence (cases per 100 inhabitants) of hospital cases for all age groups and all medical conditions. All controls are measured at the province level. Baseline characteristics at the province level interacted with year dummies (Z') are the same covariates as in X measured at their value in 2007.

Table 3. Placebo estimates. The effect of fiber penetration on the mental health of adolescents aged 15 to 19: 2007-2012

	IV estimates

	Dependent variable: hospital cases of BMH per one hundred inhabitants		
	All	Boys	Girls
	(1)	(2)	(3)
Panel a. IV for fiber penetration			
Fiber penetration	-5.208	-11.333	1.304
SE	(10.539)	(10.099)	(12.363
Mean of dependent variable	0.56	0.57	0.55
First-stage coefficient on fiber infrastructure	0.215***	0.215***	0.215***
SE	(0.054)	(0.054)	(0.054)
R2	0.07	0.05	0.11
N	250	250	250
Panel b. IV for xDSL penetration			
XDSL penetration	-61.259	-133.287	15.344
SE	(339.058)	(771.401)	(201.91)
Mean of dependent variable	0.56	0.57	0.55
First-stage coefficient on fiber infrastructure	0.018	0.018	0.018
SE	(0.108)	(0.108)	(0.108)
R2	0.33	0.69	0.19
N	250	250	250
State and year FE	YES	YES	YES
Contemporaneous controls (X')	YES	YES	YES
Baseline covariates interacted with year effects (Z')	YES	YES	YES

Notes: * Significant at 10%, ** significant at 5%, and *** significant at 1%. Robust standard errors clustered at the province level. Panel (a) shows the results of estimating the impact of fiber penetration on the mental health of adolescents during the period 2007-2013.

Table 4. The effect of fiber penetration on the mental health of adolescents aged 15 to 19. Robustness tests.

	IV estimates Dependent variable: hospital cases of BMH per one hundred inhabitants								
	All behavior and mental Health problems			Anxiety		Drugs abuse		Self-harm and suicide attempts	
	All	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

Panel a. Main specification									
Fiber penetration	**2.378***	1.199	**3.631****	0.098	**0.551***	0.761	**1.157****	-0.089	**1.123*****
SE	**(1.419)**	(1.750)	**(1.629)**	(0.202)	**(0.323)**	(0.634)	**(0.577)**	(0.181)	**(0.463)**
Panel b. Excluding population									
Fiber penetration	**2.395***	1.300	**3.557****	0.097	**0.550***	0.821	**1.150****	-0.096	**1.152*****
SE	**(1.465)**	(1.773)	**(1.716)**	(0.204)	**(0.336)**	(0.639)	**(0.599)**	(0.187)	**(0.478)**
Panel c. Extensive margin									
Fiber penetration	n.a	n.a	n.a	0.421	**2.422***	0.664	-1.530	-0.061	**2.466***
SE				(2.285)	**(1.502)**	(0.958)	(1.854)	(2.389)	**(1.540)**
Panel d. 2012-2019									
Fiber penetration	2.405	0.273	**4.660****	0.178	**0.801***	0.697	**1.700****	-0.137	**1.715*****
SE	(1.802)	(2.214)	**(2.074)**	(0.191)	**(0.484)**	(0.714)	**(0.735)**	(0.230)	**(0.666)**
Panel e. Romano-Wolf correction									
P-value of fiber penetration	n.a	n.a	n.a	[0.992]	[0.243]	[0.597]	**[0.091]***	[1.000]	**[0.050]****

Notes: * Significant at 10%, ** significant at 5%, and *** significant at 1%. Robust standard errors clustered at the province level. Panel (a) shows the results of our preferred specification to facilitate comparison with the rest of the results. In panel (b) we estimate our preferred specification removing the contemporaneous population and population density controls. Panel (c) shows the results from estimating linear probability models where the dependent variable is a dummy variable which takes value 1 if that province-year had a positive number of cases of a given medical condition. We do not report the estimated effects for all BMH cases (columns 1 to 3) because the lack of variability in the dependent variable, which takes value 1 across all provinces and years. Panel (d) displays the results of estimating our main specification using only the years from 2012 to 2019. Panel (e) reports the p-values of the estimated coefficients after implementing the Romano-Wolf (2016) step-down multiple hypothesis correction method of the standard errors on each of the nine outcomes (the nine medical conditions displayed in Table 2).

Table 5. The effect of fiber penetration on Internet use of adolescents aged 14 to 18: ESTUDES 2014-2018. IV specification.

	Dependent variable: Dummy variable indicating reason for using the Internet or impact on alternative uses of time.					
	Internet use has signs of addiction (1)	Internet use crowds-out sleep (2)	Internet use crowds-out homework (3)	Internet use crowds-out socializing (4)	Internet use as coping mechanism (5)	Online bullying (6)
Panel a. Girls						
Fiber penetration	0.683***	0.531***	0.637***	0.624***	0.726***	-0.053
SE	(0.331)	(0.187)	(0.237)	(0.226)	(0.264)	(0.158)
Impact of a one SD increase in fiber	8.96%	21.18%	30.49%	44.48%	13.25%	-15.40%
Mean of dependent variable	0.511	0.168	0.140	0.094	0.367	0.023
N	48,842	48,842	48,842	48,842	48,842	48,842
Panel b. Boys						
Fiber penetration	0.240	0.061	0.374*	0.298	0.017	0.073
SE	(0.483)	(0.259)	(0.210)	(0.233)	(0.247)	(0.109)
Impact of a one SD increase in fiber	3.65%	2.55%	16.82%	18.84%	0.42%	18.11%
Mean of dependent variable	0.440	0.160	0.149	0.106	0.273	0.027
N	47,156	47,156	47,156	47,156	47,156	47,156

Notes: * Significant at 10%, ** significant at 5%, and *** significant at 1%. Robust standard errors clustered at the province level. IV regression where fiber penetration (lines in use) is instrumented with installed FTTH infrastructure at t-1. The SD of fiber penetration is 0.067 for the entire sample period. Quality of relationship between adolescents and parents comes from ESTUDES, waves of 2006 to 2018. All first-stage coefficients have the expected sign and are statistically significant at the 1% level. All specifications include age, year and province fixed effects and controls for the country of birth of the individual, the work status and the level of education of each parent.

Table 6. The effect of fiber penetration on the relationship of adolescents aged 14 to 18 years with their parents: ESTUDES 2007-2018. IV specification.

	Boys and girls			Girls			Boys		
	All (1)	Conflict in relation (2)	No conflict in relation (3)	All (4)	Conflict in relation (5)	No conflict in relation (6)	All (7)	Conflict in relation (8)	No conflict in relation (9)
Panel a. Good relation with the father									
Fiber penetration (lines per inhabitant)	-0.131**	-0.162**	-0.038	-0.181**	-0.225**	-0.036	-0.083	-0.083	-0.042
SE	(0.066)	(0.081)	(0.070)	(0.075)	(0.097)	(0.079)	(0.081)	(0.109)	(0.083)
Impact of a one SD increase in fiber penetration	-1.10%	-1.70%	-0.29%	-1.57%	-2.43%	-0.28%	-0.67%	-0.83%	-0.32%
Mean of dependent variable	0.80	0.64	0.88	0.77	0.62	0.87	0.83	0.67	0.89
N	180,156	61,080	119,076	92,040	34,949	57,091	88,116	26,131	61,985
Panel b. Good relation with the mother									
Fiber penetration (lines per inhabitant)	-0.093*	-0.121	-0.008	-0.126*	-0.138	-0.021	-0.059	-0.097	0.004
SE	(0.048)	(0.092)	(0.035)	(0.073)	(0.143)	(0.044)	(0.042)	(0.093)	(0.045)
Impact of a one SD increase in fiber penetration	-0.72%	-1.13%	-0.06%	-1.01%	-1.30%	-0.15%	-0.45%	-0.89%	0.03%
Mean of dependent variable	0.86	0.72	0.93	0.84	0.71	0.93	0.87	0.73	0.93
N	184,587	62,878	121,709	94,649	36,092	58,557	89,938	26,786	63,152

Notes: * Significant at 10%, ** significant at 5%, and *** significant at 1%. Robust standard errors clustered at the province level. IV regression where fiber penetration (lines in use) is instrumented with installed FTTH infrastructure at t-1. The SD of fiber penetration is 0.067 for the entire sample period. Quality of relationship between adolescents and parents comes from ESTUDES, waves of 2006 to 2018. All first-stage coefficients have the expected sign and are statistically significant at the 1% level. All specifications include age, year and province fixed effects and controls for the country of birth of the individual, the work status and the level of education of each parent.

Appendix Tables and Figures

Table A.1. The effect of fiber penetration on the mental health of adolescents aged 20 to 24 years by type of medical condition: 2007-2019

IV estimates

Dependent variable: hospital cases of BMH per one hundred inhabitants

	Nutrition disorder (1)	Anxiety (2)	ADHD (3)	Mood disorder (4)	Personality disorder (5)	Schizophrenia (6)	Alcohol abuse (7)	Drugs abuse (8)	Self-harm and suicide attempt (9)
Panel a. all adolescents									
Fiber penetration	-0.025	-0.022	-0.072	0.122	0.034	-0.287	-0.002	-0.862	0.056
SE	(0.143)	(0.136)	(0.079)	(0.119)	(0.264)	(0.192)	(0.213)	(1.117)	(0.193)
Impact of a one SD increase in fiber penetration	-9.3%	-3.4%	-37.1%	14.6%	3.3%	-24.0%	-0.2%	17.7%	10.1%
Mean of dependent variable	0.018	0.044	0.013	0.056	0.069	0.080	0.070	0.326	0.037
Panel b. boys									
Fiber penetration	-0.110	0.038	-0.024	-0.061	-0.111	**-0.467***	-0.012	-0.087	0.081
SE	(0.159)	(0.150)	(0.161)	(0.199)	(0.282)	**(0.262)**	(0.333)	(1.486)	(0.232)
Impact of a one SD increase in fiber penetration	-49.1%	8.2%	-8.0%	-8.9%	-12.2%	-25.9%	-0.8%	-1.4%	18.1%
Mean of dependent variable	0.015	0.031	0.020	0.046	0.061	0.121	0.106	0.419	0.030
Panel c. girls									
Fiber penetration	0.064	-0.093	**-0.118***	0.323	0.188	-0.093	0.010	-1.631	0.029
SE	(0.186)	(0.220)	**(0.071)**	(0.231)	(0.416)	(0.247)	(0.141)	(1.357)	(0.271)
Impact of a one SD increase in fiber penetration	19.5%	-10.9%	-	32.3%	16.4%	-16.0%	2.1%	-47.7%	4.3%
Mean of dependent variable	0.022	0.057	0.005	0.067	0.077	0.039	0.032	0.229	0.045
N	600	600	600	600	600	600	600	600	600
State and year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Contemporaneous controls (X')	YES	YES	YES	YES	YES	YES	YES	YES	YES
Baseline covariates interacted with year effects (Z')	YES	YES	YES	YES	YES	YES	YES	YES	YES

Notes: * Significant at 10%, ** significant at 5%, and *** significant at 1%. Robust standard errors clustered at the province level. Robust standard errors clustered at the province level. Behavior & BMH cases is chapter 5 of the International Classification of Diseases (ICD-10). Self-harm and suicide attempt does not belong to chapter 5 of ICD-10. IV regression (except for column 1) of BMH against fiber penetration, where fiber penetration (lines in use) is instrumented with installed FTTH infrastructure at t-1. The SD of fiber penetration is 0.067 for the entire sample period. Contemporaneous controls X' include population density, total population, real GDP per capita, aggregate real GDP and the total incidence (cases per 100 inhabitants) of hospital cases for all age groups and all medical conditions. All controls are measured at the province level. Baseline characteristics at the province level interacted with year dummies (Z') are the same covariates as in X measured at their value in 2007.

Table A.2. The effect of fiber penetration on the mental health of teenagers aged 10 to 14 years by type of medical condition: 2007-2019

	IV estimates Dependent variable: hospital cases of BMH per one hundred inhabitants								
	Nutrition disorder (1)	Anxiety (2)	ADHD (3)	Mood disorder (4)	Personality disorder (5)	Schizophrenia (6)	Alcohol abuse (7)	Drugs abuse (8)	Self-harm and suicide attempt (9)
Panel a. all teenagers									
Fiber penetration	-0.037	-0.027	-0.170	0.062	0.021	-0.181	-0.005	**0.121****	0.181
SE	(0.093)	(0.150)	(0.175)	(0.070)	(0.030)	(0.196)	(0.024)	**(0.051)**	(0.121)
Impact of a one SD increase in fiber penetration	-19.1%	-12.9%	-24.8%	51.9%	35.2%	-202,1%	-16.8%	101.3%	101.1%
Mean of dependent variable	0.013	0.014	0.046	0.008	0.004	0.006	0.002	0.008	0.012
Panel b. boys									
Fiber penetration	-0.092	-0.074	-0.254	0.095	-0.001	-0.126	-0.030	0.064	-0.001
SE	(0.146)	(0.116)	(0.218)	(0.061)	(0.043)	(0.090)	(0.029)	(0.068)	(0.058)
Impact of a one SD increase in fiber penetration	-56.0%	-55.1%	-25.8%	159.1%	-3.4%	-211,0%	-201.0%	71.5%	-3.4%
Mean of dependent variable	0.011	0.009	0.066	0.004	0.002	0.004	0.001	0.006	0.002
Panel c. girls									
Fiber penetration	0.021	0.022	-0.082	0.028	0.047	-0.237	0.021	**0.183****	**0.373***
SE	(0.122)	(0.199)	(0.231)	(0.119)	(0.067)	(0.322)	(0.029)	**(0.084)**	**(0.210)**
Impact of a one SD increase in fiber penetration	9.4%	7.8%	-22.0%	17.1%	52.5%	-198,4%	70.4%	111.5%	113.6%
Mean of dependent variable	0.015	0.019	0.025	0.011	0.006	0.008	0.002	0.011	0.022
N	600	600	600	600	600	600	600	600	600
State and year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Contemporaneous controls (X')	YES	YES	YES	YES	YES	YES	YES	YES	YES
Baseline covariates interacted with year effects (Z')	YES	YES	YES	YES	YES	YES	YES	YES	YES

Notes: * Significant at 10%, ** significant at 5%, and *** significant at 1%. Robust standard errors clustered at the province level. See notes of Table A.1.

Table A3. The effect of fiber penetration on the mental health of adolescents aged 15 to 19 years: 2007-2019. <u>Excluding self-harm and suicide attempts</u>.

	Dependent variable: hospital cases of BMH per one hundred inhabitants								
	15 to 19 years old						20 to 24 years old		
	OLS	IV							
	All (1)	All (2)	All (3)	All (4)	Boys (5)	Girls (6)	All (7)	Boys (8)	Girls (9)

Fiber penetration (lines per inhabitant)	**1.095****	**1.550****	1.090	1.880	1.289	**2.509****	0.226	1.213	-0.756
SE	**(0.538)**	**(0.804)**	(0.803)	(1.244)	(1.669)	**(1.310)**	(1.038)	(1.733)	(1.620)
Impact of a one SD increase in fiber penetration	12.0%	17.0%	12.0%	20.6%	14.4%	27.1%	1.6%	7.5%	-6.2%
Mean of dependent variable	0.61	0.61	0.61	0.61	0.60	0.62	0.96	1.09	0.82
First stage coefficient		0.146***	0.138***	0.111***	0.111***	0.111***	0.111***	0.111***	0.111***
SE		(0.026)	(0.020)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
N	650	600	600	600	600	600	600	600	600
Adj R2	0.22	0.23	0.34	0.37	0.23	0.32	0.30	0.20	0.27
State and year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Contemporaneous controls (X')	NO	NO	YES	YES	YES	YES	YES	YES	YES
Baseline covariates interacted with year effects (Z')	NO	NO	NO	YES	YES	YES	YES	YES	YES

Notes: * Significant at 10%, ** significant at 5%, and *** significant at 1%. Robust standard errors clustered at the province level. Behavior & BMH cases is chapter 5 of the International Classification of Diseases (ICD-10). Self-harm and suicide attempt does not belong to chapter 5 of ICD-10 and it's excluded from the calculation of BMH. IV regression (except for column 1) of BMH against fiber penetration, where fiber penetration (lines in use) is instrumented with installed FTTH infrastructure at t-1. The SD of fiber penetration is 0.067 for the entire sample period. Contemporaneous controls X' include population density, total population, real GDP per capita, aggregate real GDP and the total incidence (cases per 100 inhabitants) of hospital cases for all age groups and all medical conditions. All controls are measured at the province level. Baseline characteristics at the province level interacted with year dummies (Z') are the same covariates as in X measured at their value in 2007.

Table A4. ESTUDES. Questions about patterns of Internet use. Waves of 2014, 2016, 2018.

INT4. PLEASE READ THE FOLLOWING STATEMENTS REGARDING THE USE OF THE INTERNET (chatting, sending or receiving e-mails, whatsapps, using social networks, playing with or without money, listening to or downloading music, watching or downloading videos...). INDICATE HOW OFTEN THE FOLLOWING SITUATIONS HAPPEN TO YOU. (Do not take into account the time you spend on the internet to do homework or work, only indicate here the time you spend on the internet for fun). Check one box per line.					
	Never	Rarely	Sometimes	Frequently	Very frequently
1. How often have you found it difficult to stop using the internet when you were online?	0	1	2	3	4
2. How often have you stayed connected to the internet despite wanting to stop?	0	1	2	3	4
3. How often do your parents or friends tell you that you should spend less time on the internet?	0	1	2	3	4
4. How often do you prefer to connect to the internet instead of spending time with others (parents, friends...)?	0	1	2	3	4
5. How often do you sleep less because you are connected to the internet?	0	1	2	3	4
6. How often do you find yourself thinking about the internet, even when you're offline?	0	1	2	3	4
7. How often are you looking forward to connecting to the internet?	0	1	2	3	4
8. How often do you think you should use the internet less?	0	1	2	3	4
9. How often have you tried to spend less time online and failed?	0	1	2	3	4
10. How often do you try to finish your work in a hurry to get online?	0	1	2	3	4
11. How often do you neglect your obligations (homework, being with the family...) because you prefer to connect to the internet?	0	1	2	3	4
12. How often do you connect to the internet when you are "low"?	0	1	2	3	4
13. How often do you connect to the internet to forget your sorrows or negative feelings?	0	1	2	3	4
14. How often do you feel restless, frustrated, or irritated if you can't use the internet?	0	1	2	3	4
15. How often have you felt harassed, threatened or do you think you have been bullied through the internet?	0	1	2	3	4