Does High-Speed Internet Access Affect the Mental Health of Older Adults?

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Abstract

Recent research has shown the negative effects of the internet on younger people's mental health. Yet, we do not know whether the same effects are present among the older population, who are especially vulnerable to certain mental health conditions and more likely to fall victim to online deception. I estimate the effect of broadband availability on the mental health of the 50+ age group in the United States from 2010 to 2018. I use individual panel data and exploit quasi-experimental variation induced by the staggered rollout of broadband at the census tract level using the latest difference-in-differences (DID) framework. Despite evidence of the internet's harmful effects on younger populations, I show that broadband rollout significantly improves older adults' mental health, reducing depression symptoms by 5.7%. Key mechanisms driving these positive gains include a decline in feelings of social isolation and loneliness and an increase in the quality of virtual social connections. Whites, rural dwellers, women, and married individuals appear to be the biggest beneficiaries of broadband's positive effects on mental health. This work highlights broadband's unmeasured additional benefits to public investments, given the recent allocation of over $65 billion to broadband expansion. JEL I12, I14, I18, L86, O18

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“We have become a lonely nation: It's time to fix that." (the Surgeon General of the US, April 2023).

“Older people are more likely to live alone in the U.S. than elsewhere in the world." (Pew Research Center, 2020)

1 Introduction

The aging US population faces increasing mental health challenges that have substantial economic costs but ineffective treatments. In 2019, 54 million Americans aged 65 and older made up 16% of the population; by 2060, this is projected to rise to 94.7 million, or 1 in 4 people (ACL Report, Vespa *et al.* (2018)). As people age, they are more prone to significant mental health decline, increased loneliness, and social isolation.[1] For instance, one in four older adults experiences depression, anxiety, or dementia.[2] Depression is often associated with suicide, and people aged 85 and above have the highest suicide rates among all age groups.[3] Further, people aged 60+ in the US are more likely to live alone than elsewhere in the world, and they have the highest rate of social isolation (Ausubel, 2020).[4] The impact of loneliness and social isolation on premature mortality is comparable and sometimes greater than lifestyle factors (smoking 15 cigarettes or six drinks a day), clinical risks (blood pressure, diabetes, obesity) and environmental factors (air pollution).[5] The estimated cost of major depressive disorders for the 50+ population was over $42 billion, and social isolation accounts for excess Medicare spending of about $6.7 billion annually (Greenberg *et al.*, 2015, Flowers *et al.*, 2017). However, mental health treatments are ineffective since many people avoid treatment due to stigma, even with lowered mental health costs (Reynolds III *et al.*, 2012, Abramson *et al.*, 2024).

The geographic distribution of older adults reveals a notable concentration in remote regions characterized by restricted availability of mental health services. About one-fifth of the older American population lives in rural areas, with some states having over half of

[1] For example, Alzheimer's is quickly becoming one of the most pressing challenges facing public health officials.

[2] National Academies of Sciences, Engineering, and Medicine. 2020

[3] Pompili *et al.* (2010), Reynolds III *et al.* (2012), American Foundation for Suicide Prevention.

[4] The U.S. Surgeon General's Advisory (2023). 27% of US older adults live alone, compared to 16% in 130 other countries.

[5] The U.S. Surgeon General's Advisory (2023)., Pantell *et al.* (2013).

elderly residents in rural places (Census report).[6] Rural residents are more likely to be older and poorer, to have lower levels of education and worse mental health, and to lack private health insurance.[7] Consequently, these areas face limited access to mental health services and a scarcity of trained mental health providers.[8]

Broadband (high-speed internet) has the potential to address some of these market failures; however, its impact on older adults' mental health is unclear.[9] Recent studies, which are mostly focused on general or relatively younger populations, have found largely positive and some negative effects of broadband on various economic outcomes.[10] For the older population, on one hand, broadband may lower the costs of communication and sharing information or social support, enabling services such as WhatsApp video calls with friends and families and virtual social connections, entertainment through platforms like Netflix, telehealth services, online learning or meditation on YouTube, or access to financial or health information. This is particularly crucial for those experiencing social isolation and loneliness, live in remote areas, or have limited access to in-person mental health services. On the other hand, if those social connections induce social strain, they may negatively affect the mental health of older adults (Chen and Feeley, 2014).[11] Likewise, older people are more likely to engage with fake news and misinformation and fall prey to online financial scams than younger populations, which may adversely impact their mental health (Brashier and Schacter (2020), Swire-Thompson *et al.* (2020), FBI Report (2023)).

This paper investigates the impact of broadband expansion on the mental health of older adults in the US. The paper employs a quasi-experimental design, using the staggered introduction of broadband in census tracts from 2010 to 2018. I focus on 'fiber broadband' expansion since it is among the fastest of all other broadband types, like cable or satellite, and it has had exponential growth in the last decade, while others are stagnant.[12] I use

[6] The share of the older population is higher in rural areas than in urban areas; about 17.5% of the rural population was 65 years and older. For urban areas, the share is 13.8% (Smith and Trevelyan, 2019).

[7] (Foutz *et al.*, 2017, Mueller *et al.*, 2018, Moy *et al.*, 2017, Pender *et al.*, 2019).

[8] More than half of all the locations with shortages of mental health professionals are located in rural areas. Medicaid and CHIP Payment and Access Commission, Issue April 2021 and Morales *et al.* (2020).

[9] Broadband is an umbrella term for reliable high-speed internet connection. Refer American Association of Retired Persons (AARP) Report.

[10] For example, Guldi and Herbst (2017), Dettling *et al.* (2018), DiNardi *et al.* (2019), Conroy and Low (2022), Campbell (2022), Amaral-Garcia *et al.* (2022), Golin (2022), Amaral-Garcia *et al.* (2022), Donati *et al.* (2022), Van Parys and Brown (2023), Johnson and Persico (2024).

[11] For instance, Facebook rollout negatively affects the mental health of college students, primarily due to unfavorable comparison (Braghieri *et al.*, 2022).

[12] Refer to section 3 for more details. Campbell (2022) is among the first to use this treatment to explore

biennial waves from the nationally representative individual panel data of the Health and Retirement Study (HRS) for individuals aged 51 and older. A crucial feature of the HRS panel dataset is its detailed measures of individual health, demographics, and key potential channels, some of which have been underexplored in the literature. Another key feature of this panel dataset is that individuals were asked about their self-use of the Internet and related activities, which are virtually absent from the related studies. The primary outcome variable is the comprehensive score, 'Center for Epidemiology Studies Depression (CESD)' or 'symptoms of depression', that measures the mental health of older adults and is commonly used in the literature (Cutler and Sportiche, 2022). I focus on depression symptoms since it is the key predictor of well-being and life satisfaction (Kahneman and Krueger, 2006).[13] I use census tract-level broadband data to observe fiber broadband rollout each year at each census tract. Merging individual panel HRS data with the broadband data at the census tract and year level allows me to exploit the spatial, temporal, and individual level variation of the broadband to estimate the intent to treat (ITT) effect.[14]

I employ the latest difference-in-differences (DID) estimators for binary and staggered treatment, accounting for the dynamic treatment effects (Sun and Abraham, 2021, Callaway and Sant'Anna, 2021, Borusyak *et al.*, 2021, De Chaisemartin and d'Haultfoeuille, 2022a). These estimators address the negative weighting problems and do not rely on the strict assumption of homogeneity as commonly done in two-way-fixed-effects (TWFE) estimation.[15] As I observe the same person over time, the key identification strategy compares changes in mental health outcomes of the same individual between pre-and post-treatment periods in areas that introduced fiber broadband and those that did not. The estimations conclude with robustness checks, heterogeneity analysis, and tests of underexplored potential mechanisms. Importantly, I also show the evidence of spatial spillover, which is often neglected in the related literature.

I find that the rollout of broadband positively affected mental health among older adults, shown by a decline in depressive symptoms by about 5.7%. This magnitude is similar but

the effects of broadband on education.

[13]I also complement the CES-D measure by using two other measures, a binary version of the CES-D score, which roughly matches the symptoms of clinical depression and the use of medicines for anxiety or depression.

[14]I use the restricted data from HRS on the census tract of residence of respondents.

[15]There are mainly four estimators for the binary and staggered treatment rollout that allow for the dynamic treatment effects. I also show that the estimates are robust to the use of any of these estimators, including the conventional TWFE.

exactly opposite in direction from recent findings on the impact of the Facebook rollout on mental health among college students (Braghieri *et al.*, 2022). Similarly, these effects are exactly opposite to a study from Italy that finds negative effects on the mental health of young cohorts but no effects on older cohorts (Donati *et al.*, 2022). This contrast underscores a key finding of this paper: the impact of similar technologies on mental health outcomes can vary significantly across age cohorts and potentially depending on how individuals engage with the technology. These gains in mental health for older adults are equivalent to about 20% of the adverse effects of job loss, 41% of recession, and 14% due to an unexpected loss of a spouse. Moreover, I find heterogeneous treatment effects with higher gains for Whites, respondents from rural areas, women, and married individuals. These results are robust to different specifications, adding control (possible confounders), different latest DID estimators and dynamic treatment effects further support the validity of the research design.

I further provide evidence on first-stage effects and novel potential channels to help explain the core result. First, I find that the fiber broadband rollout substantially increased the quality of the internet and availability of internet speed by 344 Mbps or about 172 percent. Secondly, the results indicate a substantial increase in the self-use of the Internet among older adults. First, I find a significant decline in feelings of social isolation (15%) and loneliness (9%) after the fiber broadband expansion. Secondly, I create a novel 'virtual social-connectedness index' at baseline wave using detailed questions on respondents' virtual interactions with family and friends.[16] The results show a significant improvement in mental health (twice the average effects) for highly virtually socially connected individuals (above the 75th percentile) but no effects for those below the 25th percentile, providing evidence that the broadband rollout might affect mental health through improving the quality of social connections. I find no evidence of increased use of medications for anxiety or depression, changes in employment status, or self-reported physical health, providing stronger support for the social channels. Additionally, I find suggestive evidence of improved health literacy. On the supply side, using near-universe hospital data, I find an increase in the likelihood of nearby hospitals offering telehealth services, suggesting some evidence of hospital technological improvements.

[16] The index is calculated based on the frequency with which the respondent reported that they send emails to either family, friends, or children and use social media like Facebook to connect with friends and family and regular web use for "sending and receiving e-mail or for any other purpose, such as making purchases, searching for information, or making travel reservations."

This paper contributes to the following strands of literature: economic impacts of technology, identification methods, and mechanisms that connect mental health and technology.

The first strand of literature involves technologies as determinants of economic outcomes. The emerging literature suggests that broadband can have positive effects on education, entrepreneurship, labor market outcomes, and poverty around the world (Kolko, 2012, Atasoy, 2013, Dettling *et al.*, 2018, Hjort and Poulsen, 2019, Zuo, 2021, Conroy and Low, 2022, Campbell, 2022, Amaral-Garcia *et al.*, 2022, Acosta and Baldomero-Quintana, 2024, Bahia *et al.*, 2024).[17] A small number of studies evaluate the causal effects of broadband on health and suggest mixed evidence (Guldi and Herbst, 2017, DiNardi *et al.*, 2019, Amaral-Garcia *et al.*, 2022, Golin, 2022, Van Parys and Brown, 2023). For instance, some evidence suggests that an increase in broadband coverage increases body weight among White women (DiNardi *et al.*, 2019), or, on the other hand, leads to declines in teen pregnancies (Guldi and Herbst, 2017). A very small subset of this literature studies broadband and social media as a determinant of mental health that suggests mixed effects (Braghieri *et al.*, 2022, Golin, 2022, Allcott *et al.*, 2022, Donati *et al.*, 2022, Johnson and Persico, 2024). However, this literature is largely focused on relatively younger populations. For the older population, most of the evidence on the social determinants of mental health primarily comes from other disciplines such as Psychiatry, Gerontology, or Public Health (Allen *et al.*, 2014, Cagney *et al.*, 2014, Lund *et al.*, 2018, Fan and Yang, 2022). This paper is among the first to evaluate the effect of broadband on mental health, focusing on the vulnerable age cohorts (older population) that are often overlooked.[18]

My second set of contributions is methodological, and my empirical setting presents a number of advantages and overcomes some of the limitations in the literature. The first advantage is that while earlier studies may suffer from TWFE, I use recent advances in DID for better identification. Secondly, I use data that measure broadband treatment at a finer scale (census tracts), which is more precise and helps reduce estimation bias compared to studies that use broader geographic levels, like counties or zip codes.[19] Defining treatment by a broad area can make it challenging to control for confounding variables and may also create

[17] Bakiskan and El Kaissi (2023) provides a summary of 55 quantitative studies that examine the effects of broadband on various economic outcomes across multiple countries.

[18] Related studies include evidence outside the economics literature from the US and China (Cotten *et al.*, 2014, Fan and Yang, 2022).

[19] One reason other studies analyze data at the county or zip code level is that broadband data was available at these levels before 2010, and the studies focus on that period (e.g., Johnson and Persico (2024)).

heterogeneity bias if one overlooks variations within that area. Third, the individual panel HRS data allows me to observe the same individuals and their detailed changes in social and health behavior and internet use, as opposed to many other studies, which measure the outcomes at the macro level, do not have panel data and cannot observe the take-up of the technology or key potential channels at individual level.[20] These detailed individual-level data let me analyze underexplored potential mechanisms that were hard to analyze in the previous studies. Importantly, this paper is among the first to contribute to improving the literature by documenting the spatial spillover effects of broadband expansion, which are virtually absent in the literature.[21]

My next key contribution involves a novel study of mechanisms. To my knowledge, this is one of the first papers to provide causal empirical evidence of the role of broadband in social isolation, loneliness, and virtual social connections, which may affect mental health among older adults. The discussion on the theories of social isolation hypothesis dates back to the 1930s (Faris and Dunham, 1939, Thoits, 1983). As mentioned by Robert Faris in 1934,– "Any form of isolation that cuts the person off from intimate social relations for an extended period of time may possibly lead to this form of mental disorder." Literature, primarily in psychology, sociology, or gerontology, broadly documents the adverse relationship between social isolation or loneliness and mental health or mortality, suggesting social connections are important for mental health (Holt-Lunstad *et al.*, 2010, Masi *et al.*, 2011, Holt-Lunstad *et al.*, 2015, Waldinger, 2015).[22] A subset of this literature suggests inconclusive correlations between internet use and older adults' mental health.[23] However, causal evidence on the role

[20]The data also helps with locational accuracy. Typically, the current literature fixes the location at the first year of the panel and assumes no migration because migration could be endogenous to the treatment. This assumption may inaccurately measure exposure to the treatment. I do not have to make that assumption because I observe the individual's location every survey year and accurately measure exposure to the treatment.

[21]I follow the latest innovations in spatial spillover to address some of the biases that arise due to spatial spillover of the treatment (Butts, 2021).

[22]Holt-Lunstad *et al.* (2010), Masi *et al.* (2011), and Holt-Lunstad *et al.* (2015) provide meta-analysis of various studies. Within the developing countries' context as well, these relations are documented, suggesting loneliness is a strong predictor of social isolation among older adults, and staying connected through mobile calling improves mental well-being among adults (Annan and Archibong, 2023, Banerjee *et al.*, 2023).

[23]Studies suggest a positive association between internet use and mental health, with lower loneliness and higher social contact among older adults (Cotten *et al.*, 2013, Xu and Köttl, 2020, Yu *et al.*, 2021, Lu and Kandilov, 2021, Li *et al.*, 2022). In contrast, a study suggests a negative association between internet use and mental health depending on the context of the life transition (separated, divorced, or widowed) and the type, level, and purpose of use (Yu *et al.*, 2019). Similarly, small-scale randomized controlled trials in medical science (about 200-300 participants) and correlational studies provide mixed evidence of video calls or digital literacy on social isolation (Group *et al.*, 1996).

of the internet in the social isolation hypothesis remains scarce. I contribute by providing causal evidence on the effects of broadband on social isolation and loneliness among older adults in the US. I also create a novel 'virtual social-connectedness index' that proxy for respondents' virtual interactions with family and friends to test social connection channels.

Information asymmetry is another mechanism through which broadband technology can affect mental health. A growing literature documents the role of broadband in reducing information frictions and improving health outcomes (Kolko, 2010, Amaral-Garcia *et al.*, 2022, Van Parys and Brown, 2023).[24] Literature related to information friction in health insurance broadly documents better outcomes in cost and quality (e.g., Abaluck and Gruber (2011), Kling *et al.* (2012)). However, recent evidence documents that fake news or misinformation and online financial scams have the highest prevalence among older adults.[25] I complement the evidence on the potential channels through health behavior, such as health literacy and the use of health apps or health websites, through which broadband may reduce information asymmetry, thereby affecting the mental health of older adults.

Finally, I contribute to a growing body of literature related to telehealth. Observations studies suggest a positive relation between broadband access and telemedicine (Wilcock *et al.*, 2019, Eberly *et al.*, 2020, Quinton *et al.*, 2021). These studies are primarily in medical research and focus on the demand side aspects. I contribute to this literature by providing one of the first pieces of evidence on the supply-side relationship between access to broadband and technological improvement in hospitals in terms of offering telehealth services, using a 2018 wave from the American Hospital Association (AHA) data.

This paper studies the general equilibrium effect of exposure to high-speed fiber broadband, as opposed to the partial equilibrium, estimating the intent-to-treat (ITT) effects. The introduction of fiber broadband may improve the speed of the Internet through fiber technology and may improve the quality of other technologies like cable through competition.[26] This may increase the internet speed available in homes, workplaces, and establishments like coffee shops and public libraries, where older people can potentially gain access. Similarly,

[24] A recent study suggests that internet access increased C-sections, potentially due to online information (Amaral-Garcia *et al.*, 2022). Another study finds a positive effect on the health of Medicare patients seeking hip or knee replacements, primarily due to better information about providers (Van Parys and Brown, 2023).

[25] A study documents that older people shared the most fake news during the 2016 elections in the US (Brashier and Schacter, 2020). Also, older adults are among the demographic groups most prone to engaging with online fake news, which can undermine the intended benefits of internet usage (Swire-Thompson *et al.*, 2020). Online financial scams cost over $3.4 billion in 2023 for the 60+ age group (FBI Report (2023)).

[26] Campbell (2022) has provided evidence for this competition.

exposure to broadband for family members or friends might have network effects on older adults. Such general equilibrium effects are important for technologies like broadband that exhibit strong network externalities.

2 Background

2.1 Broadband Technology

Significant progress has been made in expanding broadband technology in recent years; however, there exists regional and racial disparities in the coverage of reliable high-speed internet. In 2021, about 4.9 billion people were using the internet worldwide, with about 89.5 percent of individuals from Europe and Northern America using the internet (SDG report 2022). In 2008, a mere 16% of Americans had access to internet service with a speed of 10 Mbps. Now, approximately 95% of Americans have access to a 10 Mbps connection, and around 80% have access to speeds of up to 1 Gbps.[27] FCC established a definition of broadband in 2015 as an internet connection with a minimum of 25 megabits per second (Mbps) of download speed and a minimum of 3 Mbps of upload speed (Conroy *et al.*, 2021). However, persistent disparities in access (digital divide) remain, primarily affecting rural areas and low socioeconomic households, leaving more than 42 million Americans without internet connectivity.[28] About 81% of rural households have broadband access, compared to 86% in urban areas.[29] Similarly, in Black-majority neighborhoods, the internet speed is slower than in other areas, even though residents are paying the same prices. (The Markup). The COVID-19 pandemic has highlighted and exacerbated this digital divide, prompting policymakers to place significant emphasis on broadband connectivity. More recently, in June 2023, the Biden-Harris administration announced a $42.45 billion allocation for high-speed internet across states (“Investing in America").

Notably, broadband may contribute to the promotion of social equity and the reduction of the digital divide by overcoming barriers stemming from geography, economics, and social

[27] Refer to the Internet & Television Association report. Approximately 81% of households in the US had broadband connections in 2016 (Ryan and Lewis, 2017).

[28] For additional information on broadband access and solutions, see (Conroy and Low, 2022, Low *et al.*, 2021). Low *et al.* (2021) provides a detailed primer on broadband and summarises the benefits, challenges, and potential solutions of broadband access in the US.

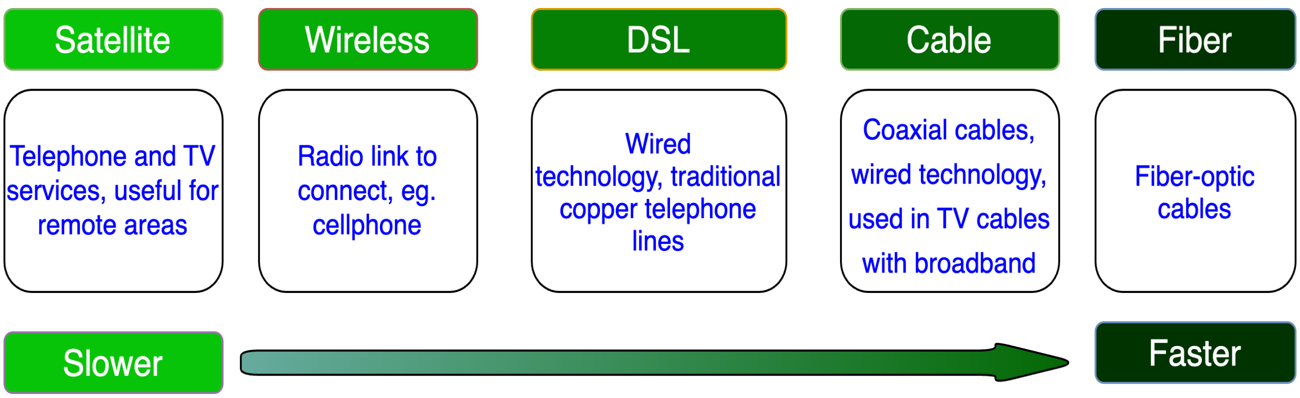
[29] The number of urban households lacking a connection is substantially higher, at 13.6 million, compared to 4.6 million rural households (Porter, 2021).

factors, thus ensuring access to information and communication technologies (Crandall and Alleman, 2004).

2.2 Types of Broadband Connections

There are five main categories of broadband that homes and businesses use to connect: fiber, cable, digital subscriber line DSL, fixed or mobile wireless, and satellite (Conroy *et al.*, 2021). The speed of the internet of each type can be categorized in the following way as shown in Figure 1.

FIGURE (1) Types of Broadband



Note: This figure shows different types of broadband commonly available for consumers. Source: Conroy *et al.* (2021).

2.3 Fiber Broadband and Exposure to Older Adults

There are two main reasons for this paper's focus on fiber broadband. First, the substantial increase in internet availability and speed in recent years can be attributed, in part, to the growing diffusion of broadband through fiber optic cables. Fiber broadband has emerged as a preferred choice, replacing older alternatives such as cable and DSL, owing to its superior speed, reliability, consistency, and reduced susceptibility to signal loss or damage; it has the potential to transmit large amounts of data.[30] Fiber broadband can transmit data at speeds reaching approximately 70% of the speed of light, equivalent to 124,274 miles per second. Commercial fiber connections typically offer signals above 10 Gbps, while residential fiber

[30] Most of the information in this section is from Century Link and Conroy *et al.* (2021).

internet connections can reach speeds of up to 940 Mbps.[31] Using Fiber broadband, users can effortlessly download a 6.5 GB file within a mere minute, a stark comparison to the 1-14 hours DSL typically requires or the up to 14 hours cable may take. Moreover, high upload speeds under fiber broadband cater to the demands of modern activities like Zoom calls, ensuring seamless communication experiences, even when multiple individuals and devices concurrently connect to the network, without the bandwidth competition common during peak hours with other technologies like cable.

The second reason is that the availability of fiber broadband for older adults in the US over the past decade has increased exponentially while the availability of other technologies remains stable. Analyzing data from the Health and Retirement Study (HRS), Figure 2 illustrates the significant upward trend in the share of the 50+ population residing in census tracts with fiber technology accessibility. The proportion has grown from approximately 22% to 75% from 2010 to 2018. In contrast, the availability of other technologies has remained relatively consistent throughout this period. This notable expansion in fiber broadband availability highlights its increasing potential relevance for older individuals. During this period, there has been growing internet use among older adults in the United States **??**.[32]

3 Data

3.1 HRS

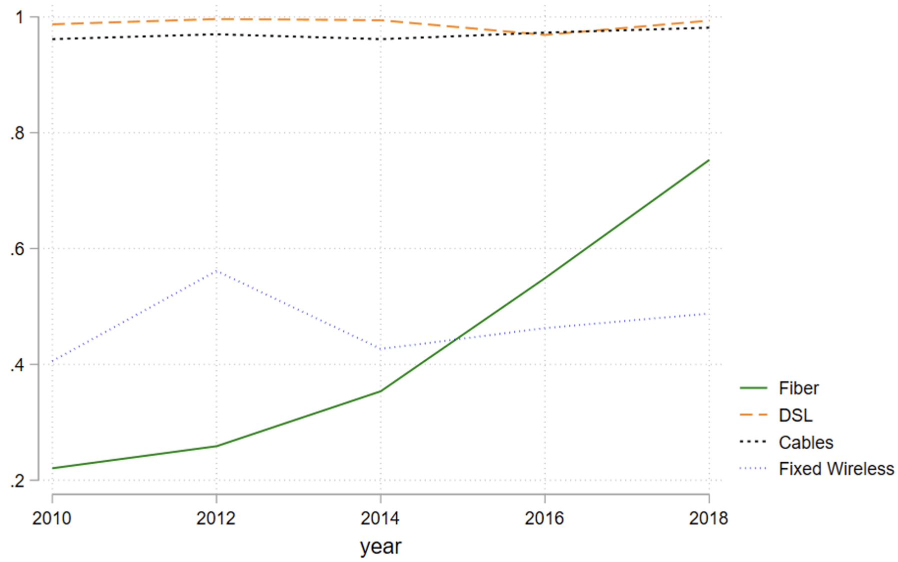
The HRS is a nationally representative panel study surveying approximately 20,000 individuals aged 51 and older ([DATASET], 2010-2018).[33] The core HRS has been conducted annually since 1992, transitioning to a biennial format in 1996. This survey collects extensive demographic, physical and mental health, relationship, income, and occupation-related information. One unique aspect of HRS is that other than demographic details, the data captures detailed individual-level panel data on physical and mental health, use of the in-

[31] The use of fiber optic technology involves converting electrical signals into light, which is then transmitted through transparent glass fibers with a diameter comparable to that of a human hair. This approach enables significantly faster data transmission than DSL or cable technologies. However, the actual speed experienced by users may vary based on factors such as proximity to the fiber provider and service configuration.

[32] (Hunsaker and Hargittai, 2018) shows a detailed review of who uses the internet and how it is used among older adults.

[33] The Health and Retirement Study data is sponsored by the National Institute on Aging (grant number U01AG009740 and is conducted by the University of Michigan.

FIGURE (2) Availability of Broadband Technologies for Older Adults



Note: The figure shows the share of older adults with the availability of various broadband technologies in their census tract of residence. The author's calculation uses HRS data merged with FCC data for 2010 to 2018. The sample is the balanced panel of HRS respondents.

ternet and other electronic technologies such as health apps or emails, and feelings of social connections, isolation, and loneliness. I use the restricted HRS files that have information on the respondents' geographic residence locations (census tract).[34] All these variables are essential to explore the role of broadband on the mental health of older adults and explore the novel channels that are understudied in the literature.

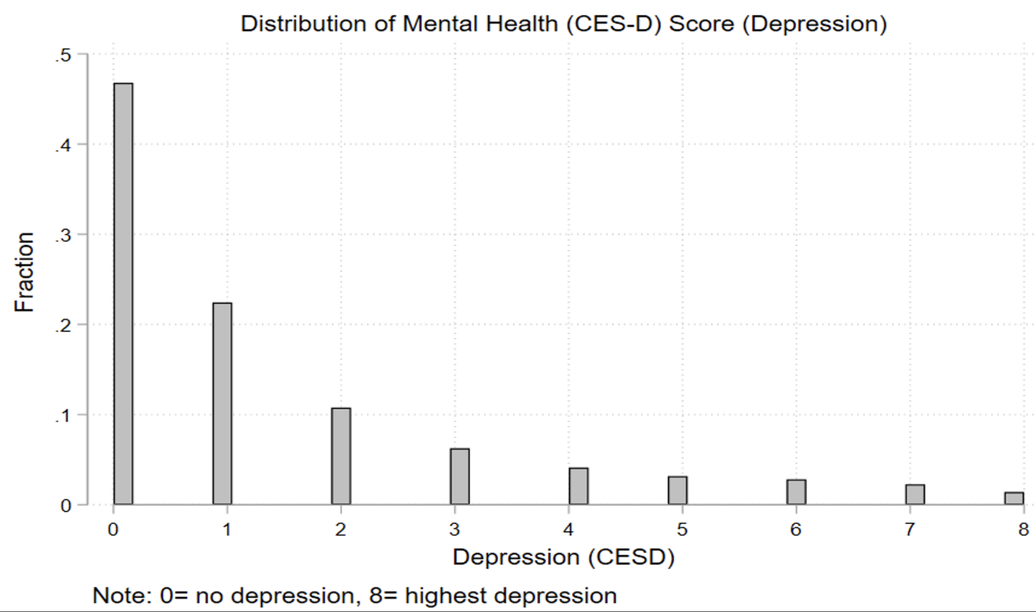
3.1.1 Primary Outcome Variables: Mental Health

I use one primary outcome and two other outcome variables that are prominent in measuring the mental health of the older population. To mitigate potential selection bias arising from examining multiple outcome variables separately and to address concerns related to multiple hypothesis testing, I employ a composite measure of symptoms of depression known as the Center for Epidemiology Studies Depression (CES-D) score as the primary outcome variable. The CES-D score is widely utilized across various social sciences and academic disciplines (Zivin *et al.*, 2010, Chatterji *et al.*, 2015, Cutler and Sportiche, 2022). The score is derived from eight questions encompassing domains such as depression, sleep quality, and feelings of loneliness and sadness. It is computed by summing the responses to six negative

[34] I obtained IRB approval from the University of Wisconsin-Madison. I use the RAND-HRS longitudinal files for most variables and borrow other variables from the raw HRS files whenever required.

indicators while subtracting the responses to two positive indicators (Refer to Appendix Table 10 for details.). The negative indicators gauge the frequency with which respondents experience sentiments such as depression, difficulty in accomplishing tasks, restless sleep, feelings of sadness, loneliness, and lack of motivation. Conversely, the positive indicators assess the extent to which individuals report feelings of happiness and enjoyment in life. The resulting CES-D mental health score ranges from 0 (best mental health) to 8 (worst mental health). Recognizing that the manifestation of depressive symptoms may differ by gender, race, geography, or age, I conduct heterogeneity analyses to explore potential differences in the effects of broadband expansion on mental health outcomes. Secondly, I also complement the CES-D measure by using a binary version of the CES-D score, which roughly matches the symptoms of clinical depression. Further, I utilize the 'use of medication for anxiety/ depression' as an additional outcome commonly used in the literature (Chatterji *et al.*, 2015, Cutler and Sportiche, 2022).

FIGURE (3) Primary Outcome Variable- CES-D Score



Note: The figure shows the distribution of the primary outcome variable–CES-D score or 'symptoms of depression.' The score is derived from eight survey questions on depression, sleep quality, and feelings of loneliness and sadness. Refer to Appendix Table 10 for the details of each question. The sample is the balanced panel of HRS respondents in survey waves from 2010 to 2018.

3.2 Broadband Data

The empirical analysis draws upon panel data from two sources. The first is from the Federal Communications Commission (FCC) Form 477, which spans 2014 to 2018. The second is from the National Telecommunications and Information Association's National Broadband Map (NBM) covering the years 2010 to 2013. This dataset encompasses the number of broadband providers, transmission technology (such as DSL, fiber, cable, or satellite), maximum download and upload speeds measured in Mbps, and whether the provider offers residential service at the census tract level.[35] To ensure comprehensive coverage, broadband providers are required to submit data biannually at the census-block level, demonstrating their ability to deliver internet service with speeds surpassing 200 Kbps in at least one direction. I aggregate the census-block level data at the census tract level by defining the census tract as treated if at least one census block had fiber in a particular year. The census tract, comprising smaller geographic units compared to counties, offers a finer granularity of analysis. There are a total of 84,414 census tracts in the United States, each ideally accommodating approximately 4,000 residents (Census Report). The census tract provides precise geographic treatment of the broadband, as opposed to aggregating at the county level, which has been done in the related literature. To ensure the most recent and reliable broadband data, the analysis primarily relies on the December dataset for each year.

The key treatment variable employed in this study pertains to the introduction of fiber broadband within a given census tract during a specific year. This binary variable takes the value of 1 in the year of introduction and persists as such in subsequent years. Conversely, for census tracts where fiber broadband has not been extended, the variable remains at 0 throughout the observation period, thus constituting the never-treated group. This research design effectively captures the staggered implementation of the treatment. The inclusion of FCC data starting in 2014 is primarily motivated by the need to address measurement issues present in earlier years. Finally, (Grubesic *et al.*, 2019) document some of the limitations of FCC data. Nevertheless, FCC data are the best publicly available records of the broadband providers in the US (Mack *et al.*, 2021).

[35] The data is at the census block level (smaller than census tract); since we do not observe the census block of the HRS respondents, we aggregate the data at the census tract level.

3.3 Sample Selection

The primary analyses focus on the balanced panel of HRS respondents observed in the waves from 2010 to 2018, observing the same person over five survey waves. However, I also provide main estimates utilizing an unbalanced panel of HRS respondents to capture a broader sample and show that the estimates do not change. This research design includes outcomes that are measured less frequently than the treatment. This is because the HRS survey takes place every two years (2010, 12, 14, 16, and 18), and we know the treatment year for each survey respondent (2010, 11, 12, 13, 14, 15, 16, 17, and 18). So, the HRS sample can be categorized into two batches. The first batch receives the treatment in the years when the outcome is measured, and the second batch receives the treatment in the non-HRS wave year.[36] The main analysis is focused on the first batch, i.e., the respondents who were treated in the same year as the survey year, since 73% of the HRS sample belongs to this batch. I conduct a separate analysis for the second batch, as suggested by De Chaisemartin *et al.* (2019). I show estimates that combine these two batches by estimating the 'length of the fiber treatment' as a treatment.

In recent studies employing the difference-in-differences (DID) methodology, a common assumption involves carrying forward the initial geographic location of each individual for the subsequent years. This assumption is primarily driven by the lack of individual-level data and precise geographic information over time. However, it poses a notable limitation as it fails to account for potential variations in broadband exposure due to migration. For example, an individual resides during the first period t_0 in a census tract where fiber broadband was rolled out in 2010. Subsequently, the individual relocates to another census tract in t_1 that did not have broadband access and stayed there until the last survey wave t_3. To control for this kind of migration, researchers usually assume that the census tract of that individual in t_1 to t_3 is the same as that of t_0, which is a strong assumption. I depart from this assumption and examine whether individuals migrate following the introduction of broadband. Leveraging the advantages of the HRS data, I observe the census tract of residence for each respondent across all survey waves from 2010 to 2018. This allows me

[36]The key reason is that, for the first batch, the first period ('instantaneous' or 'period 0') outcome is recorded. For instance, for the respondents treated in 2012, we have their first post-treatment outcome available for the wave of 2012. For the second batch, who were treated in non-HRS wave years, the first post-treatment outcome available is for the next year of treatment. For instance, the HRS respondents treated in 2011 had their first post-treatment outcome recorded in 2012.

to identify whether respondents move out of their initial census tracts over the course of the study period. It is worth considering the possibility of endogenous migration within different treatment groups of census tracts, potentially induced by broadband expansion. Such migration patterns could introduce bias into the estimated effects. To address this, I restrict the sample to non-migrants, encompassing individuals who remained in their census tracts throughout the study period. This non-migrant sample constitutes approximately 91% of the overall sample. Moreover, I present additional estimates that include both movers and non-movers in the 'robustness' section, ensuring a comprehensive analysis of the potential effects of migration on the results.

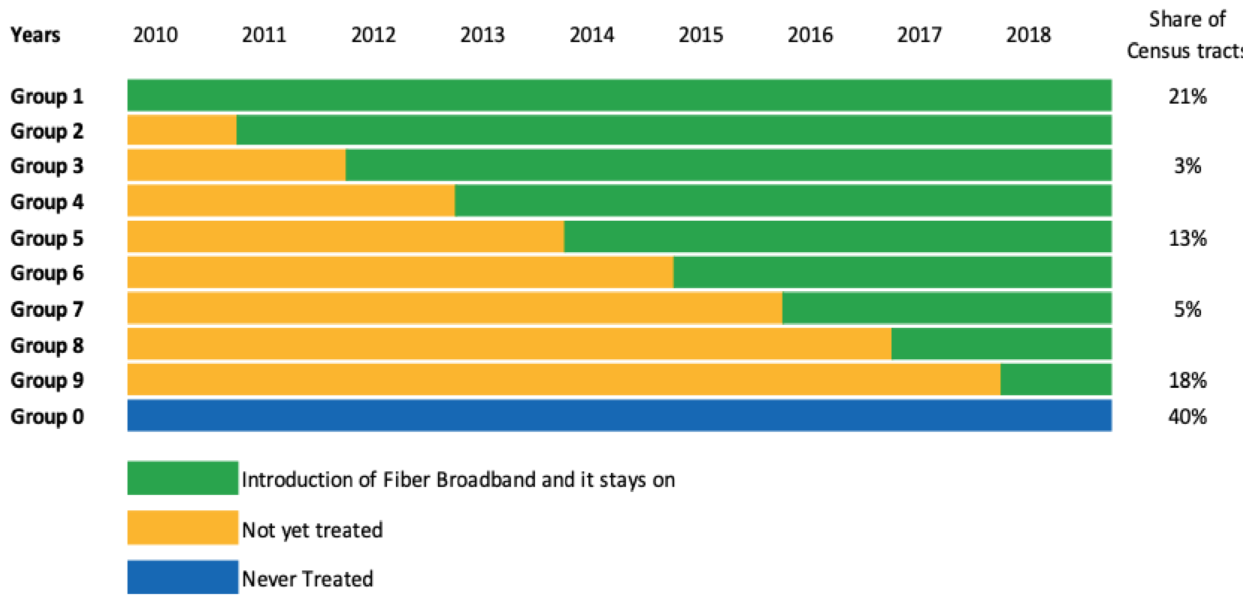
3.4 Introduction of Fiber

Figure 4 presents the categorization of the HRS sample into different cohorts based on their exposure to fiber broadband expansion. Nine distinct groups of census tracts are identified; eight correspond to each year of introduction of fiber broadband from 2010 to 2018, and a ninth group represents census tracts that never received fiber broadband during the study period. The primary sample of analysis is the group of census tracts that received the fiber in the survey year of HRS data, i.e., groups 1, 3, 5, 7, and 9. I also show the estimates, including the other groups, by redefining the treatment.

3.5 Summary Statistics

Table 1 presents the summary statistics for the merged dataset, combining the HRS with the broadband data at the census tract level, spanning the period from 2010 to 2018. The statistics provide insights into the baseline characteristics of HRS respondents across various groups, including both the fiber-expansion and no-expansion cohorts of census tracts. Additional demographic characteristics of the respondents are provided in Table 11 in the Appendix. Table 11 shows that demographic characteristics within all the groups are similar in age, gender, health, and social security benefits. One key difference that we observe is that the download speed of the internet is substantially higher in the fiber expansion groups (groups 1 to 5) than in the no-fiber expansion group (group 0). This suggests that treated groups are exposed to internet speeds that are very high compared to the control groups. Only the rural variable seems to have differences in means in some of the groups. This makes

FIGURE (4) Transition from no-Fiber to Fiber Broadband



Note: The figure shows the introduction of fiber broadband in various groups of census tracts in different years. Group 1 received the fiber in 2010, Group 2 in 2011, Cohort 3 in 2012, and so on. Group 0 does not receive any fiber.

sense because the urban areas might drive the expansion of fiber. I conduct an analysis of rural and urban areas separately.

4 Empirical Strategy

4.1 Identification Strategy

To address concerns of endogeneity, it is crucial to account for potential omitted variable bias and unobserved demand factors associated with the rollout of fiber broadband. To ensure the credibility of the causal findings, I adopt a methodology similar to Campbell (2022), leveraging the staggered nature of the fiber broadband rollout across the United States from 2010 to 2018. Moreover, in line with existing literature, I consider the evidence suggesting that access to broadband was subject to significant lag due to supply-side constraints (Dettling *et al.*, 2018, Campbell, 2022).

The introduction of fiber technology presents a quasi-experimental variation that enables the estimation of the causal impact of fiber broadband access on the mental health of older adults using a differences-in-differences (DID) approach. This identification strat-

TABLE (1) Summary Statistics

Expansion in Year	Group 1 2010	Group 2 2012	Group 3 2014	Group 4 2016	Group 5 2018	Group 0 No Fiber
CES-D Depression Score (0-8)	1.34	1.23	1.25	1.45	1.50	1.38
	(1.91)	(1.82)	(1.81)	(1.97)	(2.01)	(1.94)
Clinical Depression (0-1)	0.09	0.08	0.08	0.10	0.11	0.10
	(0.28)	(0.27)	(0.27)	(0.31)	(0.31)	(0.29)
Feel Isolated (y/n)	0.30	0.26	0.34	0.32	0.34	0.32
	(0.46)	(0.44)	(0.47)	(0.47)	(0.47)	(0.47)
Use Web (y/n)	0.55	0.57	0.53	0.53	0.51	0.51
	(0.50)	(0.49)	(0.50)	(0.50)	(0.50)	(0.50)
Email Friends/Family (y/n)	0.31	0.32	0.33	0.32	0.33	0.33
	(0.46)	(0.47)	(0.47)	(0.47)	(0.47)	(0.47)
Number of Broadband Providers	8.87	9.30	8.78	9.13	8.78	7.99
	(3.75)	(3.73)	(3.07)	(3.38)	(3.28)	(2.92)
Max Download speed (Mbps)	399.91	446.57	505.04	431.71	301.35	279.31
	(437.18)	(454.85)	(475.86)	(458.37)	(393.35)	(375.57)
N Respondents-Group year	11728	1713	4353	10438	9332	18421
Number of Census Tracts	1085	174	696	258	922	2070

Note: The table shows the mean and SD of some of the key variables for HRS respondents for different broadband expansion groups. The data are from a balanced panel of HRS that merged with FCC for the periods 2010 to 2018 every two years, using the geographical unit as a census tract. CES-D score refers to the symptoms of depression that take values from 0 to 8, with 0 being no signs of depression and 8 with the highest signs of depression. A CES-D score above three is considered indicative of clinically relevant symptoms of depression.

egy leverages the comparison of changes in mental health outcomes between the pre- and post-treatment periods among older adults residing in census tracts that introduced fiber broadband and those residing in census tracts that did not experience such introduction. I take advantage of the individual-panel HRS data by including individual fixed effects to control for unobserved heterogeneity and account for differences between the same individuals whose access to broadband changes over time and individuals whose access does not change.

I first estimate a difference-in-differences (DID) regression using the following equation.

$$Y_{igct} = \beta_0 + \beta Fiber_{ct} + \delta_i + \gamma_{gt} + \epsilon_{igct}. \tag{1}$$

Here, Y_{igct} is the outcome for individual i, living in census-tract c, belonging to the fiber expansion group g of census tracts, and surveyed in HRS survey year t. $Fiber_{ct}$ is an indicator equal to 1 if the fiber was available at census tract c in survey year t, and 0 otherwise. δ_i

is individual fixed effects that control for the time-invariant characteristics of individuals and allow identification to come from within-individual changes in fiber availability.[37] I also include the expansion group-year fixed effects γ_{gt} to account for shocks that affect all the individuals in a given group of census tracts to which fiber was expanded in a given year. I also include a specification, where I replace individual fixed effects with the census tract fixed effects α_c. I cluster the standard errors at the census-tract level to allow for the correlation among individuals in the same census tract.

The DID model specified in Equation 1 estimates the average treatment effect of the introduction of high-speed fiber broadband on the mental health of older adults. In Equation 2, I show the event study version of the DID estimation to test for parallel trends and estimate the dynamic treatment effect. By incorporating time-varying treatment effects, I account for the strategic complementarities characterized by waiting for others to adopt which are especially important for older adults (Alvarez *et al.*, 2023). This estimation provides valuable insights into the evolving impact of broadband expansion over time and allows for a more comprehensive analysis of the causal relationship between broadband access and mental health outcomes of older adults.

$$y_{igct} = \delta_i + \gamma_{gt} + \sum_{\tau=-3,\tau\neq-1}^{3} \beta_\tau Fiber_{\tau(ct)} + \epsilon_{igct}. \tag{2}$$

Here, $Fiber_{\tau(ct)}$ are indicator variables equal to 1 if the introduction of fiber was τ years away for fiber expansion group g in HRS survey wave t. I plot the estimates for three pre-periods of the treatment, out of which one year is omitted (-1), and four post-period estimates from 0 to 3 periods after the treatment, where 0 is the instantaneous treatment effect. I show the estimates with a balanced panel of HRS respondents.

Recent advances in the DID literature suggest that the conventional two-way fixed effects (TWFE) estimator provides consistent estimates under the assumption of treatment effect homogeneity (e.g., Sun and Abraham (2021), Goodman-Bacon (2021), De Chaisemartin and d'Haultfoeuille (2022a)). However, the introduction of fiber may result in heterogeneous treatment effects, given varying rates of adoption, potentially influencing the mental health

[37] Here, I cannot include both group and individual fixed effects at the same time. One of them must be dropped because there is no between-group movement for individuals. Therefore, I restrict the sample to individuals who did not migrate from their census tracts of residence during the study period of 2010-2018. I show results by including those migrants in the Robustness section.

of older adults differently. It is also possible that the treatment effects may vary across individuals, exhibiting heterogeneity based on various demographic characteristics like region, gender, or race. Another bias may arise if I compare older adults who were exposed to broadband earlier to those who were exposed later. Also, if some units are given negative weights, then the sign of the coefficients might be biased.

I address these concerns by employing the latest DID estimators. As suggested by De Chaisemartin and d'Haultfoeuille (2022b), there are four main estimators that are relevant to this study. The estimators for the binary and staggered treatment that allow for dynamic treatment effects, i.e., outcomes that can be affected by past treatment, are provided by Sun and Abraham (2021), Callaway and Sant'Anna (2021), Borusyak *et al.* (2021) and De Chaisemartin and d'Haultfoeuille (2022a). These estimators differ on various aspects including the assumption they made and or the comparison groups they choose. De Chaisemartin and d'Haultfoeuille (2022b) provides a detailed comparison among these estimators. To capture this heterogeneity in treatment effects over time and across treated units, I employ the event study methodology proposed by new DID estimators that allow for the heterogeneous treatment effects of fiber broadband introduction on mental health outcomes among older adults. These estimators account for the dynamic treatment effect, which is important for at least two reasons. First, older adults are generally less tech-savvy than younger people. Secondly, on average, about 55% of the sample respondents have below a high school degree. If we think that older people who are less tech-savvy or less educated might take more time to learn and adapt to new technology, we might see effects over time rather than instantaneous ones.

I prefer the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a) for the following reasons, but show that the results are robust across all the estimators. First, as suggested by De Chaisemartin and d'Haultfoeuille (2022b), only De Chaisemartin and d'Haultfoeuille (2022a) and Borusyak *et al.* (2021) readily provide the average treatment effects. Secondly, I prefer an estimator that takes into account the 'never-treated' group (Group 0) since it is comparable with the treated groups. However, the estimator by Borusyak *et al.* (2021) does not include the 'never-treated' group but considers the yet-to-treat group for comparison. Further, the estimator provided by Borusyak *et al.* (2021) might not work well in the presence of a strong serial correlation De Chaisemartin and d'Haultfoeuille (2022b). I test the serial correlation between the primary outcome variable and its lag values and find that the serial correlation is strong.[38]

5 Results

5.1 Effect on the Speed of Internet

As explained in the theoretical model, in the first stage of the fiber expansion, one may speculate whether the quality of the internet improved or not. Following Campbell (2022), I measure the quality of the internet as the maximum advertised download speed in Mbps in a census tract in a given year. I show the estimate of the effect of fiber expansion on the maximum advertised download speed in Table 2. These estimates suggest a significant increase in the advertised maximum download speed after the fiber broadband expansion. There could be several reasons for this massive increase in the internet speed. First, fiber broadband comes with a massive internet speed. Secondly, due to the competition among the service providers, the introduction of fiber could drive this increase in speed Campbell (2022) has documented this competition in more detail.

TABLE (2) Average Treatment Effect of Fiber Broadband on the Internet Download Speed (Mbps)

	Max Advertised Download Speed (Mbps)		
	(1)	(2)	(3)
Post Fiber	344.5***	344.5***	344.3***
	[16.1]	[17.3]	[19.9]
Observations	55,606	55,606	54,234
Year Fixed Effects	Yes	Yes	Yes
Individual Fixed Effects	Yes	Yes	
Controls		Yes	
Census-Tract Fixed Effects			Yes
Baseline Mean of Outcome	199.1	199.1	199.1

Note: This table shows the average intent-to-treat effects of the staggered introduction of fiber broadband on the availability of the average maximum download speed for older adults, using Equation 1 and the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). The sample is a balanced panel of HRS respondents for biennial waves from 2010 to 2018. The age group is 51 to 103. The treatment variable is equal to 1 if fiber is available in a census tract of residents in survey year t and 0 otherwise. The individual controls include age and whether the individual receives Medicaid, is currently married, and works for pay. I also include the HRS person weights in the estimation. Standard errors in square brackets are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.10.

[38] Coefficient 0.59, SD(0.004).

5.2 Main Results

Table 3 shows the estimates of the average treatment effect (intent-to-treat) of the introduction of fiber broadband on the mental health of older adults using the equation (Equation 1) and estimator provided by De Chaisemartin and d'Haultfoeuille (2022a) using the balanced panel of HRS respondents. The estimate in the first column with my preferred specification shows the key results of the DID specification. This specification incorporates the individual fixed effects and the fiber broadband expansion year fixed effects to ensure that identification stems from within-individual changes in fiber availability over time. Column 2 includes individual-level time-varying controls in addition to the specifications in column 1. In column 3, I replace individual fixed effects with the census-tract fixed effects. In column 4, I introduce expansion group-year fixed effects to account for the shocks that affect all individuals in an expansion group in a given year.

TABLE (3) Average Treatment Effect of Fiber Broadband on the Symptoms of Depression

	CES-D Depression Score			
	(1)	(2)	(3)	(4)
Post Fiber	-0.082^{**}	-0.073^{**}	-0.091^{**}	-0.128^{**}
	[0.032]	[0.035]	[0.039]	[0.061]
Observations	47,935	47,163	49,728	47,935
Year Fixed Effects	Yes	Yes	Yes	Yes
Individual Fixed Effects	Yes	Yes		Yes
Controls		Yes		
Census-Tract Fixed Effects			Yes	
Expansion Group-year Fixed Effects				Yes
Baseline Mean of Outcome	1.42	1.42	1.42	1.42

Note: This table shows the average intent-to-treat effects of the staggered introduction of fiber broadband on depression symptoms among older adults, using Equation 1 and the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). The outcome variable 'depression' is the CES-D mental health categorical score from 0 to 8. The sample is a balanced panel of HRS respondents for biennial waves from 2010 to 2018. The age group is 51 to 103. The treatment variable is equal to 1 if fiber is available in a census tract of residents in survey year t and 0 otherwise. The individual controls include age and whether the individual receives Medicaid, is currently married, and works for pay. I also include the HRS person weights in the estimation. Standard errors in square brackets are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.10.

Table 3 suggests that the introduction of fiber broadband decreases depression symptoms among older adults, with estimates consistently supporting these findings across the various specifications. The point estimates are statistically significant in all the specifications. For example, column 1 shows that fiber expansion reduces depression symptoms among older adults by 0.082 units. After accounting for the individual-level time-varying controls and other fixed effects, the estimates are still statistically significant and increase in some cases. This robustness in the results strengthens the evidence for the beneficial impact of fiber broadband on mental health outcomes.[39] Apart from the main analysis, I will focus on De Chaisemartin and d'Haultfoeuille (2022b) for the reasons explained in Section 5.[40]

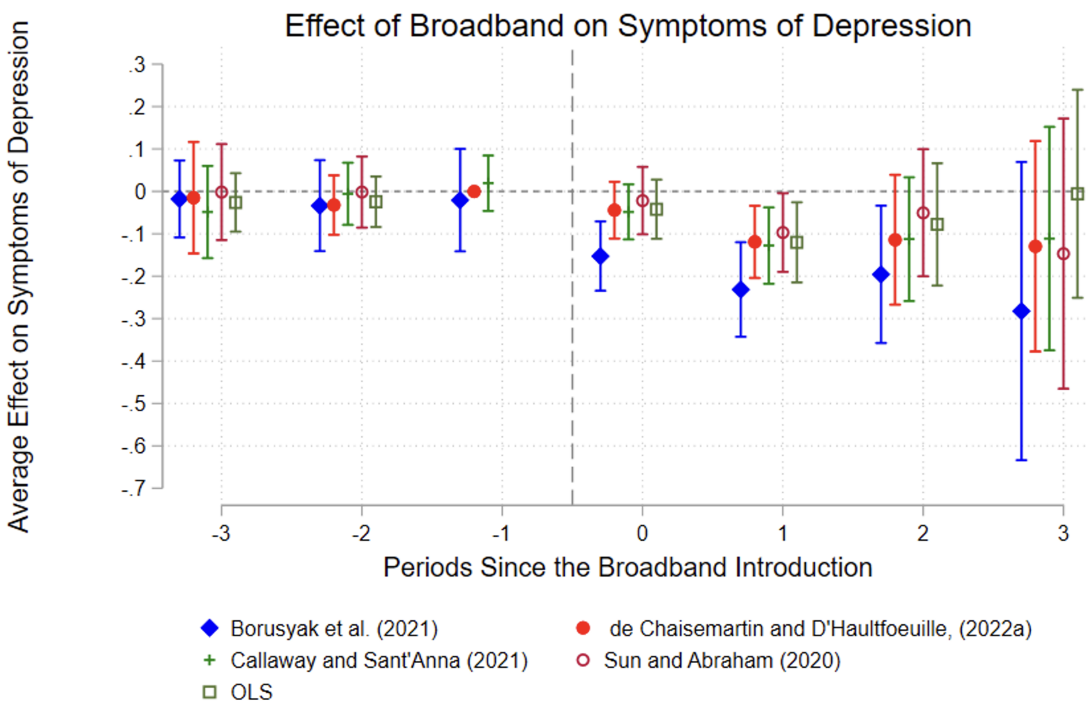
I use additional measures to illustrate the magnitude of the results. The preferred estimate from column 1 in Table 3 shows that fiber expansion reduces depression symptoms among older adults by 0.082 units on a scale of 0 to 8. This estimate is remarkably similar in magnitude (0.085) but opposite in direction to the effect observed in a study by Braghieri *et al.* (2022), which suggests that the expansion of Facebook increased mental health problems among college students in the US. These contrasting findings highlight a key result of this paper, indicating that the impact of a similar technology on mental health outcomes can vary based on age cohorts and potentially on how individuals engage with the technology. Section 8 provides further insights into the underlying reasons for this divergence. Additionally, I compare the estimates with a closely related meta-analysis conducted by Paul and Moser (2009). The results suggest that the positive effect of broadband expansion on depression symptoms is approximately 20% of the negative effect of job loss. Another comparison can be made with the study by McInerney *et al.* (2013), which examines the effect of the 2008 recession on the mental health of older adults. The estimates from my paper indicate that the benefit of broadband expansion is roughly 41% of the negative effect of the recession. These comparisons provide a context for understanding the relative importance of broadband expansion in affecting mental health as compared to the effects of other factors.

Further, I show the results with the dynamic treatment effects in Figure 5 using Equation 2 and the DID estimators proposed by De Chaisemartin and d'Haultfoeuille (2022a), Borusyak *et al.* (2021), Sun and Abraham (2021), Callaway and Sant'Anna (2021), and the

[39]Appendix Table 13 shows the estimates of the average effects of the introduction of fiber broadband on the mental health of older adults using an alternate DID estimator provided by Borusyak *et al.* (2021) and replicates similar positive effects of fiber broadband expansion.

[40]Because the Borusyak *et al.* (2021) estimator does not include the 'never-treated' group but considers the yet-to-treat group for comparison, the sample size in Appendix Table 13 is smaller than in Table 3. Secondly, Borusyak *et al.* (2021) may not work well in the presence of a strong serial correlation.

FIGURE (5) Dynamic Treatment Effects of Broadband Expansion on the Symptoms of Depression



Note: This figure shows the dynamic effects plots using Equation 2 with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a), Borusyak *et al.* (2021), Sun and Abraham (2021), Callaway and Sant'Anna (2021), and the traditional TWFE. The sample is from the HRS respondents for biennial waves from 2010 to 2018. The age group is 51 to 103. The outcome variable 'depression' is a CES-D mental health categorical score from 0 to 8, 0 being no depression and 8 being the highest depression. For Borusyak *et al.* (2021) and De Chaisemartin and d'Haultfoeuille (2022a), I include a fiber broadband expansion year and HRS respondents' individual fixed effects. For Callaway and Sant'Anna (2021), I include expansion group fixed effects in addition to the above two FEs. Standard errors are clustered at the census tract level. The bars show the 95 percent confidence interval. Sample size for DCDH estimator: N= 47,935 (switchers =6,726); N_{t0} = 23,694 (switchers =3,655), N_{t1} = 14,668 (switchers =2,155), N_{t2}= 7079 (switchers =735), N_{t3} = 2,494 (switchers =181).

traditional TWFE. Figure 5 suggests that depression symptoms are declining after the introduction of high-speed fiber broadband and are statistically significant, no matter which estimator I use, providing confidence in the main results. Figure 5 also suggests that the estimates prior to the introduction of the fiber broadband (period -2 and -3) are closer to 0 and insignificant, providing evidence for no pre-trends and consistent with the parallel trend assumption.

5.3 Self-use of Internet

The estimates presented in Table 3 reflect the ITT effect, which captures the overall effect of the availability of fiber broadband. This effect encompasses both the direct impact on individuals who actively use the internet and the potential indirect effects arising from others in the household or network using the internet. However, a significant contribution of this study lies in leveraging the rich data provided by the HRS to disentangle the direct and indirect effects. This is a departure from similar research.[41]

To distinguish between the direct and indirect effects, I incorporate variables from the HRS survey that capture respondents' use of the internet. Specifically, I consider measures such as regular web use and whether respondents engage in email communication with their children, family, or friends. By including these variables, I aim to provide a more nuanced understanding of the mechanisms through which broadband availability affects mental health outcomes among older adults.

The survey question is–[42]

"Do you regularly use the Internet (or the World Wide Web) for sending and receiving e-mail or for any other purpose, such as making purchases, searching for information, or making travel reservations?"

To assess the impact of broadband expansion on older adults' use of the internet, I transform positive responses to the above survey questions into a binary variable, assigning a value of 1 if the respondent answers affirmatively and 0 otherwise. Figure 8 presents the dynamic effects, using estimators provided by De Chaisemartin and d'Haultfoeuille (2022a) and Borusyak *et al.* (2021). Importantly, the pre-trend estimates are close to zero and mostly statistically insignificant, providing support for the validity of the parallel trend assumption in our analysis. Figure 8 shows mixed evidence on the effect of the rollout of fiber broadband on the use of the internet. The estimates are statistically significant under the Borusyak *et al.* (2021) estimation. However, under the De Chaisemartin and d'Haultfoeuille (2022a) estimation, the effect is not significant. One explanation is that the Borusyak *et al.* (2021) estimation, unlike De Chaisemartin and d'Haultfoeuille (2022a), does not include the 'never-treated' group; this is because the estimator provided by Borusyak *et al.* (2021) works well when there is not much serial correlation. Here, the serial correlation in the outcome variable is very small, so I prefer the Borusyak *et al.* (2021) estimator.

[41] For instance, Braghieri *et al.* (2022) documents that they cannot observe whether or not college students use Facebook, and their estimates are a combination of direct and indirect treatment effects. Note that I do not observe whether the respondent has access to fiber broadband at home.

[42] For the missing values, I impute the value =1 if the respondents report that they send emails to friends or families.

5.4 Heterogeneity

In this section, I explore the heterogeneity of the effects of broadband expansion based on various characteristics shown in Figure 6.[43] To begin, I investigate whether the effects differ based on gender, taking into account the well-documented differences in baseline depression levels between men and women, in that women tend to experience higher levels of depression across countries and age groups. If women are less likely to be exposed to fiber broadband, then one may expect even lesser benefits for women. Then, I examine whether the effects vary between urban and rural areas. Rural regions may be less likely to adopt fiber broadband and maybe less likely to experience an improvement in mental health. Additionally, I examine the differential impact of broadband expansion based on race, considering the higher prevalence of mental health issues among African Americans and disparities in access to the Internet based on race. Moreover, I study the effect based on marital status. Married couples often rely on each other for social interaction and support. Broadband access may affect their mental health differently depending on how they utilize it for social engagement. Finally, I analyze whether the estimates vary across age groups, separating out people who might still be below the retirement age (below 65) and may have access to broadband through their workplace. I expect higher access to the internet and potentially higher benefits for working people. Importantly, instead of using the traditional two-way fixed effects (TWFE) estimator commonly used to explore these heterogeneities, I estimate the effects using one of the latest DID estimators.[44]

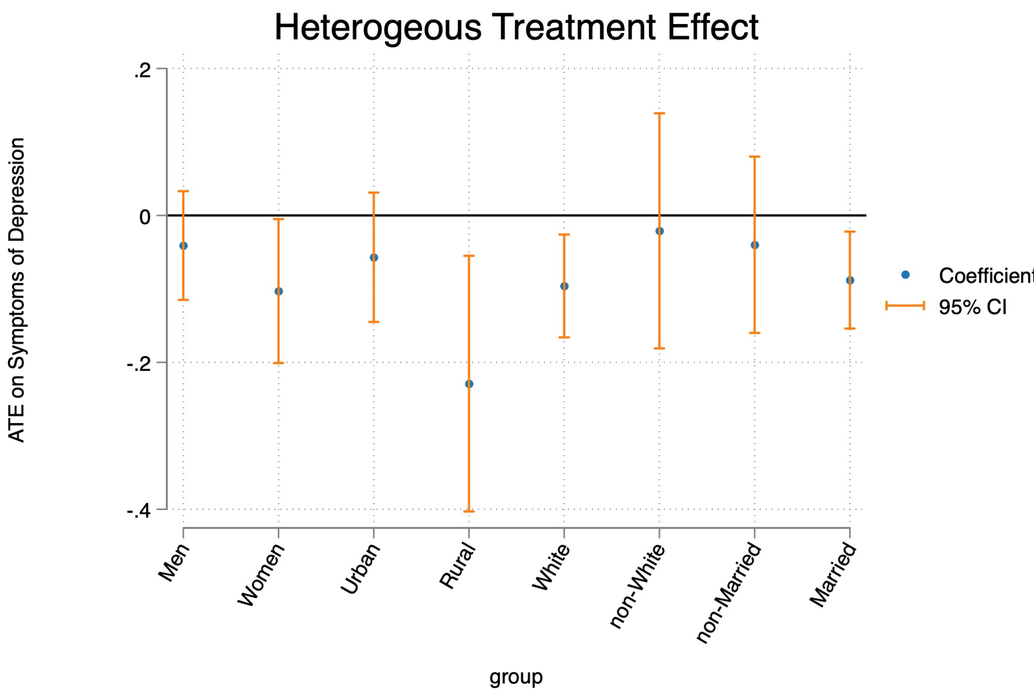
5.4.1 By Gender

Across nations and age groups, women have higher levels of depressive symptoms (Nolen-Hoeksema and Hilt, 2008, Salk *et al.*, 2017, Banerjee *et al.*, 2023). For the sample in this study, the mean depression (CES-D) score for women (1.52 (sd 2.07)) is higher than that of men (1.19 (sd 1.76)). The estimates in Figure 6 indicate a statistically significant decline in depression symptoms among women, while the decline for men is not statistically significant. These positive effects on women contrast with the findings of Braghieri *et al.* (2022), who find the adverse effects of social media (Facebook) on the mental health of female college

[43] I provide the table of the average treatment effects in Appendix Table 14.

[44] As mentioned in the previous sections, this estimator allows for treatment effect heterogeneity across groups and over time, providing a more robust analysis of the differential impacts of broadband expansion.

FIGURE (6) Heterogeneity



Note: This figure shows the treatment effects plots using Equation 2 estimating with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a) for different sub-groups. The outcome variable is the CES-D score. The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from 51 to 103. I include the individual fixed effects and survey wave fixed effects. Standard errors are clustered at the census tract level. The bars show the 95 percent confidence interval.

students primarily due to unfavorable social comparisons. On the other hand, relatively older women use the internet for purposes such as emails, accessing health-related information, and seeking support for personal and health-related issues (Pew Research). These findings suggest important benefits of broadband for older women and highlight that the impact of similar technology can vary based on age and potentially how the technologies are being used. In the Mechanism section, I explore the other potential mechanisms more.

5.4.2 Rural vs. Urban

The effect of the broadband rollout appears to be larger among rural residents. Appendix Table 11 suggests that fiber broadband expansion was slower in rural areas during the initial years. Rural residents tend to be older and poorer, with lower levels of education, worse mental health, and lower levels of private health insurance; they also have less access to mental health professionals because of shortages of such services in rural areas (Foutz *et al.*, 2017, Mueller *et al.*, 2018, Moy *et al.*, 2017, Pender *et al.*, 2019).[45] The estimates in Figure 6 indicate that the introduction of fiber broadband reduced depression symptoms among older adults in both urban and rural areas, with a statistically significant decline in rural areas. One potential reason for the positive benefits for rural dwellers could be better baseline mental health in urban areas, resulting in smaller gains. Another reason, as a recent report suggests, is the higher monthly frequency of Internet use for health information among rural Medicare beneficiaries compared to their urban counterparts (MCBS, 2022).[46]

5.4.3 Race

I estimate the model separately for Whites and non-Whites, considering the higher prevalence of mental health problems among African Americans. In the sample, the mean CES-D depression score for Whites is 1.27 (sd 1.88), while for African Americans, it is 1.69 (sd 2.00). Recent reports also suggest disparities in internet access and speed, with non-Whites and economically disadvantaged areas experiencing slower internet speeds for the same price (Wisconsin State Journal Report, 2022). The estimates in Figure 6 show a decline in depression symptoms among older Whites, while the results for non-Whites are not statistically significant. These findings suggest fiber broadband expansion may not significantly reduce depression symptoms for non-Whites, highlighting the existence of other structural barriers and the need for further efforts to address these disparities.

5.4.4 Marital Status

I estimate the effects based on the marital status.[47] I find in Figure 6 that the decline in depression symptoms is statistically significant for married couples, which supports the recent evidence that suggests the existence of spousal spillover of mental health among older English couples (Jain and Ma, 2024).

[45] Medicaid and CHIP Payment and Access Commission, Issue April 2021.

[46] This evidence is also consistent with Bundorf *et al.* (2006), who suggest that individuals with longer travel time from the source of care are more likely to use the internet for information.

[47] I define married couples as people in the data who are always married during the study period. Non-married categories include whether the respondent reported being divorced, separated, widowed, never married, or partnered.

5.4.5 Age Groups

Finally, in Appendix Table 15, I show the effect of broadband expansion based on the age groups of the respondents for different age groups: below 65, above 65, below 85, and above 85 years old.[48] The findings indicate a statistically significant (10% level) decline in depression symptoms for the age groups of above 65 and below 85, but no evidence of decline for those under 65 or over 85, suggesting an inverted U-shaped effect by age. These results suggest broadband's impact on mental health varies by age. For individuals under 65, broadband may affect mental health at the intensive margin if they have some internet access. For those over 65, the effect may be more pronounced at the extensive margin due to limited access. These findings highlight the potential mental health benefits of broadband expansion for the mid-age cohort.

5.5 Effect Based on the Length of Exposure

I extend the analysis by examining the effects of broadband expansion based on the length of exposure. For instance, in 2014, individuals who received broadband in 2011 would have been exposed for three years, while those who received broadband in 2012 would have been exposed for only two years. I also included the individuals who were exposed to fiber broadband during the non-HRS survey years, i.e., respondents exposed in 2011, 2013, 2015, and 2017. By incorporating the length of exposure in the analysis, I aim to capture the cumulative effects of broadband. I follow Braghieri *et al.* (2022) and estimate the following equation-

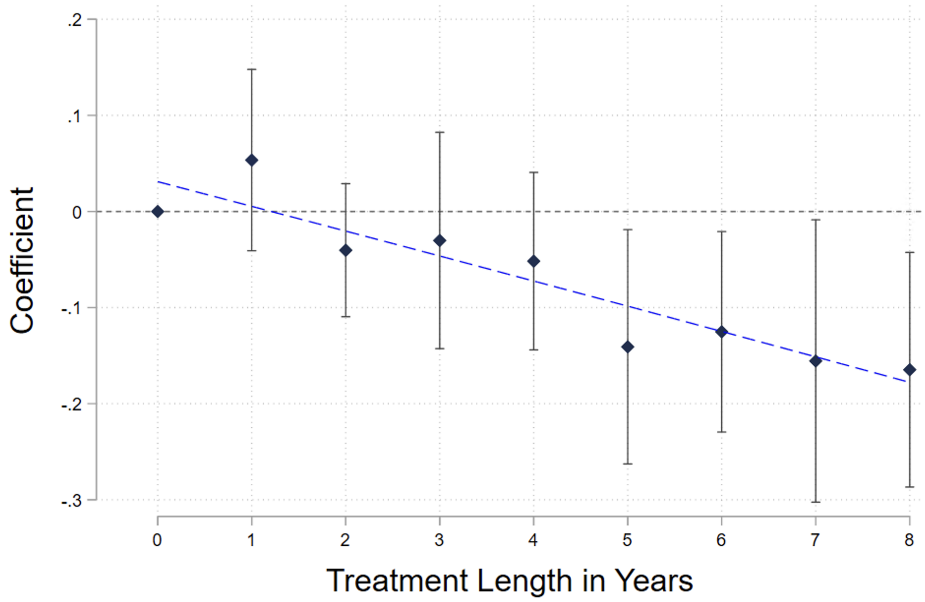
$$Y_{icgt} = \alpha_c + \gamma_t + \sum_{\tau=0}^{8} \beta_\tau \times \text{Years in Fiber}_{\tau(ict)} + \mathbf{X'}_i \times \lambda + \epsilon_{icgt}, \tag{3}$$

where 'Years in $\text{Fiber}_{\tau(ict)}$' are indicators equal to 1 if HRS respondent i at census-tract c in survey-wave t had access to fiber for τ years. The number of treated years is calculated as $\tau = Fiber_{gt} \times (t - \text{Year of treatment})$ where t is the survey year. α_c is the census-tract fixed effects and γ_t is the survey year fixed effects. I also include a vector of individual-level controls X'_i. Figure 7 shows the β_τ estimates and suggests a decline in mental health CES-D depression score over time. The figure shows that the number of treated years has a significant effect over time on the decline in depression symptoms. These estimates provide

[48] One key reason for making these groups is that the respondents below 65 might be more likely to still be working. Secondly, the 85+ age group has a higher prevalence of suicide-related deaths.

evidence that the mental health of older adults gets better the longer they are exposed to broadband.

FIGURE (7) Effect on Mental Health CES-D score by Length of Exposure



Note: This figure shows the estimates of the effect of the length of exposure to fiber broadband on the CES-D depression score. The dashed curve is the quadratic curve of best fit. The coefficients are estimated using the Equation 3 and the TWFE estimation. The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from 51 to 103. The outcome variable 'depression' is a CES-D mental health categorical score from 0 to 8, 0 being no depression and 8 being the highest depression. Individual controls include binary indicators if the respondent is male, enrolled in Medicaid, rural, White, has education more than high school, receives social security disability insurance (SSDI), and is currently married. Also, individual controls include age-fixed effects. I included the missing dummies for the covariates which are missing and replaced them with a value of 1. Standard errors are clustered at the census tract level. The bars show the 95 percent confidence interval.

5.6 Spatial Spillover

Previous literature often neglects bias due to such spatial spillover. There could be a bias in the estimates if spatial spillover effects exist. For instance, an individual living in a census tract does not receive the treatment, but the nearby census tracts receive the treatment. This gives an individual access to the resources in the areas with fiber broadband, such as medical facilities (for in-person or virtual visits) or a public library for health-related information, telehealth, or connecting with friends and families through the web. The health of this person might get better with the introduction of fiber internet in the nearby census tract. In this case, the estimates are biased downward.

I address these concerns in the following ways. First, I use the DID estimator by Borusyak *et al.* (2021) in Figure 5 and Table 13, which does not include the 'always control group.' The estimates shown in Table 13 are higher than if I include the 'always control group' and the main effects in Table 3 are potentially the lower bounds of the actual effects. This differential impact provides evidence of the presence of spatial spillover from the 'always control group,' and after correcting for the potential bias, the treatment effect persists and even becomes stronger. Secondly, I follow Butts (2021) in part to randomly choose a census tract from each county to reduce the bias in the estimation due to spillover effects. The estimates are shown in Table 4, which shows that the estimates are almost doubled. This also provides evidence that there may exist a spatial spillover effect, and the main effects shown Table 3 are lower bounds of the actual effects.

TABLE (4) Average Treatment Effect of Fiber Broadband on the Symptoms of Depression for one random census tract from each county

	CES-D Score		
	(1)	(2)	(3)
Post Fiber	-0.199^{**}	-0.186^{***}	-0.198^{**}
	[0.079]	[0.065]	[0.085]
Observations	9,372	9,372	9,710
Year Fixed Effects	Yes	Yes	Yes
Individual Fixed Effects	Yes	Yes	
Controls		Yes	
Census-Tract Fixed Effects			Yes

Note: This table shows the average effect of the staggered introduction of fiber broadband on depression symptoms among older adults, using Equation 1 and the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). In this estimation, I focus on one randomly chosen census tract in each county. The outcome variable 'depression' is the CES-D mental health categorical score from 0 to 8. The sample is a balanced panel of HRS respondents for biennial waves from 2010 to 2018. The treatment variable is equal to 1 if fiber is available in a census tract of residents in survey year t and 0 otherwise. The individual controls include whether the individual receives Medicaid, is married, and works for the pay. I also included the HRS person weights in the estimation. Standard errors in square brackets are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.10.

6 Robustness

The primary results suggest that the broadband expansion positively affects the mental health of older adults. I perform several sensitivity analyses to check the robustness of these results.

First, in Table 3, I show estimates with different specifications, including individual time-varying controls, the census-tract fixed effects, and group-year fixed effects. These estimates suggest a consistent decline in depression symptoms and provide evidence of the positive impact of broadband expansion on the mental well-being of older adults. The estimates are statistically significant across different specifications. This analysis strengthens the validity of the findings, suggesting that omitted variables or confounding factors do not drive the observed effects that can be attributed to the introduction of broadband technology.

Secondly, I use the latest DID estimators relevant to the binary and staggered treatment to check the sensitivity of my findings. The results are shown in Figure 5 and Table 13. Figure 5 shows a consistent decline in depression symptoms across different DID estimators and with traditional TWFEs. Similarly, the estimates in Table 13 that use the estimator provided by Borusyak *et al.* (2021) suggest the same conclusion, in fact, a higher decline in the depression symptoms.[49] Note that, for the table estimates, I focus on estimators provided by De Chaisemartin and d'Haultfoeuille (2022a) and Borusyak *et al.* (2021) because, as suggested by De Chaisemartin and d'Haultfoeuille (2020), we cannot readily obtain the standard errors of the average treatment effects from the commands used in Callaway and Sant'Anna (2021) and Sun and Abraham (2021).

Third, I show the estimates by including the respondents who moved out of their census tract during the study period (movers). The main estimation is focused on the 'stayers,' i.e., individuals who do not move out of their census tract for the study period. This is because, first, migration could be endogenous. If people with better mental health are more likely to migrate in or out after the rollout of broadband, the main estimates could be biased. Secondly, I find that older adults are less likely to migrate. About 91% of the sample referred to as 'stayers' during the study period, but only about 9% of the respondents were 'movers' and relocated at least once from their census tract of residence. I include 'movers' in addition to the primary sample in Table 5 (column 1), which shows that the estimates are slightly lower than the main estimates but statistically significant. The estimates suggest that the movers are not driving the estimates and provide reassurance that mobility patterns do not drive the observed effects, which are consistent even when considering the impact of migration on the estimates.

Further, column 2 of Table 5 shows the effect of fiber broadband rollout on a relatively extreme measure of symptoms of depression – 'clinical depression.' In the HRS, a CES-D

[49] One key reason for the different point estimates in Table 3 and Table 13 is that the Table 13 does not include the 'never treated' group.

TABLE (5) Average Treatment Effect of Fiber Broadband on the Symptoms of Depression–Robustness Checks

Sample	Stayers and Movers (1)	Outcome-Clinical Symptoms of Depression (2)	Outcome-Mortality (3)
Post Fiber	-0.076^{***}	-0.014^{**}	-0.004^{*}
	[0.026]	[0.007]	[0.002]
Observations	71,323	47,935	60,123
Year Fixed Effects	Yes	Yes	Yes
Individual Fixed Effects	Yes	Yes	Yes
Baseline Mean of Outcome		0.14	0.016

Note: This table shows the effects of the staggered introduction of fiber broadband on depression symptoms among older adults, using Equation 1 and the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). For column 1, the outcome variable is the CES-D score, and the estimate focuses on both movers and stayers. In column 2, the outcome variable is referred to as 'clinical depression', which is an extreme version of the CES-D score which takes a value of 1 if the CES-D score is greater than 3 and 0 otherwise. The outcome variable in column 3 is individual mortality, i.e., whether the individual has died or not in the survey year. The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The treatment variable is equal to 1 if fiber is available in a census tract of residents in survey year t and 0 otherwise. I also included the HRS person weights in the estimation. *** p<0.01, ** p<0.05, * p<0.10.

score above three is considered indicative of clinically relevant symptoms of depression or 'caseness' (Schane *et al.*, 2008, McInerney *et al.*, 2013). Table 5 supports the main conclusion of the paper, that the clinical symptoms of depression decline after the introduction of fiber broadband technology. To put these findings into context, I compare them with research that examines the effect of unexpected widowhood on depression. The results from my study suggest that the benefit of broadband expansion is about 14% of the negative effects associated with the unexpected loss of a spouse (Siflinger, 2017).[50] This comparison sheds light on the relative impact of broadband expansion in mitigating depression symptoms compared to other significant life events.

Another concern could be mortality selection. Even though the main estimates are focused on the individual balance panel sample from HRS. However, if more depressed individuals are dropping out of the sample and only the mentally healthier individuals are surviving, then the estimates shown in Table 3 could be downward biased. On the other hand, if broadband expansion makes more depressed individuals survive on the margin, then

[50] I compare my DID estimate that has individual fixed effects.

the estimates in Table 3 could be upward biased. I show the estimates in column 3 of Table 5 where the outcome is whether the individual has died or not. The estimates suggest that the rollout of fiber broadband declines individual-level mortality, suggesting other positive benefits of the broadband rollout. Additionally, I control for baseline self-reported health status (1 if health is excellent, very good, or good, and 0 if fair or poor), which may affect mortality risk and mental health outcomes. Controlling for this variable may reduce the bias due to unobserved heterogeneity. The estimate of this regression is (-0.070, $p\text{-}value < 0.1$), which replicates the estimates in column 2 of Table 3, suggesting that the estimates are robust to the mortality selection.

Finally, I control whether the individual takes regular medicine for anxiety or depression to control the underlying mental health conditions. Specifically, I added an additional control in the specification in Column 2 of Table 3. I find the magnitude of the estimates is consistent (-0.073, $p\text{-}value < 0.1$), which may suggest that the main estimates are less likely to be biased due to unobserved heterogeneity.

7 Mechanisms

In this section, I present empirical evidence regarding the potential mechanisms underlying the positive effect of broadband expansion on the mental health of older adults. Specifically, I test whether broadband affects mental health through feelings of social isolation and loneliness, social connections, use of medications for anxiety or depression, health literacy, use of mobile health apps or websites, and technological efficiency through telehealth. This study is among the first to empirically test the causal relationship between high-speed broadband technology and some of these key channels.

7.1 Social Isolation and Loneliness

To explore the impact of broadband expansion on the feelings of social isolation among older adults, I utilize specific questions from the HRS survey that assess feelings of being isolated from others. Column 1 in Table 6 indicates a 15% decline in the feelings of social isolation among older adults following the expansion of broadband. Similarly, column 2 indicates a 9% decline in feelings of loneliness. Both of these estimates are statistically significant. This causal evidence supports the claim from the correlational studies in medical research Cotten *et al.* (2013), Yu *et al.* (2019). These key findings support the social isolation hypothesis, suggesting that broadband expansion has been instrumental in mitigating feelings of social isolation and loneliness among older individuals.

TABLE (6) Average Treatment Effect of Fiber Broadband on the Feelings of Social Isolation and Loneliness

	Felt Isolated (1)	Felt Lonely (2)
Post Fiber	-0.050^{***}	-0.014^{**}
	[0.019]	[0.007]
Observations	6,006	47,830
Year Fixed Effects	Yes	Yes
Individual Fixed Effects	Yes	Yes
Mean of Dependent Var	0.319	0.154

Note: This table shows the average treatment effects of the staggered introduction of the fiber broadband on the 'feeling of social isolation' and the 'feeling of loneliness' among older adults using Equation 1 and estimating with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). The 'feeling of loneliness' question is used to calculate the CES-D score and is asked to everyone. However, the 'feeling of social isolation' question is asked to a subset, and that's why the sample size is smaller. The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018, aged 51+. The treatment variable is equal to 1 if the fiber is available in a census tract of residents in survey year t and 0 otherwise. Standard errors in square brackets are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.10.

7.2 Virtual Social Connectedness

The Internet can serve as a source of social support (Pescosolido, 2011). A plausible pathway through which broadband technology may influence mental well-being among older adults is by facilitating virtual connectedness with family members and friends. To examine this, I construct a novel index for 'virtual social connectedness using relevant baseline (2010) survey questions from the HRS.[51] These questions inquire about the frequency of sending emails to family, friends, and children, as well as the use of social media platforms such as Facebook or Skype to connect with loved ones. Additionally, the survey captures regular web usage. Combining these variables, I create an index that I convert into an indicator variable, taking a value of 0 to indicate low virtual social connectedness if the index is below the 25th percentile and a value of 1 if the index is above the 75th percentile, signifying high virtual social connectedness. I conduct separate estimations for these two groups.

[51] The index is partly motivated by a seminal work in epidemiology– Berkman-Syme Social Network Index (Berkman and Syme, 1979).

Table 7 shows the effects of broadband expansion on mental health differ for these two groups. The results reveal a significant decline in depression symptoms for highly socially connected individuals while indicating no statistically significant change in depression symptoms for those with low levels of social connectedness. These findings also align with the social isolation hypothesis, which posits that limited social connections can have detrimental effects on mental health. Overall, these empirical findings shed light on the unexplored potential mechanisms through which broadband expansion may influence the mental well-being of older adults, emphasizing the role of virtual connectedness and the consequences on mental health outcomes.

TABLE (7) Average Treatment Effects of Broadband on Depression Symptoms Based on Social Connectedness

	Outcome: CES-D Depression Score	
	Social Connectedness Index	
	Below 25 pct	Above 75 pct
	(1)	(2)
Post Fiber	−0.060	−0.163**
	[0.068]	[0.065]
Observations	7,857	7,852
Year Fixed Effects	Yes	Yes
Individual Fixed Effects	Yes	Yes

Note: The estimator is by Borusyak *et al.* (2021) since the . The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from 51 to 103. The outcome variable 'depression' is a CES-D mental health categorical score from 0 to 8, 0 being no depression and 8 being the highest depression. The treatment variable is equal to 1 if the fiber is available in a census tract of residents in survey year t and 0 otherwise. The social-connectedness index is calculated based on the frequency with which the respondent reported that they send emails to either family, friends, or children and use social media like Facebook to connect with friends and family and regular web use for "sending and receiving e-mail or for any other purpose, such as making purchases, searching for information, or making travel reservations." The time variable is the survey wave, and the fiber group variable is the group of census tracts in which fiber was introduced in various years. Standard errors are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.10.

7.3 Use of Medications

Further, I test whether better mental health is translated through the increase in the regular use of medications for anxiety or depression.[52] I provide the estimates with the medication as an outcome in Appendix Table 16. These estimates suggest a null effect on the use of

[52] I find a strong correlation (0.328, *p-value* < 0.01) between the use of medication for anxiety or depression and the primary measure of depression symptoms (CES-D score).

the medications for anxiety and depression. This provides further evidence that the primary channels through which broadband may affect the mental health of older adults could be likely through social network channels, as explained previously.

7.4 Health Literacy

Another potential mechanism through which the introduction of high-speed fiber broadband may positively impact the mental health of older adults is through improvements in health literacy. It is possible that within-household spillovers or social circles contribute to enhanced health literacy among individuals. Additionally, the self-use of health apps may also play a role in improving mental health outcomes.

I follow the literature to define health literacy from the 2010 wave of HRS, where the respondents were asked:

How confident are you filling out medical forms by yourself – extremely confident, quite confident, somewhat confident, a little confident, not at all confident?.

I use a scoring system that takes the value 0 if the response is 'not at all' and the value 1 if 'extremely' and 0.25, 0.5, and 0.75 in between (Bavafa *et al.*, 2019). Table 8 columns 1 and 2 suggest that the introduction of fiber is strongly and significantly correlated with health literacy.

Secondly, I use two survey questions from the 2014 HRS survey to test the likelihood of using health-related applications or websites. The questions in HRS are

In the past month, have you used any downloaded health-related mobile applications or "apps" on a smartphone or tablet computer such as an iPad, Android, or Kindle Fire?

And,

In the past month, have you used any online health-management tools or websites, including those connected with your doctor's office, health care agency, insurance company, pharmacy, or other health-related sites such as Patient Portals or Weight Watchers Online?

Columns 3 and 4 in Table 3 indicate a positive relationship between the introduction of fiber broadband and the use of health-related apps. While none of the estimates reach statistical significance, the magnitudes of the coefficients are more than double the mean of the outcome variable. These findings suggest a strong correlation between the availability of fiber broadband and the utilization of medical apps, even though the lack of statistical significance indicates the need for further research to explore these mechanisms more comprehensively.

TABLE (8) Mechanisms: Effect on Health Literacy, Use of Health Apps and Health Websites

	Health Literacy		Use of Health Apps		Use Health Management Sites	
	(1)	(2)	(3)	(4)	(5)	(6)
Fiber X Post	0.341**	0.408***	0.519	0.625	0.211	0.340
	[0.141]	[0.149]	[0.374]	[0.392]	[0.215]	[0.226]
Observations	896	893	820	804	820	804
Individual Controls		Yes		Yes		Yes
Mean of Outcome Var	0.672	0.673	0.036	0.037	0.133	0.136
HRS Survey Year	2010		2014		2014	

Note: The sample is the cross-section data of HRS for the specified periods. Refer to the text for the definition of the outcome variables. I use the logit model for the estimations in columns 3 to 6. Individual controls include gender, binary indicators if the respondent is enrolled in Medicare or Medicaid, age-fixed effects, rural, White, an indicator for more than high school, an indicator if the respondent receives social security disability insurance, whether receives a pension, and whether the respondent is currently married. I also include the missing dummies for the covariates. Standard errors are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.10.

It is, however, important to exercise caution when interpreting the findings presented in Table 8. The mechanisms analyzed in this table are based on survey questions that were administered to a limited number of HRS respondents in either one or two waves. Consequently, the small sample size may limit the statistical power to detect significant effects accurately. Another concern could be reverse causation. For instance, internet use may affect health literacy, and health literacy may affect internet use. The presence of such reverse causation is evident in studies (Levy *et al.*, 2015, Bavafa *et al.*, 2019). Since the primary treatment here is the 'introduction of fiber broadband in a census tract', I believe reverse causation may be less of a concern.

7.5 Technological Efficiency for Telehealth

In this subsection, I examine whether the introduction of broadband improves the technological efficiency of nearby hospitals by investigating the availability of telehealth services. Telehealth has been recognized as an efficient and effective tool in healthcare, but its widespread implementation has been hindered by the lack of high-speed internet access, particularly in rural and underserved areas(Gajarawala and Pelkowski, 2021). Recent evidence suggests that access to telemedicine during the COVID-19 pandemic increased primary care visits without adverse effects on health outcomes (Zeltzer *et al.*, 2023). To explore this hypothesis, I utilize data from the 2018 Annual Survey Database administered by the American Hospital Association (AHA).[53] This voluntary survey collects information on hospital organizational structure, utilization, finances, facilities, and staffing. I analyzed 24 survey questions related to the availability of telehealth services for various types of care and hospital networks. (See Appendix Table 12 for the list of the questions). Since the AHA data is at the county level, I calculate the average number of broadband providers and speed at the county level. Using a logit model, Table 9 presents estimates that demonstrate a strong and statistically significant relationship between the number of broadband providers and the likelihood of hospitals offering telehealth services. Similarly, a strong relationship is observed when considering download speed instead of the number of providers. However, it is important to note that these estimates represent correlation rather than causal evidence due to the limited availability of AHA survey data for multiple years. [54]

8 Conclusion

This study contributes to the existing literature by examining the causal relationship between the rollout of high-speed broadband technology and the mental health outcomes of older adults. Furthermore, this research explores the unexplored pathways through which these effects may manifest. The findings demonstrate that the expansion of broadband significantly reduces symptoms of depression among individuals aged 50 and above, providing

[53]The primary reason that I use the AHA survey for only 2018 is that the surveys are paid data, and UW-Madison had access to only the 2018 wave. In my other work in progress, I collaborate with other researchers who have access to more waves of data, and we are answering this question in more detail.

[54]One may use the number of broadband providers as an instrument for whether or not a hospital offers telehealth services and then look into the mental health outcomes. This instrument, however, may not satisfy the exclusion restrictions.

TABLE (9) Mechanisms: Hospitals offer Telehealth Services

VARIABLES	Offer Telehealth Services	Offer Telehealth Services
	(1)	(2)
# Broadband Providers	0.136***	
	[0.013]	
Log (Download Speed +1)		0.131***
		[0.021]
Observations	6,941	6,941
Mean of Outcome Var	0.446	0.446

Note: The data is the American Hospital Association (AHA) survey 2018 merged with the broadband data for the year 2018 at the County level. The outcome variable is an indicator equal to 1 if the hospital or its network offers telehealth services and 0 if not. Standard errors are clustered at the county level. *** p<0.01, ** p<0.05, * p<0.10.

robust statistical evidence of sustained improvements in mental health over time. Heterogeneity analysis reveals that older adults residing in rural areas experience greater benefits compared to their urban counterparts, emphasizing the importance of geographic context. Moreover, the study identifies an inverted U-shaped effect based on age groups, indicating that individuals aged 65 and above but below 85 derive the most significant and substantial benefits. Conversely, the average treatment effects for individuals below the age of 65, who are more likely to be employed, are positive but not statistically significant. Additionally, the study uncovers racial disparities, as Whites drive the positive effects of broadband expansion, while no significant effects are observed for non-Whites. Further investigation is needed to address this gap. Furthermore, the results indicate that women experience slightly larger average treatment effects compared to men. Exploring potential mechanisms, the study highlights the role of higher social connectedness, lower social isolation, improved health literacy, enhanced cognitive function, and technological advancements in nearby hospitals as potential pathways through which the effects of broadband technology may translate into better mental health outcomes for older adults. These findings contribute important insights to the literature, informing policymakers and stakeholders about the implications of broadband expansion for the mental well-being of older adults.

Recent research has highlighted the adverse mental health effects of social media, particularly on college students, with young women being more susceptible due to *social comparisons*. Concerns arise regarding whether the internet may impact older individuals in a similar manner, raising public health implications. Surprisingly, this study finds that internet availability is beneficial for older adults, with the mental health benefits approximately equal in magnitude to the costs observed among youth. The primary driver of these benefits is *social connectedness*, which stands in contrast to the costs experienced by teenagers due to social comparison. This finding emphasizes that the impact of similar technologies can differ significantly based on the user and individual patterns of technology use. It underscores the importance of investing in broadband technology and implementing policies that foster social connections, telehealth, and other mechanisms.

One important limitation of this study is that the data does not provide information on whether the survey respondents have fiber broadband at their homes. Internet use could occur at various locations such as home, work, coffee shops, or public libraries. As a result, the estimates presented in this study represent intent-to-treat effects. Nonetheless, the findings are important for policymakers seeking to understand the potential health benefits of broadband expansion for older adults, understand the potential mechanisms underlying these effects, and assess whether there are specific benefits for rural communities.

These findings emphasize the need for policies that promote broadband expansion and investments in these mechanisms in mental health resources for older adults, both electronic and in-person.

9 Discussion

The estimates presented in this paper hold significant relevance for several reasons. Firstly, the global population is aging, leading to an increase in issues such as mental health and social isolation. Concurrently, there has been substantial growth in internet usage, with approximately 63% of the world's population utilizing the internet in 2021, compared to just 7% in 2000. Moreover, there are around 1.33 billion fixed broadband subscriptions worldwide (World Bank 2021). High-speed internet has become a necessity regardless of age or occupation, as it plays a crucial role in various daily activities. The usage of the internet and social media technologies has also seen a significant increase among older adults, making it imperative to focus on this vulnerable age group. The findings of this paper underscore the benefits of high-speed broadband for the well-being of older adults, emphasizing the importance of internet access for maintaining social connections with family and friends.

Secondly, broadband has demonstrated its positive influence on these technological advances, such as telehealth, which can have significant implications for the well-being of older adults. As telehealth services become increasingly important, reliable and high-speed internet access becomes a critical component for enabling effective healthcare delivery and remote consultations.

Thirdly, it is essential to recognize that not everyone has equal access to high-speed internet. Disparities in internet availability based on geographical location, race, and income have been documented, and the COVID-19 pandemic has further highlighted these disparities. To address these inequities, substantial government investments using public funds have been allocated to initiatives such as the Internet for All and Affordable Connectivity Program (ACP), which have dedicated over $65 billion USD to expand internet access. Understanding the potential effects of such substantial investments on the health of one of a vulnerable age group is of utmost importance in ensuring equitable outcomes and maximizing the benefits of these initiatives.

This paper's findings shed light on the significant implications of broadband expansion for the mental health and well-being of older adults, highlighting the importance of internet access for staying socially connected. Moreover, it underscores the role of broadband in facilitating technological advancements like telehealth. Finally, the study emphasizes the need to address disparities in internet access, particularly for vulnerable populations, as substantial investments are made to bridge the digital divide and promote equitable outcomes. While my research period is till 2018, exploring the role of broadband during the COVID-19 era in the mental health of older people is a promising avenue for future research.

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Appendices

A Data and Descriptive Statistics

TABLE (10) HRS question for the CESD Score

CES-D depression indicators	"Much of the time during the past week, you..." (Y/N)
Negative (1: Yes, 0: No)	1. Felt depressed 2. Felt lonely 3. Felt sad 4. Could not get going 5. Felt that everything was an effort 6. Your sleep was restless
Positive (1: No, 0: Yes)	7. Felt happy 8. Enjoyed Life

TABLE (11) Summary Statistics on Various Characteristics

Variables Fiber Expansion Year	Group 1 2010	Group 3 2012	Group 5 2014	Group 7 2016	Group 9 2018	Group 0 No Fiber
Self Repo. Good Health	0.74	0.77	0.75	0.71	0.70	0.73
Normal BMI (18.5-24.9)	0.20	0.22	0.20	0.19	0.20	0.19
Age	70	70	70	69	70	70
Male	0.42	0.42	0.43	0.43	0.41	0.42
Above High School	0.50	0.57	0.48	0.48	0.45	0.45
White	0.70	0.71	0.76	0.71	0.74	0.78
Rural	0.14	0.05	0.37	0.13	0.10	0.27
Medicare	0.51	0.54	0.54	0.51	0.53	0.54
Medicaid	0.09	0.06	0.07	0.08	0.09	0.08
Gets SSDI	0.06	0.04	0.05	0.07	0.06	0.06
Gets Pension	0.21	0.23	0.22	0.19	0.20	0.22
Working for Pay	0.34	0.33	0.34	0.32	0.32	0.31
Currently Married	0.50	0.58	0.54	0.55	0.50	0.52
N Respondents-Group year	11728	1713	4353	10438	9332	18421
Number of Census Tracts	1085	174	696	258	922	2070

Note: The data are the balanced panel of HRS respondents merged with FCC for the periods 2010 to 2018 for every even year, using the geographical unit as census tracts.

TABLE (12) Questions in AHA data related to telehealth

Telehealth consultation and office visits hospital
Telehealth consultation and office visits health system
Telehealth consultation and office visits joint venture
Telehealth elCU - hospital
Telehealth elCU - health system
Telehealth elCU - joint venture
Telehealth stroke care - hospital
Telehealth stroke care - health system
Telehealth stroke care - joint venture
Telehealth psychiatric and addiction treatment - hospital
Telehealth psychiatric and addiction treatment - health system
Telehealth psychiatric and addiction treatment - joint venture
Telehealth remote patient monitoring: post-discharge - hospital
Telehealth remote patient monitoring: post-discharge - health system
Telehealth remote patient monitoring: post-discharge - joint venture
Telehealth remote patient monitoring: ongoing chronic care management - hospital
Telehealth remote patient monitoring: ongoing chronic care management - health system
Telehealth remote patient monitoring: ongoing chronic care management - joint venture
Telehealth other remote patient monitoring - hospital
Telehealth other remote patient monitoring - health system
Telehealth other remote patient monitoring - joint venture
Other telehealth - hospital
Other telehealth - health system
Other telehealth - joint venture

B Methods

B.1 Recent DID estimators

Borusyak *et al.* (2021) have proposed an estimator that may be more efficient than those in Callaway and Sant'Anna (2021) and Sun and Abraham (2021) under some assumptions. Estimators addressing this challenge take an intuitive "imputation" form when treatment-effect heterogeneity is unrestricted. This approach estimates fixed effects only among the non-treated observations (never-treated or not-yet-treated); it imputes untreated outcomes for treated observations and then computes the weighted average over the differences between actual and imputed outcomes as average treatment effects. This estimator is typically used to characterize under-identification when there is no never-treated group and in the case of spurious identification of long-run treatment effects that arise in conventional implementations of event study designs. Researchers sometimes prefer to drop the never-treated group since that may be less comparable to the treated groups. Also, even with the existence of the never-treated group, the not-yet-treated group is a larger control group and may lead to precise estimators (De Chaisemartin and d'Haultfoeuille, 2022b). Compared to Callaway and Sant'Anna (2021) and Sun and Abraham (2021), estimation from Borusyak *et al.* (2021) have a lower variance. De Chaisemartin and d'Haultfoeuille (2022a) use the never-treated group in the estimation. For these reasons, my estimate based on Borusyak *et al.* (2021) drops the never-treated group.

For estimating dynamic effects, I include the 'robust dynamic' option in the De Chaisemartin and d'Haultfoeuille (2022a) estimator, which computes DID_l estimators. The dynamic effect is essential to include the effect of past treatment (introduction of fiber broadband) on the current outcomes. The DID_l is a weighted average across time t and the treatment of fiber ($d \in 0, 1$) that compares $t - l - 1$ to t outcome evolution in groups that have a treatment 0 at the start of the panel and whose treatment changed (became 1) for the first time in $t - l$ (first time switchers) and in groups with treatment 0 from period 1 to t (not yet switchers). DID_l estimates the effect of having switched treatment for the first time l periods ago. Accordingly, DID_l estimates the cumulative effect of having been treated for $l + 1$ periods. DID_l are unbiased under heterogeneous and dynamic effects. I include three periods for the DID_1 to compute estimates for the three post-treatment periods.

I include placebo estimators to test the assumptions of parallel trends, non-anticipation, and strong exogeneity for the DID_l estimator. The placebo estimator is calculated by comparing the outcome's evaluation from $t - 2$ to $t - 1$ in groups that switch and do not switch treatment between $t - 1$ and t. In other words, placebo estimators compare first-time switchers' and not-yet switchers' outcome evolution before first-time switchers' treatment changes. Given the dynamic option, the long-difference placebos, which are a more powerful test than the first differences, are computed in order to test whether the trends are parallel over several periods. Under these assumptions, β is the average intent-to-treat effect of the introduction of fiber broadband on mental health.

I estimate the equation using the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a), denoted as DID_M. To address potential confounding factors, several additional specifications are considered. First, expansion group-time fixed effects are incorporated to account for the shocks that affect all individuals in a given expansion group in a given year. Additionally, census-tract fixed effects α_c are included in certain specifications to control for unobserved heterogeneity specific to each census tract. To account for potential autocorrelation within the treatment unit level over time, standard errors are clustered at the census tract level, which is a common practice in the differences-in-differences (DID) literature.

Callaway and Sant'Anna (2021) extend those baseline estimators in various directions. First, they propose more aggregated estimators, such as DID, a weighted average of the DIDc estimators across all cohorts reaching periods after their first treatment before the end of the panel. Second, they propose estimators that use the not-yet-treated instead of the never-treated as controls. Third, they propose estimators relying on a conditional parallel trends assumption. Fourth, they suggest placebo estimators to test the parallel trend assumptions underlying their estimators. These placebos are robust to heterogeneous effects.

Sun and Abraham (2021) provides an estimator that either uses the never-treated groups as controls or uses the last-treated groups if there are no never-treated. With the former control group, their estimators are identical to those proposed by Callaway and Sant'Anna (2021) with the same control group. Unlike Callaway and Sant'Anna (2021), they do not propose estimators relying on a conditional parallel trends assumption, nor do they propose estimators using the not-yet-treated as controls.

C Results

C.1 Alternate Estimator

The results in the Table 3 are based on the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). In Table 13, I show estimates with Borusyak *et al.* (2021). The estimates are consistent with the results in Table 3 and, in some cases, even stronger.

D Heterogeneity

TABLE (13) Average Treatment Effect of Fiber Broadband on the Symptoms of Depression (Using Alternate DID Estimator by Borusyak *et al.* (2021))

	CES-D Score			
	(1)	(2)	(3)	(4)
Post Fiber	-0.096^{***}	-0.083^{**}	-0.113^{***}	-0.188^{***}
	[0.035]	[0.035]	[0.043]	[0.050]
Observations	36,206	36,206	36,230	36,772
Expansion Year Fixed Effects	Yes	Yes	Yes	Yes
Individual Fixed Effects	Yes	Yes		
Controls		Yes		
Census-Tract Fixed Effects			Yes	
Fiber Expansion group FE				Yes

Note: This table shows the average treatment effects of the staggered introduction of the fiber broadband on the depression symptoms among older adults using Equation 1 estimating with the estimator provided by Borusyak *et al.* (2021). The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from 51 to 103. The treatment variable is equal to 1 if the fiber is available in a census tract of residents in survey year t and 0 otherwise. The outcome variable 'depression' is a CES-D mental health categorical score from 0 to 8, 0 being no depression and 8 being the highest depression. The individual controls include whether the individual receives Medicaid, is currently married, and works for the pay. I also include the HRS person weights in the estimation. Standard errors in square brackets are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.10.

TABLE (14) Average Treatment Effect of Fiber Broadband on the Depression Symptoms-By Region

	Rural	Urban	Men	Women	Whites	Non-Whites	Married	non-Married
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post Fiber	-0.229^{***}	-0.057	-0.041	-0.103^{**}	-0.096^{***}	-0.021	-0.088^{***}	-0.040
	[0.087]	[0.044]	[0.037]	[0.049]	[0.035]	[0.080]	[0.033]	[0.060]
Observations	9,930	37,779	19,453	28,482	36,403	11,396	25,487	15,969
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Individual FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean of Outcome	1.37	1.43					1.07	1.78

Note: This table shows the average treatment effects of the staggered introduction of the fiber broadband on the depression symptoms (CES-D) among older adults using Equation 1 and estimating with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). The sample is a balanced panel of HRS respondents for biennial waves from 2010 to 2018, aged 51+. The treatment variable is equal to 1 if fiber is available in a census tract of residents in survey year t and 0 otherwise. Standard errors in square brackets are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.10.

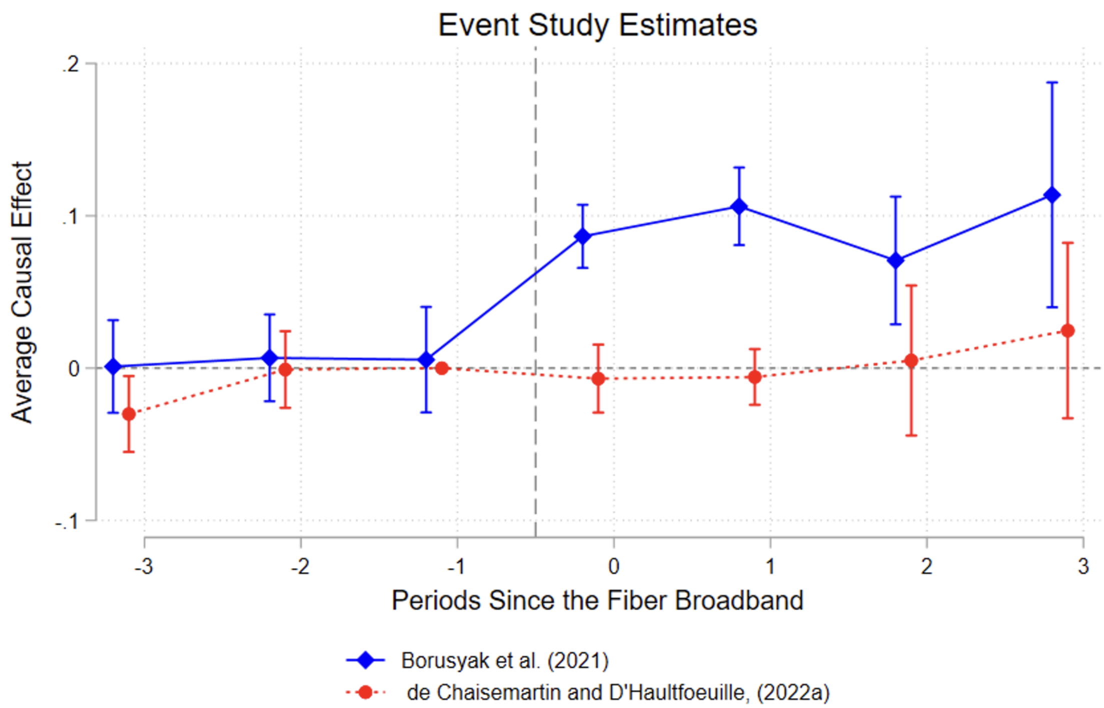
TABLE (15) Average Treatment Effect on Depression Symptoms: By Age Groups

	Below 65	65 to 85	Above 85
	(1)	(2)	(3)
Post Fiber	−0.068	−0.084*	0.041
	[0.066]	[0.043]	[0.101]
Observations	12,190	31,226	7,681
Year Fixed Effects	Yes	Yes	Yes
Individual Fixed Effects	Yes	Yes	Yes
Mean of Outcome Var	1.58	1.30	1.42

Note: This table shows the average treatment effects of the staggered introduction of the fiber broadband on the depression symptoms among older adults using Equation 1 and estimating with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). The outcome variable 'depression' is a CES-D mental health categorical score from 0 to 8, 0 being no depression and 8 being the highest depression. The sample is a balanced panel of HRS respondents for biennial waves from 2010 to 2018. The treatment variable is equal to 1 if the fiber is available in a census tract of residents in survey year t and 0 otherwise. Standard errors in square brackets are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.10.

E Mechanisms

FIGURE (8) Dynamic Treatment Effects- Outcome: Self Use of Internet



Note: This figure shows the dynamic effects plots using Equation 2 estimating with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a) and Borusyak *et al.* (2021). Note here that Borusyak *et al.* (2021) does not use the 'never-treated' group while De Chaisemartin and d'Haultfoeuille (2022a) does. The outcome variable is an indicator equal to 1 if the respondent uses the regular web or sends emails to children, friends, or family and 0 otherwise. The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from 51 to 103. The time variable is the survey wave, and the fiber group variable is the group of census tracts in which fiber was introduced in different years. I include group and treatment year fixed effects. Standard errors are clustered at the census tract level. The bars show the 95 percent confidence interval.

TABLE (16) Average Treatment Effect of Fiber Broadband on Use of Medications for Anxiety or depression

	Using DCDH Estimator	Using Borusyak Estimator
	(1)	(2)
Post Fiber	0.003	0.001
	[0.006]	[0.006]
Observations	38,479	30,270
Year Fixed Effects	Yes	Yes
Individual Fixed Effects	Yes	Yes
Mean of Outcome Variable	0.208	0.208

Note: This table shows the average treatment effects of the staggered introduction of the fiber broadband on whether the respondents take drugs for anxiety or depression using Equation 1 and estimating with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a) in column 1 and by Borusyak *et al.* (2021) in column 2. Note that the estimator in column 1 includes the never-treated units in the estimation, while the estimator in column 2 does not, and that's why there is a difference in the sample sizes. The sample is a balanced panel of HRS respondents for biennial waves from 2010 to 2018, aged 51+. The treatment variable is equal to 1 if the fiber is available in a census tract of residents in survey year t and 0 otherwise. Standard errors in square brackets are clustered at the census tract level. *** $p<0.01$, ** $p<0.05$, * $p<0.10$.