

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

VIKAS PD GAWAI*

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Abstract

Recent research has shown important negative effects of social networks on younger people's mental health. Yet, we do not know if the same effects are present across the population, particularly for older adults, who are especially vulnerable to certain mental health conditions. I estimate the effect of broadband internet access on the mental health of older adults (aged 50+) in the United States, using individual panel data and recent advances in difference-in-differences (DID) methods for staggered rollouts of treatment. In contrast to the literature that finds nefarious effects of the internet among younger populations, my results show that broadband rollout significantly reduces depression symptoms by 5.3% among older adults. The results show that an increase in social connectedness and a decline in social isolation are the primary mechanisms driving these positive effects. Improved health literacy and technological efficiency (telehealth) also partly drive the results. I also find important heterogeneity by gender and geography, with rural dwellers and women being the biggest beneficiaries of broadband's positive effects on mental health. The magnitudes of my estimates of the impact of broadband access are comparable with other major life events known to affect the mental health of older adults, such as job loss, recession, and the death of a spouse. These results highlight the significant benefits of broadband for the mental health of older adults and suggest an unmeasured additional benefit to public investments in broadband infrastructure. JEL I12, I14, I18, L86, O18

*Ag. & Applied Economics Department, University of Wisconsin-Madison. Email: gawai@wisc.edu

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

1 Introduction

The aging US population faces increasing mental health challenges with substantial economic costs and partially effective available treatments. About 54 million individuals aged 65 and above represent 16% of the US population in 2019, and by 2060, 1 in 4 people will be 65 or older with about 94.7 million individuals ([ACL Report](#), [Vespa *et al.* \(2018\)](#)). As people live longer, they are more likely to experience significant mental health deterioration.¹ One in four older adults experiences depression, anxiety, or dementia.² Aged 60+ people in the US are more likely to live alone than elsewhere in the world ([Ausubel, 2020](#)).³ Loneliness and social isolation have a similar impact on premature mortality as smoking 15 cigarettes and six drinks a day.⁴ Mental health-related issues were exacerbated during COVID-19, as many older adults died due to isolation.⁵ Depression is often associated with suicide cases⁶ and people aged 85 and above have the highest suicide rates among all age groups.⁷ These mental health problems among older adults are a public health issue that can have enormous economic costs, both in direct medical expenses and indirect costs, such as caregiver burdens and lost productivity. The cost of major depressive disorders was over \$42 billion for the 50+ population in 2010 ([Greenberg *et al.*, 2015](#)), and social isolation accounts for excess Medicare spending of about \$6.7 billion annually ([Flowers *et al.*, 2017](#)). However, the available treatments for mental health are only about 50% effective in achieving quality of life improvements ([Reynolds III *et al.*, 2012](#)).

The geographic distribution of older adults reveals a notable concentration in remote regions characterized by restricted availability of mental health services. Rural areas accommodate approximately one-fifth of the older American population, with certain states witnessing more than half of their elderly residents residing in rural locations. ([Census re-](#)

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

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

³27% of US older adults live alone, compared to 16% in 130 other countries.

⁴[The U.S. Surgeon General’s Advisory on the Healing Effects of Social Connection and Community \(2023\)](#).

⁵(Scott Simon report in NPR Feb 19, 2022.)

⁶([Pompili *et al.*, 2010](#), [Reynolds III *et al.*, 2012](#))

⁷[American Foundation for Suicide Prevention](#).

port).⁸ Rural residents are more likely to be older, poorer, have lower levels of education, have worse mental health, and lack private health insurance.⁹ Consequently, the prevailing circumstances in these areas are marred by limited access to mental health services and a scarcity of trained mental health providers. More than half of all the mental health professional shortage areas are located in rural areas.¹⁰ Furthermore, regions with inadequate mental health services exhibit higher suicide rates (Henning-Smith, 2020).

Broadband has the potential to address some of the above-mentioned market failures; however, there remains a significant disparity in access to broadband, and its causal impact on older adults' mental health has not been studied well.¹¹ Broadband access may lower costs of communication and sharing information with others, enabling services like WhatsApp video calls with friends and families, entertainment through platforms like Netflix, video calls for telehealth, online learning or meditation through YouTube to stay mentally active, health information, and other social media use. Some of these utilities are crucial for older adults who live alone, feel lonely or isolated, have limitations on mobility, and are in remote areas with limited access to mental health services. On the other hand, recent evidence in economics suggests that a medium facilitated by the internet (social media) has adverse effects on the mental health of college students, especially due to 'unfavorable comparison' among girls (Braghieri *et al.*, 2022). So, the net effect of the internet on older adults' mental health is unclear. Secondly, a significant geographic disparity exists in the reliable high-speed internet (digital divide).¹³ This disparity in internet access was further exacerbated by the COVID-19 pandemic, prompting policymakers to invest over \$65 billion in broadband infrastructure policies in recent years, like Internet for All.¹⁴ With broadband's potential for various economic outcomes, researchers are increasingly focusing on understanding its causal effects on various economic outcomes (Dettling *et al.*, 2018, Conroy and Low, 2022, Campbell, 2022, Amaral-Garcia *et al.*, 2022). It is, however, unclear whether and to what extent the above tools enabled by the high-speed internet affect the worrying trends in mental

⁸The share of the older population is higher in rural areas than in urban areas and about 17.5% of the rural population was 65 years and older, and for urban areas, it is 13.8% (Smith and Trevelyan, 2019).

⁹(Foutz *et al.*, 2017, Mueller *et al.*, 2018, Moy *et al.*, 2017, Pender *et al.*, 2019).

¹⁰Medicaid and CHIP Payment and Access Commission, Issue April 202 and (Morales *et al.*, 2020).

¹¹Broadband is an umbrella term for reliable and high-speed internet connection.¹²

¹³(Conroy and Low, 2022, Low *et al.*, 2021). Some reports also suggest that the divide also exists based on race since the internet speed varies substantially for the Black neighborhood for the same price The Markup.

¹⁴'Internet For All' allocates \$42.45 billion for the Broadband Equity, Access, and Deployment (BEAD) in June 2023.

health, social isolation, and loneliness among older adults.

This work investigates the impact of high-speed internet (broadband) technology on the mental health of older adults in the US. The paper employs a quasi-experimental design, using the staggered introduction of high-speed ‘fiber broadband’ in census tracts from 2010 to 2018.¹⁵ I use the biennial waves from nationally representative data from the Health and Retirement Study (HRS), which is an individual panel of individuals aged 51+.¹⁶ The key dependent variable in my regressions is the commonly used CES-D score or ‘symptoms of depression’ to measure the mental health of older adults.¹⁷ I focus on depression symptoms as a primary outcome since it is the key predictor of poor well-being and low life satisfaction (Kahneman and Krueger, 2006). I use census tract-level broadband data, observing the fiber broadband rollout each year.¹⁸ Merging individual panel 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.¹⁹ I employ new difference-in-differences (DID) estimators useful for the binary and staggered treatment and account for the dynamic treatment effects.²⁰ These new DID 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.²¹ The estimations conclude with robustness checks, heterogeneity analysis, and tests of underexplored potential mechanisms.

I find that the introduction of high-speed fiber broadband technology positively affected mental health (decline in depressive symptoms CES-D score) among older adults. The most conservative DID estimate with individual fixed effects is remarkably similar in magnitude but exactly opposite in direction to the effects observed in a recent study by (Braghieri

¹⁵Refer to section 3 on why this paper focuses on Fiber Broadband. [Campbell \(2022\)](#) also uses this definition.

¹⁶HRS data is most useful in this setting due to its richness in detailed measures of mental health, social isolation, social connectedness, and the use of internet technology among older adults.

¹⁷([Cutler and Sportiche, 2022](#)). The score is calculated by the Center for Epidemiology Studies Depression (CESD). I also complement the CES-D measure by using a binary version of the CES-D score, which roughly matches the symptoms of clinical depression.

¹⁸I use two yearly data sets on broadband at the census tract level from the period 2010 to 2018, one from the Federal Communication Commission (FCC) Form 477 and the other from the National Telecommunications and Information Association’s National Broadband Map (NBM). The FCC data is from 2014-18, and the NBM data is from 2010-13. I use FCC data from 2014 onward, based on the insights from the FCC team about the measurement issues before 2014 FCC data.

¹⁹HRS has restricted data on the census-tract of residence of respondents.

²⁰There are mainly four estimators for the binary and staggered treatment rollout that allow for the dynamic treatment effects. I also show estimates with some of them.

²¹I also show the estimates using the conventional event study version of TWFE.

et al., 2022), which found that the expansion of Social Media (Facebook) increased mental health problems among college students. This contrast in the effects highlights one of the key findings of this paper, indicating that the impact of a similar technology on mental health outcomes can vary substantially based on age cohorts and potentially on how individuals engage with the technology. I find that the average gain in mental health for older adults is equivalent to about 20% of the adverse effects of job loss, 41% of recession, and 14% due to an unexpected loss of a spouse. I find heterogeneous treatment effects based on race, gender, and geography with positive and significant effects for Whites, women, and respondents from rural areas. I find an increase in ‘social connectedness’ and a decline in ‘feeling of social isolation’ primarily drive the positive effects. Further, improving health literacy and the likelihood of nearby hospitals offering telehealth services partially drive the results. I, however, do not find evidence of any improvement in cognitive function.

This paper makes several contributions to the literature. First, I contribute to a growing literature in economics on the determinants of mental health. Research on mental health is a relatively newer area in economics, and for older cohorts, such work is even scarcer. Current evidence suggests the adverse effect on mental health due to negative income shocks like job loss and positive gain in mental health due to cash transfers or antipoverty programs (Ridley *et al.*, 2020). However, this literature is primarily focused on the relatively younger populations. The evidence on the social determinants of the mental health of the older population is majorly outside of the economics (Allen *et al.*, 2014, Lund *et al.*, 2018). I contribute to this literature by studying the more vulnerable age cohorts that are often overlooked in the literature.

Secondly, I contribute to a small and emerging literature in economics that studies technologies as determinants of various economic outcomes, specifically broadband and social media technology. Recent studies suggest broadband technology can have a positive effect on education, entrepreneurship, and labor market outcomes (Dettling *et al.*, 2018, Conroy and Low, 2022, Campbell, 2022, Amaral-Garcia *et al.*, 2022). Within this literature, a small number of studies evaluate the causal effects of broadband on health and suggest mixed evidence (Guldi and Herbst, 2017, DiNardi *et al.*, 2019, Johnson and Persico, 2021, Donati *et al.*, 2022, Amaral-Garcia *et al.*, 2022, Golin, 2022, Van Parys and Brown, 2023). For instance, some evidence suggests that an increase in broadband coverage increases the body weight among white women (DiNardi *et al.*, 2019), on the other hand, declines teen preg-

nancies (Guldi and Herbst, 2017). On mental health, most of the literature is primarily focused on the relatively younger population and suggests an adverse effect of technologies like broadband and social media on the mental health of the young population (Braghieri *et al.*, 2022, Golin, 2022, Allcott *et al.*, 2022, Donati *et al.*, 2022). I improve on this literature in various ways. First, this paper is among the first that evaluate the effect of broadband on the mental health of older adults. Secondly, I contribute by using a better identification strategy through advanced DID estimation. Much of this literature was written before the recent advances in DID literature and may suffer from the challenges of two-way fixed effects (TWFE). Finally, this paper uses data that helps to overcome some of the limitations in the literature. First, it helps in the precision of the measurement of the broadband treatment. Most of the studies use the broadband treatment at the broader geography, like counties or zip codes.²² Defining treatment at the broader level can make it more challenging to control for confounding variables and may also create heterogeneity bias if one overlooks variations within that area. I define the treatment at a finer scale (census tracts) for more accurate treatment assessment and to reduce the bias in the estimation.²³ Secondly, the individual panel nature of the data helps me observe the same individuals for ten years (5 survey waves), including their detailed changes in social and health behavior and take-up of the internet, providing unexplored potential mechanisms that some of the other studies could not explore. Finally, the data also helps me with locational accuracy. Typically, the current literature fixes the location at the first year of the panel and assumes no migration since the migration could be endogenous to the treatment. This assumption may inaccurately measure the exposure of the treatment. I, on the other hand, do not make that assumption since I observe the location of the individual for every survey year and accurately measure the exposure of the treatment.

Third, I contribute to the literature by providing novel mechanisms through which broadband may affect the mental health of older adults. To my knowledge, this is one of the first papers to provide causal empirical evidence on the social isolation theory, cognitive function, and technological improvement in nearby hospitals by studying the effect of broadband on social connectedness and mental health among older adults. The social isolation hypothesis suggests that social connections and networks are important for mental health. Similarly,

²²One reason was that the broadband data was available at the zip/ county level before 2010.

²³Campbell (2022) uses the treatment at the census block level. I use codes generously provided by Dr. Campbell.

loneliness is a strong predictor of social isolation (Banerjee *et al.*, 2023). However, causal evidence on the social isolation hypothesis remains exceedingly scarce. Most of the evidence on the social isolation hypothesis is from other fields like psychology and sociology and suggests inconclusive correlations between internet use and older adults' mental health.²⁴ Similarly, I provide one of the first evidence on the effect of broadband on cognitive function among older adults. Broadband access may induce the use of various technologies like mobile, tablet, and computers, and that may induce some of the cognitive functions among older adults. Finally, I also provide one of the first evidence on whether higher access to broadband may also correlate with the technological improvement in nearby hospitals. For instance, a major obstacle to the implementation of telehealth services is the lack of enough internet bandwidth, majorly in rural areas (Gajarawala and Pelkowski, 2021). I find an increase in the likelihood of nearby hospitals offering telehealth services when fiber broadband is available.

Fourth, I contribute to the economic literature on information asymmetry through which broadband technology can affect the mental health of older adults. A recent study suggests that internet access increased C-sections among mothers, potentially due to the online information; however, the mechanisms are not clear (Amaral-Garcia *et al.*, 2022). One related recent study finds a positive effect on the health of Medicare patients seeking hip or knee replacements, primarily due to better information about the providers Van Parys and Brown (2023). In a developing county's setup, a recent study in an experimental setting suggests that staying connected through mobile calling improves mental well-being among low-income adults (Annan and Archibong, 2021). I contribute to the literature by complementing the evidence on the potential channels that may reduce information asymmetry through which broadband can affect the mental health of older adults.

Finally, some related recent literature in economics focuses on the experimental effects of social media exposure on college students' mental health. Most of these studies are limited to self-reported well-being or digital addiction (Allcott *et al.*, 2022). Similarly, some observational studies also focus on a relatively younger population than what I study (Golin, 2022). I complement this literature in at least two critical dimensions. First, I study detailed mental health using the CESD score from the HRS data. Secondly, these studies are limited

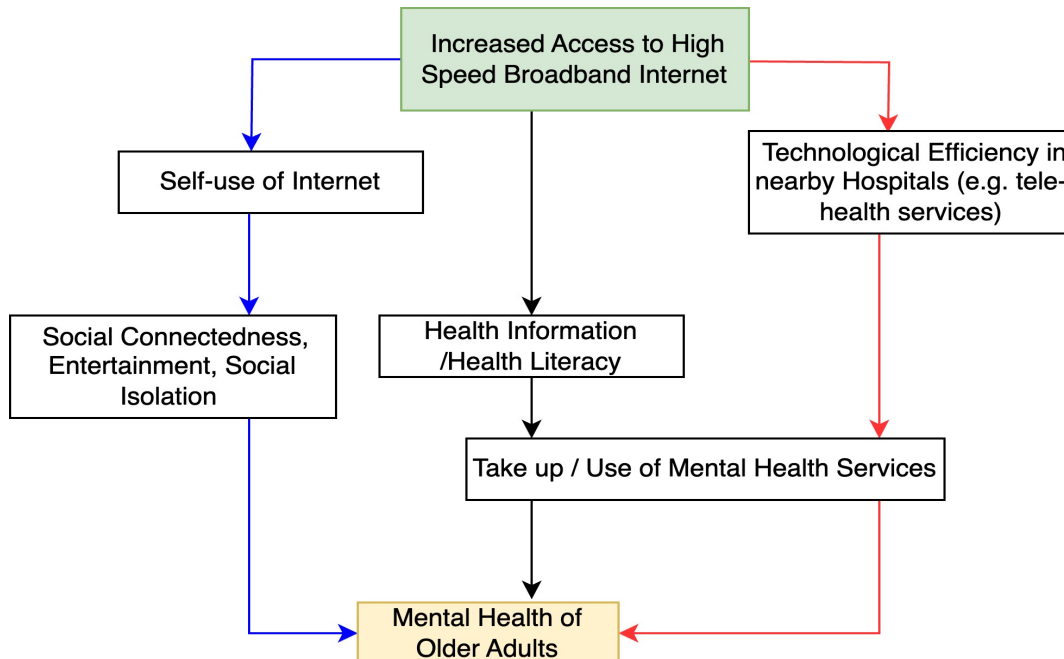
²⁴For instance, some studies suggest a positive association between internet use and mental health, with a decrease in loneliness and increased social contact among older adults (Yu *et al.*, 2021, Lu and Kandilov, 2021, Cotten *et al.*, 2013). In contrast, a study suggests a negative association between internet use and mental health depending on the context of life transition (separated, divorced, or widowed), type, level, and purpose of use (Yu *et al.*, 2019).

to the partial equilibrium effects of studying self-isolated respondents. In contrast, I study the general equilibrium effect of having exposure to high-speed fiber broadband, estimating the intent-to-treat (ITT) effects. Such general equilibrium effects are important for technologies like broadband that exhibit strong network externalities.

I emphasize that I study the Intent to treat (ITT) effect. The introduction of fiber broadband may improve the speed of the internet where people live, and people may access the high-speed internet through local public libraries or coffee shops. Fortunately, unlike other studies, I observe an individual’s use of the internet, which gives me confidence in the first-stage effect of the use of the internet. Fiber broadband availability may also give individuals access to adequate internet speed required for virtual medical visits (telehealth), video calls to friends and families, or online entertainment, which requires an immense amount of internet speed.

2 Conceptual Framework

FIGURE (1) Potential Mechanisms



The impact of high-speed broadband on the mental health of older adults encompasses various potential pathways (Figure 1). One such mechanism pertains to social connectedness. While increased virtual connectedness facilitated by high-speed broadband could theoreti-

cally mitigate social isolation, it is important to consider the possibility of a counteractive effect. Specifically, a higher reliance on virtual interactions may diminish opportunities for in-person social engagements, potentially exacerbating symptoms of depression. Consequently, the impact of high-speed broadband on the mental health of older adults through social connectedness is an empirical question that this paper answers.

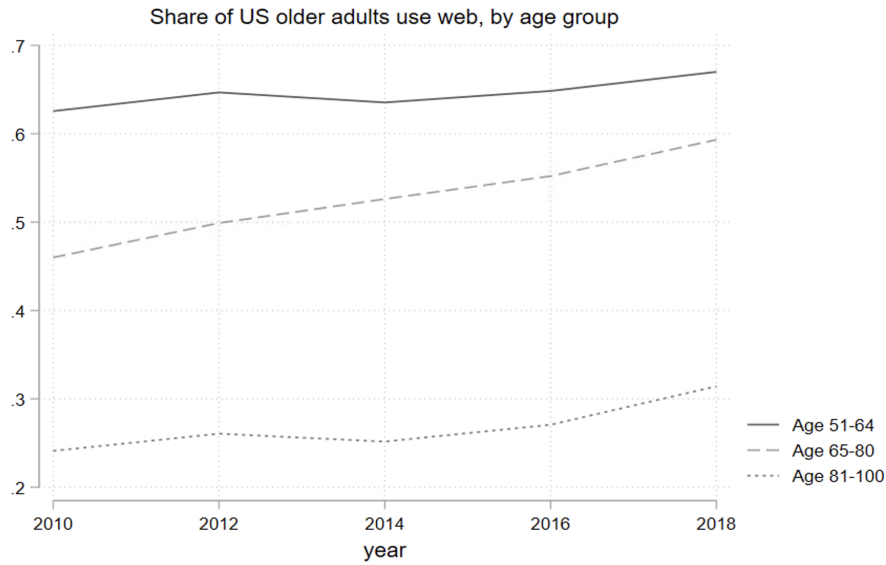
The second potential mechanism through which high-speed broadband may impact the mental health of older adults relates to the availability of online (mis)information. Evidence suggests that internet usage for information purposes enhances health literacy among older adults by approximately 12% (Bavafa *et al.*, 2019).²⁵ Moreover, the accessibility of the Internet plays a pivotal role in facilitating enrollment in various federal and state programs, such as the Social Security program, where participants often rely on online platforms to access and submit necessary forms. This increased internet utilization has the potential to improve health-related information, enhance health literacy, and facilitate enrollment in safety net programs, ultimately influencing the mental well-being of older adults. Nevertheless, it is important to acknowledge the potential drawbacks stemming from misinformation. Notably, research suggests that 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).²⁶

The third potential mechanism by which high-speed broadband may impact the health of older individuals relates to improvements in technological and operational efficiencies within medical facilities. Telehealth services have been identified as efficient and effective tools for healthcare delivery, resulting in improved outcomes. Emerging evidence suggests that access to telemedicine during the COVID-19 lockdowns led to increased primary care visits without adverse effects on health (Zeltzer *et al.*, 2023). Enhanced broadband services hold the potential to improve medical services, particularly in terms of consumer-facing digital technologies such as virtual visits, online bill payment and scheduling, virtual triage, and registration. Notably, a report based on the American Hospital Association’s (AHA) IT survey indicates that hospitals experienced an increase in the adoption of digital tools for patient-generated data submissions (23%), appointment scheduling (24%), prescription refill

²⁵Studies also suggest that providing access and support on the use of technology has an enormous potential to facilitate technology adoption among older adults (Pruchno, 2019). This support may come from anyone in the household who knows the use of technology, e.g., children, relatives, neighbors, or friends.

²⁶The study documents two other groups of people who engage in online fake news- individuals who are conservative-leaning and who are highly engaged in political news.

FIGURE (2) 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.

requests (25%), and bill payments (8%) between 2015 and 2019. However, a major obstacle to the widespread implementation of telehealth is the lack of adequate high-speed internet bandwidth, particularly in rural and underserved areas (Gajarawala and Pelkowski, 2021). However, it is important to consider the potential ramifications of viewing telehealth services as substitutes for essential in-person visits with specialists, as this may translate into worse mental health outcomes. To the best of my knowledge, no prior studies have examined the empirical question of whether broadband technology affects the technology at healthcare facilities that may play a role in the mental health of older adults. Consequently, this paper aims to fill this research gap and shed light on this important empirical inquiry.

3 Background

3.1 Broadband Technology

Over the years, significant progress has been made in expanding broadband availability; however, there exists a geographical variation in the coverage of reliable high-speed internet. For instance, in 2008, a mere 16% of Americans had access to internet service with a speed of 10 Mbps. However, the situation has markedly improved, with approximately 95% of Amer-

icans now having access to a 10 Mbps connection and around 80% having access to speeds of up to 1 Gbps.²⁷ Approximately 81% of households had broadband connections in 2016 (Ryan and Lewis, 2017). However, a persistent "digital divide" remains, primarily affecting rural areas and low socioeconomic households, leaving more than 42 million Americans without internet connectivity.²⁸ Disparities in access are evident, with estimates indicating that 81% of rural households have broadband access compared to 86% in urban areas.²⁹ The COVID-19 pandemic has further highlighted and exacerbated this digital divide, prompting policymakers to place significant emphasis on broadband connectivity. Notably, the Affordable Connectivity Program has allocated \$65 billion in funding to expand high-speed internet access, and more recently, in June 2023, the Biden-Harris administration announced a \$42.45 billion allocation for high-speed internet across states ("Investing in America"). Importantly, Figure 2 illustrates the growing internet use among older adults in the United States over the past decade.³⁰ By enabling seamless communication, learning, work, and community participation, regardless of geographical location or physical abilities, broadband has the potential to serve as a transformative technology.

3.2 Type of Broadband Connections

There are five main categories of broadband that homes and businesses use to connect—fiber, cable, digital subscriber line DSL, fixed or mobile wireless, and satellite (Conroy *et al.*, 2021). The speed of the internet of each type can be categorized in the following way as shown in Figure 3.

There are primarily two reasons for fiber broadband being the primary focus of this paper. First, the notable increase in internet availability and speed in recent years can be attributed,

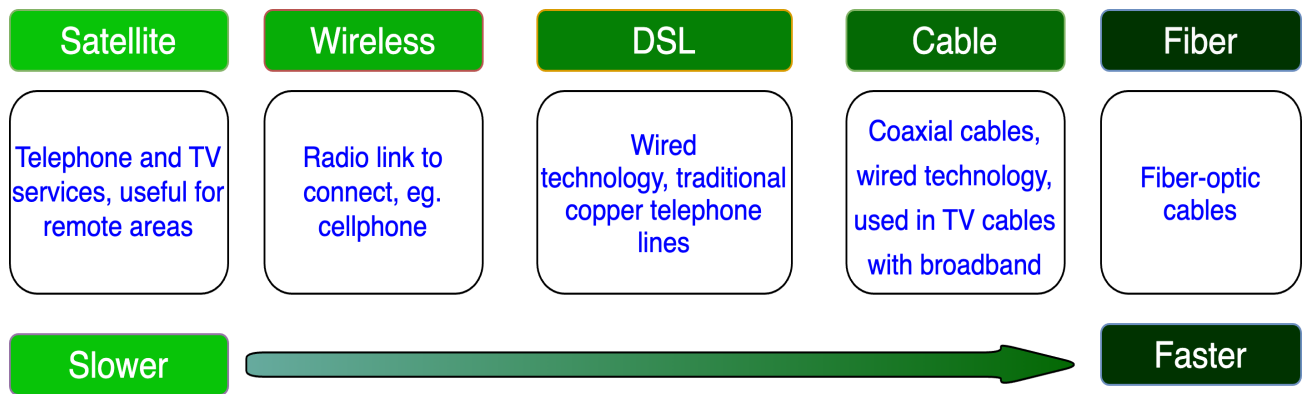
²⁷Refer [the Internet & Television Association report](#). FCC established a definition of broadband in 2015 as an internet connection with a minimum of 25 megabits per second (Mbps) of download speed and a minimum of 3 Mbps of upload speed (Conroy *et al.*, 2021). Between 2015 and 2020, the fourth-generation (4G) network coverage doubled globally. 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).

²⁸Please refer for additional information on broadband technology access and solutions (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.

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

³⁰(Hunsaker and Hargittai, 2018) shows a detailed review of who and how uses the internet among older adults.

FIGURE (3) Types of Broadband



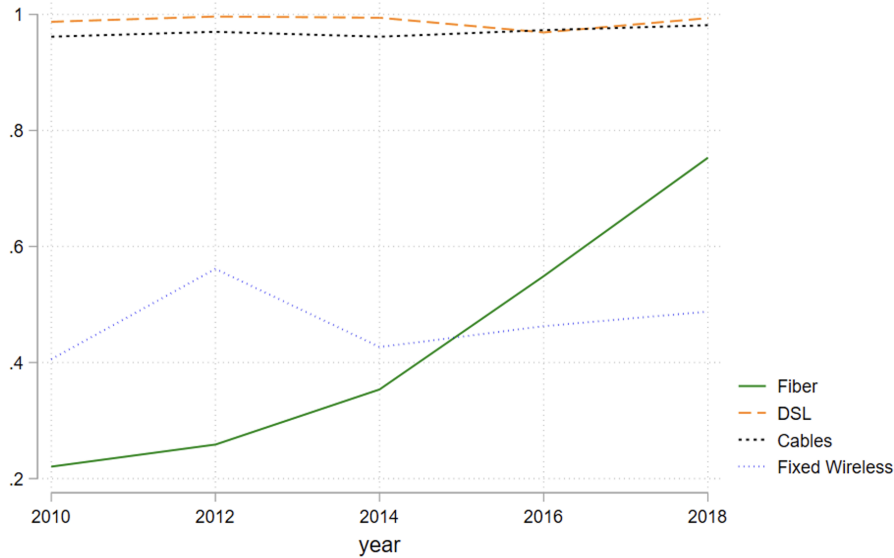
Note: Source (Conroy *et al.*, 2021)

in part, to the growing diffusion of broadband through fiber optics cables. Fiber broadband has emerged as a preferred choice, replacing older alternatives like cable and DSL, owing to its superior speed, reliability, consistency, and reduced susceptibility to signal loss or damage and is viewed as the most preferred as it has the potential for transmitting large amounts of data.³¹ They can transmit data at speeds reaching approximately 70% of the speed of light, equivalent to 124,274 miles per second. Commercial fiber connections typically offer signals above 10 Gbps, while residential fiber internet connections can reach speeds of up to 940 Mbps. 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 human hair. This approach enables significantly faster data transmission when compared to 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.

Secondly, the availability of fiber broadband for older adults in the US over the past decade has increased exponentially while the availability of other technologies remains stable. Analyzing data from the Health and Retirement Study (HRS), Figure 4 illustrates the significant upward trend in the share of the 50+ population residing in census tracts with fiber technology accessibility. The proportion has grown from approximately 22% to 75% from 2010 to 2018. In contrast, the availability of other technologies has remained relatively consistent throughout this period. This notable expansion in fiber broadband availability highlights its increasing prominence and potential relevance for older individuals.

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

FIGURE (4) 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 using HRS data merged with FCC data for 2010 to 2018. The sample is the balanced panel of HRS respondents.

4 Data

4.1 HRS

The Health and Retirement Study (HRS) serves as a nationally representative panel study, surveying approximately 20,000 individuals aged 51 and older.³² The core HRS has been conducted annually since 1992, transitioning to a biennial format from 1996 onwards. This comprehensive survey collects extensive demographic, health, relationship, income, and occupation-related information. Importantly, HRS also captures data on internet use, the presence of electronic devices within households, social connections and isolation, and the use of electronic technologies like health apps. Furthermore, the restricted files of the HRS contain information concerning respondents’ geographic residence locations. Restricted files of HRS have information on the respondent’s geographic residence locations.³³

³²The University of Michigan conducts HRS and is sponsored by the National Institute on Aging (NIA).

³³I obtained IRB approval from the University of Wisconsin-Madison. I use the RAND-HRS longitudinal version of HRS for most of the variables and borrow other variables from the raw HRS files whenever required.

4.2 Broadband Data

The empirical analysis draws upon panel data from two sources. The first is from the Federal Communications Commission (FCC) Form 477, which spans 2014 to 2018. The second is from the National Telecommunications and Information Association’s National Broadband Map (NBM) covering the years 2010 to 2013. This dataset encompasses crucial information, including the number of broadband providers, transmission technology (such as DSL, fiber, cable, or satellite), maximum download and upload speeds measured in Mbps, and whether the provider offers residential service at the census tract level.³⁴ To ensure comprehensive coverage, broadband providers are required to submit data biannually at the census-block level, demonstrating their ability to deliver internet service with speeds surpassing 200 Kbps in at least one direction. I aggregate the census-block level data at the census tract level by defining the census tract as treated if at least one of the census-block had fiber in a particular year. The census tract, comprising smaller geographic units compared to counties, offers a finer granularity of analysis. With a total of 84,414 census tracts in the United States, each ideally accommodating approximately 4,000 residents ([Census Report](#)). The census tract provides precise geographic treatment of the broadband, as opposed to aggregating at the county level, which has been done in the related literature. To ensure the most recent and reliable broadband data, the analysis primarily relies on the December dataset for each year.

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

³⁴The data is at the census block level (smaller than census tract), but since we do not observe census block of the HRS respondents, we aggregate the data at the census tract level.

4.3 Sample Selection

The primary analyses focus on the balanced panel of HRS respondents observed in the waves from 2010 to 2018, observing the same person over five survey waves. However, I also provide main estimates utilizing an unbalanced panel of HRS respondents to capture a broader sample and show that the estimates do not change. Secondly, this research design includes the outcomes that are measured less frequently than the treatment. This is because the HRS survey takes place every two years (2010, 12, 14, 16, and 18), and we know the treatment year for each survey respondent (2010, 11, 12, 13, ..., 18). So, the HRS sample can be categorized into two batches. The first batch receives the treatment in the years when the outcome is measured, and the second batch receives the treatment in the non-HRS wave year.³⁵ According to [De Chaisemartin *et al.* \(2019\)](#), we have to conduct the analysis separately for these two groups. 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. However, I also conduct the analysis separately for the second batch, as suggested by [De Chaisemartin *et al.* \(2019\)](#), and also show the estimates by combining these two batches by estimating the ‘length of the fiber treatment’ as a treatment, where I also include the HRS respondents who were exposed to fiber at the odd years and were surveyed at the even survey waves. In both of these cases, the results do not change.

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 till the last survey wave t_3 . To control for this kind of migration, usually, researchers assume that the census tract of that individual in t_1 to t_3 is the same as that of the t_0 , which is presumably a strong assumption. To

³⁵The key reason is that for this group, 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 other group, who were treated in non-HRS wave years, the first post-treatment outcome available is for the next year of treatment. For instance, for the HRS respondents treated in 2011, we have their first post-treatment outcome recorded in 2012.

address this concern, I depart from the aforementioned assumption and examine whether individuals migrate following the introduction of broadband. Leveraging the advantages of the Health and Retirement Study (HRS) data, I observed 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 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 exclusively 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.

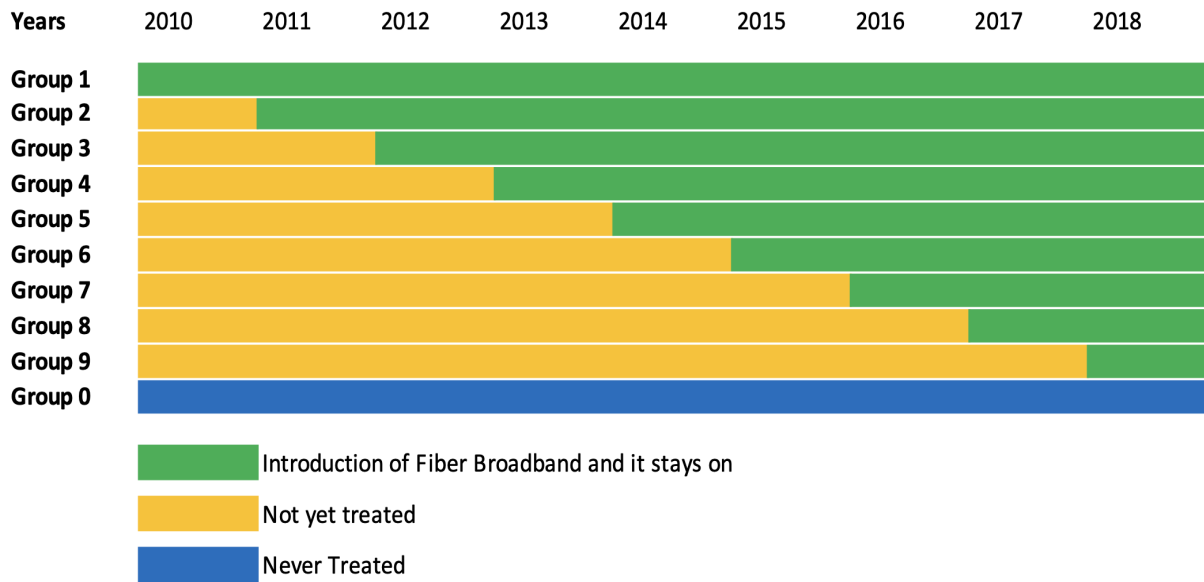
4.4 Introduction of Fiber

Figure 6 presents the categorization of the Health and Retirement Study (HRS) sample into different cohorts based on their exposure to fiber broadband expansion. Nine distinct groups of census tracts are identified, eight corresponding to each year of introduction of fiber broadband from 2010 to 2018, and a ninth group representing census tracts that never received fiber broadband during the study period. The primary sample of analysis is the group of census tracts that receive the fiber on the survey year of HRS data, i.e., groups 1, 3, 5, 7, and 9. I also show the estimates, including the other groups, by redefining the treatment.

4.5 Outcome Variable- Mental health CES-D score

To mitigate potential selection bias arising from examining multiple outcome variables separately and to address concerns related to multiple hypothesis testing, I employ a composite measure of mental health known as the Center for Epidemiology Studies Depression (CES-D) score. The CES-D score is one of the important aspects of mental health and is widely utilized across various social sciences and academic disciplines (Zivin *et al.*, 2010, Cutler and Sportiche, 2022). CES-D score is derived from eight questions encompassing domains such

FIGURE (5) Transition from no-Fiber to Fiber Broadband



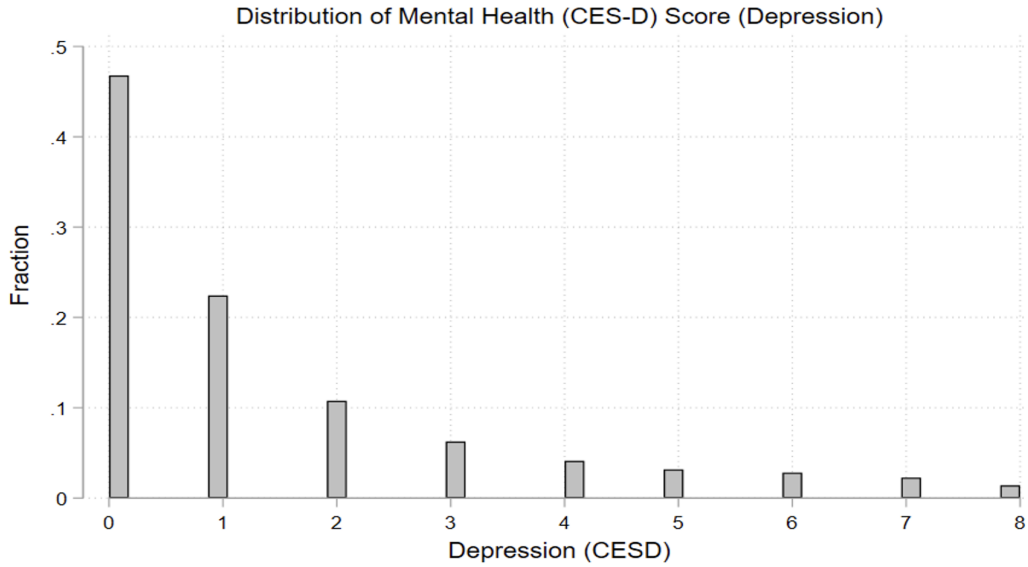
Note: The figure shows the introduction of fiber broadband in various groups of census tracts in different years. Group 1 received the fiber in 2010, Group 2 in 2011, Cohort 3 in 2012, and so on and so forth. Group 0 does not receive any fiber.

as depression, sleep quality, feelings of loneliness, and sadness. Specifically, the CES-D score is computed by summing the responses to six "negative" indicators while subtracting the responses to two "positive" indicators (Appendix Table 12). 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.

4.6 Summary Statistics

Table 1 presents the summary statistics for the merged dataset, combining the Health and Retirement Study (HRS) with the broadband data at the census tract level, spanning the

FIGURE (6) Primary Outcome Variable



Note: Sample is the balanced panel of HRS respondents in survey waves 2010, 12, 14, 16, and 18. N=87,872

period from 2010 to 2018. The statistics provide insights into the baseline characteristics of HRS respondents across various groups, including both the fiber-expansion and no-expansion cohorts of census tracts. Additional demographic characteristics of the respondents are provided in [Table 13](#) in the Appendix. [Table 13](#) shows that demographic characteristics within all the groups are similar in age, gender, health, and social security benefits. Only the 'rural' variable seems to have differences in means in some of the groups. This makes sense since the expansion of fiber might be driven by the urban areas. I conduct an analysis of rural and urban separately.

5 Empirical Strategy

5.1 Identification Strategy

This paper examines the causal relationship between high-speed internet (fiber broadband) and the mental health outcomes of older adults. To address concerns of endogeneity that may compromise the interpretation of causal estimates, 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

TABLE (1) Summary Statistics

Variables	Group 1 2010	Group 2 2012	Group 3 2014	Group 4 2016	Group 5 2018	Group 6 No Fiber
CES-D Depression Score (0-8)	1.34 (1.91)	1.23 (1.82)	1.25 (1.81)	1.45 (1.97)	1.50 (2.01)	1.38 (1.94)
Clinical Depression (0-1)	0.09 (0.28)	0.08 (0.27)	0.08 (0.27)	0.10 (0.31)	0.11 (0.31)	0.10 (0.29)
Feel Isolated (y/n)	0.30 (0.46)	0.26 (0.44)	0.34 (0.47)	0.32 (0.47)	0.34 (0.47)	0.32 (0.47)
Use Web (y/n)	0.55 (0.50)	0.57 (0.49)	0.53 (0.50)	0.53 (0.50)	0.51 (0.50)	0.51 (0.50)
Email Friends/Family (y/n)	0.31 (0.46)	0.32 (0.47)	0.33 (0.47)	0.32 (0.47)	0.33 (0.47)	0.33 (0.47)
Number of Broadband Providers	8.87 (3.75)	9.30 (3.73)	8.78 (3.07)	9.13 (3.38)	8.78 (3.28)	7.99 (2.92)
Max Download speed (Mbps)	399.91 (437.18)	446.57 (454.85)	505.04 (475.86)	431.71 (458.37)	301.35 (393.35)	279.31 (375.57)
N Respondents-Group year	11728	1713	4353	10438	9332	18421
Number of Census Tracts	1085	174	696	258	922	2070

Note: Mean and (SD) are shown. The data are the unbalanced panel of HRS merged with FCC for the periods 2010 to 2018 for every even year, using the geographical unit as census tracts. ‘Depression’ is the CESD score equal to 0 if there is no depression and 8 with the highest depression.

to [Campbell \(2022\)](#), leveraging the staggered nature of the fiber broadband rollout across the United States from 2010 to 2018. Moreover, in line with existing literature, I consider the evidence suggesting that access to broadband was subject to significant lag due to supply-side constraints ([Dettling *et al.*, 2018](#), [Campbell, 2022](#)).

Under the set of assumptions outlined, 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. The most conservative model includes individual fixed effects and the treatment year fixed effect, which account for differences between individuals whose access to fiber changes over time and individuals whose access does not change.

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

$$Y_{igt} = \beta_0 + \beta Fiber_{ct} + \delta_i + \gamma_{gt} + \epsilon_{igt}. \quad (1)$$

Here, Y_{igt} is the outcome for individual i , living in census-tract c , belongs 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 tracts 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.³⁶ I also include the group-year fixed effects γ_{gt} , to account for shocks that affect all the individuals in a given expansion group (of census tracts) in a given year. I cluster the standard errors at the census-tract level to allow for the correlation among individuals in the same census tract.

The DID model specified in [Equation 1](#) estimates the average treatment effect of the introduction of high-speed fiber broadband on the mental health of older adults. I show in [Equation 2](#) 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, this estimator 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 among older adults.

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

Here $Fiber_{\tau(ct)}$ are indicator variables equal to 1 if, for fiber expansion group g in HRS survey wave t , the introduction of fiber was τ years away. 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. For the main results, I show the estimates with a balanced and an unbalanced panel of HRS respondents. For all the subsequent analyses, I focus on the strictly balanced panel.

Recent advancements in the difference-in-differences (DID) literature suggest that the

³⁶Note here that I cannot include both group and individual fixed effects together as one of them drops since there is no between-group movement for individuals, as I restrict the sample individuals who do not migrate from their census tracts of residence during the study period of 2010-2018.

conventional two-way fixed effects (TWFE) estimator provides consistent estimates under the assumption of treatment effect homogeneity (Sun and Abraham, 2021, De Chaisemartin and d’Haultfoeuille, 2022a). However, it is plausible to expect that the introduction of high-speed fiber broadband may result in a heterogeneous treatment effect, given the varying rates of adoption among different economic agents, potentially influencing the mental health of older adults differently. Moreover, it is also conceivable that the treatment effects may vary across individuals, exhibiting interesting heterogeneity based on various demographic characteristics. To capture this heterogeneity in treatment effects over time and across treated units, I employ the event study methodology proposed by new DID estimators, as discussed below, that allow for the heterogeneous treatment effect of fiber broadband introduction on mental health outcomes among older adults.

As suggested by De Chaisemartin and d’Haultfoeuille (2022b), there are four main estimators that are relevant to the case of this study. The estimators for the binary and staggered treatment that allow for the dynamic treatment effects, i.e., outcomes can be affected by the 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). Older adults are less likely to be tech-savvy than younger people. Also, on average, about 55% of the sample respondents are below a high school degree. If we think that the less educated older people might take more time to learn new technology, we might see the treatment effect over time. So, I focus on estimators that account for the dynamic treatment effect and are more relevant in this case.

Finally, I prefer the estimator provided by De Chaisemartin and d’Haultfoeuille (2022a) and De Chaisemartin and d’Haultfoeuille (2020) for various reasons. First, only De Chaisemartin and d’Haultfoeuille (2020) and Borusyak *et al.* (2021) readily provide the average treatment effects. First, note that Borusyak *et al.* (2021) estimator does not include the ‘never-treated’ group but considers the yet-to-treat group for comparison. Secondly, as suggested by De Chaisemartin and d’Haultfoeuille (2022b), the estimator provided by Borusyak *et al.* (2021) might not work well in the presence of a strong serial correlation. I test the serial correlation between the outcome variable and its lag values and find that the serial correlation is strong (coefficient 0.59, sd(0.004)).

6 Results

6.1 Main Results

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

TABLE (2) Average Treatment Effect of Fiber Broadband on the Symptoms of Depression

	CES-D Depression Score			
	(1)	(2)	(3)	(4)
Post Fiber	-0.082** [0.032]	-0.073** [0.035]	-0.091** [0.039]	-0.128** [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

Note: This table shows the average (Intent-to-treat) effects of the staggered introduction of the fiber broadband on the depression symptoms among older adults using Equation 1 and estimating with the estimator provided by De Chaisemartin and d’Haultfoeuille (2022a). The outcome variable ‘depression’ is a CES-D mental health categorical score from 0 to 8, 0 being no depression and 8 being the highest depression. The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from 51 to 103. The treatment variable is equal to 1 if the fiber is available in a census tract of residents in survey year t and 0 otherwise. The individual controls include age, whether the individual receives Medicaid, is currently married, and works for the pay. I also include the HRS person weights in the estimation. Standard errors in square brackets are clustered at the census tract level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

The table suggests that the introduction of fiber broadband decreases depression symptoms among older adults, with estimates consistently supporting these findings across the various specifications. The point estimates are statistically significant in all the specifications. Appendix [Table 14](#) shows the estimates of the average effects of the introduction of fiber broadband on the mental health of older adults using the DID estimator by [Borusyak *et al.* \(2021\)](#). The estimates in Appendix [Table 14](#) replicate similar results, suggesting the introduction of fiber broadband declined the depression symptoms among older adults, and estimates are statistically significant. However, apart from the main analysis, I will focus on [De Chaisemartin and d’Haultfoeuille \(2022b\)](#) for the reasons explained in Section 5.³⁷

To gain a better understanding of the findings, I provide additional measures to illustrate the magnitude of the results. The preferred estimate from column 1, incorporating expansion year and individual fixed effects, indicates that fiber expansion reduces depression symptoms among older adults by 0.082 units. This estimate is remarkably similar in magnitude (0.085) but opposite in direction to the effect observed in a study by [Braghieri *et al.* \(2022\)](#), which suggests that the expansion of Facebook increased mental health problems among college students in the US. These contrasting findings highlight a key result of this paper, indicating that the impact of a similar technology on mental health outcomes can vary based on age cohorts and potentially on how individuals engage with the technology. Section 8 provides further insights into the underlying reasons for this divergence.

Additionally, I compare the estimates with a closely related meta-analysis conducted by [Paul and Moser \(2009\)](#). First, the results suggest that the positive effect of broadband expansion on depression symptoms is approximately 20% of the negative effect of job loss. The second comparison can be made with the study by [\(McInerney *et al.*, 2013\)](#), which examines the effect of the recession on the mental health of older adults. The estimates from my paper indicate that the benefit of broadband expansion is roughly 41% of the negative effect of the recession. These comparisons provide a context for understanding the relative importance of broadband expansion in influencing mental health outcomes compared to other factors.

Further, I show the results with the dynamic treatment effects in [Figure 7](#) using [Equation 2](#) and using the DID estimators proposed by [De Chaisemartin and d’Haultfoeuille](#)

³⁷Note that [Borusyak *et al.* \(2021\)](#) estimator does not include the ‘never-treated’ group but considers the yet-to-treat group for comparison. That is why the sample size in Appendix [Table 14](#) is smaller than the [Table 2](#). Secondly, [Borusyak *et al.* \(2021\)](#) may not work well in the presence of a strong serial correlation.

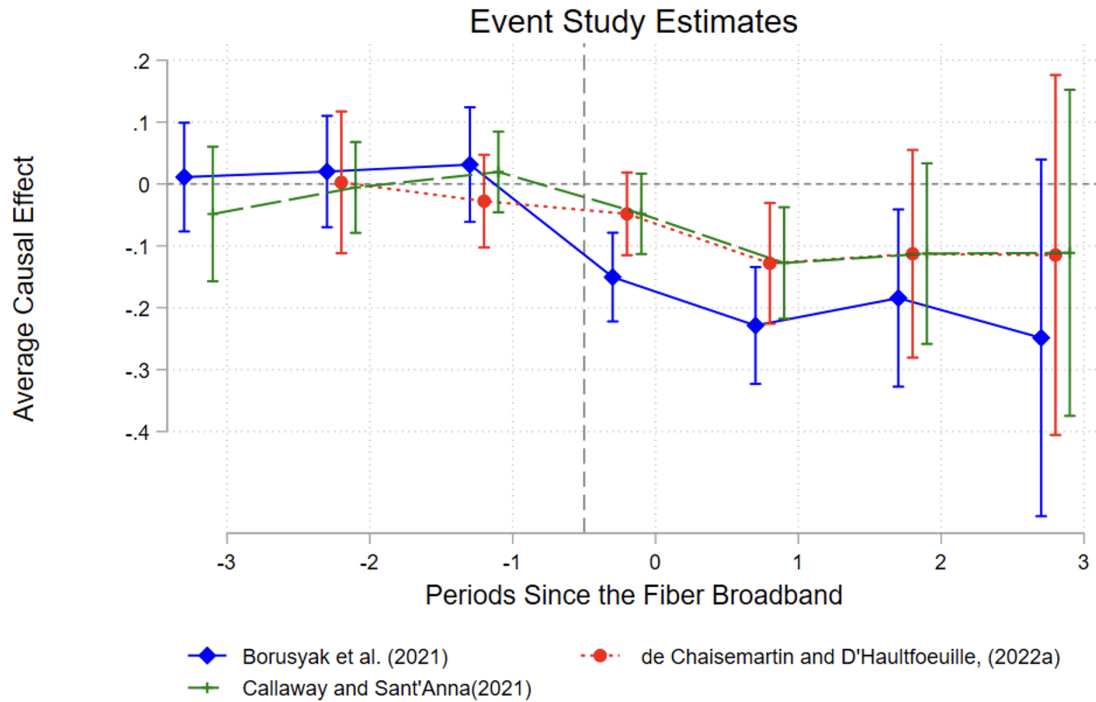
(2022a), [Borusyak *et al.* \(2021\)](#), and [Callaway and Sant’Anna \(2021\)](#). In [Figure 7](#), I show the estimates with the balanced panel of HRS respondents. [Figure 7](#) suggests that depression symptoms are declining after the introduction of high-speed fiber broadband and are statistically significant, suggesting positive benefits for older adults over time. [Figure 7](#) also suggests that the estimates prior to the introduction of the fiber broadband (period -2 and -3) are closer to 0 and insignificant. I consider this as evidence for no pre-trends and consistent with the parallel trend assumption. In Appendix [Figure 17](#), I also show estimates with the event study version of conventional TWFE, which shows a similar decline in depression symptoms after the introduction of fiber broadband.

Further, Appendix [Figure 16](#) shows the dynamic effect estimates for the outcome as the ‘clinical depression’ using [Equation 2](#) and estimated using the DID estimator proposed by [De Chaisemartin and d’Haultfoeuille \(2022a\)](#). In the Health and Retirement Study (HRS), a CES-D score above 3 is considered indicative of clinically relevant symptoms of depression or ‘caseness’ ([Schane *et al.*, 2008](#), [McInerney *et al.*, 2013](#)). The coefficients on the treatment variable prior to the introduction of fiber broadband are found to be close to 0 and statistically insignificant, providing evidence of no pre-existing trends and aligning with the assumption of parallel trends. [Figure 16](#) illustrates that the clinical symptoms of depression decline after the introduction of fiber broadband technology, with the estimates being statistically significant for the first and second periods and insignificant in the third period (again primarily due to the reduced sample size). To put these findings into context, it is worthwhile to compare them with research that examines the effect of unexpected widowhood on depression. The results from my study suggest that the benefit of broadband expansion is about 14% of the negative effects associated with the unexpected loss of a spouse ([Sifinger, 2017](#)).³⁸ This comparison helps shed light on the relative impact of broadband expansion in mitigating depression symptoms compared to other significant life events.

It is important to note that the statistically significant effects of fiber broadband on mental health outcomes grow over time. This delayed impact can be attributed to several potential factors. Firstly, older adults, who are typically less technologically adept compared to younger age groups, may require more time to familiarize themselves with and adapt to new technologies such as smartphones, computers, and video calling platforms. Additionally, they may need time to develop habits such as utilizing high-speed internet services at public

³⁸I compare the DID estimate from my paper that has individual fixed effects.

FIGURE (7) Dynamic Treatment Effects- Outcome: Outcome: CES-D score (Symptoms of Depression)



Note: This figure shows the dynamic effects plots using Equation 2 estimating with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a), Borusyak *et al.* (2021), and Callaway and Sant'Anna (2021). The sample from the 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. For Borusyak *et al.* (2021) and De Chaisemartin and d'Haultfoeuille (2022a), I include a fiber broadband expansion year and HRS respondents' individual fixed effect. For Callaway and Sant'Anna (2021), in addition to the above two FEs, I include expansion group fixed effects. 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); $N_{t_0} = 23,694$ (switchers = 3,655), $N_{t_1} = 14,668$ (switchers = 2,155), $N_{t_2} = 7,079$ (switchers = 735), $N_{t_3} = 2,494$ (switchers = 181).

libraries or coffee shops. Similarly, healthcare providers in the vicinity of older adults may take time to upgrade their technological infrastructure and train healthcare professionals to effectively implement telemedicine services, which can influence the mental health of older adults. Secondly, strategic complementarities, characterized by a 'waiting for others to adopt' behavior, may also play a role (Alvarez *et al.*, 2023). This suggests that the positive increase in the effect, such as a reduction in depression symptoms following the introduction of fiber technology, could be driven by various mechanisms outlined in Section 8. These mechanisms

shed light on the potential pathways through which the availability of high-speed broadband can improve mental health outcomes among older adults.

6.2 Self-use of Internet

The estimates presented in [Table 2](#) reflect the intent-to-treat (ITT) effect, which captures the overall effect of the availability of fiber broadband. This effect encompasses both the direct impact on individuals who actively use the internet and the potential indirect effects arising from others in the household or network using the internet. However, a significant contribution of this study lies in leveraging the rich data provided by the Health and Retirement Study (HRS) to disentangle the direct and indirect effects. This is a departure from similar research in the literature.³⁹

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

The question that asks about the regular use of the web is⁴⁰
"Do you regularly use the Internet (or the World Wide Web) for sending and receiving e-mail or for any other purpose, such as making purchases, searching for information, or making travel reservations?"

To assess the impact of broadband expansion on self-use of the internet among older adults, I transform positive responses to the above survey questions into a binary variable, assigning a value of 1 if the respondent answers affirmatively and 0 otherwise. [Figure 20](#) presents the dynamic effects, using estimators provided by [De Chaisemartin and d'Haultfoeuille \(2022a\)](#) and [Borusyak *et al.* \(2021\)](#). Importantly, the pre-trend estimates are close to zero and mostly statistically insignificant, providing support for the validity of the

³⁹For instance, ([Braghieri *et al.*, 2022](#)) documents that they cannot observe whether college students use Facebook or not, and their estimates are purely a combination of direct and indirect treatment effects. Note that I do not observe whether the respondent has access to fiber broadband at home.

⁴⁰For the missing values, I impute the value =1 if the respondents report that they send emails to friends or families.

parallel trend assumption in our analysis. [Figure 20](#) shows mixed evidence on the effect of the rollout of fiber broadband on the self-use of the internet. Under [Borusyak *et al.* \(2021\)](#) estimation, the estimates are statistically significant and virtually growing over time. However, under the [De Chaisemartin and d’Haultfoeuille \(2022a\)](#) estimation, the effect is not significant. One explanation for this vague effect is that the [Borusyak *et al.* \(2021\)](#) estimation does not include the ‘never-treated’ group, while [De Chaisemartin and d’Haultfoeuille \(2022a\)](#). Since the estimator provided by [Borusyak *et al.* \(2021\)](#) works well with not much serial correlation. The serial correlation in the outcome variable is very small, so I prefer the [Borusyak *et al.* \(2021\)](#) estimator in this case.

6.3 Heterogeneous Effects

In this section, I explore the heterogeneity of the effects of broadband expansion based on various characteristics. Firstly, I examine whether the effects vary between urban and rural areas. This analysis is motivated by the observation that the expansion of broadband was slower in rural areas during the initial years compared to urban areas. Secondly, I investigate whether the effects differ based on gender, taking into account the well-documented differences in baseline depression levels between men and women. Women tend to experience higher levels of depression across countries and age groups. Additionally, I examine the differential impact of broadband expansion based on race, considering the higher prevalence of mental health issues among African Americans. Moreover, I analyze whether the estimates vary across different age groups, including those below 65, above 65, and below 85. Importantly, instead of using the traditional two-way fixed effects (TWFE) estimator, I estimate the average treatment effects and dynamic treatment effects using the latest DID estimator proposed by [De Chaisemartin and d’Haultfoeuille \(2022a\)](#). This estimator allows for treatment effect heterogeneity across groups and over time, providing a more robust analysis of the differential impacts of broadband expansion.

6.3.1 Rural vs. Urban

Appendix [Table 13](#) provides evidence that the expansion of broadband was slower in rural areas during the initial years compared to urban areas. Also, rural residents are more likely to be older, poorer, have lower levels of education, have worse mental health, and lack private

health insurance (Foutz *et al.*, 2017, Mueller *et al.*, 2018, Moy *et al.*, 2017, Pender *et al.*, 2019). Similarly, more than half of all the mental health professional shortage areas are located in rural areas.⁴¹ To assess whether the positive effects of fiber broadband are concentrated in a specific region, I analyze the effects separately for urban and rural areas based on the HRS respondents’ residential locations. Table 7 shows the average treatment effects, and Figure 8 shows the dynamic treatment effects of fiber broadband on depression symptoms separately for urban and rural areas. The estimates in Table 7 and Figure 8 indicate that the introduction of fiber broadband declined depression symptoms among older adults in both urban and rural areas; however, there was a statistically significant decline in rural areas. These findings suggest that fiber broadband expansion has the potential to deliver significant benefits for the rural community in terms of mental health outcomes.

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

	Rural	Urban
Post Fiber	-0.229*** [0.087]	-0.057 [0.044]
Observations	9,930	37,779
Year Fixed Effects	Yes	Yes
Individual Fixed Effects	Yes	Yes

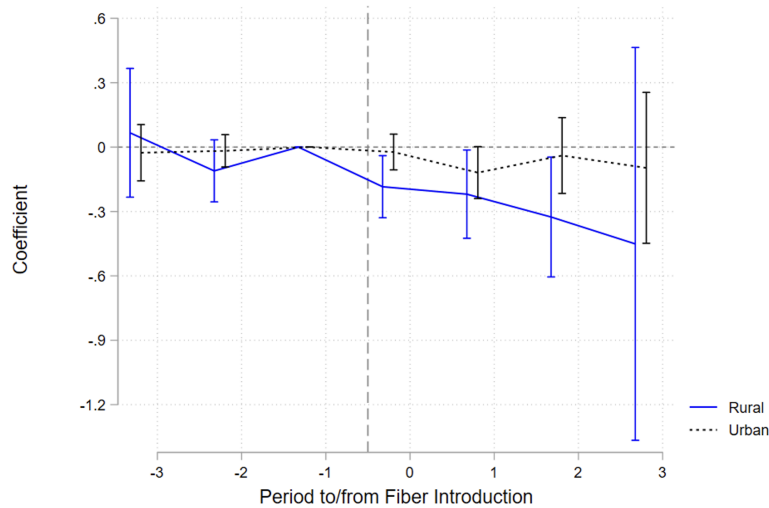
Note: This table shows the average treatment effects of the staggered introduction of the fiber broadband on the depression symptoms (CES-D) among older adults using Equation 1 and estimating with the estimator provided by De Chaisemartin and d’Haultfoeuille (2022a). The sample is a balanced panel of 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. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

6.3.2 Age Groups

The effect of broadband expansion on mental health outcomes may vary based on the age of the respondents. To investigate this, I analyze the effects separately for different age groups. Specifically, I focus on individuals below 65, above 65, below 85, and above 85 years old. Figure 9 shows the estimates for these age groups. The findings indicate a decline in

⁴¹Medicaid and CHIP Payment and Access Commission, Issue April 2021.

FIGURE (8) Dynamic Treatment Effect of Fiber Broadband on the Depression Symptoms-By Region



Note: This figure shows the dynamic effects plots using Equation 2 estimating with the estimator provided by De Chaisemartin and d’Haultfoeuille (2022a). The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from 51 to 103. The time variable is the survey wave, and the fiber group variable is the group of census tracts in which fiber was introduced in different years. 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 individual and treatment-year fixed effects. Standard errors are clustered at the census tract level. The bars show the 95 percent confidence interval. Sample size: N (Rural)= 9,930. N(Urban)= 37,779.

depression symptoms over time for the age groups below 85 and above 65, with the effects becoming statistically significant as time progresses. However, I do not find evidence of a decline in mental health among individuals below 65 and those above 85. This suggests that the expansion of fiber broadband may have potential benefits for the mid-age group cohort, specifically individuals aged 65 to 85, suggesting an inverted U-shaped effect based on the age groups.

These results align with the idea that the impact of broadband technology on mental health might operate differently at the intensive and extensive margins depending on the age group. For individuals below 65 who are likely to be still working, the broadband effect may have some effect at the intensive margin, given their existing access to the internet at their workplace. In contrast, individuals above 65 may have limited access to broadband, making the effect more pronounced at the extensive margin. Overall, these findings shed light on the potential benefits of fiber broadband expansion on mental health outcomes for the mid-age group cohort.

TABLE (4) Average Treatment Effect on Depression Symptoms: By Age Groups

	Age Above 65 (1)	Age Below 65 (2)	Above 85 (3)
Post Fiber	-0.084* [0.043]	-0.074 [0.060]	-0.000 [0.143]
Observations	25,663	16,749	2,507
Year Fixed Effects	Yes	Yes	Yes
Individual Fixed Effects	Yes	Yes	Yes

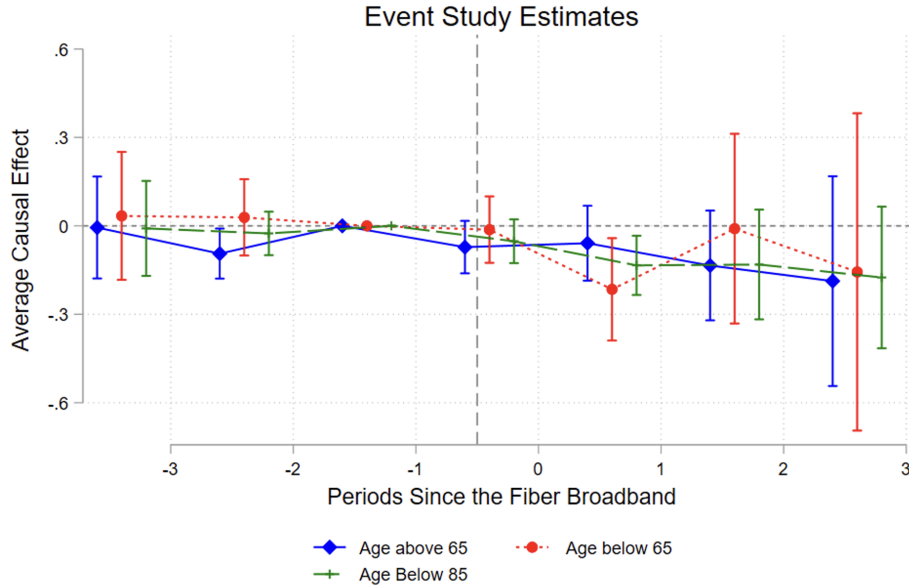
Note: This table shows the average treatment effects of the staggered introduction of the fiber broadband on the depression symptoms among older adults using Equation 1 and estimating with the estimator provided by De Chaisemartin and d’Haultfoeuille (2022a). The outcome variable ‘depression’ is a CES-D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

6.3.3 By Gender

It is imperative to understand the treatment effect heterogeneity by gender for two main reasons. First, the data suggest that the mean depression (CES-D) score for women (1.52 (sd 2.07)) is higher than that of men (1.19 (sd 1.76)). The fact that women have higher levels of depressive symptoms than men is the general consensus across nations and age groups (Nolen-Hoeksema and Hilt, 2008, Salk *et al.*, 2017, Banerjee *et al.*, 2023). Secondly, some reports indicate that women are more likely than men to use the internet for purposes such as emails, accessing health-related information, and seeking support for personal and health-related issues (Pew Research). This suggests important potential benefits of broadband for women.

The estimates presented in Figure 10 indicate a declining trend in depression symptoms among men compared to women following the introduction of fiber broadband. Both of these estimates are not statistically significant in either case. However, on average, women experience a higher decline in depression symptoms (estimates -0.031, SE 0.046) compared to men (estimates -0.028, SE 0.094) after the broadband expansion, and the difference between the two is -0.003 (p-value 0.07). The difference is statistically significant at the 10% level, suggesting potentially higher benefits of broadband expansion for women than men.

FIGURE (9) Dynamic Treatment Effects: By Age Groups



Note: This figure shows the dynamic effects plots, using the estimator provided by [De Chaisemartin and d’Haultfoeuille \(2022a\)](#) for various age groups. The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. 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 individual fixed effects and treatment year fixed effects. Standard errors are clustered at the census tract level. The bars show the 95 percent confidence interval. Sample sizes: $N_{Above65} = 25,663$; $N_{Below65} = 16,749$; $N_{Below85} = 42,795$.

It is noteworthy that these estimates are in contrast to the findings of [Braghieri *et al.* \(2022\)](#), who observed the adverse effects of social media (Facebook) on the mental health of college students, especially girls. This suggests that the impact of technology can vary across gender and age groups. Additionally, it is worth mentioning that while the trend of CES-D depression score estimates is increasing for women over time and declining among men, these trends are statistically insignificant. Nonetheless, these estimates contribute valuable insights into the potential differential effects of broadband expansion on mental health outcomes between men and women.

6.3.4 Race

In order to examine the potential heterogeneity of the effects, I estimate the model separately for Whites and non-Whites, considering the higher prevalence of mental health problems among African Americans. The mean CES-D depression score for Whites is 1.27 (sd 1.88), while for African Americans, it is 1.69 (sd 2.00). Recent reports also suggest disparities in

TABLE (5) Average Treatment Effect– By Gender

	Men	Women
Post Fiber	−0.041 [0.037]	−0.103** [0.049]
Observations	19,453	28,482
Year Fixed Effects	Yes	Yes
Individual Fixed Effects	Yes	Yes

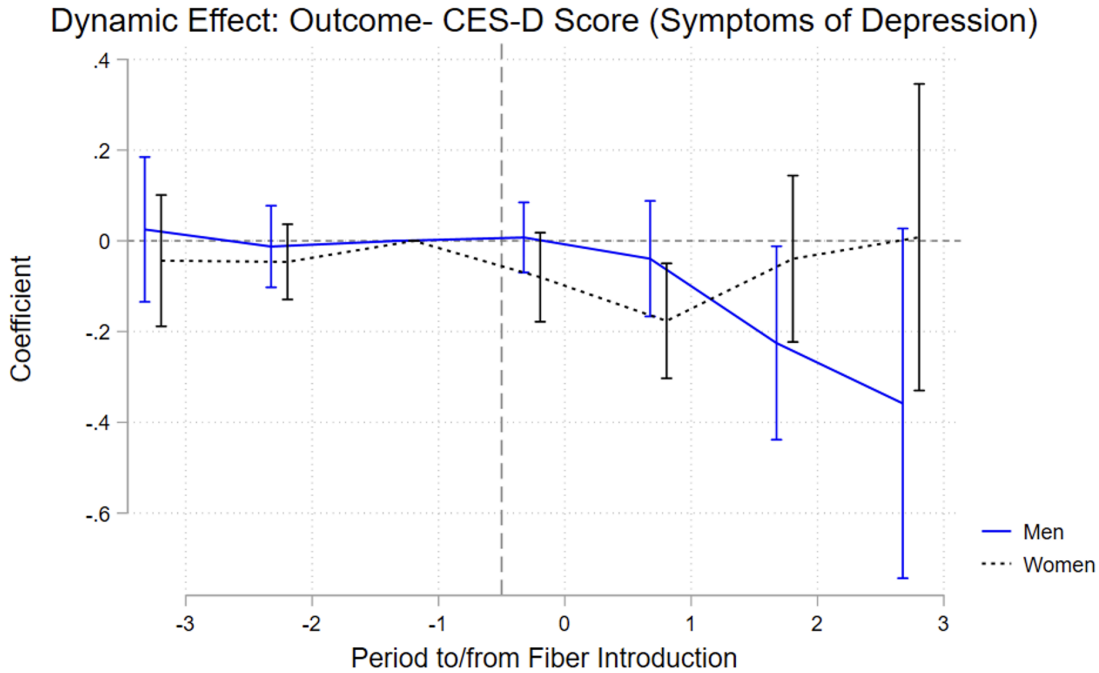
Note: This table shows the average treatment effects of the staggered introduction of the fiber broadband on the depression symptoms (CES-D) among older adults using Equation 1 and estimating with the estimator provided by De Chaisemartin and d’Haultfoeuille (2022a), estimated by gender. The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from 51 to 103. The treatment variable is equal to 1 if the fiber is available in a census tract of residents in survey year t and 0 otherwise. Standard errors in square brackets are clustered at the census tract level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

internet access, with non-White and economically disadvantaged areas experiencing slower internet speeds for the same price (Wisconsin State Journal Report, 2022). The estimates in Figure 11 present the dynamic treatment effects for Whites and African Americans. The results indicate a decline in depression symptoms among older Whites, with the estimates becoming statistically significant over time. Conversely, for African Americans, the estimates show an increasing trend over time, although they are not statistically significant from zero. One potential reason for the noisy estimates might be the sample size for the African Americans, who represent about 19% of the HRS sample. These findings suggest that fiber broadband expansion may not yield significant benefits for African Americans in terms of reducing depression symptoms. These estimates highlight the need for further research to understand the potential barriers or factors that may contribute to the lack of significant effects among African Americans. Examining other socio-economic and contextual factors could provide valuable insights into the underlying mechanisms and help address disparities in the impact of broadband expansion on mental health outcomes.

6.4 Effect Based on the Length of Exposure

To capture the potential effects of the length of exposure to fiber broadband at the individual level, I extend the analysis by examining the effects at the census-tract-survey-year level.

FIGURE (10) Dynamic Treatment Effects by Gender



Note: This figure shows the dynamic effects plots, using the estimator provided by [De Chaisemartin and d'Haultfoeuille \(2022a\)](#) for men and women separately. 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. I include the group and expansion year fixed effects. Standard errors are clustered at the census tract level. The bars show the 95 percent confidence interval.

This approach allows me to study the impact of different exposure lengths on broadband technology. Specifically, in the main sample, I include HRS respondents who were exposed to broadband during odd years, namely 2011, 2013, 2015, and 2017.

By considering the length of exposure, I can compare the effects of different exposure lengths. For instance, in the year 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. This enables a more nuanced understanding of the relationship between broadband expansion and mental health outcomes, taking into account the varying lengths of exposure among older adults. By incorporating the length of exposure in the analysis, I aim to capture the potential cumulative effects of broadband technology on mental health over time. This provides a more comprehensive perspective on the relationship between broadband expansion and mental well-being among older adults.

TABLE (6) Average Treatment Effect – By Race

	White	Non-White
Post Fiber	-0.096*** [0.035]	-0.021 [0.080]
Observations	36,403	11,396
Year Fixed Effects	Yes	Yes
Individual Fixed Effects	Yes	Yes

Note: This table shows the average treatment effects of the staggered introduction of the fiber broadband on the depression symptoms (CES-D) among older adults using Equation 1 and estimating with the estimator provided by De Chaisemartin and d’Haultfoeuille (2022a), estimated by race. The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from 51 to 103. The treatment variable is equal to 1 if the fiber is available in a census tract of residents in survey year t and 0 otherwise. Standard errors in square brackets are clustered at the census tract level. *** p<0.01, ** p<0.05, * p<0.10.

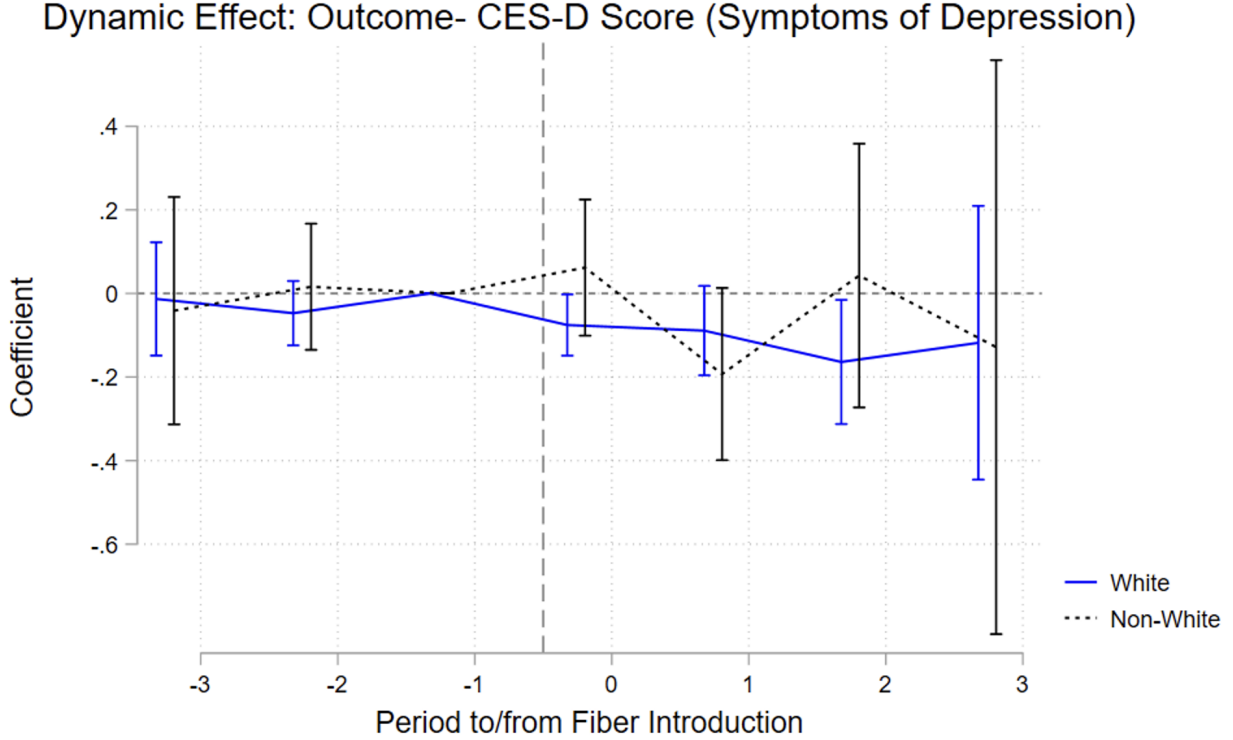
TABLE (7) Average Treatment Effect of Fiber Broadband on the Depression Symptoms-By Marital Status

	Married	non-Married
Post Fiber	-0.088*** [0.033]	-0.040 [0.060]
Observations	25,487	15,969
Year Fixed Effects	Yes	Yes
Individual Fixed Effects	Yes	Yes
Mean of Outcome Variable	1.07	1.78

Note: This table shows the average treatment effects of the staggered introduction of the fiber broadband on the depression symptoms (CES-D) among older adults using Equation 1 and estimating with the estimator provided by De Chaisemartin and d’Haultfoeuille (2022a). The estimates are separated for the marital status, i.e., married and non-married (divorced, separated, widowed, never married, and partnered). I include the individuals whose marital status does not change over time. 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.

To study the effect of length of exposure, I follow Braghieri *et al.* (2022) and estimate the following equation-

FIGURE (11) Dynamic Treatment Effects by Race



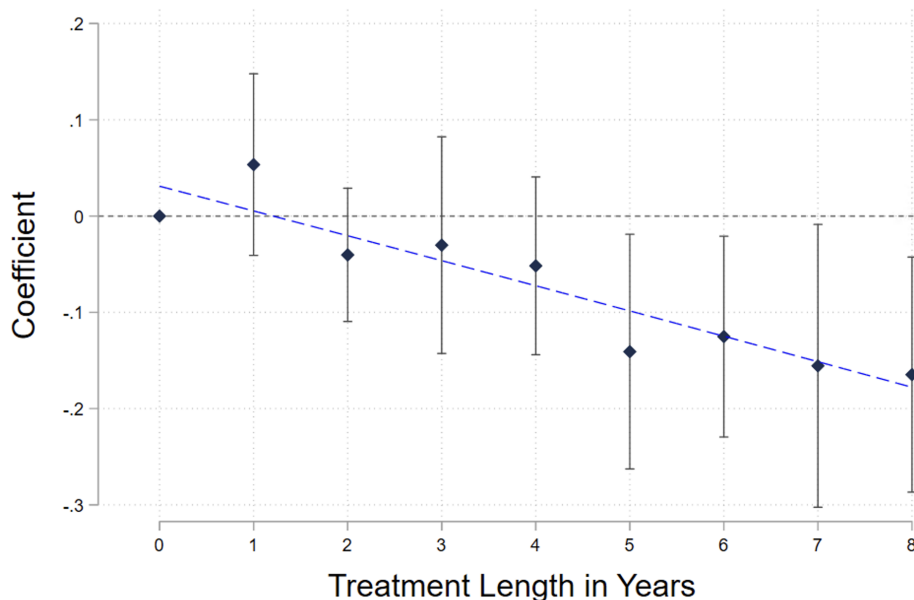
Note: This figure shows the dynamic effects plots, using the estimator provided by [De Chaisemartin and d’Haultfoeuille \(2022a\)](#) for Whites and non-Whites. The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The outcome variable ‘depression’ 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 census tract level. The bars show the 95 percent confidence interval.

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

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 as $\tau = \text{Fiber}_{gt} \times (t - \text{Year of treatment})$ 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 12](#) 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 excluding HRS sample respondents who were exposed to fiber broadband in

odd years and interviewed in even survey years does not bias the results.

FIGURE (12) 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.

7 Robustness

I report several sensitivity analyses. I show estimates with different specifications in Table 2 using the estimator provided by De Chaisemartin and d’Haultfoeuille (2022b) and by using other DID estimator by Borusyak *et al.* (2021) in Table 14. Note that 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), so I show the average treatment effects without those estimators. Further in Figure 13, I show the estimates including the ‘movers’, since the main estimation is focused on the the ‘stayers’, i.e., individuals who do

not move out of their census tract for the study period.

In [Table 2](#), I show the robustness of the estimates, including controls, the census tract fixed effects, and group-year fixed effects. Column 2 of [Table 2](#) suggests that the estimates with controls demonstrate robustness, indicating a consistent decline in depression symptoms and providing evidence of the positive impact of broadband expansion on the mental well-being of older adults. The estimates are statistically significant, with standard errors almost the same, this analysis strengthens the validity of the findings, suggesting that omitted variables or confounding factors do not drive the observed effects that can be attributed to the introduction of broadband technology.

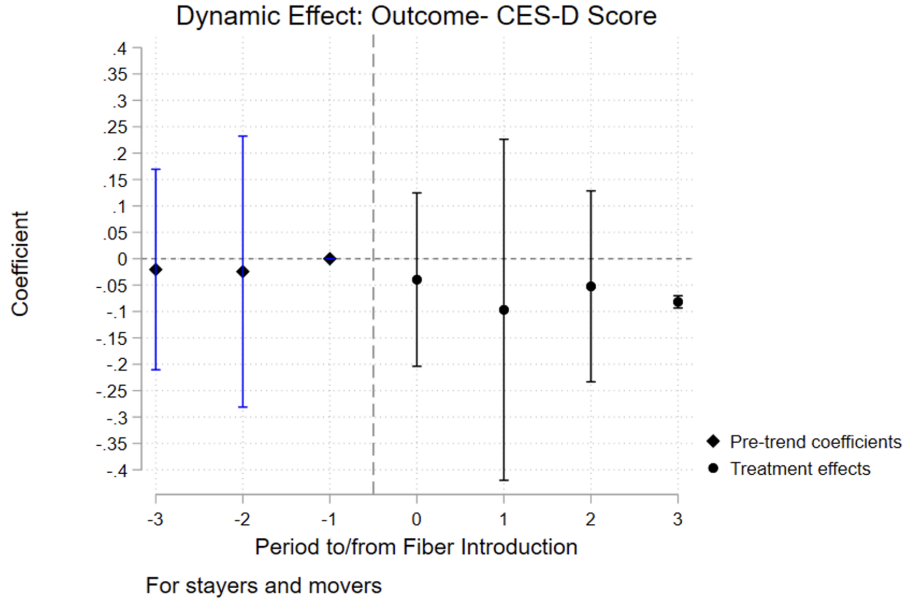
7.1 Stayers and Movers

Among the balanced panel of HRS respondents, approximately 91% of the sample, referred to as "stayers," did not move out of their census tracts of residence during the period of 2010-2018. On the other hand, around 9% of the respondents, referred to as "movers," relocated at least once from their census tract of residence during the same period. In the primary analysis, I focus exclusively on the stayers to mitigate the potential endogeneity issues associated with migration and its relationship with broadband treatment. By restricting the sample to the stayers, I can examine the effects of broadband expansion while accounting for potential biases that may arise from migration patterns. To test the robustness of the estimates, I also include the movers in the main sample. [Figure 13](#) shows the estimates for the stayers and movers. The dynamic effect persists with the evidence of parallel trend assumption and a slightly lower estimate in the third period. The estimates suggest that the movers are not driving the estimates remarkably. This analysis provides reassurance that mobility patterns do not solely drive the observed effects but are consistent even when considering the impact of migration on the estimates.

8 Mechanism

In this section, I present empirical evidence regarding the potential mechanisms underlying the positive effect of high-speed broadband on the mental health of older adults. Specifically, I test whether broadband affects social connectedness, social isolation, health literacy, cognitive score, and technological efficiency in nearby hospitals. Notably, this study is among the

FIGURE (13) Robustness: Stayers and Movers



Note: N: 76,162. The estimator is by [De Chaisemartin and d’Haultfoeuille \(2022a\)](#). 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 is the mental health score CES-D. 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. The bars show the 95 percent confidence interval.

first to empirically test the causal relationship between high-speed broadband technology and most of these key channels.

8.1 Social Isolation and Loneliness

To further 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 socially isolated from others. I estimate the [Equation 2](#) and the estimator provided by [De Chaisemartin and d’Haultfoeuille \(2022a\)](#) to evaluate whether the expansion broadband also affects the instances of social isolation. [Table 8](#) indicate a substantial decrease in the instances of social isolation among older adults following the expansion of broadband technology. These findings provide further support for the social isolation hypothesis, suggesting that broadband expansion has been instrumental in mitigating feelings of social isolation among older individuals. This causal evidence also supports the claim from the correlational studies in medical research [Cotten et al. \(2013\)](#). The results underscore the significance of technological

advancements in promoting social connectedness and well-being among older adults.

TABLE (8) Average Treatment Effect of Fiber Broadband on the Feelings of Social Isolation and Loneliness

	(1)	(2)
	Felt Isolated	Felt Lonely
Post Fiber	-0.050*** [0.019]	-0.014** [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 in calculating the CES-D score. 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. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

8.2 Social Connectedness

A plausible pathway through which broadband technology may influence mental well-being is by facilitating virtual connectedness with family members and friends. Existing literature suggests that the internet can serve as a source of social support Pescosolido (2011). To examine this, I construct a proxy for social connectedness using relevant survey questions from the HRS. These questions inquire about the frequency of sending emails to family, friends, and children, as well as the use of social media platforms like Facebook or Skype for connecting with loved ones. Additionally, the HRS survey captures regular web usage. Combining these scores, I create an index that I convert into an indicator variable, taking a value of 0 to indicate low or negligible social connectedness and a value of 1 for positive values signifying high social connectedness. Estimates using the Equation 2 and the estimator by (De Chaisemartin and d’Haultfoeuille, 2022a) with the outcome as social connectedness index, Figure 15 Panel a displays the results, indicating a statistically significant increase

in social connectedness over time. These estimates provide empirical support for the notion of technological complementarities, where the availability of broadband technology enhances the functional use of other technological tools, such as video calls with family and friends.

Moreover, in Panel b of [Figure 15](#), I conduct separate estimations for individuals categorized as low and high in terms of social connectedness. This analysis explores whether the effects of broadband expansion on mental health differ for these two groups. The results reveal a decline in depression symptoms over time for highly socially connected individuals while indicating a slight increase in depression symptoms for those with low levels of social connectedness. These findings align with the social isolation hypothesis, which posits that limited social connections can have detrimental effects on mental health. Overall, these empirical findings shed light on the potential mechanisms through which broadband expansion influences the mental well-being of older adults, emphasizing the role of virtual connectedness and the consequences of social isolation on mental health outcomes.

TABLE (9) Average Treatment Effects of Broadband on Depression Symptoms Based on Social Connectedness

	Social Connectedness Index		
	Above 25 pct (1)	Above 75 pct (2)	below 25 pct (3)
Post Fiber	-0.121** [0.048]	-0.137** [0.067]	-0.001 [0.081]
Observations	28,251	14,202	7,173
Year Fixed Effects	Yes	Yes	Yes
Individual Fixed Effects	Yes	Yes	Yes

Note: The estimator is by [De Chaisemartin and d'Haultfoeuille \(2022a\)](#). 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. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

FIGURE (14) Dynamic Treatment Effects of Broadband on Depression Symptoms Based on Social Connectedness

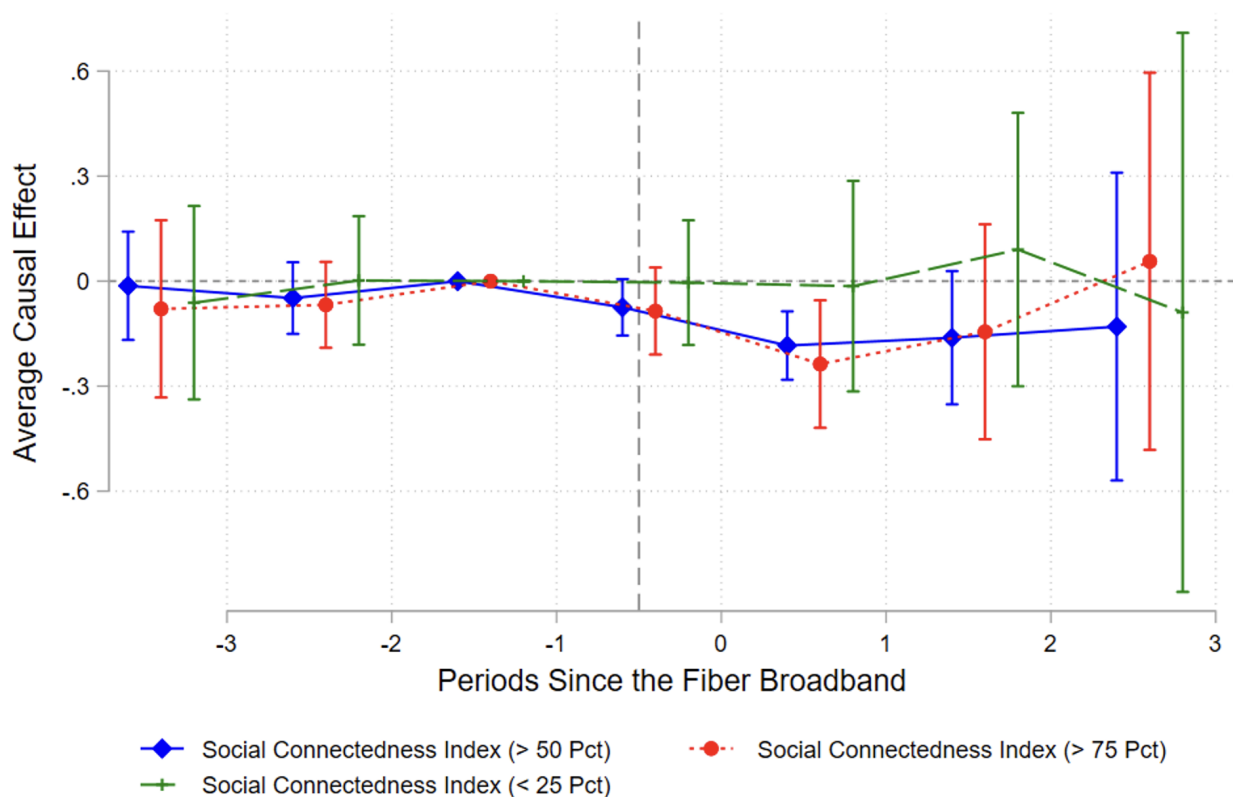


FIGURE (15) Outcome: Mental health CESD Depression Score

Note: The estimator is by [De Chaisemartin and d'Haultfoeuille \(2022a\)](#). 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. The bars show the 95 percent confidence interval. N for social connectedness index (>50)= 28,251; for (>50) = 14,202; for (<25) = 7,173.

8.3 Health Literacy

Another potential mechanism through which the introduction of high-speed fiber broadband may positively impact the mental health of older adults is through improvements in health literacy. It is possible that within-household spillovers or social circles contribute to enhanced

health literacy among individuals. Additionally, the self-use of health apps may also play a role in improving mental health outcomes. However, it is important to exercise caution when interpreting the findings presented in [Table 10](#). The mechanisms analyzed in this table are based on survey questions that were administered to a limited number of HRS respondents in either one or two waves. Consequently, the small sample size may limit the statistical power to detect significant effects accurately.

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 10](#) columns (1) and (2) suggest that the introduction of fiber is strongly and significantly correlated with health literacy.

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

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

And,

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

Columns (3) and (4) in [Table 3](#) indicate a positive relationship between the introduction of fiber broadband and the use of health-related apps. While none of the estimates reach statistical significance, the magnitudes of the coefficients are more than double the mean of the outcome variable. These findings suggest a strong correlation between the availability

of fiber broadband and the utilization of medical apps, even though the lack of statistical significance indicates the need for further research to explore these mechanisms more comprehensively.

TABLE (10) Mechanisms: Effect on Health Literacy, Use of Health Apps and Health Websites

	(1)	(2)	(3)	(4)	(5)	(6)
	Health Literacy		Use of Health Apps		Use Health Management Sites	
Fiber X Post	0.341** [0.141]	0.408*** [0.149]	0.519 [0.374]	0.625 [0.392]	0.211 [0.215]	0.340 [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. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

8.4 Technological Efficiency for Telehealth

In this subsection, I examine whether the introduction of broadband improves the technological efficiency of nearby hospitals by investigating the availability of telehealth services. Telehealth has been recognized as an efficient and effective tool in healthcare, but its widespread implementation has been hindered by the lack of high-speed internet access, particularly in rural and underserved areas (Gajarawala and Pelkowski, 2021). Recent evidence suggests that access to telemedicine during the COVID-19 pandemic increased primary care visits without adverse effects on health outcomes (Zeltzer *et al.*, 2023). To explore this hypothesis, I utilize data from the 2018 Annual Survey Database administered by the American Hospital Association (AHA).⁴² This voluntary survey collects information on hospital organizational structure, utilization, finances, facilities, and staffing. I analyzed 24 survey questions related

⁴²The Primary reason that I include the AHA survey for only 2018 is that the surveys are paid data, and UW-Madison had access to only the 2018 wave. In my other work in progress, I collaborate with other researchers who have access to more waves of data, and we are answering this question in more detail.

to the availability of telehealth services for various types of care and hospital networks (Refer Appendix [Table 15](#) for the list of the questions). Since the AHA data is at the county level, I calculate the average number of broadband providers and speed at the county level. Using a logit model, [Table 11](#) presents estimates that demonstrate a strong and statistically significant relationship between the number of broadband providers and the likelihood of hospitals offering telehealth services. Similarly, a strong relationship is observed when considering download speed instead of the number of providers. However, it is important to note that these estimates represent correlation rather than causal evidence due to the limited availability of AHA survey data for multiple years.⁴³

TABLE (11) Mechanisms: Hospitals offer Telehealth Services

VARIABLES	(1) Offer Telehealth Services	(2) Offer Telehealth Services
# 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.

8.5 Cognition

Recent research using neuroimaging techniques has highlighted the association between social isolation and cognitive decline ([Lammer *et al.*, 2023](#)). Additionally, utilizing broadband, smartphones, and computer-related technologies requires a certain level of cognitive ability. While the gerontology literature extensively examines the relationship between internet use and cognitive functions, the economics literature lacks sufficient causal evidence in this area. Previous studies have shown that internet use engages the brain in multitasking, executive

⁴³One may use the number of broadband as an instrument for whether a hospital offers telehealth services or not, and looks into the outcome of mental health. This instrument, however, may not satisfy the exclusion restrictions.

thinking, and information processing. At the extensive margin, older adults who are just starting to use these technologies might develop some improvement in cognitive abilities. For instance, to make video calls on WhatsApp, you need first to download the app, set up the account, add the contacts, and then call the people in the contacts by pressing the video call option. Motivated by these theories, I investigate whether the expansion of broadband technology affects cognitive functions among older adults. This study represents the first attempt in the economics literature to shed light on the potential cognitive pathways influenced by broadband technology.

Figure 18 displays the distribution of the "total cognition score," which combines scores of word recall and mental status summary, ranging from 0 (indicating the worst cognitive function) to 35 (indicating the best). To examine the dynamic treatment effect on cognitive scores, I present Appendix Figure 19. The estimates do not suggest a significant improvement in cognitive scores in the early years, but they become statistically significant in the final period. These findings provide some evidence of potential cognitive improvement over time following the introduction of broadband. However, it is important to note that this paper primarily focuses on exploring the broader effects of broadband technology on mental health, and a detailed analysis of the specific mechanisms underlying its impact on cognitive function is beyond the scope of this study.⁴⁴

9 Conclusion

This study contributes to the existing literature by examining the causal relationship between the rollout of high-speed broadband technology and the mental health outcomes of older adults, addressing a unique and understudied research question. Furthermore, this research explores the unexplored pathways through which these effects may manifest. The findings demonstrate that the expansion of broadband significantly reduces symptoms of depression among individuals aged 50 and above, providing robust statistical evidence of sustained improvements in mental health over time. Heterogeneity analysis reveals that older adults residing in rural areas experience greater benefits compared to their urban counterparts, emphasizing the importance of geographic context. Moreover, the study identifies an inverted U-shaped effect based on age groups, indicating that individuals aged 65

⁴⁴I have a work in progress that focuses on the role of broadband on cognition in more detail.

and above but below 85 derive the most significant and substantial benefits. Conversely, the average treatment effects for individuals below the age of 65, who are more likely to be employed, are positive but not statistically significant. Additionally, the study uncovers racial disparities, as the positive effects of broadband expansion are driven by Whites, while no significant effects are observed for Blacks, necessitating further investigation to address this gap. Furthermore, the results indicate that women experience slightly larger average treatment effects compared to men. Exploring potential mechanisms, the study highlights the role of higher social connectedness, lower social isolation, improved health literacy, enhanced cognitive function, and technological advancements in nearby hospitals as potential pathways through which the effects of broadband technology may translate into better mental health outcomes for older adults. These findings contribute important insights to the literature, informing policymakers and stakeholders about the implications of broadband expansion for the mental well-being of older adults.

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

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

benefits for rural communities.

10 Policy Implications

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

Secondly, with the growing attention of policymakers and researchers toward technologies like telehealth, broadband has demonstrated its positive influence on these technological advancements, which can have significant implications for the health and well-being of older adults. As telehealth services become increasingly important, reliable and high-speed internet access becomes a critical component for enabling effective healthcare delivery and remote consultations.

Thirdly, it is essential to recognize that not everyone has equal access to high-speed internet. Disparities in internet availability based on geographical location, race, and income have been documented, and the COVID-19 pandemic has further highlighted these disparities. To address these inequities, substantial government investments using public funds have been allocated to initiatives such as the Internet for All and Affordable Connectivity Program (ACP), which have dedicated over \$100 billion USD to expand internet access. Understanding the potential effects of such substantial investments on the health and well-being of one of the most vulnerable age groups, older adults, is of utmost importance in ensuring

equitable outcomes and maximizing the benefits of these initiatives.

This paper's findings shed light on the significant implications of broadband expansion for the mental health and well-being of older adults, highlighting the importance of internet access for staying socially connected. Moreover, it underscores the role of broadband in facilitating technological advancements like telehealth. Finally, the study emphasizes the need to address disparities in internet access, particularly for vulnerable populations, as substantial investments are made to bridge the digital divide and promote equitable outcomes.

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Appendices

TABLE (12) 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 (13) 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

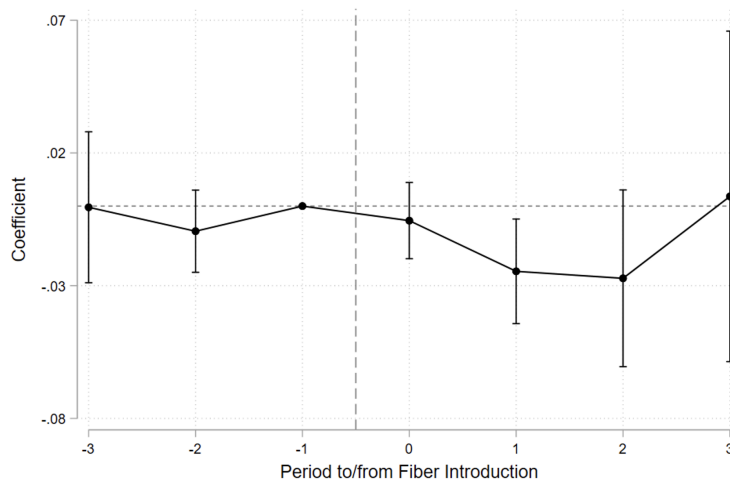
Note: The data are the balanced panel of HRS respondents merged with FCC for the periods 2010 to 2018 for every even year, using the geographical unit as census tracts.

TABLE (14) Average Treatment Effect of Fiber Broadband on the Symptoms of Depression (Using Borusyak et al. (2021) Estimator)

	Borusyak et al. (2021)			
	(1)	(2)	(3)	(4)
Post Fiber	-0.096*** [0.035]	-0.083** [0.035]	-0.113*** [0.043]	-0.188*** [0.050]
Observations	36,206	36,206	36,230	36,772
Expansion Year Fixed Effects	Yes	Yes	Yes	Yes
Individual Fixed Effects	Yes	Yes		
Controls		Yes		
Census-Tract Fixed Effects			Yes	
Fiber Expansion group FE				Yes

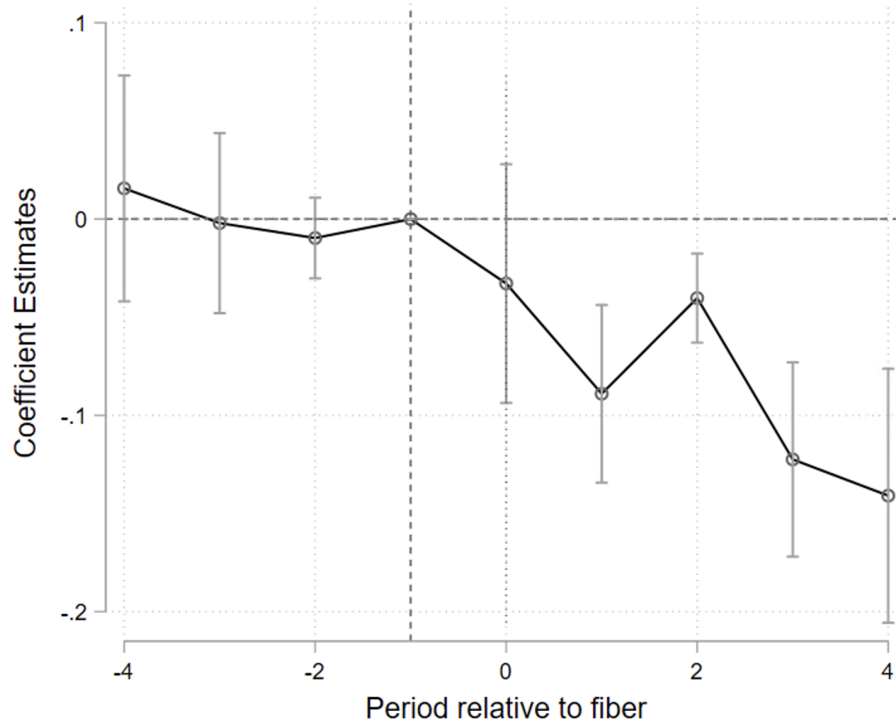
Note: This table shows the average treatment effects of the staggered introduction of the fiber broadband on the depression symptoms among older adults using Equation 1 estimating with the estimator provided by Borusyak *et al.* (2021). The sample is a balanced panel of Health and Retirement Study (HRS)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

FIGURE (16) Dynamic Treatment Effects- Outcome: Clinical Depression



Note: This figure shows the dynamic effects plots using Equation 2 estimating with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from 51 to 103. The time variable is the survey wave, and the fiber group variable is the group of census tracts in which fiber was introduced in different years. The outcome variable is 1 if the 'symptoms of depression' CES-D score is above 3 and 0 otherwise. I include individual fixed effects and treatment-year fixed effects. Standard errors are clustered at the census tract level. The bars show the 95 percent confidence interval. $N = 47,935$; $N_0 = 23,694$, $N_1 = 14,668$, $N_2 = 7,079$, $N_3 = 2,494$, $N(\text{pre } 1) = \text{omitted}$, $N(\text{pre } 2) = 17,244$, $N(\text{pre } 3) = 4,581$.

FIGURE (17) Dynamic Treatment Effects Using Two-Way Fixed Effects (TWFE)

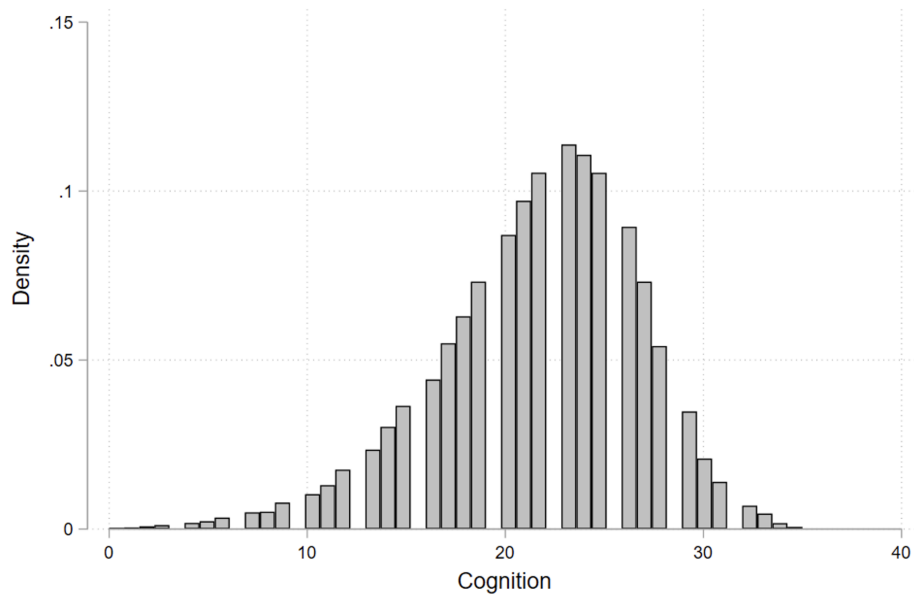


Note: This figure shows the dynamic effects plots using Equation 2 estimating with the conventional TWFE. The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from 51 to 103. The time variable is the survey wave, and the fiber group variable is the group of census tracts in which fiber was introduced in different years. 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 census tract level. The bars show the 95 percent confidence interval.

TABLE (15) Questions in AHA data related to telehealth

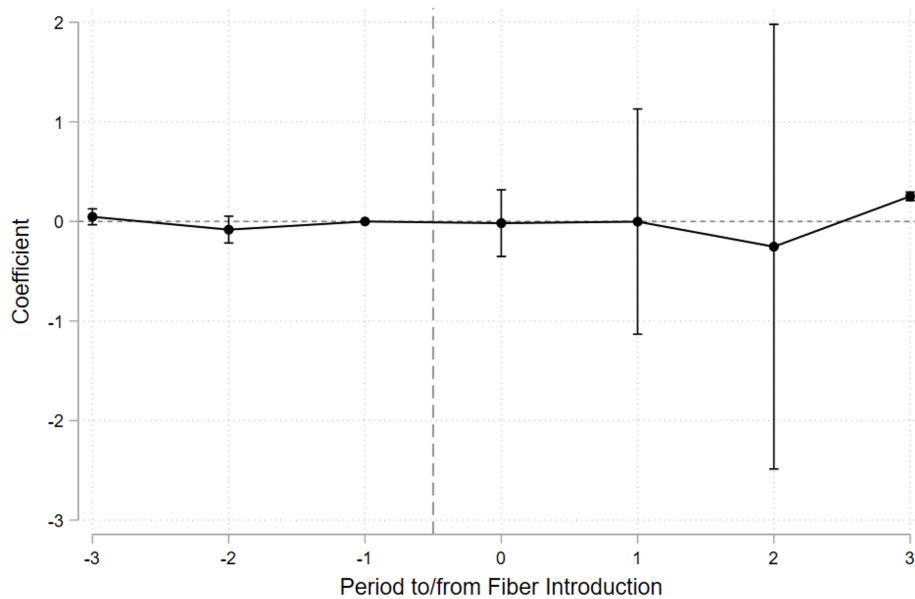
Telehealth consultation and office visits hospital
Telehealth consultation and office visits health system
Telehealth consultation and office visits joint venture
Telehealth eICU - hospital
Telehealth eICU - health system
Telehealth eICU - joint venture
Telehealth stroke care - hospital
Telehealth stroke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

FIGURE (18) Distribution of Total Cognitive Score



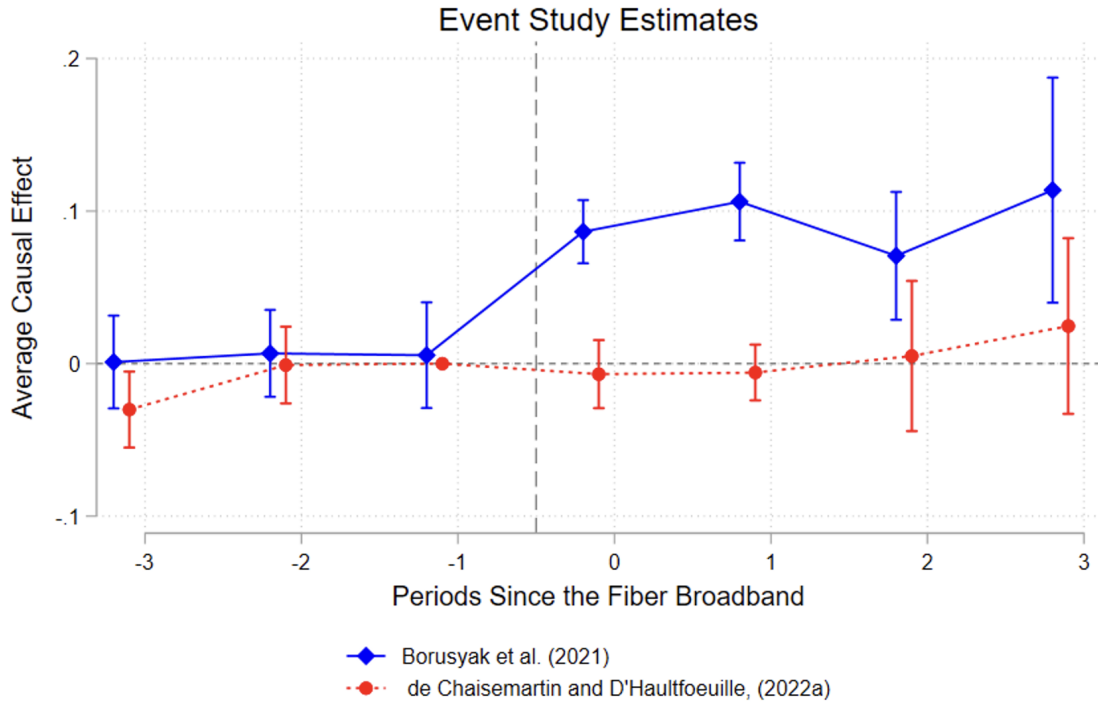
Note: This figure shows the distribution of the total cognitive score. The score ranges from 0 to 35, with 0 being the lowest cognition and 35 being the highest. The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from 51 to 103.

FIGURE (19) Dynamic Treatment Effects on Total Cognition Score



Note: This figure shows the dynamic effects plots using Equation 2 estimating with the estimator provided by De Chaisemartin and d’Haultfoeuille (2022a). The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from 51 to 103. The time variable is the survey wave, and the fiber group variable is the group of census tracts in which fiber was introduced in different years. The outcome variable is the total cognition score (0-35). I include group and treatment year fixed effects. Standard errors are clustered at the census tract level. The bars show the 95 percent confidence interval.

FIGURE (20) Dynamic Treatment Effects- Outcome: Self Use of Internet



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