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

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Abstract

Recent research has shown the negative effects of social media on younger people's mental health. Yet, we do not know whether 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 harmful effects of the internet among younger populations, my results show that broadband rollout significantly reduces depression symptoms by 5.7% 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 major life events known to negatively 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

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

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

1 Introduction

The aging US population faces increasing mental health challenges, with substantial economic costs and partially effective available treatments. About 54 million individuals aged 65 and above represent 16% of the US population as of 2019; by 2060, 1 in 4 people (about 94.7 million individuals) will be 65 or older (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 15 cigarettes and six drinks a day.[4] Mental health-related issues were exacerbated during COVID-19, as isolation among older adults compounded their risks of death.[5] Depression is often associated with suicide.[6] 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. Approximately

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

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

[3] 27% 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.

one-fifth of the older American population lives in rural areas; in certain states, more than half of the elderly residents live in rural locations (Census report).[8] Rural residents are more likely to be older and poorer, to have lower levels of education and worse mental health, and to lack private health insurance.[9] Consequently, these areas are characterized by limited access to mental health services and a scarcity of trained mental health providers. More than half of all the locations with shortages of mental health professionals 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 such as 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 uses 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 social media has adverse effects on the mental health of college students, especially due to 'unfavorable comparison' among girls (Braghieri *et al.*, 2022). With this background, the net effect of the internet on older adults' mental health is unclear. Secondly, a significant geographic and demographic disparity – the 'digital divide' – exists in access to reliable high-speed internet.[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, such as Internet for All.[14] Researchers are increasingly focusing on understanding the causal effects of broadband on various economic outcomes (Dettling *et al.*, 2018, Conroy and Low, 2022, Campbell, 2022, Amaral-Garcia *et al.*, 2022). It is, however,

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

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

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

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

[13] (Conroy and Low, 2022, Low *et al.*, 2021). For example, internet speed is slower in Black-majority neighborhoods than the speed enjoyed in other neighborhoods, despite paying the same price. The Markup.

[14] "Internet For All" allocated $42.45 billion for Broadband Equity, Access, and Deployment (BEAD) in June 2023.

unclear whether and to what extent the tools enabled by high-speed internet affect the worrying trends in mental 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.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.[18] I employ new difference-in-differences (DID) estimators useful for the binary and staggered treatment and account for the dynamic treatment effects.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 among older adults, shown by a decline in depressive symptoms using the CES-D score. 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 *et al.*, 2022), which found that the expansion of social media (such as 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%

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

[16] HRS 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.

[18] HRS has restricted data on the census-tract of residence of respondents.

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 that 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 do not, however, find evidence of any improvement in cognitive function.

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

Research on mental health is a relatively new area in economics, and such work is even scarcer for older cohorts. Current evidence suggests the adverse effect on mental health due to negative income shocks such as job loss and the positive gain in mental health due to cash transfers or antipoverty programs (Ridley *et al.*, 2020). However, this literature is primarily focused on younger populations. Most of the evidence on the social determinants of the mental health of the older population comes from other disciplines (Allen *et al.*, 2014, Lund *et al.*, 2018). I contribute to the limited economics literature by studying vulnerable age cohorts that are often overlooked.

The next strand of literature involves technologies as determinants of economic outcomes. The emerging literature suggests that broadband can have positive effects on education, entrepreneurship, and labor market outcomes (Dettling *et al.*, 2018, Conroy and Low, 2022, Campbell, 2022, Amaral-Garcia *et al.*, 2022). 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 body weight among white women (DiNardi *et al.*, 2019), or, on the other hand, leads to declines in teen pregnancies (Guldi and Herbst, 2017). However, most of the literature on mental health is focused on younger populations and suggests an adverse effect of broadband and social media (Braghieri *et al.*, 2022, Golin, 2022, Allcott *et al.*, 2022, Donati *et al.*, 2022). This paper is among the first to evaluate the effect of broadband on the mental health of older adults.

My third set of contributions is methodological. While earlier studies on technology may suffer from the challenges of two-way fixed effects (TWFE), I use recent advances in DID for better identification. I also use data that overcomes some of the limitations in the literature. My measurement of broadband treatment is more precise than most studies, which define treatment at a broad geographic level, such as counties or zip codes.[19] Defining treatment by a broad area can make it challenging to control for confounding variables and may also create heterogeneity bias if one overlooks variations within that area. I define the treatment at a finer scale (census tracts) for more accurate treatment assessment and to reduce bias in the estimation.[20] Further, the individual panel nature of the data allows me to observe the same individuals for ten years (five survey waves), including detailed changes in social and health behavior and take-up of the internet. As discussed below, this lets me analyze potential mechanisms that some other studies could not explore. Finally, the data also helps with locational accuracy. Typically, the current literature fixes the location at the first year of the panel and assumes no migration because migration could be endogenous to the treatment. This assumption may inaccurately measure exposure to the treatment. I do not have to make that assumption because I observe the location of the individual for every survey year and accurately measure exposure to the treatment.

My next key contribution involves a novel study of mechanisms. To my knowledge, this is one of the first papers to provide causal empirical evidence on how broadband may affect social isolation, loneliness, cognitive function, and technology in nearby hospitals, which in turn may affect mental health among older adults. The social isolation hypothesis suggests that social connections and networks are important for mental health. Similarly, 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, such as psychology and sociology, and suggests inconclusive correlations between internet use and older adults' mental health.[21] In addition, I provide some of the first evidence on the effect of broadband on cognitive function among older adults. Broadband access may induce the use of various technologies such as mobile

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

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

[21] For 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, one study suggests a negative association between internet use and mental health depending on the context of the life transition (separated, divorced, or widowed) and the type, level, and purpose of use (Yu *et al.*, 2019).

phones, tablets, and computers, and these activities may improve some cognitive functions among older adults. Finally, I provide some of the first evidence on whether greater access to broadband may correlate with technological improvement in nearby hospitals. For instance, a major obstacle to the implementation of telehealth services is the lack of enough internet bandwidth, mostly 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.

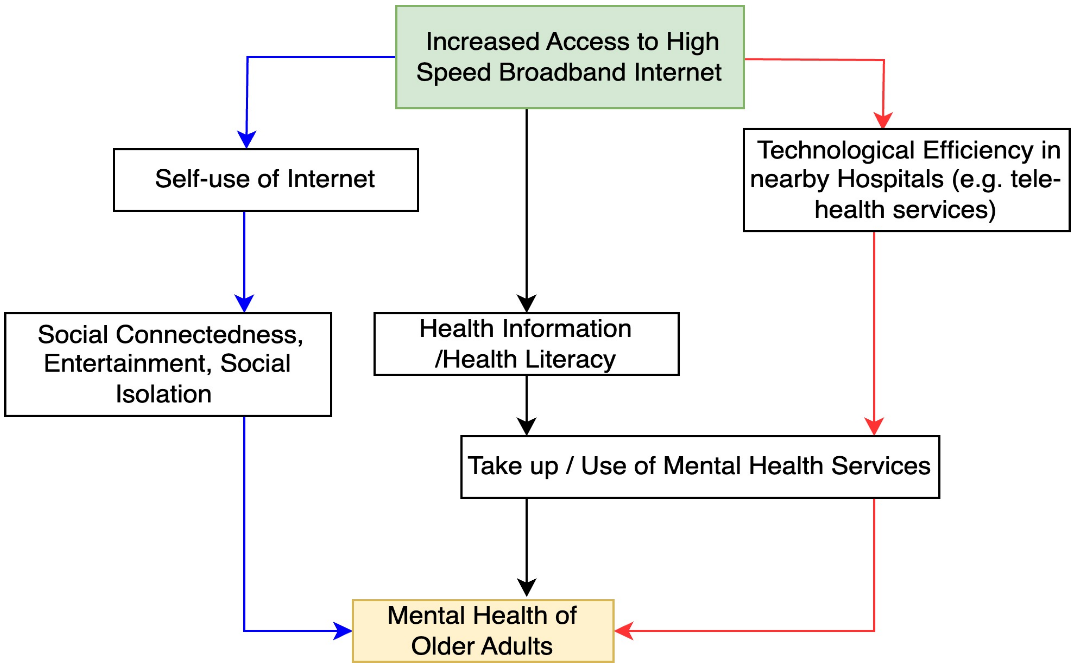
Information asymmetry is another mechanism through which broadband technology can affect mental health. A recent study suggests that internet access increased C-sections, potentially due to online information; however, the mechanisms are not clear (Amaral-Garcia *et al.*, 2022). One recent study finds a positive effect on the health of Medicare patients seeking hip or knee replacements, primarily due to better information about providers Van Parys and Brown (2023). In a developing country, 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 complement the evidence on the potential channels through which broadband may reduce information asymmetry and thereby affect the mental health of older adults.

Social media is a potential mechanism suggested by studies of 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 younger population than I study (Golin, 2022). I complement this literature in at least two critical dimensions. First, I study detailed mental health using the CES-D score from the HRS data. Secondly, the cited studies are limited 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 study intent to treat (ITT) because the introduction of fiber broadband may improve the speed of the internet in homes, and people also may access high-speed internet through local public libraries or coffee shops. 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



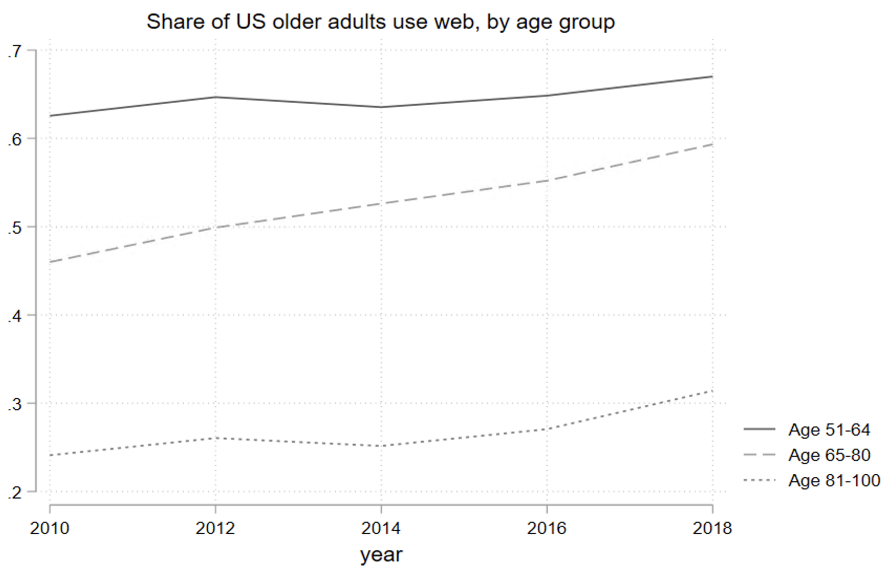
The impact of high-speed broadband on the mental health of older adults encompasses various potential pathways (Figure 1). One such mechanism pertains to social connectedness. While increased virtual connectedness could theoretically mitigate social isolation, it is important to consider a possible counteractive 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.

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).[22] 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

[22] Studies 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 how to use technology, e.g., children, relatives, neighbors, or friends.

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).[23]

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.

The third potential mechanism 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

[23]The 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.

tools for patient-generated data submissions (23%), appointment scheduling (24%), prescription refill requests (25%), and bill payments (8%) between 2015 and 2019. 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

Significant progress has been made in expanding broadband availability; however, there exists geographical variation in the coverage of reliable high-speed internet. In 2008, a mere 16% of Americans had access to internet service with a speed of 10 Mbps. Now, approximately 95% of Americans have access to a 10 Mbps connection, and around 80% have access to speeds of up to 1 Gbps.[24] 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.[25] Disparities in access are evident, with estimates indicating that 81% of rural households have broadband access, compared to 86% in urban areas.[26] The COVID-19 pandemic has highlighted and exacerbated this digital divide, prompting policymakers

[24]Refer to 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).

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

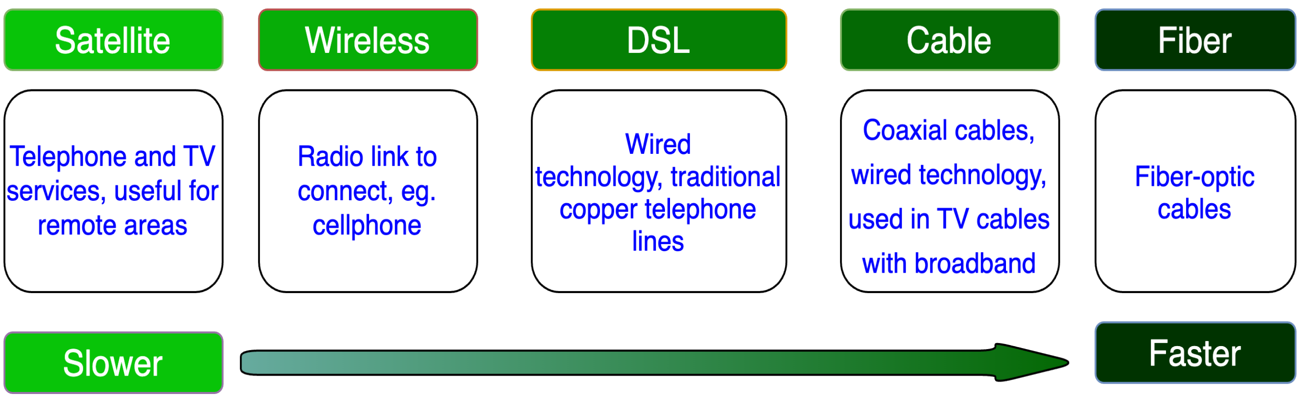
[26]The number of urban households lacking a connection is substantially higher, at 13.6 million, compared to 4.6 million rural households (Porter, 2021).

to place significant emphasis on broadband connectivity. More recently, in June 2023, the Biden-Harris administration announced a $42.45 billion allocation for high-speed internet across states ("Investing in America"). Figure 2 illustrates the growing internet use among older adults in the United States over the past decade.[27]

3.2 Types of Broadband Connections

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

FIGURE (3) Types of Broadband



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

There are two main reasons for my focus on fiber broadband. First, the notable increase in internet availability and speed in recent years can be attributed, in part, to the growing diffusion of broadband through fiber optic cables. Fiber broadband has emerged as a preferred choice, replacing older alternatives such as cable and DSL, owing to its superior speed, reliability, consistency, and reduced susceptibility to signal loss or damage; it has the potential to transmit large amounts of data.[28] Fiber broadband can transmit data at speeds reaching approximately 70% of the speed of light, equivalent to 124,274 miles per second. Commercial fiber connections typically offer signals above 10 Gbps, while residential fiber

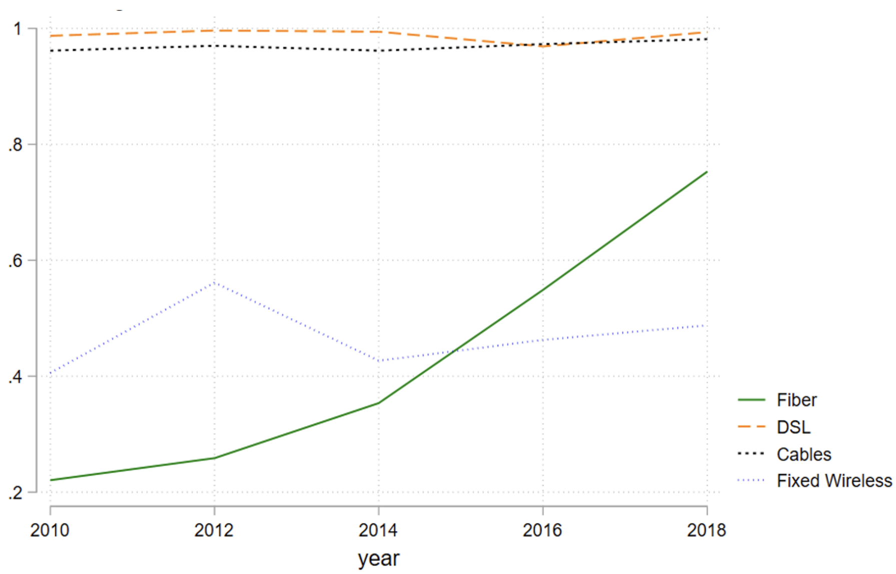
[27](Hunsaker and Hargittai, 2018) show a detailed review of who uses the internet and how it is used among older adults.

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

internet connections can reach speeds of up to 940 Mbps. The use of fiber optic technology involves converting electrical signals into light, which is then transmitted through transparent glass fibers with a diameter comparable to that of a human hair. This approach enables significantly faster data transmission 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.

Second, 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 potential relevance for older individuals.

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 uses 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 HRS serves as a nationally representative panel study, surveying approximately 20,000 individuals aged 51 and older.[29] The core HRS has been conducted annually since 1992, transitioning to a biennial format in 1996. This 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 such as health apps. Restricted files of HRS have information on the respondents' geographic residence locations.[30]

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 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.[31] To ensure comprehensive coverage, broadband providers are required to submit data biannually at the census-block level, demonstrating their ability to deliver internet service with speeds surpassing 200 Kbps in at least one direction. I aggregate the census-block level data at the census tract level by defining the census tract as treated if at least one census block had fiber in a particular year. The census tract, comprising smaller geographic units compared to counties, offers a finer granularity of analysis. There are a total of 84,414 census tracts in the United States, each ideally accommodating approximately 4,000 residents (Census Report). The census tract provides precise geographic treatment of the broadband, as opposed to aggregating at the county level, which has been done in the related literature. To ensure the most recent and reliable broadband data, the

[29]The University of Michigan conducts HRS, and it is sponsored by the National Institute on Aging (NIA).

[30]I 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.

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

analysis primarily relies on the December dataset for each year.

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

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. This research design includes outcomes that are measured less frequently than the treatment. This is because the HRS survey takes place every two years (2010, 12, 14, 16, and 18), and we know the treatment year for each survey respondent (2010, 11, 12, 13,....,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.[32] The main analysis is focused on the first batch, i.e., the respondents who were treated in the same year as the survey year, since 73% of the HRS sample belongs to this batch. I conduct a separate analysis for the second batch, as suggested by De Chaisemartin *et al.* (2019). I also show estimates that combine these two batches by estimating the 'length of the fiber treatment' as a treatment. In both of these cases, the results do not change.

In recent studies employing the difference-in-differences (DID) methodology, a common

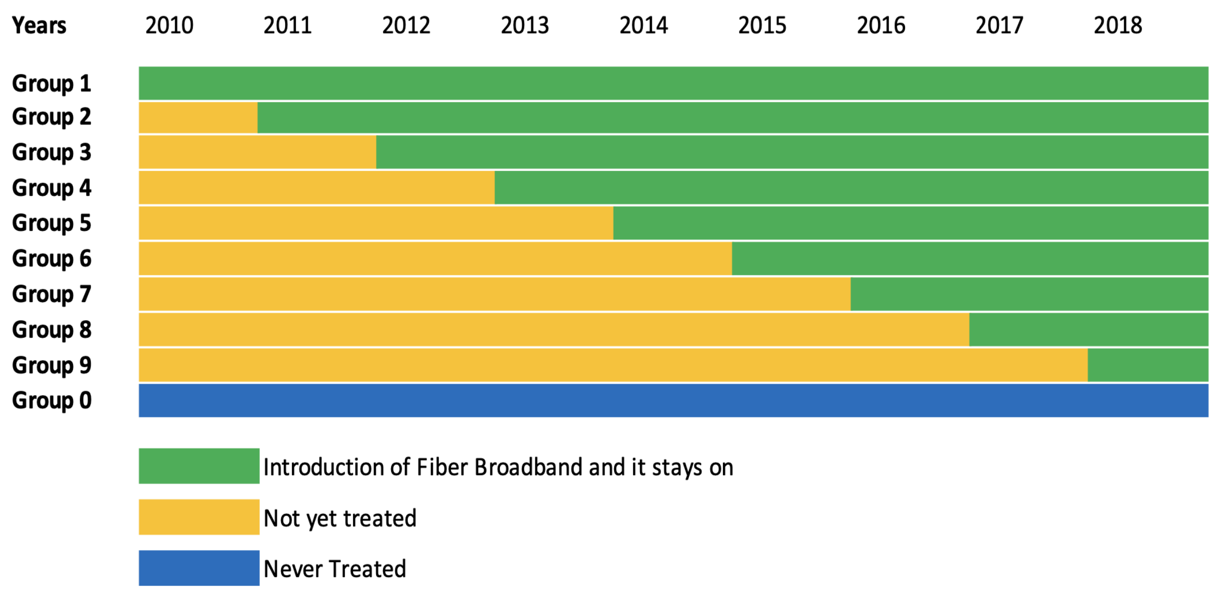
[32]The key reason is that, for the first batch, the first period ('instantaneous' or 'period 0') outcome is recorded. For instance, for the respondents treated in 2012, we have their first post-treatment outcome available for the wave of 2012. For the second batch, who were treated in non-HRS wave years,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

assumption involves carrying forward the initial geographic location of each individual for the subsequent years. This assumption is primarily driven by the lack of individual-level data and precise geographic information over time. However, it poses a notable limitation as it fails to account for potential variations in broadband exposure due to migration. For example, an individual resides during the first period t_0 in a census tract where fiber broadband was rolled out in 2010. Subsequently, the individual relocates to another census tract in t_1 that did not have broadband access and stayed there until the last survey wave t_3. To control for this kind of migration, researchers usually assume that the census tract of that individual in t_1 to t_3 is the same as that of t_0, which is a strong assumption. I depart from this assumption and examine whether individuals migrate following the introduction of broadband. Leveraging the advantages of the HRS data, I observe the census tract of residence for each respondent across all survey waves from 2010 to 2018. This allows me to identify whether respondents move out of their initial census tracts over the course of the study period. It is worth considering the possibility of endogenous migration within different treatment groups of census tracts, potentially induced by broadband expansion. Such migration patterns could introduce bias into the estimated effects. To address this, I restrict the sample to non-migrants, encompassing individuals who remained in their census tracts throughout the study period. This non-migrant sample constitutes approximately 91% of the overall sample. Moreover, I present additional estimates that include both movers and non-movers in the 'robustness' section, ensuring a comprehensive analysis of the potential effects of migration on the results.

4.4 Introduction of Fiber

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

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

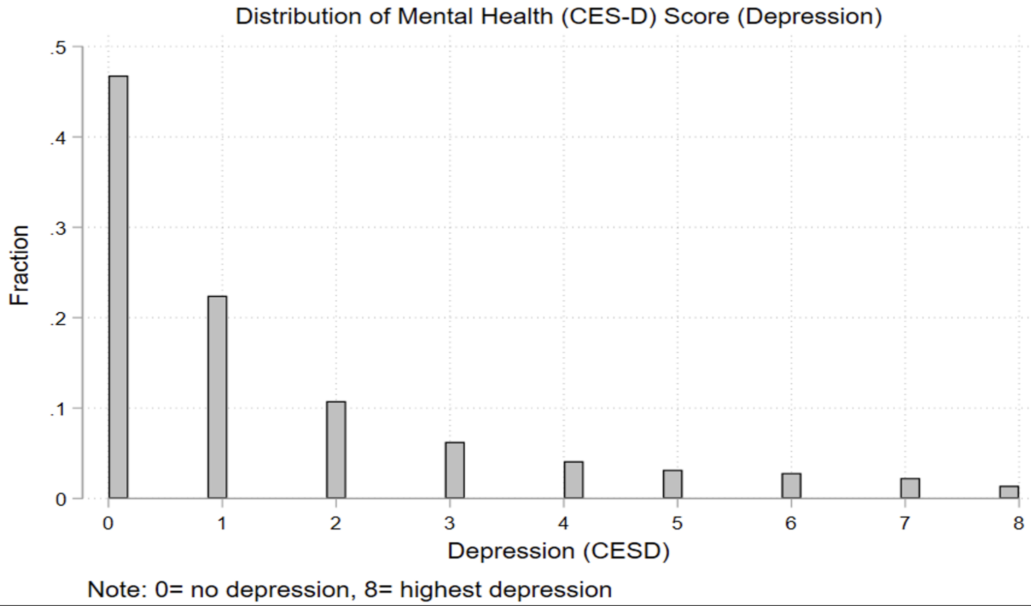


Note: The figure shows the introduction of fiber broadband in various groups of census tracts in different years. Group 1 received the fiber in 2010, Group 2 in 2011, Cohort 3 in 2012, and so on. Group 0 does not receive any fiber.

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 widely utilized across various social sciences and academic disciplines (Zivin *et al.*, 2010, Cutler and Sportiche, 2022). The score is derived from eight questions encompassing domains such as depression, sleep quality, and feelings of loneliness and sadness. It is computed by summing the responses to six negative indicators while subtracting the responses to two positive indicators (Appendix Table 13). 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.

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

4.6 Summary Statistics

Table 1 presents the summary statistics for the merged dataset, combining the HRS with the broadband data at the census tract level, spanning the period from 2010 to 2018. The statistics provide insights into the baseline characteristics of HRS respondents across various groups, including both the fiber-expansion and no-expansion cohorts of census tracts. Additional demographic characteristics of the respondents are provided in Table 14 in the Appendix. Table 14 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 because the urban areas might drive the expansion of fiber. I conduct an analysis of rural and urban separately.

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	1.23	1.25	1.45	1.50	1.38
	(1.91)	(1.82)	(1.81)	(1.97)	(2.01)	(1.94)
Clinical Depression (0-1)	0.09	0.08	0.08	0.10	0.11	0.10
	(0.28)	(0.27)	(0.27)	(0.31)	(0.31)	(0.29)
Feel Isolated (y/n)	0.30	0.26	0.34	0.32	0.34	0.32
	(0.46)	(0.44)	(0.47)	(0.47)	(0.47)	(0.47)
Use Web (y/n)	0.55	0.57	0.53	0.53	0.51	0.51
	(0.50)	(0.49)	(0.50)	(0.50)	(0.50)	(0.50)
Email Friends/Family (y/n)	0.31	0.32	0.33	0.32	0.33	0.33
	(0.46)	(0.47)	(0.47)	(0.47)	(0.47)	(0.47)
Number of Broadband Providers	8.87	9.30	8.78	9.13	8.78	7.99
	(3.75)	(3.73)	(3.07)	(3.38)	(3.28)	(2.92)
Max Download speed (Mbps)	399.91	446.57	505.04	431.71	301.35	279.31
	(437.18)	(454.85)	(475.86)	(458.37)	(393.35)	(375.57)
N Respondents-Group year	11728	1713	4353	10438	9332	18421
Number of Census Tracts	1085	174	696	258	922	2070

Note: 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 CES-D score equal to 0 if there is no depression, and 8 with the highest depression.

5 Empirical Strategy

5.1 Identification Strategy

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

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

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

Here, Y_{igct} is the outcome for individual i, living in census-tract c, belonging to the fiber expansion group g of census tracts, and surveyed in HRS survey year t. $Fiber_{ct}$ is an indicator equal to 1 if fiber was available at census tract c in survey year t, and 0 otherwise. δ_i is individual fixed effects that control for the time-invariant characteristics of individuals and allow identification to come from within-individual changes in fiber availability.[33] I also include the group-year fixed effects γ_{gt}, to account for shocks that affect all the individuals in a given group of census tracts to which fiber was expanded in a given year. I cluster the standard errors at the census-tract level to allow for the correlation among individuals in the same census tract.

The DID model specified in Equation 1 estimates the average treatment effect of the introduction of high-speed fiber broadband on the mental health of older adults. In Equation 2, I show the event study version of the DID estimation to test for parallel trends and estimate the dynamic treatment effect. By incorporating time-varying treatment effects, 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.

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

Here, $Fiber_{\tau(ct)}$ are indicator variables equal to 1 if the introduction of fiber was τ years

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

away for fiber expansion group g in HRS survey wave t. I plot the estimates for three pre-periods of the treatment, out of which one year is omitted (-1), and four post-period estimates from 0 to 3 periods after the treatment, where 0 is the instantaneous treatment effect. 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 advances in the DID literature suggest that the conventional two-way fixed effects (TWFE) estimator provides consistent estimates under the assumption of treatment effect homogeneity (Sun and Abraham, 2021, De Chaisemartin and d'Haultfoeuille, 2022a). However, the introduction of fiber may result in heterogeneous treatment effects, given varying rates of adoption, potentially influencing the mental health of older adults differently. It is also conceivable that the treatment effects may vary across individuals, exhibiting 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, discussed below, that allow for the heterogeneous treatment effects 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 this study. The estimators for the binary and staggered treatment that allow for dynamic treatment effects, i.e., outcomes that can be affected by past treatment, are provided by Sun and Abraham (2021), Callaway and Sant'Anna (2021), Borusyak *et al.* (2021) and De Chaisemartin and d'Haultfoeuille (2022a). Older adults are less likely to be tech-savvy than younger people. Also, on average, about 55% of the sample respondents have 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.

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. Note that the Borusyak *et al.* (2021) estimator does not include the 'never-treated' group but considers the yet-to-treat group for comparison. Further, 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. Here, 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. This specification incorporates the individual fixed effects and the fiber broadband expansion year fixed effects to ensure that identification stems from within-individual changes in fiber availability over time. Column 2 includes individual-level time-varying controls in addition to the specifications in column 1. In column 3, I replace individual fixed effects with the census-tract fixed effects. In column (4), I introduce expansion group-year fixed effects to account for the shocks that affect all individuals in an expansion group in a given year.

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 15 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 15 replicate similar results, suggesting that the introduction of fiber broadband reduced depression symptoms among older adults; these estimates are statistically significant. Apart from the main analysis, I will focus on De Chaisemartin and d'Haultfoeuille (2022b) for the reasons explained in Section 5.[34]

I use 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 on a scale of 0 to 8. This estimate is remarkably similar in magnitude (0.085) but opposite in

[34] Because the Borusyak *et al.* (2021) estimator does not include the 'never-treated' group but considers the yet-to-treat group for comparison, the sample size in Appendix Table 15 is smaller than in Table 2. Secondly, Borusyak *et al.* (2021) may not work well in the presence of a strong serial correlation.

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^{**}	-0.073^{**}	-0.091^{**}	-0.128^{**}
	[0.032]	[0.035]	[0.039]	[0.061]
Observations	47,935	47,163	49,728	47,935
Year Fixed Effects	Yes	Yes	Yes	Yes
Individual Fixed Effects	Yes	Yes		Yes
Controls		Yes		
Census-Tract Fixed Effects			Yes	
Expansion Group-year Fixed Effects				Yes
Baseline Mean of Outcome	1.42	1.42	1.42	1.42

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

direction to the effect observed in a study by Braghieri *et al.* (2022), which suggests that the expansion of Facebook increased mental health problems among college students in the US. These contrasting findings highlight a key result of this paper, indicating that the impact of a similar technology on mental health outcomes can vary based on age cohorts and potentially on how individuals engage with the technology. Section 8 provides further insights into the underlying reasons for this divergence.

Additionally, I compare the estimates with a closely related meta-analysis conducted by Paul and Moser (2009). The results suggest that the positive effect of broadband expansion on depression symptoms is approximately 20% of the negative effect of job loss. Another comparison can be made with the study by (McInerney *et al.*, 2013), which examines the effect of the 2008 recession on the mental health of older adults. The estimates from my paper indicate that the benefit of broadband expansion is roughly 41% of the negative effect of the recession. These comparisons provide a context for understanding the relative importance of broadband expansion in influencing mental health outcomes compared to other factors.

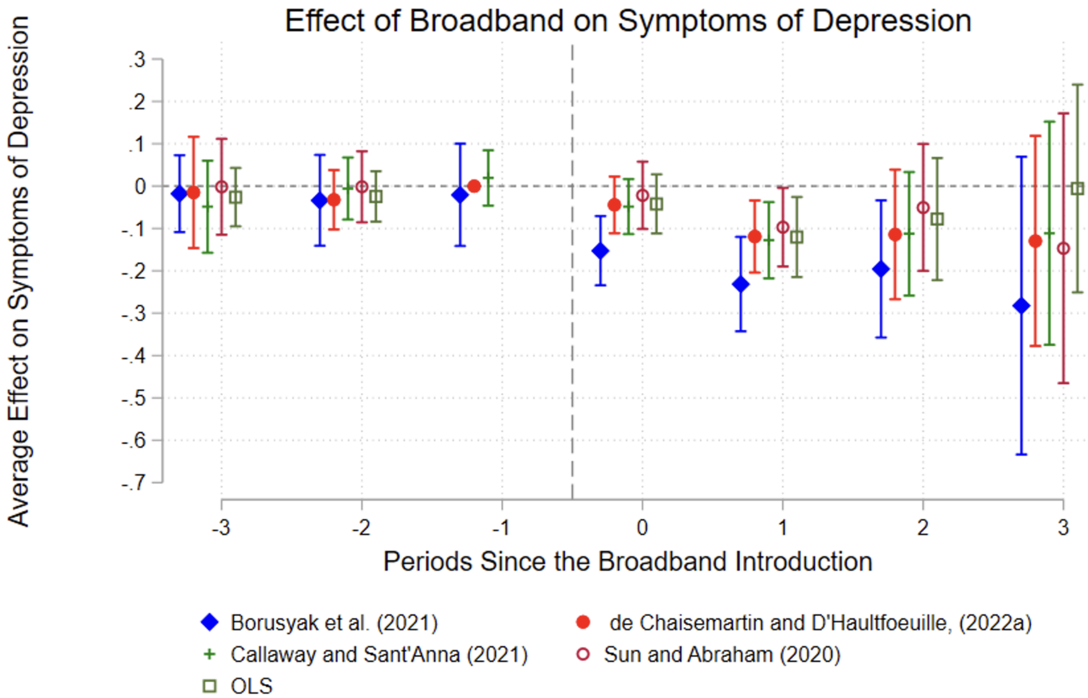
Further, I show the results with the dynamic treatment effects in Figure 7 using Equation 2 and the DID estimators proposed by De Chaisemartin and d'Haultfoeuille (2022a), Borusyak *et al.* (2021), and Callaway and Sant'Anna (2021). In Figure 7, I show the estimates with the balanced panel of HRS respondents. 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 13, 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 Table 16 and Figure 12 shows the average and dynamic effect estimates for the outcome 'clinical depression' using Equation 2 and estimated using the DID estimator proposed by De Chaisemartin and d'Haultfoeuille (2022a). In the 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. Appendix Table 16 and Figure 12 supports 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, I compare them with research that examines the effect of unexpected widowhood on depression. The results from my study suggest that the benefit of broadband expansion is about 14% of the negative effects associated with the unexpected loss of a spouse (Siflinger, 2017).[35] This comparison sheds light on the relative impact of broadband expansion in mitigating depression symptoms compared to other significant life events.

The statistically significant effects of fiber broadband on mental health outcomes grow over time. This delayed impact can be attributed to several potential factors. Older adults, who are typically less technologically adept compared to younger age groups, may require more time to familiarize themselves with new technologies such as smartphones, computers,

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

FIGURE (7) Dynamic Treatment Effects of Broadband Expansion on the Symptoms of Depression



Note: This figure shows the dynamic effects plots using Equation 2 with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a), Borusyak *et al.* (2021), and Callaway and Sant'Anna (2021). The sample is from the HRS respondents for biennial waves from 2010 to 2018. The age group is 51 to 103. The outcome variable 'depression' is a CES-D mental health categorical score from 0 to 8, 0 being no depression and 8 being the highest depression. For Borusyak *et al.* (2021) and De Chaisemartin and d'Haultfoeuille (2022a), I include a fiber broadband expansion year and HRS respondents' individual fixed effects. For Callaway and Sant'Anna (2021), 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_{t0} = 23,694 (switchers =3,655), N_{t1} = 14,668 (switchers =2,155), N_{t2}= 7079 (switchers =735), N_{t3} = 2,494 (switchers =181).

and video calling platforms. Additionally, they may need time to develop habits such as utilizing high-speed internet services at public 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. Further, strategic complementarities, characterized by waiting for others to adopt, may play a role (Alvarez *et al.*, 2023). This suggests that the reduction in depression symptoms 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 ITT effect, which captures the overall effect of the availability of fiber broadband. This effect encompasses both the direct impact on individuals who actively use the internet and the potential indirect effects arising from others in the household or network using the internet. However, a significant contribution of this study lies in leveraging the rich data provided by the HRS to disentangle the direct and indirect effects. This is a departure from similar research.[36]

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

The survey question is–[37]
"Do you regularly use the Internet (or the World Wide Web) for sending and receiving e-mail or for any other purpose, such as making purchases, searching for information, or making travel reservations?"

To assess the impact of broadband expansion on older adults of the internet, I transform positive responses to the above survey questions into a binary variable, assigning a value of 1 if the respondent answers affirmatively and 0 otherwise. Figure 16 presents the dynamic effects, using estimators provided by De Chaisemartin and d'Haultfoeuille (2022a) and Borusyak *et al.* (2021). Importantly, the pre-trend estimates are close to zero and mostly statistically insignificant, providing support for the validity of the parallel trend assumption in our analysis. Figure 16 shows mixed evidence on the effect of the rollout of fiber broadband on use of the internet. Under the Borusyak *et al.* (2021) estimation, the estimates are

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

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

statistically significant and growing over time. However, under the De Chaisemartin and d'Haultfoeuille (2022a) estimation, the effect is not significant. One explanation is that the Borusyak *et al.* (2021) estimation, unlike De Chaisemartin and d'Haultfoeuille (2022a), does not include the 'never-treated' group; this is because the estimator provided by Borusyak *et al.* (2021) works well when there is not much serial correlation. Here, the serial correlation in the outcome variable is very small, so I prefer the Borusyak *et al.* (2021) estimator.

6.3 Heterogeneous Effects

In this section, I explore the heterogeneity of the effects of broadband expansion based on various characteristics. To begin, 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. Then, I investigate whether the effects differ based on gender, taking into account the well-documented differences in baseline depression levels between men and women, in that women tend to experience higher levels of depression across countries and age groups. 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 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 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 14 provides evidence that the expansion of broadband was slower in rural areas during the initial years. As noted above, rural residents tend to be older and poorer, with lower levels of education, worse mental health, and lower levels of private health insurance; they also have less access to mental health professionals because of shortages of such services in rural areas(Foutz *et al.*, 2017, Mueller *et al.*, 2018, Moy *et al.*, 2017, Pender *et al.*, 2019). [38] 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 reduced depression symptoms among older adults in both urban and rural areas; however, there was a statistically significant decline in rural areas. The second reason could be that the frequency of monthly and yearly internet use for health information by older rural residents is significantly higher than that of urban areas (MCBS, 2022). These findings suggest that fiber broadband expansion has the potential to deliver significant benefits for the rural community in terms of mental health outcomes. One potential reason could be the baseline mental health is already better in Urban areas, so the gain is not much.

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

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

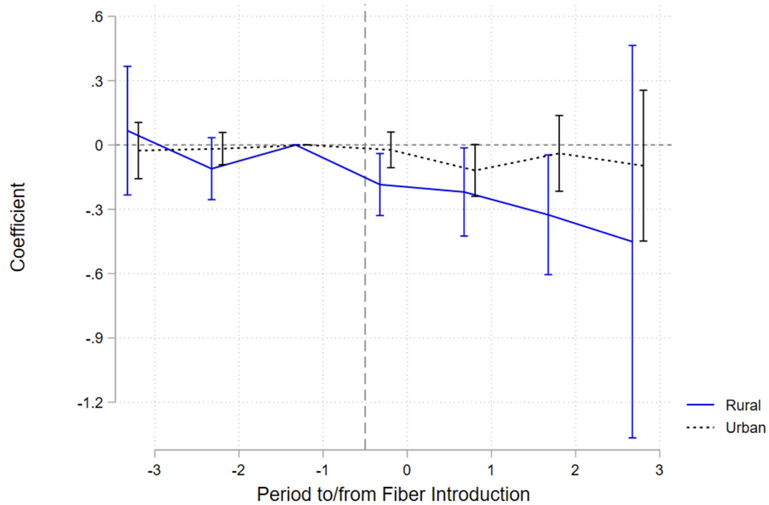
Note: This table shows the average treatment effects of the staggered introduction of the fiber broadband on the depression symptoms (CES-D) among older adults using Equation 1 and estimating with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). The sample is a balanced panel of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

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:

[38] Medicaid 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 with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). The sample is a balanced panel of HRS respondents for biennial waves from 2010 to 2018. The age group is 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.

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 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 still be working, broadband may have some effect at the intensive margin if they have 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

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

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

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

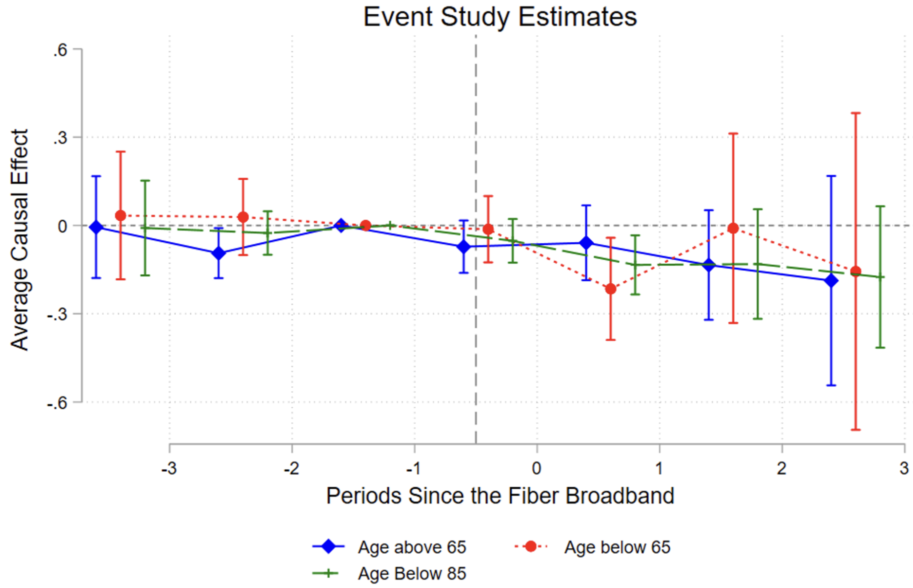
cohort.

6.3.3 By Gender

The mean depression (CES-D) score for women (1.52 (sd 2.07)) is higher than that of men (1.19 (sd 1.76)). Across nations and age groups, women have higher levels of depressive symptoms (Nolen-Hoeksema and Hilt, 2008, Salk *et al.*, 2017, Banerjee *et al.*, 2023). However, women may be more likely 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. Neither of these estimates is statistically significant. However, on average, women experience a greater decline in depression symptoms (estimates -0.031, SE 0.046) compared to men (estimates -0.028, SE 0.094). The difference between the two is -0.003 (p-value 0.07) and is statistically significant at the 10% level. This suggests potentially greater benefits of broadband expansion for women.

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 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.

These estimates contrast to the findings of Braghieri *et al.* (2022), who observed the adverse effects of social media (Facebook) on the mental health of female college students. This suggests that the impact of technology can vary across gender and age groups. 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

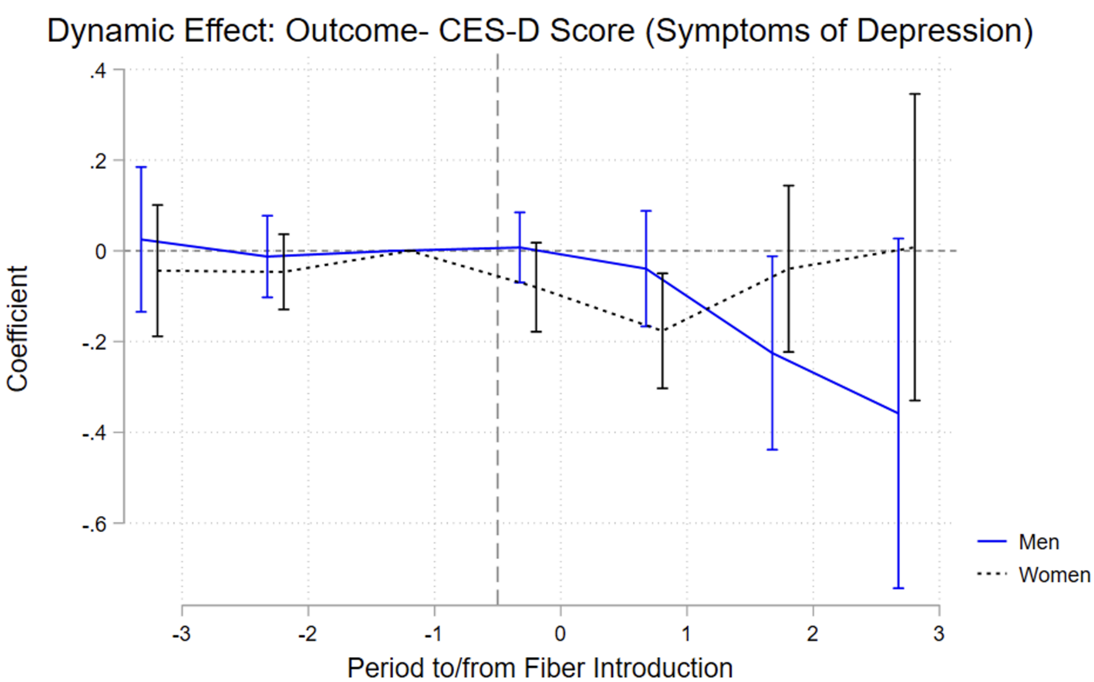
In order to examine the potential heterogeneity of the effects, I estimate the model separately for Whites and non-Whites, considering the higher prevalence of mental health problems among African Americans. The mean CES-D depression score for Whites is 1.27 (sd 1.88), while for African Americans, it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

TABLE (5) Average Treatment Effect– By Gender

	Men	Women
Post Fiber	−0.041	−0.103**
	[0.037]	[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 HRS respondents for biennial waves from 2010 to 2018. The age group is 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.

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 HRS respondents for biennial waves from 2010 to 2018. The age group is 51 to 103. The outcome variable 'depression' is a CES-D mental health categorical score from 0 to 8, 0 being no depression and 8 being the highest depression. 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.

riencing slower internet speeds for the same price (Wisconsin State Journal Report, 2022). The estimates in Table 6 and Appendix Figure 17 present the dynamic treatment effects for Whites and African Americans. The results indicate a decline in depression symptoms among older Whites. Conversely, for African Americans, they are not statistically significant. 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 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.

TABLE (6) Average Treatment Effect – By Race

	White	Non-White
Post Fiber	-0.096^{***}	-0.021
	[0.035]	[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 HRS respondents for biennial waves from 2010 to 2018. The age group is 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.

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. In the main sample, I include HRS respondents who were exposed to broadband during odd years: 2011, 2013, 2015, and 2017. For instance, in the year 2014, individuals who

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

	Married	non-Married
Post Fiber	-0.088^{***}	-0.040
	[0.033]	[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 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.

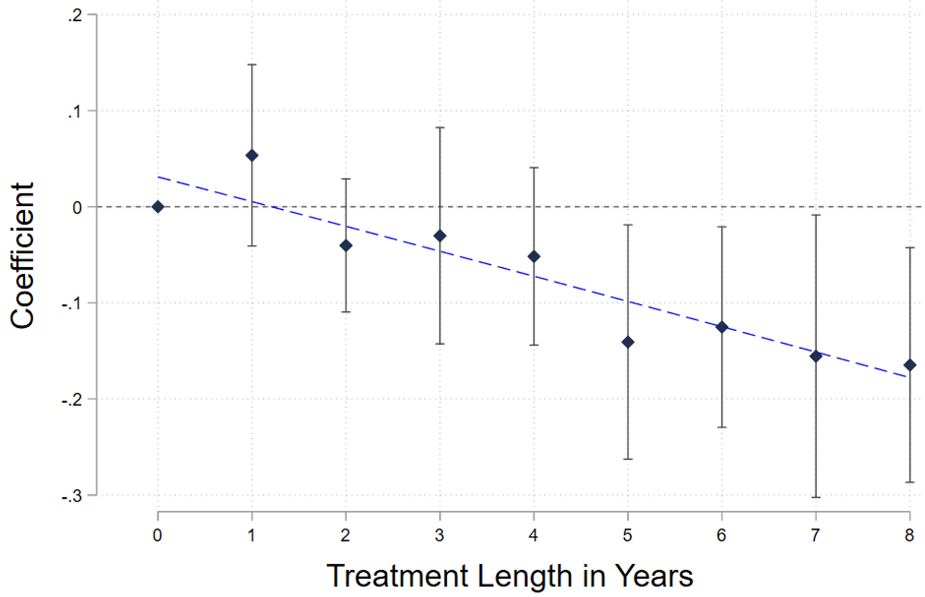
received broadband in 2011 would have been exposed for three years, while those who received broadband in 2012 would have been exposed for only two years. By incorporating the length of exposure in the analysis, I aim to capture the potential cumulative effects of broadband technology on mental health over time. This provides a more comprehensive perspective on the relationship between broadband expansion and mental well-being among older adults.

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

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

where 'Years in Fiber$_{\tau(ict)}$' are indicators equal to 1 if HRS respondent i at census-tract c in survey-wave t had access to fiber for τ years. The number of treated years is calculated as $\tau = Fiber_{gt} \times (t - \text{Year of treatment})$ where t is the survey year. α_c is the census-tract fixed effects and γ_t is the survey year fixed effects. I also include a vector of individual-level controls X'_i. Figure 11 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 (11) 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 another DID estimator by Borusyak *et al.* (2021) in Table 15. Because 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), I show the average treatment effects without those estimators. Further, in Table 8, I show the estimates, including the 'movers', since the main estimation is focused on 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. To test the robustness of the estimates, I also include the movers in the main sample. Table 8 shows the estimates for the stayers and movers. The dynamic effect persists, with evidence supporting the parallel trend assumption and a slightly lower estimate in the third period. The estimates suggest that the movers are not driving the estimates. This analysis provides reassurance that mobility patterns do not drive the observed effects, which are consistent even when considering the impact of migration on the estimates.

8 Mechanisms

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. This study is among the first to

TABLE (8) Average Treatment Effect of Fiber Broadband on the Symptoms of Depression

	CES-D Score		
	(1)	(2)	(3)
Post Fiber	-0.076^{***}	-0.072^{**}	-0.071
	[0.026]	[0.033]	[0.045]
Observations	71,323	70,129	53,459
Year Fixed Effects	Yes	Yes	Yes
Individual Fixed Effects	Yes	Yes	
Controls		Yes	
Census-Tract Fixed Effects			Yes

Note: Estimates are using Equation 1 and estimating with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). The individual controls include whether the individual receives Medicaid, is married, and works for the pay. I also included the HRS person weights in the estimation. *** p<0.01, ** p<0.05, * p<0.10.

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 isolated from others. I estimate the Equation 2 and the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a) to evaluate whether broadband expansion affects the incidence of social isolation. Table 9 indicate a substantial decrease in 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 advances in promoting social connectedness and well-being among older adults.

TABLE (9) Average Treatment Effect of Fiber Broadband on the Feelings of Social Isolation and Loneliness

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

Note: This table shows the average treatment effects of the staggered introduction of the fiber broadband on the 'feeling of social isolation' and the 'feeling of loneliness' among older adults using Equation 1 and estimating with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). The 'feeling of loneliness' question is used 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

Because the internet can serve as a source of social support Pescosolido (2011), a plausible pathway through which broadband technology may influence mental well-being is by facilitating virtual connectedness with family members and friends. 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 such as Facebook or Skype to connect 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.

Moreover, in Table 10, 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 significant decline in depression symptoms for highly socially connected individuals while indicating no significant change 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 (10) Average Treatment Effects of Broadband on Depression Symptoms Based on Social Connectedness

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

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

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 11. 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 11 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 (11) Mechanisms: Effect on Health Literacy, Use of Health Apps and Health Websites

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

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

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).[39] This voluntary survey collects information on hospital organizational structure, utilization, finances, facilities, and staffing. I analyzed 24 survey questions related to the availability of telehealth services for various types of care and hospital networks. (See Appendix Table 17 for the list of the questions). Since the AHA data is at the county

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

level, I calculate the average number of broadband providers and speed at the county level. Using a logit model, Table 12 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. [40]

TABLE (12) Mechanisms: Hospitals offer Telehealth Services

	(1)	(2)
VARIABLES	Offer Telehealth Services	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 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.

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

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 14 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 15. 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, 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.[41]

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. 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 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,

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

the study uncovers racial disparities, as Whites drive the positive effects of broadband expansion, while no significant effects are observed for Blacks. Further investigation is needed to address this gap. Furthermore, the results indicate that women experience slightly larger average treatment effects compared to men. Exploring potential mechanisms, the study highlights the role of higher social connectedness, lower social isolation, improved health literacy, enhanced cognitive function, and technological advancements in nearby hospitals as potential pathways through which the effects of broadband technology may translate into better mental health outcomes for older adults. These findings contribute important insights to the literature, informing policymakers and stakeholders about the implications of broadband expansion for the mental well-being of older adults.

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

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

10 Policy Implications

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

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

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

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

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Appendices

TABLE (13) 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 (14) Summary Statistics on Various Characteristics

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

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

TABLE (15) 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^{***}	-0.083^{**}	-0.113^{***}	-0.188^{***}
	[0.035]	[0.035]	[0.043]	[0.050]
Observations	36,206	36,206	36,230	36,772
Expansion Year Fixed Effects	Yes	Yes	Yes	Yes
Individual Fixed Effects	Yes	Yes		
Controls		Yes		
Census-Tract Fixed Effects			Yes	
Fiber Expansion group FE				Yes

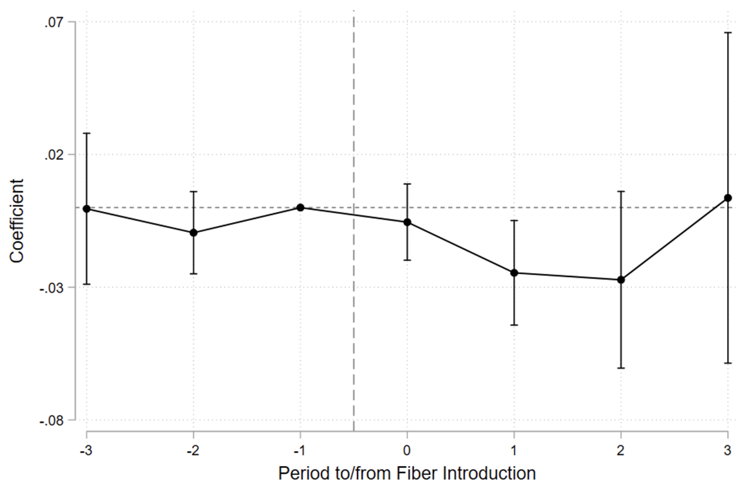
Note: This table shows the average treatment effects of the staggered introduction of the fiber broadband on the depression symptoms among older adults using Equation 1 estimating with the estimator provided by Borusyak *et al.* (2021). The sample is a balanced panel of Health and Retirement Study (HRS)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

TABLE (16) Average Treatment Effect of Fiber Broadband on the Clinical Symptoms of Depression

	Dummy=1 if CES-D>3, 0 otherwise			
	(1)	(2)	(3)	
Post Fiber	-0.014^{**}	-0.012^{*}	-0.015^{*}	
	[0.007]	[0.007]	[0.008]	
Observations	47,935	47,163	49,728	
Year Fixed Effects	Yes	Yes	Yes	
Individual Fixed Effects	Yes	Yes		
Controls		Yes		
Census-Tract Fixed Effects			Yes	
Baseline Mean of Outcome	0.14	0.14	0.14	0.14

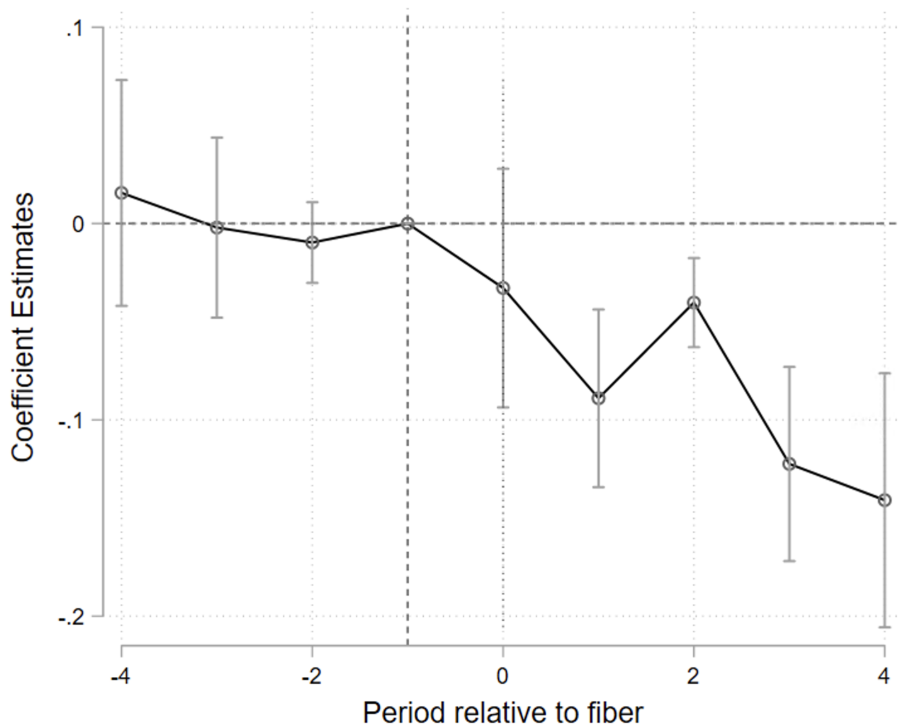
Note: This table shows the average intent-to-treat effects of the staggered introduction of fiber broadband on depression symptoms among older adults, using Equation 1 and the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). The outcome variable 'depression' is the CES-D mental health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

FIGURE (12) 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; N0 = 23,694, N1 = 14,668, N2= 7079, N3 = 2,494, N(pre 1)= ommitted, N(pre 2) = 17,244, N(pre 3) = 4,581.

FIGURE (13) Dynamic Treatment Effects Using Two-Way Fixed Effects (TWFE)

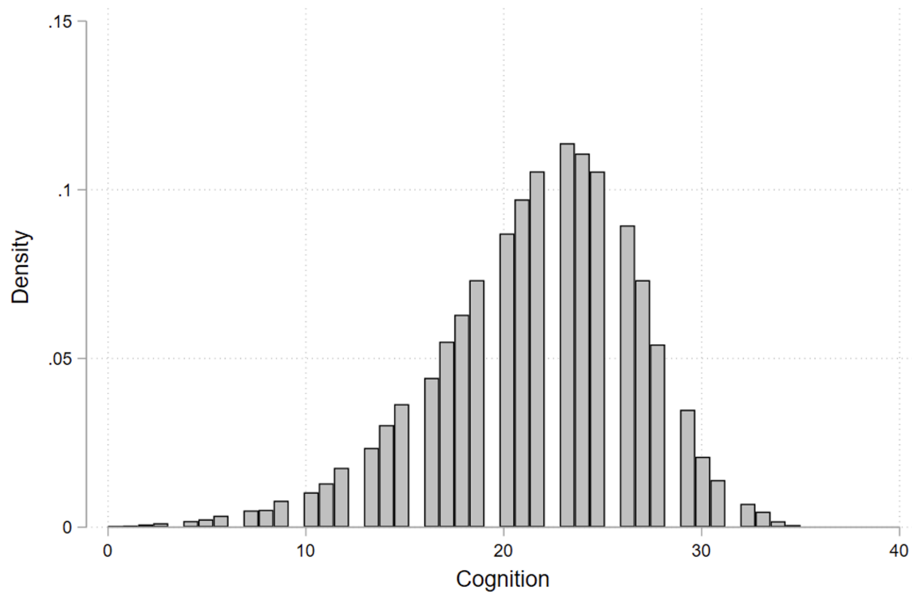


Note: This figure shows the dynamic effects plots using Equation 2 estimating with the conventional TWFE. The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from 51 to 103. The time variable is the survey wave, and the 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 (17) Questions in AHA data related to telehealth

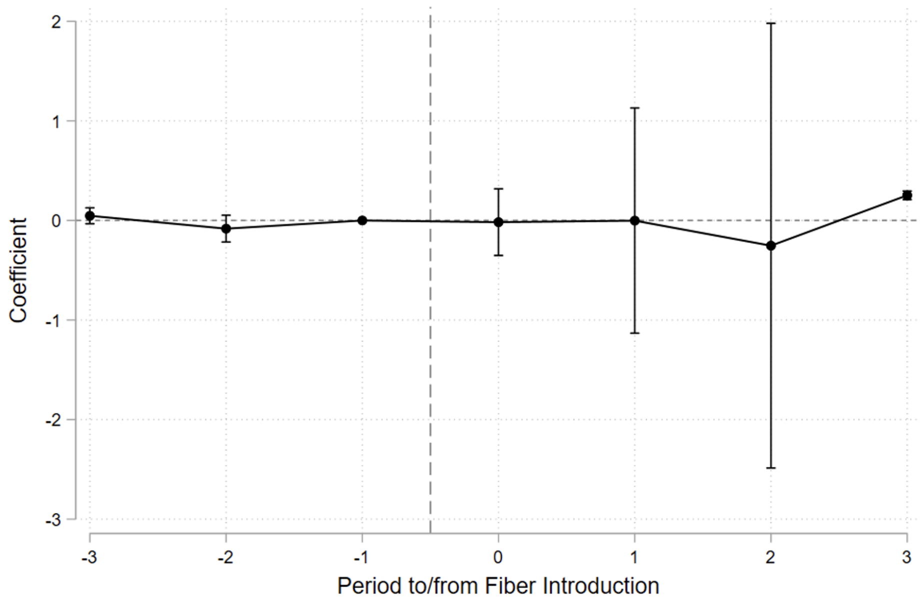
Telehealth consultation and office visits hospital
Telehealth consultation and office visits health system
Telehealth consultation and office visits joint venture
Telehealth elCU - hospital
Telehealth elCU - health system
Telehealth elCU - joint venture
Telehealth stroke care - hospital
Telehealth stroke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

FIGURE (14) Distribution of Total Cognitive Score



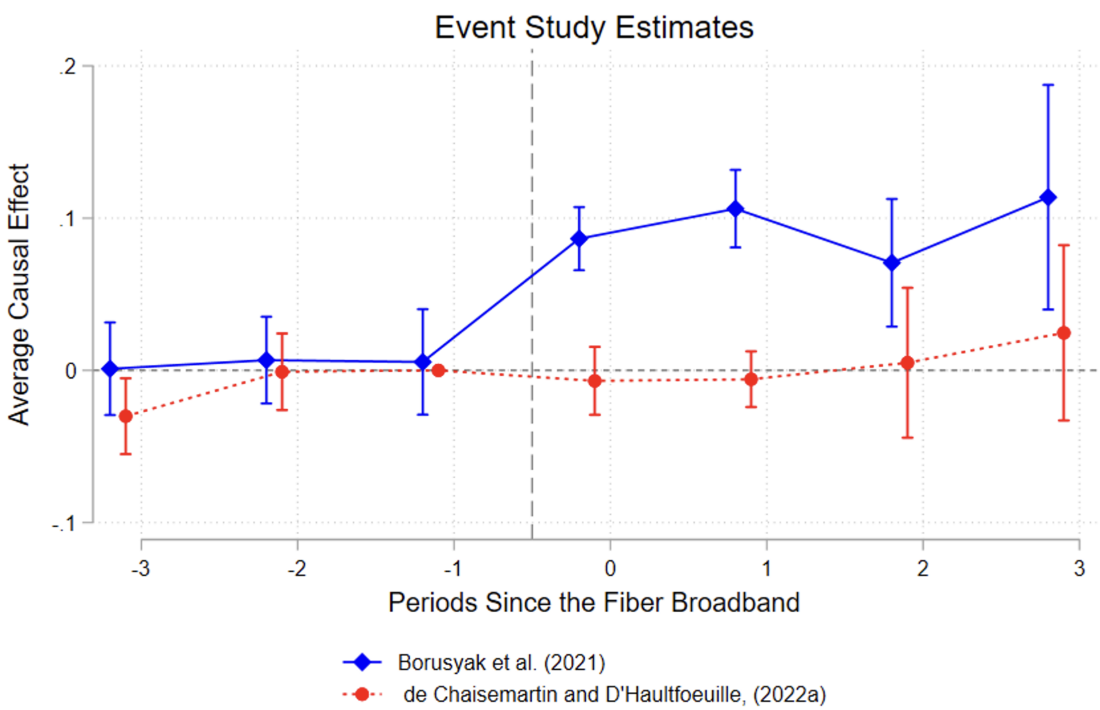
Note: This figure shows the distribution of the total cognitive score. The score ranges from 0 to 35, with 0 being the lowest cognition and 35 being the highest. The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from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

FIGURE (15) Dynamic Treatment Effects on Total Cognition Score



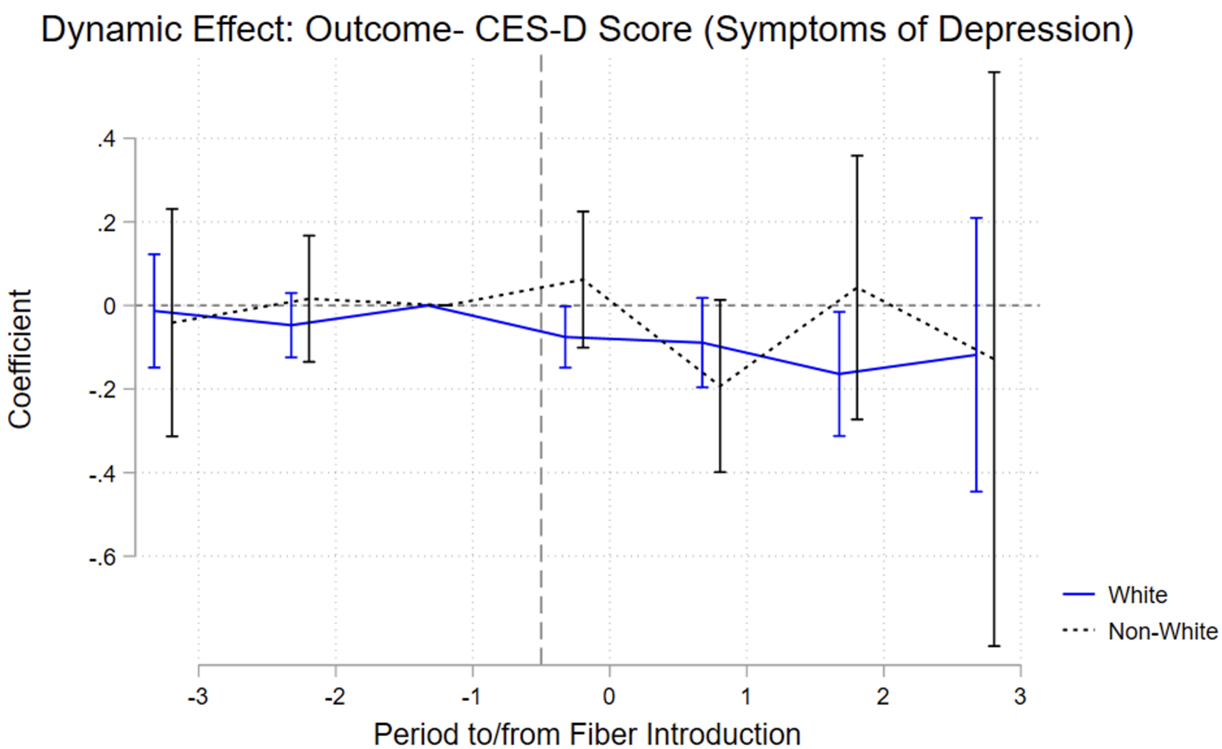
Note: This figure shows the dynamic effects plots using Equation 2 estimating with the estimator provided by De Chaisemartin and d'Haultfoeuille (2022a). The sample is a balanced panel of Health and Retirement Study (HRS) respondents for biennial waves from 2010 to 2018. The age group is from 51 to 103. 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 (16) 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.

FIGURE (17) 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 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.