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

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Abstract

Recent evidence finds a negative effect of the internet on younger people's mental health, but less is known about older adults, who are more vulnerable to both mental health issues and online deception. This study estimates the effect of broadband expansion on the mental health of older adults in the United States. Using individual panel data, a staggered broadband rollout, and the latest difference-in-differences (DID) methods, I find broadband significantly improves older adults' mental health, reducing depression symptoms by 5.7%. Potential novel mechanisms uncovered include increasing digital use, quality of social connections, and declining social isolation and loneliness. JEL I12, I14, I18, L86, O33, P25

"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" (Ausubel, 2020).

1 Introduction

The aging US population faces increasing mental health challenges that have substantial economic costs but ineffective treatments. In 2019, the 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), Shumaker *et al.* (2023)). 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). Unfortunately, treatments for mental health are often ineffective, as many individuals avoid such treatments due to the stigma attached to mental illness, even with lowered mental health costs (Reynolds III *et al.*,

[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).

2012, Abramson *et al.*, 2024, National Academies of Sciences *et al.*, 2023).

The geographic distribution of older adults shows 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 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 lack 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 mostly focus on relatively younger populations and have found largely positive and some negative effects of broadband on various economic outcomes.[10] For older adults, on one hand, broadband may reduce the costs associated with communication and information sharing, as well as provide social support. This can be achieved through virtual social connections with friends and family members via video calls or social media platforms, access to entertainment through streaming services such as Netflix, the utilization of telehealth for mental health services, the pursuit of better wellbeing through online learning or meditation on YouTube, and the access to financial or health information through various online sources. Broadband access can be 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 have a detrimental impact on the

[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]Refer Foutz *et al.* (2017), Mueller *et al.* (2018), Moy *et al.* (2017), and 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 to 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 (2024), Amaral-Garcia *et al.* (2022), Golin (2022), Amaral-Garcia *et al.* (2022), Donati *et al.* (2022), Van Parys and Brown (2023), Bloom *et al.* (2024), Johnson and Persico (2024), Pugno (2024), Gawai and Deller (2024).

mental health of older adults (Chen and Feeley, 2014).[11] Likewise, older individuals are more prone to engaging with misinformation and falling prey to online scams than younger populations, which may have adverse effects on their mental health (Brashier and Schacter (2020), Swire-Thompson *et al.* (2020), FBI Report (2023)).

This work investigates the impact of broadband expansion on the mental health of older adults in the US. I adopt a quasi-experimental framework, leveraging the staggered rollout of broadband across census tracts between 2010 and 2018 for identification. The analysis focuses primarily on fiber broadband, given its rapid expansion and massive speed over the past decade. While other broadband technologies have stagnated or been superseded, fiber broadband has demonstrated substantial technological advancements.[12] I use 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. Furthermore, the HRS panel dataset includes detailed information on individuals' personal internet usage and related activities, a dimension often overlooked in 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 they are the key predictors of well-being and life satisfaction (Kahneman and Krueger, 2006).[13] 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]

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

[12]Fiber broadband is the fastest among all broadband types. Refer to section 3 for more details. Campbell (2024) was among the first to use this treatment to explore 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.

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 spillovers, which is often neglected in the related broadband and health literatures.

The results demonstrate that the rollout of broadband increased mental health among older adults, shown by a decline in depressive symptoms by about 5.7%. This magnitude is comparable to, yet 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 contrast to those in a study from Italy that finds negative effects of the internet on the mental health of young cohorts but no effects on older cohorts (Donati *et al.*, 2022). This contrast in findings underscores one of the key findings of this paper: the impact of similar technologies on mental health outcomes can vary significantly across age cohorts. These gains in mental health for older adults are equivalent to about 20% of the adverse effects of job loss, 41% of effects of a recession, and 14% of effects 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 controls (possible confounders), different DID estimators and dynamic treatment effects, which all further support the validity of the research design.

[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.

I further provide evidence on first-stage effects and novel potential channels to help explain the core results. First, I find that the fiber broadband rollout substantially increased the speed of the internet by 344 Mbps or about 172 percent. Secondly, the results indicate a substantial increase in the self-use of the Internet among older adults. Third, I find a significant decline in feelings of social isolation (15%) and loneliness (9%) after the fiber broadband expansion. Furthermore, I create a novel 'virtual social-connectedness index' at the baseline wave using detailed questions on respondents' virtual interactions with family and friends.[16] The results show a significant improvement in mental health for highly virtually socially connected individuals but no effects for those with lower connections, providing evidence that the broadband rollout might improve mental health by enhancing the quality of social connections. Again, these results are in contrast to social media's negative effects on the mental health of younger populations due to 'unfavorable social comparison' (Braghieri *et al.*, 2022). This contrast underscores another key finding of this paper: the impact of similar technologies on mental health outcomes varies significantly through how individuals engage with the technology. Further, 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 social channels being the explanation. Additionally, I find suggestive evidence of improved health literacy among the elder adults who received broadband. 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 due to broadband that may play a role in the improved mental health of older adults.

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

[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."

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, Akerman *et al.*, 2015, Dettling *et al.*, 2018, Hjort and Poulsen, 2019, Zuo, 2021, Conroy and Low, 2022, Campbell, 2024, Amaral-Garcia *et al.*, 2022, Acosta and Baldomero-Quintana, 2024, Bahia *et al.*, 2024).[17] A few 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 small subset of this literature studies broadband and social media as a determinant of mental health and 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 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. This empirical setting presents a number of advantages and overcomes some of the limitations in the current literature. The first advantage is that while earlier studies may suffer from TWFE bias, I use recent advances in DID for better identification. Secondly, I use data that measures broadband treatment at a finer scale (census tracts), which is more precise and helps reduce estimation bias compared

[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).

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 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 literature. Importantly, this paper is also among the first to document the spatial spillover effects of broadband expansion using the latest innovations, which are virtually absent in the literature.[21]

My next key contribution is a novel study of mechanisms. To the best of my knowledge, this is one of the first papers to offer causal empirical evidence on the role of broadband in digital usage, social isolation, loneliness, and virtual social connections, all of which may influence mental health among older adults.[22] The discussion on the theories of social isolation hypothesis dates back to the 1930s (Faris and Dunham, 1939, Thoits, 1983). As noted 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." The literature, primarily in psychology, sociology, and 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, Hajek *et al.*, 2023, Pizzi and

[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.

[20] The data used here 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 even if individuals move locations.

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

[22] Some of the similar mechanisms are explored in a context of China Ding *et al.* (2023), Ma (2025).

Amir, 2024).[23] A subset of this literature suggests inconclusive correlations between internet use and older adults' mental health.[24] However, empirical evidence on the role of the internet in the social isolation hypothesis remains scarce. I address this gap by providing causal evidence on the effects of broadband on social isolation and loneliness among older adults in the US. To test social connection channels, I also create a novel 'virtual social-connectedness index' that proxy for respondents' virtual interactions with family and friends.

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 (Baker *et al.*, 2003, Kolko, 2010, Amaral-Garcia *et al.*, 2022, Van Parys and Brown, 2023).[25] Literature related to information frictions in health insurance broadly documents better outcomes in cost and quality with reduced frictions (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.[26] I complement the evidence on the potential channels of health behavior, such as health literacy and the use of health apps or health websites, through which broadband may reduce information asymmetry for older adults.

Finally, I contribute to a growing body of literature related to telehealth. Observational

[23] 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).

[24] 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, Chai *et al.*, 2024, Ma, 2025). In contrast, one 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).

[25] 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).

[26] One recent 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)). Also refer to Cao *et al.* (2023), who studies social media and anti-Asian incidents in the US.

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 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.

In addition, this work studies the general equilibrium effect of exposure to high-speed fiber broadband, as opposed to the partial equilibrium estimates of individuals, 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.[27] 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, exposure to broadband for family members or friends might have network effects on older adults. Such general equilibrium effects are crucial for technologies like broadband that exhibit significant 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, only 16% of Americans had access to internet service with speeds of 10 Mbps. Today, about 95% of Americans have access to 10 Mbps connections, and around 80% can access speeds up to 1 Gbps.[28] In 2015, the FCC defined broadband as an

[27] Campbell (2024) has provided evidence for this competition.

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

internet connection with a minimum download speed of 25 megabits per second (Mbps) and a minimum upload speed of 3 Mbps (Conroy *et al.*, 2021, Wilson *et al.*, 2021).

Despite the rapid rollout of broadband, persistent disparities in access, commonly known as the digital divide, remain primarily affecting rural areas and low socioeconomic households, leaving more than 42 million Americans without internet connectivity.[29] About 81% of rural households have broadband access, compared to 86% in urban areas.[30] Similarly, in Black-majority neighborhoods, internet speeds are 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. For instance, in June 2023, the Biden-Harris administration announced a $42.45 billion allocation for high-speed internet across states ("Investing in America") that is intended to reduce the digital divide.

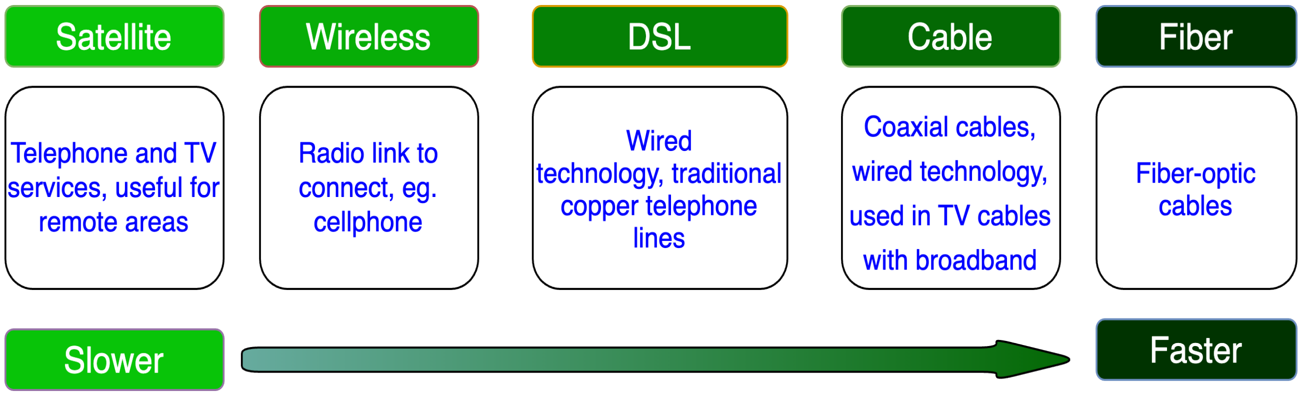
2.2 Types of Broadband Connections

Broadband connections utilized by homes and businesses generally fall into five main categories: fiber, cable, digital subscriber line (DSL), fixed or mobile wireless, and satellite (Conroy *et al.*, 2021). The speed and the utility of each type of broadband can be categorized in the way shown in Figure 1. For instance, satellite broadband is mainly used in telephone or TV services and typically has the lowest speed. Wireless broadband technologies use radio links and are primarily used on cell phones. Digital Subscriber Lines (DSL) are wired technology that utilizes copper telephone lines and is generally the least preferred option compared to other high-speed broadband options. Cable utilizes coaxial cables and is primarily used in cable television. Finally, fiber-optic broadband is considered the most preferred option because it can transmit large volumes of data.

[29]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.

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

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 and it has the potential to transmit large amounts of data.[31] 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 generally provide speeds exceeding 10 Gbps, whereas residential fiber internet connections typically offer speeds up to 940 Mbps.[32] 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 video calls, ensuring seamless communication experiences, even when multiple individuals and devices concurrently connect to the network, without the bandwidth

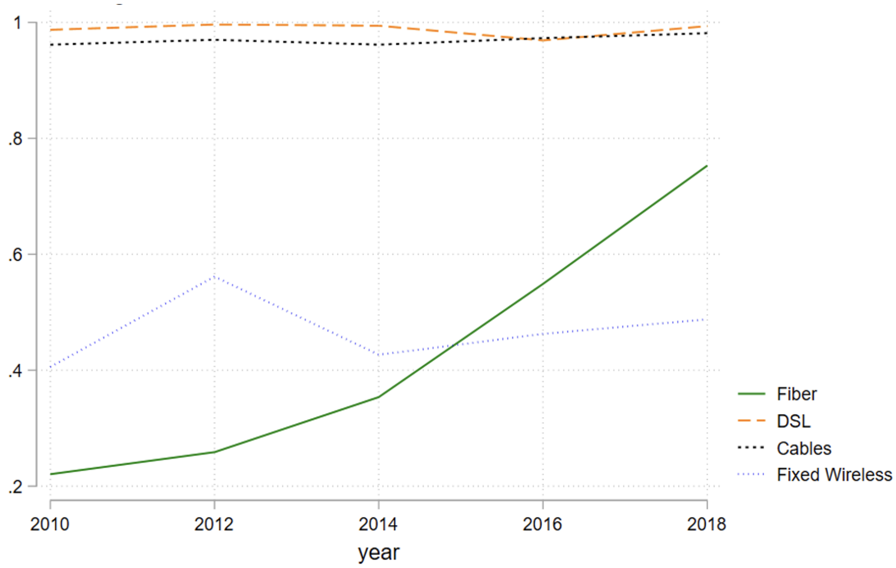
[31] Most of the information in this section is from Century Link and Conroy *et al.* (2021).

[32] 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.

competition common during peak hours with other technologies like cable.

The second key reason is that the availability of fiber broadband for older adults has witnessed a remarkable surge over the past decade, whereas the availability of other broadband types has remained relatively consistent. Figure 2 illustrates the significant upward trend in the share of the 50+ population residing in census tracts with fiber broadband technology. 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 relevance for older individuals. As would be expected, internet use has been growing substantially among older adults as shown in (Figure 3).[33]

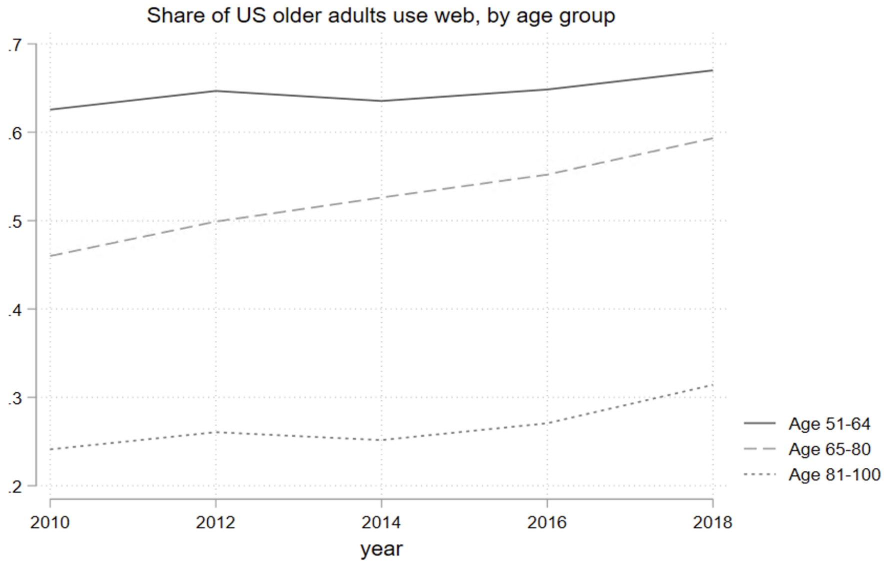
FIGURE (2) Availability of Broadband Technologies for Older Adults



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.

[33] Hunsaker and Hargittai (2018) show a detailed review of who uses the internet and how it is used among older adults. This increasing trend in the use of the internet among older adults is also supported by (Yoon *et al.*, 2021).

FIGURE (3) Internet Users



Note: Author's calculation using biennial waves from 2010 to 2018 of a nationally representative survey from the Health and Retirement Study (HRS). The sample is the balanced panel of HRS respondents.

3 Data

3.1 Health and Retirement Study (HRS)

The HRS is a nationally representative panel study surveying approximately 20,000 individuals aged 51 and older ([DATASET], 2010-2018).[34] The core HRS has been conducted annually since 1992, transitioning to a biennial format in 1996. HRS collects extensive demographic, physical and mental health, relationship, income, and occupation-related information. One unique feature of HRS is that it includes comprehensive individual-level panel data on physical and mental health, utilization of internet-related technologies such as use of email, and state of alienation such as feelings of social isolation and loneliness. I use the restricted HRS files that have information on the respondents' geographic residence locations (census tract).[35] These key variables are essential to analyze the role of broadband on the mental health of older adults and explore the novel channels that are understudied

[34]The HRS data is supported by the National Institute on Aging (grant number U01AG009740) and is administered by the University of Michigan.

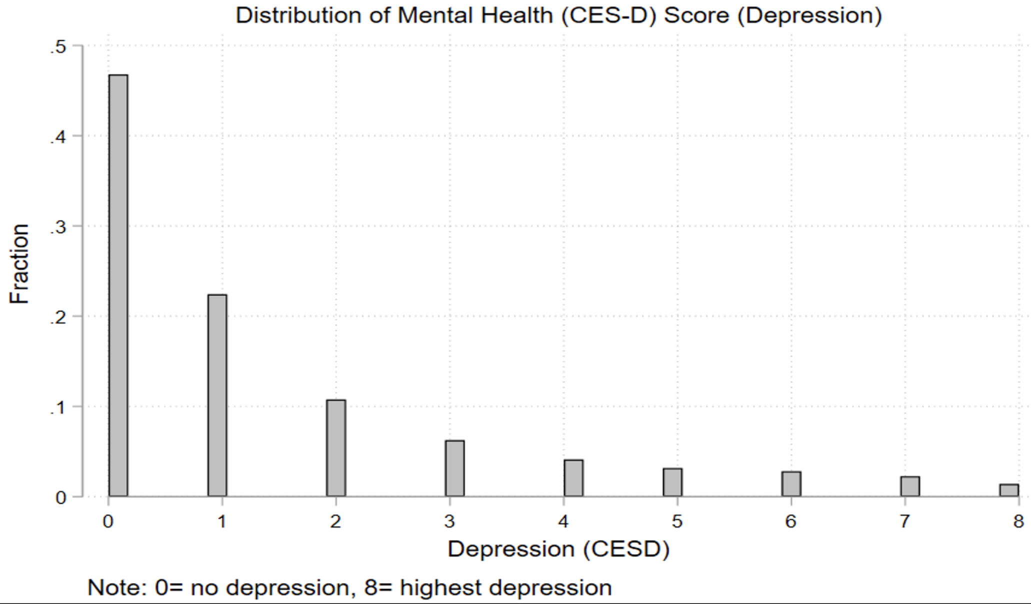
[35]I obtained IRB approval from the University of Wisconsin-Madison. I use the RAND-HRS longitudinal files for most variables and borrow other variables from the raw HRS files whenever required.

in the literature.

3.1.1 Primary Outcome Variables: Mental Health

I use one primary and two secondary outcome variables that are prominent in the literature in measuring the mental health of the older population. First, I employ a composite measure of depression symptoms as the primary outcome variable, known as the Center for Epidemiology Studies Depression (CES-D) score. This composite measure mitigates potential selection bias arising from examining multiple outcome variables separately and addresses concerns related to multiple hypothesis testing with multiple outcome measures. The CES-D score is widely used across many 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 indicators while subtracting the responses to two positive indicators (Appendix Table 11 provides 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 complement the CES-D measure with two other common measures of mental health. First is a binary version of the CES-D score, which roughly matches the symptoms of clinical depression, and second is the 'use of medication for anxiety/ depression' to proxy for diagnosed symptoms of depression (Chatterji *et al.*, 2015, Cutler and Sportiche, 2022).

FIGURE (4) 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 11 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 panel data on broadband are drawn from two sources. The first is from the Federal Communications Commission (FCC) Form 477, which covers the period from 2014 to 2018. The second is from the National Telecommunications and Information Association's National Broadband Map (NBM) covering the years 2010 to 2013.[36] These datasets encompass the number of broadband providers, transmission technologies (DSL, fiber, cable, or satellite), maximum advertised download and upload speeds measured in Mbps, and whether the provider offers residential service at the census block level. To ensure comprehensive coverage, the government requires broadband providers to submit this information biannually at the census-block level, demonstrating their ability to deliver internet service with speeds surpassing 200 Kbps in at least one direction. To ensure the most recent and reliable broadband data, the analysis primarily relies on the last version for each year.

[36]The inclusion of FCC data starting in 2014 is primarily motivated by the need to address measurement issues present in earlier years.

The key treatment variable in this study is the introduction of fiber broadband within a given census tract during a specific year. To measure this, I aggregate the census-block level data at the census tract level, the level of the HRS data, defining a census tract as treated if at least one census block within it had fiber broadband in a particular year. The census tract provides precise geographic treatment of the broadband, as opposed to aggregating at the county or zip code level, which has been done in the related literature. [37] The binary treatment variable is set to 1 in the year of the introduction of fiber broadband and remains 1 in subsequent years. Conversely, for census tracts where fiber broadband has not been introduced, the variable remains at 0 throughout the observation period, constituting the never-treated group. In this way, the research design effectively captures the staggered implementation of the treatment over time.

The literature has documented some limitations to the FCC data (Grubesic *et al.*, 2019), but most of these limitations are minor concerns in this study. One documented concern is the accuracy of the information reported by Internet service providers (ISPs). Since ISPs self-report data, they may over-report certain information, like the speed of the internet. I, however, do not use speed as a primary treatment, and thus, it is less of a concern. A second concern is about comprehensiveness. ISPs may underreport broadband services in some census blocks to avoid regulations, win government contracts, or avoid competition. To address this, I define treatment as if any block in a census tract has fiber broadband; then, the census tract is considered treated. This definition is more practical since fiber broadband needs massive infrastructural investment, and it is very easy to expand to nearby blocks, not just to one block. Irrespective of these limitations, FCC data are the best publicly available records of the broadband providers in the US (Mack *et al.*, 2021).

[37] There are a total of 84,414 census tracts in the United States, each ideally accommodating approximately 4,000 residents (Census Report).

3.3 Sample Selection

The primary analyses focus on a balanced panel of HRS respondents observed in the waves from 2010 to 2018, observing the same person over five survey waves. I also provide estimates using an unbalanced panel of HRS respondents to capture a broader sample and show that the main estimates are robust to this change. This research design includes outcomes that are measured less frequently than the treatment because the HRS survey takes place every two years from 2010 to 2018, but broadband is measured every year. Because of this, 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.[38] As suggested by De Chaisemartin *et al.* (2019), we should conduct separate analyses for these two batches. 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. In the robustness section, I also show estimates that combine these two batches by estimating the 'length of the fiber treatment' as a treatment, which suggests a similar effect to the main specification.

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

[38] 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.

individual in t_1 to t_3 is the same as that of t_0, which is a strong assumption. I am able to examine whether individuals migrate following the introduction of broadband. Leveraging the HRS data, I observe the census tract of residence for each respondent across all survey waves from 2010 to 2018. This allows me to identify whether respondents move out of their initial census tracts over the course of the study period. It is, however, 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.

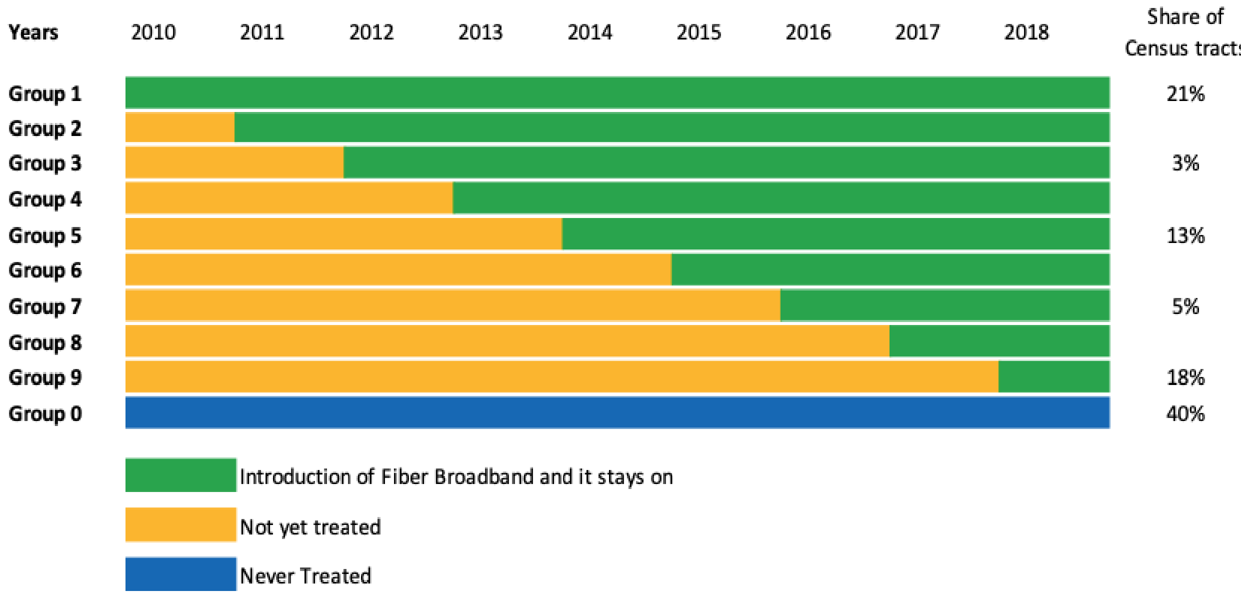
3.4 Introduction of Fiber

Figure 5 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 (baseline), 3, 5, 7, and 9. I also show the estimates by including the remaining groups in the robustness section. By focusing on these time points, the analysis captures the dynamics of broadband adoption and its potential effects on mental health within the HRS sample.

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

FIGURE (5) 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.

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 12 in the Appendix. Table 12 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 sense because the urban areas might drive the expansion of fiber. To study this, I conduct an analysis of rural and urban areas separately.

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.

4 Empirical 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 (2024), 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, 2024).

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 strategy 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.[39] I 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. The standard errors are clustered at the level of treatment, the census-tract, and 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 those waiting for others to

[39]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.

adopt, which could be important in the case of 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.

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

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 mainly focus on the balanced panel of HRS respondents but also show robustness checks with the unbalanced panel.

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 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 heterogeneity 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 in various aspects, including the assumptions they make and/or the comparison groups they select.[40] 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.

While the results are robust across all the new DID estimators. I prefer the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a) in most cases for the following reasons. 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, instead considering the yet-to-treat group as a comparison group. Further, the estimator provided by Borusyak *et al.* (2021) might not work well in the presence of a strong serial correlation as suggested by De Chaisemartin and d'Haultfoeuille (2022b). When I test the serial correlation between the primary outcome variable and its lag values, I find that the serial correlation is strong (Coefficient 0.59, SD(0.004)).

[40] De Chaisemartin and d'Haultfoeuille (2022b) provides a detailed comparison among these estimators.

5 Results

The results proceed as follows. First, I test whether broadband did indeed increase internet speeds and whether it did so for HRS survey respondents. Then, having validated our treatment variable, I show our main results: how broadband availability impacts the mental health of older adults. The work then tests for heterogeneity of those effects by gender, region, race, marital status, and age. Next, I tested for treatment heterogeneity by length of exposure. Finally, I test for spatial spillovers.

5.1 Effect on Internet Speed

First, I test whether the quality of the internet improved after the first stage of fiber broadband expansion in order to assure the effectiveness of our treatment. Following Campbell (2024), 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 demonstrate a significant increase in the advertised maximum download speed after fiber broadband expansion. The large increase is because fiber broadband itself is characterized by a massive internet speed, and even while the speed of the internet might be directly affected by the introduction of fiber, local competition among the internet service providers likely increased, thereby increasing internet speed (Montenegro and Araral, 2020, Campbell, 2024, Kearns, 2023).

5.2 Effect on Digital Usage

Next, the estimates presented in Appendix Table 13 demonstrate the ITT effect: how the overall effect of the availability of fiber broadband expanded individual's use of the internet. 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

TABLE (2) Effect of Broadband Expansion on the Availability of Download Speed of Internet in Mbps

	Max Advertised Download Speed (Mbps)	
	(1)	(2)
Post Fiber	344.5***	344.3***
	[16.1]	[19.9]
Observations	55,606	54,234
Year Fixed Effects	Yes	Yes
Individual Fixed Effects	Yes	
Census-Tract Fixed Effects		Yes
Baseline Mean of Outcome	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 in census tracts, using Equation 1 and the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). The sample is a balanced panel of census tracts from 2010 to 2018 merged with the HRS data. The treatment variable is equal to 1 if fiber is available in a census tract in 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.

internet.

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. [41]

To assess the impact of broadband expansion on older adults' digital use, I transform positive responses into a binary variable, assigning a value of 1 if the respondent answers affirmatively and 0 otherwise.[42] I show the estimates in Table 13, which demonstrate a significant increase in digital usage among older adults. Specifically, fiber broadband expansion in the census tract of an HRS respondent increased digital use by about 18%. This magnitude is consistent with the correlational studies in the medical research literature (Okoye *et al.*,

[41]The survey question is: "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?"

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

2021).

5.3 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 Equation 1 and the De Chaisemartin and d'Haultfoeuille (2022a) estimator. 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, while column 3 replaces individual fixed effects with the census-tract fixed effects. Column 4 has expansion group-year fixed effects to account for the shocks that affect all individuals in an expansion group in a given year.

TABLE (3) Main Result: 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 shows that the introduction of fiber broadband decreases depression symptoms among older adults, with all estimates significantly supporting these findings across the various specifications. Column 1, the preferred estimate, shows that fiber expansion reduces depression symptoms among older adults by 0.082 units. After accounting for individual-level time-varying controls and other fixed effects, the estimates remain 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.[43]

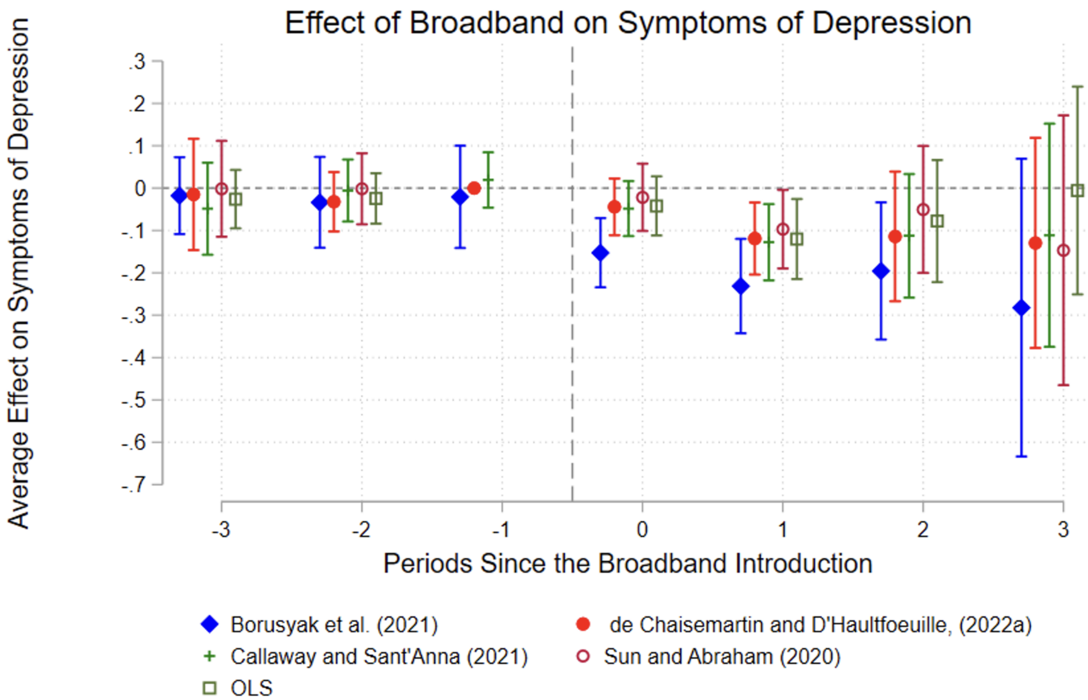
In terms of magnitudes, the preferred estimate from column 1 in Table 3 shows that fiber expansion reduces depression symptoms among older adults by 0.082 units on a scale of 0 to 8, or nearly 6% of the baseline mean of 1.42. This estimate is remarkably similar in magnitude (0.085) but opposite in direction 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.[44] 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. Additionally, in comparing my estimates with a closely related meta-analysis in the medical literature on changes to mental health Paul and Moser (2009), we find 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), examining the effect of the 2008 recession on the mental health of older adults. The estimates in this paper indicate that the benefit of broadband expansion is roughly 41% of the negative effect of the 2008 recession. Additionally, these results support the gerontology literature, which finds a positive association between the Internet and the mental health of older adults (Cotten *et al.*, 2014).

Further, to confirm the pre-treatment trends for the parallel trends assumption, evalu-

[43] Appendix Table 14 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.

[44] The results from this paper can also be compared with the adverse effects of retirement on mental health of older adults (Dave *et al.*, 2008).

FIGURE (6) 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).

ate the existence of strategic complementarities, and test the validity of the main results, Figure 6 shows the results with the dynamic treatment effects. I use the latest DID estimators relevant to the binary and staggered treatment proposed by De Chaisemartin and d'Haultfoeuille (2022a), Borusyak *et al.* (2021), Sun and Abraham (2021), Callaway and Sant'Anna (2021), as well as the traditional TWFE estimator. Figure 6 suggests that depression symptoms are declining after the introduction of high-speed fiber broadband and are statistically significant, no matter which estimator I use. Figure 6 also suggests that the estimates prior to the introduction of the fiber broadband (period -2 and -3) are close to 0 and insignificant, providing evidence for there being no pre-trends and consistent with the parallel trend assumption. Additionally, the estimates in Appendix Table 14 that use the estimator provided by Borusyak *et al.* (2021) suggest the same conclusion, in fact, a higher decline in the depression symptoms.[45] 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).

TABLE (4) Effect of Fiber Broadband on Clinical Symptoms of Depression and Mortality

Outcome	Clinical Symptoms of Depression (1)	Mortality (2)
Post Fiber	-0.014^{**}	-0.004^{*}
	[0.007]	[0.002]
Observations	47,935	60,123
Year Fixed Effects	Yes	Yes
Individual Fixed Effects	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. For clinical depression, the sample is a balanced panel, and for mortality, it is the unbalanced 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.

Further, Table 4 shows the effect of fiber broadband rollout on a relatively extreme measure of symptoms of depression – 'clinical symptoms of depression.' In the HRS, a CES-D score above three is typically considered indicative of clinically relevant symptoms of depression or 'caseness' (Schane *et al.*, 2008, McInerney *et al.*, 2013). Table 4 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

[45]One key reason for the different point estimates under estimators provided by De Chaisemartin and d'Haultfoeuille (2022a) and Borusyak *et al.* (2021) is that Borusyak *et al.* (2021) does not include the 'never treated' group.

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). This comparison sheds light on the relative impact of broadband expansion in mitigating depression symptoms compared to other significant life events.

Finally, I show the effect of broadband expansion on the mortality among older adults. 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 the estimates in Table 3 could be upward biased. To address this mortality selection concern, I show the estimates in column 2 of **??**, where the outcome is whether the individual has died or not. The estimates suggest that the rollout of fiber broadband decreases individual-level mortality, suggesting other positive benefits of the broadband rollout.

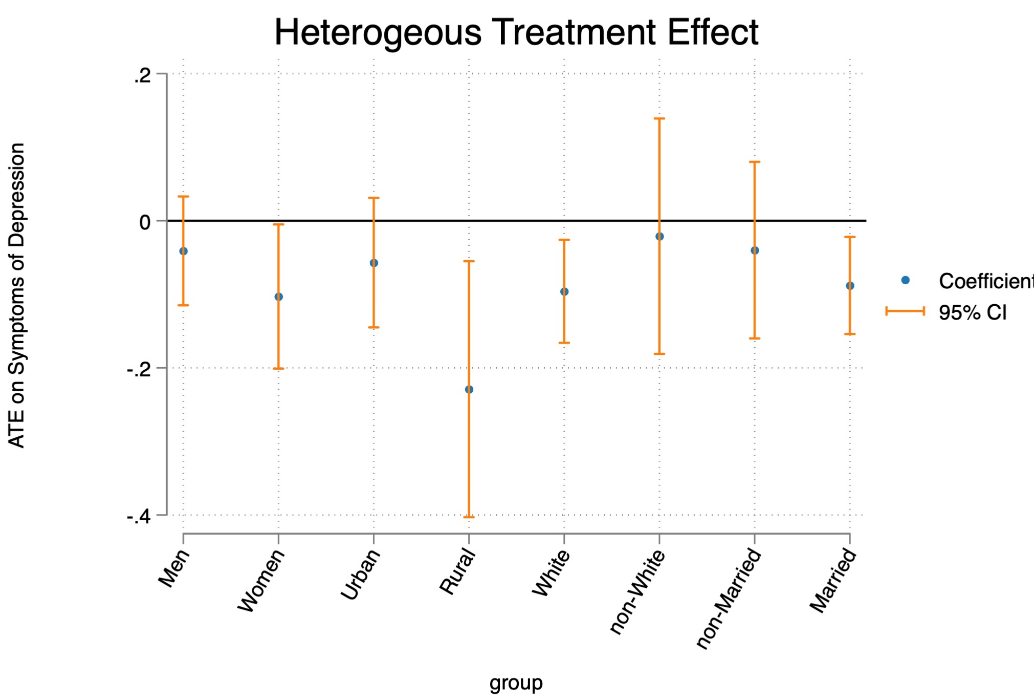
5.4 Heterogeneity

In this section, I explore the heterogeneity of the effects of broadband expansion based on various characteristics. The key coefficient estimates are shown in Figure 7, from estimating Equation 2 with the De Chaisemartin and d'Haultfoeuille (2022a) estimator for different sub-groups.[46] 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

[46] I provide the full table of the average treatment effects in Appendix Table 15.

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, since married couples often rely on each other for social interaction and support, implying a potentially lower effect of broadband access on mental health. 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 the population that is still working.

FIGURE (7) 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.

5.4.1 Gender

The public health literature shows that 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 statistically significantly higher than that of men (1.19 (sd 1.76)). The estimates in Figure 7 indicate a statistically significant decline in depression symptoms among women, while the decline for men is not statistically significant. These positive effects observed among older women stand in contrast to the findings of Braghieri *et al.* (2022), who document the adverse impact of social media (Facebook) on the mental health of female college students, primarily driven by negative social comparisons. In contrast, older women tend to use the internet for activities that may positively impact mental health, such as emailing, accessing health-related information, and seeking support for personal and mental health concerns(Pew Research). These findings suggest important benefits of broadband for older women and highlight that the impact of the same technology can vary based on age and potentially how the technology is being used.

5.4.2 Region

Next, I will test whether the effects of broadband expansion vary distinctly between rural and urban residents. Rural residents tend to be older and poorer, with lower levels of education and private health insurance, shortage of mental health professionals, and worse mental health (Foutz *et al.*, 2017, Mueller *et al.*, 2018, Moy *et al.*, 2017, Pender *et al.*, 2019).[47] Appendix Table 12 also suggests that fiber broadband expansion was slower in rural areas during the initial years of the study period. The estimates in Figure 7 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, and the magnitude is almost threefold larger (16%) compared to the main results (5.7%).

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

One potential reason for the higher benefits for rural dwellers could be due to the higher monthly frequency of Internet use for health information among rural Medicare beneficiaries compared to their urban counterparts (MCBS Report, 2022). 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. Smaller gains for urban areas could be due to better baseline mental health than rural areas. These findings suggest fiber broadband expansion in rural areas has the potential to reduce regional disparities in mental health outcomes among older adults.

5.4.3 Race

I estimate the model separately for Whites and non-Whites, considering the higher prevalence of mental health problems among non-Whites found in the literature and these data. In the sample, the symptoms of depression CES-D score for non-Whites (1.69) is higher than for Whites (1.27). 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 7 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 racial disparities.

5.4.4 Marital Status

I also estimate the effects based on marital status. Married individuals are defined as those who reported being continuously married throughout the study period, and non-married individuals are categorized as divorced, separated, widowed, never married, or partnered. As shown in Figure 7, the decline in depression symptoms is statistically significant for married individuals, consistent with recent research suggesting the existence of spousal spillover effects on mental health among older couples in England (Jain and Ma, 2024).

5.4.5 Age Groups

Finally, in Appendix Table 16, 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 estimates suggest that the effect of broadband expansion on depression symptoms varies by age group. Individuals aged 65-84 experienced a statistically significant (10% level) decline in depressive symptoms. No significant effects, however, were observed for those other two age groups, indicating a potential inverted U-shaped relationship between age and broadband's impact on mental well-being. These findings highlight the importance of considering age-specific factors when evaluating the mental health benefits of broadband expansion.

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 to capture the cumulative effects. 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. In this heterogeneity test, I include the individuals who were exposed to fiber broadband during the non-HRS survey years, i.e., respondents exposed in 2011, 2013, 2015, and 2017. I follow Braghieri *et al.* (2022) and estimate the following equation-

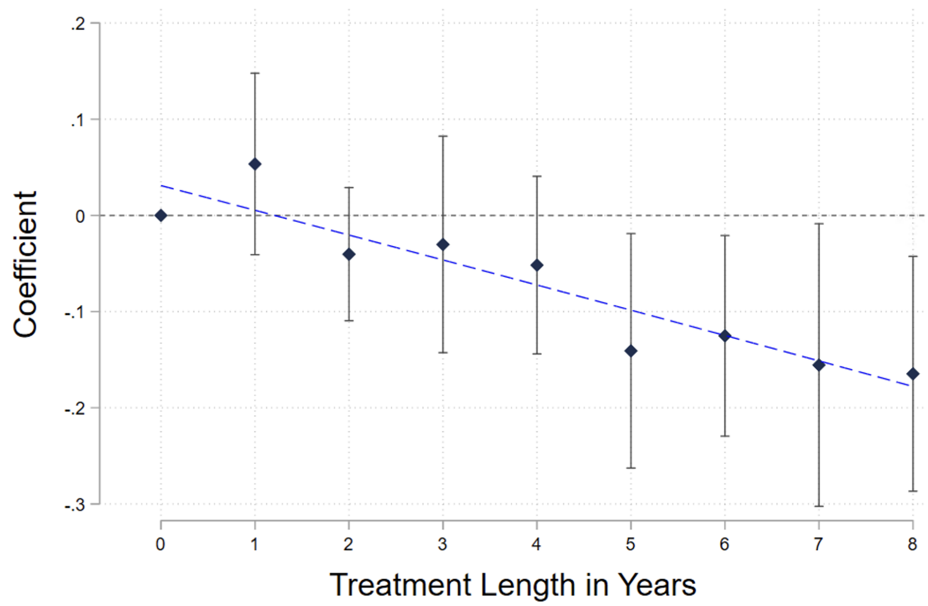
$$Y_{icgt} = \alpha_c + \gamma_t + \sum_{\tau=0}^{8} \beta_\tau \times \text{Years in Fiber}_{\tau(ict)} + \mathbf{X'}_i \times \lambda + \epsilon_{icgt}, \tag{3}$$

where 'Years in 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

[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 been found to have a higher prevalence of suicide-related deaths American Foundation for Suicide Prevention..

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

FIGURE (8) 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

There could also be a bias in the estimates of broadband's effects if spatial spillover from neighboring census tracts predominate. For instance, this could happen if an individual living in a particular census tract does not receive broadband, but the nearby census tracts receive the treatment and this gives them access to the benefits of broadband. There could be 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, all of which might affect mental health in neighboring census tracts. The mental health of such an individual might get better with the introduction of fiber internet in the nearby census tract, biasing our estimates downward.

I address these concerns in the following ways. First, I use the DID estimator by Borusyak *et al.* (2021) in Figure 6 and Table 14, which does not include the 'always control group.' The estimates of that estimator shown in Table 14 are higher than if I include the 'always control group', suggesting that the main effects in Table 3 are potentially the lower bounds of the actual effects. This differential impact provides evidence consistent with the presence of spatial spillovers from the 'always control group,' since after correcting for the potential bias, the treatment effect persists and even becomes stronger. Secondly, I follow the suggestions in Butts (2021) 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 5 and show coefficients that are almost double our main result. This further provides evidence that there may exist a spatial spillover effect and that the main effects shown in Table 3 are lower bounds of the actual effects.

6 Robustness

The primary results suggest that the broadband expansion positively affects the mental health of older adults. We have already seen in Table 3 that the main result is robust to varying the controls and types of fixed effects. Similarly, the main estimates are robust to using different latest DID estimators that are suitable for the binary treatment. In this section, I perform sensitivity analyses to check the robustness of these results.

First, I show the robustness of the estimates to potential selective migration by including

TABLE (5) 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.

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 do so because older adults are less likely to migrate. About 91% of the sample referred to as 'stayers' during the study period, with 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 6 (column 1), which shows that the estimates are slightly lower than the main estimates but remain statistically significant. The estimates suggest that dropping the movers is not driving the results and provide reassurance that mobility patterns do not drive the observed effects.

Secondly, 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

TABLE (6) Effect of Fiber Broadband on the Symptoms of Depression accounting for Migration

Sample	Stayers and Movers
	(1)
Post Fiber	-0.076^{***}
	[0.026]
Observations	71,323
Year Fixed Effects	Yes
Individual Fixed Effects	Yes

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). The outcome variable is the CES-D score, and the estimate focuses on both movers and stayers. 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.

outcomes. Controlling for this variable may reduce the bias due to unobserved heterogeneity. The estimate of this regression is (-0.070, *p-value* $<$ *0.1*), which replicates the estimates in column 2 of Table 3, suggesting that the results are robust to the mortality selection. Further, 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-value* $<$ *0.1*), which may suggest that the main estimates are less likely to be biased due to unobserved heterogeneity. Finally, I show the dynamic treatment effects using the unbalanced panel of HRS in Appendix Figure 9, replicating the main effects in Figure 6.

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. I use the DID set up to causally identify whether broadband has an effect on these mechanism outcomes.

7.1 Social Isolation and Loneliness

To explore the impact of broadband expansion on 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 7 indicates a statistically significant 15% decline in feelings of social isolation among older adults following the expansion of broadband in their census tract. Similarly, column 2 indicates a 9% decline in their feelings of loneliness, also statistically significant. This causal evidence supports the claims from the correlational studies in medical research about the internet's positive effect on loneliness 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 (7) 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

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 (Pescosolido, 2011). To examine this, I construct a novel index for 'virtual social connectedness' using baseline (2010) survey questions from the HRS.[49] 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 at the baseline survey, 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 then conduct separate estimations of the effects of broadband for each of these two subgroups: highly connected and poorly connected.

Table 8 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 are consistent with the social isolation hypothesis, which suggests that restricted social connections adversely affect 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. They also suggest that the positive results of broadband expansion on mental health are knock-on effects for older adults who were already socially connected, rather than bringing additional social connections to those who did not have them.

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

TABLE (8) 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 a change in the regular use of medications for anxiety or depression.[50] I provide the estimates with the medication as an outcome in Appendix Table 17, which show a null effect of broadband connectivity on the use of 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 is likely through social network channels.

7.4 Physical Health

Physical and mental health are strongly positively correlated (Ohrnberger *et al.*, 2017), which suggests a possible mechanism of broadband's effects through improved physical health. To test this, I use the self-reported health status as an outcome, which takes a value of 1 if

[50] 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).

health is excellent, very good, or good, and 0 if fair or poor. The estimates in Table 18 find no statistically significant change in self-reported physical health even though the magnitude is positive. This suggests improvements in physical health is unlikely to be the mechanism leading to broadband's effect on mental health.

7.5 Employment

Since the advent of broadband in a census tract might improve employment possibilities, I explore whether better mental health outcomes due to the broadband expansion could be mediated through better labor market outcomes for older adults. In Table 18, I find no evidence in the respondents' self-reported employment status after the broadband expansion. This evidence is in contrast to the evidence in Johnson and Persico (2024), which suggests that broadband expansion between 2000 and 2008 improved the health of the general population through lower unemployment rates. My finding of no employment effect strengthens the support for under-explored social connection channels for older adults as the likely mechanism.

7.6 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 facilitated by broadband access 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 9 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 9 indicate a positive but insignificant relationship between the introduction of fiber broadband and the use of health-related apps. Similarly columns 5 and 6 show a positive but insignificant effect of broadband and the use of health management sites. These results are suggestive of some 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.[51]

7.7 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 is widely acknowledged as an effective and efficient healthcare tool, yet its broader adoption has been constrained by limited access to high-speed internet, especially in rural

[51] 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 limits the statistical power to detect significant effects. Another concern could be reverse causality. For instance, internet use may affect health literacy, and health literacy may affect internet use. The presence of such reverse causality is evident in studies (Levy *et al.*, 2015, Bavafa *et al.*, 2019).

TABLE (9) 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.

and underserved regions (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 supplement the HRS data with data from the hospital survey administered by the American Hospital Association (AHA) ([DATASET], 2018). This voluntary survey collects information on hospital organizational structure, utilization, finances, facilities, and staffing. I use the 2018 year data and analyzed 24 survey questions related to the availability of telehealth services for various types of care and hospital networks.[52] 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 10 presents estimates that demonstrate a strong and statistically significant relationship between both the number of broadband providers and download speeds with the likelihood of hospitals offering telehealth services. This is consistent with telehealth availability being a potential mechanism for the improved mental health of older adults. However, it is important to note that these estimates represent correlations rather than causal evidence due to the cross-section nature

[52]See AHA Data for the list of the questions.

of the AHA survey data.

TABLE (10) Effect of on Telehealth Services by Hospitals

VARIABLES	Offer Telehealth Services (1)	Offer Telehealth Services (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.

8 Conclusion

This study examines the causal relationship between the rollout of broadband expansion and the mental health of older adults and investigates the novel pathways through which these effects may manifest. The findings suggest that the expansion of broadband significantly reduces symptoms of depression by about 5.7% among individuals aged 50 and above, providing robust statistical evidence of improvements in mental health. This effect is similar in magnitude but opposite in direction with negative effects due to other important life events such as job loss, recession, and unexpected loss of a spouse. By exploring underlying potential mechanisms, this study underscores the significance of broadband expansion in improving the quality of virtual social connections with friends and families and mitigating feelings of social isolation and loneliness among older adults. Results also suggest some evidence that improved health literacy and technological advancements in nearby hospitals through telehealth services could be other potential pathways through which the effects of broadband technology may translate into better mental health outcomes.

This positive impact of broadband on the mental health of older adults is more pronounced for residents in rural areas, women, Whites, and married individuals who experienced a 16.7, 6.7, 7.5, and 8.2 percent decline in depression symptoms, respectively. These estimates uncover the importance of broadband expansion to reduce the regional and gender disparities in mental health and call for policy attention to address the racial gap. Further empirical evidence reveals a non-linear relationship between age and treatment effects. Individuals 65 to 84 years old demonstrate the most substantial positive impact from the expansion, suggesting that this demographic benefits disproportionately. In contrast, 50 to 64 years old individuals, who are more likely to be actively engaged in the labor force, exhibit a positive treatment effect that is not statistically significant.

The findings of this study contribute to the literature by providing policymakers and stakeholders with evidence on the potential mental health benefits of expanding broadband access for older adults. Recent research has highlighted the adverse mental health effects of social media, particularly on college students, with young women being more susceptible to social comparisons. In contrast, 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.[53] The primary driver of these benefits is virtual 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 likely mechanisms.

In order to understand the economic importance of broadband's effects on older adult mental health I conduct a back-of-the-envelope calculation of the cost savings to Medicare, the primary health insurer of older adults. Using Medicare's spending on depression symptoms and my estimated 5.7% reduction due to broadband, these results suggest that broadband expansion has reduced the cost of excess Medicare spending on mental health

[53]The evidence in this paper is also similar to a study in China (Ding *et al.*, 2023).

by about $5 billion. This suggests very large cost savings in federal health expenditures from broadband expansion. This is not large enough to alone justify the costs of broadband expansion, but rather represents a large positive extrernality to broadband expansion, which is easily justified on other economic grounds.

This research also holds significant policy relevance due to several converging trends. First, the global population is aging and experiencing rising rates of mental health concerns, particularly social isolation and loneliness. Second, internet access and usage have surged, with global penetration exceeding 63% in 2021, compared to just 7% in 2000. Furthermore, fixed broadband subscriptions have reached approximately 1.33 billion worldwide (World Bank 2021). High-speed internet transcends age and occupation, becoming essential for daily activities. Particularly, older adults are increasingly utilizing the internet and social media, highlighting the need to focus on this vulnerable demographic. This study underscores the well-being benefits of high-speed broadband for older adults, emphasizing the importance of internet access in fostering social connections, mitigating social isolation and loneliness, and enhancing health literacy and telehealth policies.

A potential limitation of this study is the lack of information on whether respondents have fiber broadband at home. Internet use may occur in various settings, such as homes, workplaces, coffee shops, or public libraries. Consequently, the estimates represent intent-to-treat effects. Secondly, data in the HRS is based on self-reports, which can be subject to recall bias and other measurement errors. I show the robustness of the main results by addressing some of these biases. Nevertheless, the findings from this paper offer valuable insights for policymakers interested in the health benefits of broadband expansion for older adults, understanding the underlying mechanisms, and assessing potential benefits for underserved communities.

While this work has shown strong positive effects, internet access disparities persist based on location, race, and income, some of which were exacerbated by the COVID-19 pandemic. To address these inequities, significant government investments are being directed towards initiatives like the Internet for All and Affordable Connectivity Program (ACP), allocating over $65 billion USD to expand internet access. Understanding the potential health effects of such investments on a vulnerable population is crucial for ensuring equitable outcomes and maximizing program benefits. While this study examines the pre-COVID-19 period, future research could investigate the effects of broadband access on the mental health of older adults during the pandemic.

References

Abaluck, J. and Gruber, J. (2011). Choice inconsistencies among the elderly: evidence from plan choice in the medicare part d program. *American Economic Review*, **101** (4), 1180–1210.

Abramson, B., Boerma, J. and Tsyvinski, A. (2024). *Macroeconomics of Mental Health*. Tech. rep., National Bureau of Economic Research.

Acosta, C. and Baldomero-Quintana, L. (2024). Quality of communications infrastructure, local structural transformation, and inequality. *Journal of Economic Geography*, **24** (1), 117–144.

Akerman, A., Gaarder, I. and Mogstad, M. (2015). The skill complementarity of broadband internet. *The Quarterly Journal of Economics*, **130** (4), 1781–1824.

Allcott, H., Gentzkow, M. and Song, L. (2022). Digital addiction. *American Economic Review*, **112** (7), 2424–63.

Allen, J., Balfour, R., Bell, R. and Marmot, M. (2014). Social determinants of mental health. *International review of psychiatry*, **26** (4), 392–407.

Alvarez, F. E., Argente, D., Lippi, F., Méndez, E. and Van Patten, D. (2023). *Strategic complementarities in a dynamic model of technology adoption: P2P digital payments*. Tech. rep., National Bureau of Economic Research.

Amaral-Garcia, S., Nardotto, M., Propper, C. and Valletti, T. (2022). Mums go online: Is the internet changing the demand for health care? *Review of Economics and Statistics*, **104** (6), 1157–1173.

Annan, F. and Archibong, B. (2023). *The value of communication for mental health*. Tech. rep., National Bureau of Economic Research.

Atasoy, H. (2013). The effects of broadband internet expansion on labor market outcomes. *ILR review*, **66** (2), 315–345.

Ausubel, J. (2020). Older people are more likely to live alone in the us than elsewhere in the world. *Pew Research Center*.

Bahia, K., Castells, P., Cruz, G., Masaki, T., Pedrós, X., Pfutze, T., Rodríguez-Castelán, C. and Winkler, H. (2024). The welfare effects of mobile broadband internet: Evidence from nigeria. *Journal of Development Economics*, **170**, 103314.

Baker, L., Wagner, T. H., Singer, S. and Bundorf, M. K. (2003). Use of the internet and e-mail for health care information: results from a national survey. *Jama*, **289** (18), 2400–2406.

Bakiskan, A. and El Kaissi, S. (2023). *Literature Review of the Economic Impacts of Broadband*. Centre for the Study of Living Standards.

Banerjee, A., Duflo, E., Grela, E., McKelway, M., Schilbach, F., Sharma, G. and Vaidyanathan, G. (2023). Depression and loneliness among the elderly in low-and middle-income countries. *Journal of Economic Perspectives*, **37** (2), 179–202.

Bavafa, H., Liu, J. and Mukherjee, A. (2019). Building financial and health literacy at older ages: the role of online information. *Journal of Consumer Affairs*, **53** (3), 877–916.

Berkman, L. F. and Syme, S. L. (1979). Social networks, host resistance, and mortality: a nine-year follow-up study of alameda county residents. *American journal of Epidemiology*, **109** (2), 186–204.

Bloom, D. E., Sousa-Poza, A. and Sunde, U. (2024). *The Routledge Handbook of the Economics of Ageing*. Routledge.

Borusyak, K., Jaravel, X. and Spiess, J. (2021). Revisiting event study designs: Robust and efficient estimation. *arXiv preprint arXiv:2108.12419*.

Braghieri, L., Levy, R. and Makarin, A. (2022). Social media and mental health. *American Economic Review*, **112** (11), 3660–3693.

Brashier, N. M. and Schacter, D. L. (2020). Aging in an era of fake news. *Current directions in psychological science*, **29** (3), 316–323.

Bundorf, M. K., Wagner, T. H., Singer, S. J. and Baker, L. C. (2006). Who searches the internet for health information? *Health services research*, **41** (3p1), 819–836.

Butts, K. (2021). Difference-in-differences estimation with spatial spillovers. *arXiv preprint arXiv:2105.03737*.

Cagney, K. A., Browning, C. R., Iveniuk, J. and English, N. (2014). The onset of depression during the great recession: foreclosure and older adult mental health. *American journal of public health*, **104** (3), 498–505.

Callaway, B. and Sant'Anna, P. H. (2021). Difference-in-differences with multiple time periods. *Journal of econometrics*, **225** (2), 200–230.

Campbell, R. C. (2024). Need for speed: Fiber and student achievement. *Telecommunications Policy*, **48** (6), 102767.

Cao, A., Lindo, J. M. and Zhong, J. (2023). Can social media rhetoric incite hate incidents? evidence from trump's "chinese virus" tweets. *Journal of Urban Economics*, **137**, 103590.

Chai, Y., Xian, G., Wang, M., Guo, L. and Luo, S. (2024). Aging wisely: The impact of internet use on older adults' mental health. *Journal of Affective Disorders*, **364**, 139–145.

Chatterji, S., Byles, J., Cutler, D., Seeman, T. and Verdes, E. (2015). Health, functioning, and disability in older adults—present status and future implications. *The lancet*, **385** (9967), 563–575.

Chen, Y. and Feeley, T. H. (2014). Social support, social strain, loneliness, and well-being among older adults: An analysis of the health and retirement study. *Journal of Social and Personal Relationships*, **31** (2), 141–161.

Conroy, T., Deller, S., Kures, M., Low, S., Glazer, J., Huyke, G. and Stark, C. (2021). Broadband and the wisconsin economy.

— and Low, S. A. (2022). Entrepreneurship, broadband, and gender: Evidence from establishment births in rural america. *International Regional Science Review*, **45**, 3–35.

Cotten, S. R., Anderson, W. A. and McCullough, B. M. (2013). Impact of internet use on loneliness and contact with others among older adults: cross-sectional analysis. *Journal of medical Internet research*, **15** (2), e2306.

—, Ford, G., Ford, S. and Hale, T. M. (2014). Internet use and depression among retired older adults in the united states: A longitudinal analysis. *Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, **69** (5), 763–771.

Cutler, D. M. and Sportiche, N. (2022). *Economic Crises and Mental Health: Effects of the Great Recession on Older Americans*. Tech. rep., National Bureau of Economic Research.

[DATASET] (2010-2018). Health and Retirement Study. Produced and distributed by the University of Michigan with funding from the National Institute on Aging (grant number U01AG009740), Ann Arbor, MI.

— (2018). American Hospital Association. American Hospital Association (AHA) Annual Survey Database - 2018. Ithaca, NY: Cornell University. Cornell Center for Social Sciences.

DAVE, D., RASHAD, I. and SPASOJEVIC, J. (2008). The effects of retirement on physical and mental health outcomes. *Southern Economic Journal*, **75** (2), 497–523.

DE CHAISEMARTIN, C. and D'HAULTFOEUILLE, X. (2022a). *Difference-in-differences estimators of intertemporal treatment effects*. Tech. rep., National Bureau of Economic Research.

— and — (2022b). *Two-way fixed effects and differences-in-differences with heterogeneous treatment effects: A survey*. Tech. rep., National Bureau of Economic Research.

—, — and GUYONVARCH, Y. (2019). *DID_MULTIPLEGT: Stata module to estimate sharp Difference-in-Difference designs with multiple groups and periods*. Tech. rep., HAL.

— and D'HAULTFOEUILLE, X. (2020). Two-way fixed effects estimators with heterogeneous treatment effects. *American Economic Review*, **110** (9), 2964–2996.

DETTLING, L. J., GOODMAN, S. and SMITH, J. (2018). Every little bit counts: The impact of high-speed internet on the transition to college. *Review of Economics and Statistics*, **100** (2), 260–273.

DINARDI, M., GULDI, M. and SIMON, D. (2019). Body weight and internet access: evidence from the rollout of broadband providers. *Journal of Population Economics*, **32**, 877–913.

DING, X., YUAN, L. and ZHOU, Y. (2023). Internet access and older adults' health: evidence from china. *China Economic Review*, **82**, 102047.

DONATI, D., SOBBRIO, F., DURANTE, R. and ZEJCIROVIC, D. (2022). Lost in the Net? Broadband Internet and Youth Mental Health.

EBERLY, L. A., KALLAN, M. J., JULIEN, H. M., HAYNES, N., KHATANA, S. A. M., NATHAN, A. S., SNIDER, C., CHOKSHI, N. P., ENEANYA, N. D., TAKVORIAN, S. U. *et al.* (2020). Patient characteristics associated with telemedicine access for primary and specialty ambulatory care during the covid-19 pandemic. *JAMA network open*, **3** (12), e2031640–e2031640.

Fan, S. and Yang, Y. (2022). How does internet use improve mental health among middle-aged and elderly people in rural areas in china? a quasi-natural experiment based on the china health and retirement longitudinal study (charls). *International journal of environmental research and public health*, **19** (20), 13332.

Faris, R. E. L. and Dunham, H. W. (1939). Mental disorders in urban areas: an ecological study of schizophrenia and other psychoses.

Flowers, L., Houser, A., Noel-Miller, C., Shaw, J., Bhattacharya, J., Schoemaker, L. and Farid, M. (2017). Medicare spends more on socially isolated older adults. *Insight on the Issues*, **125**, 1119–1143.

Foutz, J., Artiga, S. and Garfield, R. (2017). The role of medicaid in rural america. *Kaiser Family Foundation*.

Gajarawala, S. N. and Pelkowski, J. N. (2021). Telehealth benefits and barriers. *The Journal for Nurse Practitioners*, **17** (2), 218–221.

Gawai, V. and Deller, S. (2024). Is there a link between access to broadband and health outcomes? *American Journal of Economics and Sociology*.

Golin, M. (2022). The effect of broadband internet on the gender gap in mental health: Evidence from germany. *Health Economics*, **31**, 6–21.

Goodman-Bacon, A. (2021). Difference-in-differences with variation in treatment timing. *Journal of Econometrics*, **225** (2), 254–277.

Greenberg, P. E., Fournier, A.-A., Sisitsky, T., Pike, C. T. and Kessler, R. C. (2015). The economic burden of adults with major depressive disorder in the united states (2005 and 2010). *The Journal of clinical psychiatry*, **76** (2), 5356.

Group, C. P. H., Noone, C., McSharry, J., Smalle, M., Burns, A., Dwan, K., Devane, D. and Morrissey, E. C. (1996). Video calls for reducing social isolation and loneliness in older people: a rapid review. *Cochrane Database of Systematic Reviews*, **2020** (7).

Grubesic, T. H., Helderop, E. and Alizadeh, T. (2019). Closing information asymmetries: A scale agnostic approach for exploring equity implications of broadband provision. *Telecommunications Policy*, **43** (1), 50–66.

Guldi, M. and Herbst, C. M. (2017). Offline effects of online connecting: the impact of broadband diffusion on teen fertility decisions. *Journal of Population Economics*, **30**, 69–91.

Hajek, A., Riedel-Heller, S. G. and König, H.-H. (2023). *Loneliness and Social Isolation in Old Age: Correlates and Implications*. Taylor & Francis.

Hjort, J. and Poulsen, J. (2019). The arrival of fast internet and employment in africa. *American Economic Review*, **109** (3), 1032–79.

Holt-Lunstad, J., Smith, T. B., Baker, M., Harris, T. and Stephenson, D. (2015). Loneliness and social isolation as risk factors for mortality: a meta-analytic review. *Perspectives on psychological science*, **10** (2), 227–237.

—, — and Layton, J. B. (2010). Social relationships and mortality risk: a meta-analytic review. *PLoS medicine*, **7** (7), e1000316.

Hunsaker, A. and Hargittai, E. (2018). A review of internet use among older adults. *New media & society*, **20** (10), 3937–3954.

Jain, U. and Ma, M. (2024). Together in sickness and in health: Spillover of physical, mental, and cognitive health among older english couples. *Health Economics*.

JOHNSON, K. R. and PERSICO, C. (2024). *Broadband Internet Access, Economic Growth, and Wellbeing*. Tech. rep., National Bureau of Economic Research.

KAHNEMAN, D. and KRUEGER, A. B. (2006). Developments in the measurement of subjective well-being. *Journal of Economic perspectives*, **20** (1), 3–24.

KEARNS, A. (2023). Does competition from cable providers spur the deployment of fiber? *Available at SSRN 4523529*.

KLING, J. R., MULLAINATHAN, S., SHAFIR, E., VERMEULEN, L. C. and WROBEL, M. V. (2012). Comparison friction: Experimental evidence from medicare drug plans. *The quarterly journal of economics*, **127** (1), 199–235.

KOLKO, J. (2010). How broadband changes online and offline behaviors. *Information economics and policy*, **22** (2), 144–152.

— (2012). Broadband and local growth. *Journal of Urban Economics*, **71** (1), 100–113.

LEVY, H., JANKE, A. T. and LANGA, K. M. (2015). Health literacy and the digital divide among older americans. *Journal of general internal medicine*, **30**, 284–289.

LI, Y., BAI, X. and CHEN, H. (2022). Social isolation, cognitive function, and depression among chinese older adults: examining internet use as a predictor and a moderator. *Frontiers in public health*, **10**, 809713.

LOW, S. A., ISLEY, C., SPELL, A., KURES, M., CONROY, T. and DELLER, S. (2021). Broadband technologies: a primer on access and solutions.

LU, H. and KANDILOV, I. T. (2021). Does mobile internet use affect the subjective well-being of older chinese adults? an instrumental variable quantile analysis. *Journal of Happiness Studies*, pp. 1–20.

LUND, C., BROOKE-SUMNER, C., BAINGANA, F., BARON, E. C., BREUER, E., CHANDRA, P., HAUSHOFER, J., HERRMAN, H., JORDANS, M., KIELING, C. *et al.* (2018). Social determinants of mental disorders and the sustainable development goals: a systematic review of reviews. *The Lancet Psychiatry*, **5** (4), 357–369.

Ma, J. (2025). The causal effect of internet use on rural middle-aged and older adults' depression: A propensity score matching analysis. *Digital Health*, **11**, 20552076241310041.

Mack, E. A., Helderop, E., Ma, K., Grubesic, T. H., Mann, J., Loveridge, S. and Maciejewski, R. (2021). A broadband integrated time series (bits) for longitudinal analyses of the digital divide. *PloS one*, **16** (5), e0250732.

Masi, C. M., Chen, H.-Y., Hawkley, L. C. and Cacioppo, J. T. (2011). A meta-analysis of interventions to reduce loneliness. *Personality and social psychology review*, **15** (3), 219–266.

McInerney, M., Mellor, J. M. and Nicholas, L. H. (2013). Recession depression: mental health effects of the 2008 stock market crash. *Journal of health economics*, **32** (6), 1090–1104.

Montenegro, L. O. and Araral, E. (2020). Can competition-enhancing regulation bridge the quality divide in internet provision? *Telecommunications Policy*, **44** (1), 101836.

Morales, D. A., Barksdale, C. L. and Beckel-Mitchener, A. C. (2020). A call to action to address rural mental health disparities. *Journal of clinical and translational science*, **4** (5), 463–467.

Moy, E., Garcia, M. C., Bastian, B., Rossen, L. M., Ingram, D. D., Faul, M., Massetti, G. M., Thomas, C. C., Hong, Y., Yoon, P. W. *et al.* (2017). Leading causes of death in nonmetropolitan and metropolitan areas—united states, 1999–2014. *MMWR Surveillance Summaries*, **66** (1), 1.

Mueller, K. J., Alfero, C., Coburn, A. F., Lundblad, J. P., MacKinney, A. C., McBride, T. D. and Weigel, P. (2018). Taking stock: Policy opportunities for advancing rural health. *Report. Rural Policy Research Institute Health Panel, University of Iowa College of Public Health, Iowa City.*

National Academies of Sciences, E., Medicine *et al.* (2023). Addressing the rising mental health needs of an aging population: Proceedings of a workshop.

Nolen-Hoeksema, S. and Hilt, L. M. (2008). The emergence of gender differences in depression in adolescence. In *Handbook of depression in adolescents*, Routledge, pp. 127–152.

Ohrnberger, J., Fichera, E. and Sutton, M. (2017). The relationship between physical and mental health: A mediation analysis. *Social science & medicine*, **195**, 42–49.

Okoye, S. M., Mulcahy, J. F., Fabius, C. D., Burgdorf, J. G. and Wolff, J. L. (2021). Neighborhood broadband and use of telehealth among older adults: cross-sectional study of national survey data linked with census data. *Journal of medical Internet research*, **23** (6), e26242.

Pantell, M., Rehkopf, D., Jutte, D., Syme, S. L., Balmes, J. and Adler, N. (2013). Social isolation: a predictor of mortality comparable to traditional clinical risk factors. *American journal of public health*, **103** (11), 2056–2062.

Paul, K. I. and Moser, K. (2009). Unemployment impairs mental health: Meta-analyses. *Journal of Vocational behavior*, **74** (3), 264–282.

Pender, J., Hertz, T., Cromartie, J. and Farrigan, T. (2019). Rural america at a glance, 2019 edition. *Economic Information Bulletin*, **212** (6).

Pescosolido, B. (2011). Social connectedness in health, morbidity and mortality, and health care-the contributions, limits and further potential of health and retirement study. In *Forum for Health Economics & Policy*, De Gruyter, vol. 14.

Pizzi, M. and Amir, M. (2024). *Interprofessional Perspectives for Community Practice: Promoting Health, Well-being, and Quality of Life*. Taylor & Francis.

Pompili, M., Serafini, G., Innamorati, M., Dominici, G., Ferracuti, S., Kotzalidis, G. D., Serra, G., Girardi, P., Janiri, L., Tatarelli, R. *et al.* (2010). Suicidal behavior and alcohol abuse. *International journal of environmental research and public health*, **7** (4), 1392–1431.

Porter, E. (2021). A rural-urban broadband divide, but not the one you think of. *The New York Times*, pp. 06–03.

Pugno, M. (2024). Social media effects on well-being: The hypothesis of addiction of a new variety. *Kyklos*.

Quinton, J. K., Ong, M. K., Vangala, S., Tetleton-Burns, A., Webb, A., Sarkisian, C., Casillas, A., Kakani, P., Han, M. and Pirtle, C. J. (2021). The association of broadband internet access and telemedicine utilization in rural western tennessee: an observational study. *BMC Health Services Research*, **21** (1), 765.

Reynolds III, C. F., Cuijpers, P., Patel, V., Cohen, A., Dias, A., Chowdhary, N., Okereke, O. I., Amanda Dew, M., Anderson, S. J., Mazumdar, S. *et al.* (2012). Early intervention to reduce the global health and economic burden of major depression in older adults. *Annual review of public health*, **33**, 123–135.

Ryan, C. L. and Lewis, J. M. (2017). *Computer and internet use in the United States: 2015*. US Department of Commerce, Economics and Statistics Administration, US Census Bureau.

Salk, R. H., Hyde, J. S. and Abramson, L. Y. (2017). Gender differences in depression in representative national samples: Meta-analyses of diagnoses and symptoms. *Psychological bulletin*, **143** (8), 783.

Schane, R. E., Woodruff, P. G., Dinno, A., Covinsky, K. E. and Walter, L. C. (2008). Prevalence and risk factors for depressive symptoms in persons with chronic obstructive pulmonary disease. *Journal of general internal medicine*, **23**, 1757–1762.

Shumaker, E. M., Nilsson, S. H., Mak, W. J. A., Miodownik, A. and Kehn, M. M. (2023). Mental health and aging.

Siflinger, B. (2017). The effect of widowhood on mental health-an analysis of anticipation patterns surrounding the death of a spouse. *Health economics*, **26** (12), 1505–1523.

Smith, A. S. and Trevelyan, E. (2019). *The older population in rural America: 2012-2016*. US Department of Commerce, Economics and Statistics Administration, US Census Bureau.

Sun, L. and Abraham, S. (2021). Estimating dynamic treatment effects in event studies with heterogeneous treatment effects. *Journal of Econometrics*, **225** (2), 175–199.

Swire-Thompson, B., Lazer, D. *et al.* (2020). Public health and online misinformation: challenges and recommendations. *Annu Rev Public Health*, **41** (1), 433–451.

Thoits, P. A. (1983). Multiple identities and psychological well-being: A reformulation and test of the social isolation hypothesis. *American sociological review*, pp. 174–187.

Van Parys, J. and Brown, Z. Y. (2023). *Broadband Internet Access and Health Outcomes: Patient and Provider Responses in Medicare*. Tech. rep., National Bureau of Economic Research.

Vespa, J., Armstrong, D. M., Medina, L. *et al.* (2018). *Demographic turning points for the United States: Population projections for 2020 to 2060*. US Department of Commerce, Economics and Statistics Administration, US ....

Waldinger, R. (2015). What makes a good life. *Lessons from the longest study on happiness*.

Wilcock, A. D., Rose, S., Busch, A. B., Huskamp, H. A., Uscher-Pines, L., Landon, B. and Mehrotra, A. (2019). Association between broadband internet availability and telemedicine use. *JAMA internal medicine*, **179** (11), 1580–1582.

Wilson, K., Xiao, M. and Orazem, P. F. (2021). Entry threat, entry delay, and internet speed: The timing of the us broadband rollout. *Journal of Economics & Management Strategy*, **30** (1), 3–44.

Xu, W. and Köttl, H. (2020). Internet use and loneliness among older adults: The moderating role of self-perceptions of ageing. In *Human Aspects of IT for the Aged Population. Technology and Society: 6th International Conference, ITAP 2020, Held as Part of the 22nd HCI International Conference, HCII 2020, Copenhagen, Denmark, July 19–24, 2020, Proceedings, Part III 22*, Springer, pp. 364–381.

Yoon, H., Jang, Y., Kim, S., Speasmaker, A. and Nam, I. (2021). Trends in internet use among older adults in the united states, 2011–2016. *Journal of Applied Gerontology*, **40** (5), 466–470.

Yu, K., Wu, S. and Chi, I. (2021). Internet use and loneliness of older adults over time: The mediating effect of social contact. *The Journals of Gerontology: Series B*, **76** (3), 541–550.

—, —, —, Shim, H., Ailshire, J. A., Crimmins, E. M., Cotten, S., Cotten, S. R., Kadylak, T., Lin, X. Y. and Lachman, M. E. (2019). Internet use and loneliness of older adults over time: The mediation effect of social contact internet use and social isolation: The significance of life transitions social interactions and well-being: The role of communication method.

Zeltzer, D., Einav, L., Rashba, J. and Balicer, R. D. (2023). The Impact of Increased Access to Telemedicine. *Journal of the European Economic Association*, p. jvad035.

Zivin, K., Llewellyn, D. J., Lang, I. A., Vijan, S., Kabeto, M. U., Miller, E. M. and Langa, K. M. (2010). Depression among older adults in the united states and england. *The American Journal of Geriatric Psychiatry*, **18** (11), 1036–1044.

Zuo, G. W. (2021). Wired and hired: Employment effects of subsidized broadband internet for low-income americans. *American Economic Journal: Economic Policy*, **13** (3), 447–482.

Appendices

A Data and Descriptive Statistics

TABLE (11) 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 (12) Summary Statistics on Various Characteristics

Variables	Group 1	Group 3	Group 5	Group 7	Group 9	Group 0
Fiber Expansion Year	2010	2012	2014	2016	2018	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.

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. Placebo estimators compare first-time switchers' and not-yet switchers' outcome evolution before first-time switchers' treatment changes. Under these assumptions, β is the average treatment effect of the fiber broadband rollout on the key outcomes of interests.

I primarily estimate the equation using the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). To address potential confounding factors, I consider several additional specifications. First, I incorporate expansion group-time fixed effects to account for the shocks that affect all individuals in a given expansion group in a given year. Similarly, I include census-tract fixed effects to control for unobserved heterogeneity specific to each census tract. I cluster the standard errors at the census tract level to account for potential autocorrelation within the treatment unit over time.

Callaway and Sant'Anna (2021) propose estimators with various characteristics. For instance, their estimators are more aggregated with the weighted average of all the DID estimators across all cohorts. Similarly, other estimators rely on conditional parallel trend assumptions. In their study, Sun and Abraham (2021) introduces an estimator that uses either the never-treated groups or the last-treated groups, depending on whether there are any never-treated groups.

TABLE (13) Effect of Broadband Expansion on the Use of Internet

	(1)	(2)	(3)
Post Fiber	0.100***	0.090***	0.075***
	[0.008]	[0.011]	[0.022]
Observations	36,206	36,206	36,230
Year Fixed Effects	Yes	Yes	Yes
Individual Fixed Effects	Yes	Yes	
Controls		Yes	
Census-Tract Fixed Effects			Yes
Baseline Mean of Outcome	0.55	0.55	0.55

Note: This table shows the effects of the rollout of fiber broadband on the use of the web (internet) among older adults using the estimator provided by Borusyak *et al.* (2021) using Equation 1. Note that this estimator is useful in the absence of the serial correlation, and that's why it is preferred in this estimation. The sample is a balanced panel of Health and Retirement Study respondents from 2010 to 2018 (every two years). The sample consists of a balanced panel of Health and Retirement Study (HRS) respondents from biennial survey waves between 2010 and 2018, with individuals aged 51 and older. The treatment variable takes a value of 1 if fiber broadband is available in the respondent's census tract during survey year t and 0 otherwise. Individual-level control variables include Medicaid receipt, marital status, and labor force participation. I include the HRS person weights. Standard errors are clustered at the census tract level.

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 14, 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 (14) Effect Using Alternate DID Estimator: 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 effects of the rollout of fiber broadband on the depression symptoms among older adults using the estimator provided by Borusyak *et al.* (2021) using Equation 1. The sample is a balanced panel of Health and Retirement Study respondents from 2010 to 2018 (every two years). The sample consists of a balanced panel of Health and Retirement Study (HRS) respondents from biennial survey waves between 2010 and 2018, with individuals aged 51 and older. The treatment variable takes a value of 1 if fiber broadband is available in the respondent's census tract during 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. Individual-level control variables include Medicaid receipt, marital status, and labor force participation. I include the HRS person weights. Standard errors are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.10.

TABLE (15) Heterogeneity

	Outcome: CES-D Score							
	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	1.19	1.52	1.27	1.69	1.07	1.78

Note: This table shows the effects of the rollout of the fiber broadband on the depression symptoms (CES-D) among older adults for different subgroups estimating with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a) using Equation 1. he sample consists of a balanced panel of Health and Retirement Study (HRS) respondents from biennial survey waves between 2010 and 2018, with individuals aged 51 and older. The treatment variable takes a value of 1 if fiber broadband is available in the respondent's census tract during survey year t and 0 otherwise. Standard errors are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.10.

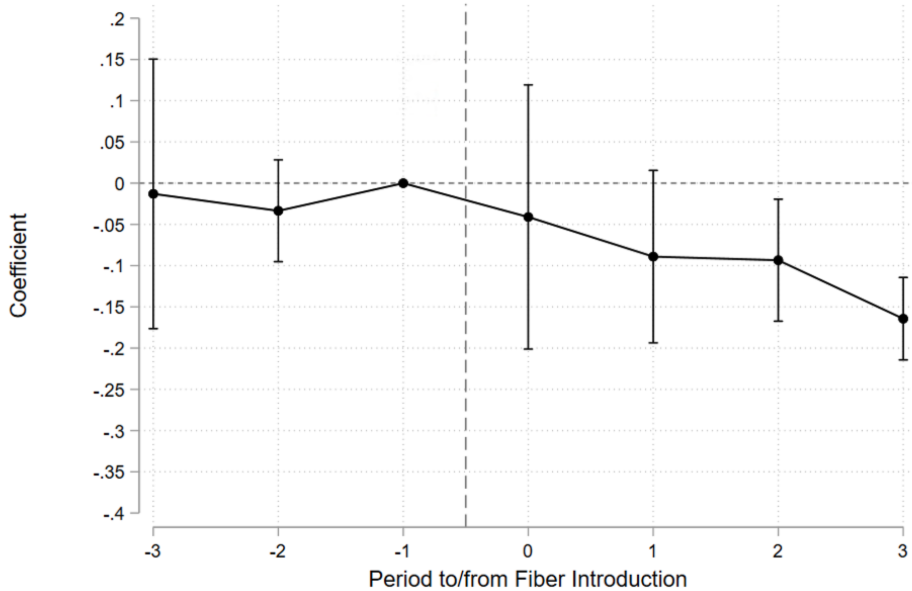
TABLE (16) Effect By Age Groups

	Outcome: CES-D Score		
	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 effect of the staggered rollout of the fiber broadband on the depression symptoms among older adults for various age groups using the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a) and using Equation 1. 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 consists of a balanced panel of Health and Retirement Study (HRS) respondents from biennial survey waves between 2010 and 2018, with individuals aged 51 and older. The treatment variable takes a value of 1 if fiber broadband is available in the respondent's census tract during survey year t and 0 otherwise. Standard errors are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.10.

E Robustness

FIGURE (9) Dynamic Treatment Effects Using the Unbalanced Panel of HRS



Note: The figure shows the dynamic treatment effects using the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). The sample is from the unbalanced panel of the Health and Retirement Study (HRS) respondents from 2010 to 2018 (every two years). The age group is 51 and older. 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. 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. I include group and treatment year fixed effects. Standard errors are clustered at the expansion group level. The bars show the 95 percent confidence interval.

F Mechanisms

TABLE (17) Effect on Use of Medications for Anxiety or depression

	(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

This table reports the effects of the staggered rollout of fiber broadband on the likelihood of respondents using prescription medication for anxiety or depression. The analysis applies Equation 1 and employs the estimator of De Chaisemartin and d'Haultfoeuille (2022a) in column (1) and that of Borusyak *et al.* (2021) in column (2). The estimator in column (1 includes never-treated units, whereas the estimator in column (2) does not, leading to differences in sample sizes. The sample consists of a balanced panel of Health and Retirement Study (HRS) respondents from biennial survey waves between 2010 and 2018, with individuals aged 51 and older. The treatment variable takes a value of 1 if fiber broadband is available in the respondent's census tract during survey year t and 0 otherwise. Standard errors, presented in square brackets, are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.10.

TABLE (18) Effect on Physical Health and Employment

	(1) Physical health is 'Good'	(2) Employment
Post Fiber	0.004	-0.000
	[0.007]	[0.007]
Observations	50,574	49,733
Year Fixed Effects	Yes	Yes
Individual Fixed Effects	Yes	Yes
Mean of Y	0.72	0.37

Note: This table examines the effect of the staggered fiber broadband rollout on self-reported physical health and employment outcomes among older adults. 'Physical health is 'Good" takes a value of 1 if health is excellent, very good, or good, and zero if fair or poor. The analysis employs Equation 1 and the estimator introduced by De Chaisemartin and d'Haultfoeuille (2022a). The sample is a balanced panel of biennial waves from the Health and Retirement Study (HRS) spanning 2010 to 2018, with respondents aged 51 to 103. The treatment variable equals one if fiber broadband is available in the respondent's census tract during the survey year t and zero otherwise. Control variables include individual age, Medicaid receipt, marital status, and employment status, with HRS-provided person weights incorporated into the estimation. Standard errors, shown in square brackets, are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.10.